MODELLING THE INTERACTIONS BETWEEN INFORMATION AND COMMUNICATION TECHNOLOGIES AND TRAVEL BEHAVIOUR

Jacek Pawlak

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Centre for Transport Studies
Department of Civil and Environmental Engineering
Imperial College London
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To my parents,

Danuta and Zbyszko

‘Never stop because you are afraid.
You are never so likely to be wrong.’

Fridtjof Nansen
Declaration

The research that is presented in this thesis is my own, except where the work of others is referenced.

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Abstract

The growing capabilities and widespread proliferation of information and communication technologies (ICT) into virtually every aspect of lifestyle, combined with the continuing challenges faced by transport systems, has ensured ongoing interest in the interactions between ICT and travel behaviour. Yet, despite more than three decades of efforts to understand these relationships, few points of consensus have so far emerged, partly due to the rapidly evolving character of ICT, and partly due to the inherent complexity of such interactions.

This thesis seeks to develop novel understandings of such interactions by introducing a number of extensions to the existing modelling frameworks. This is achieved through three interrelated research objectives which seek to explore the topic from macro, micro, and temporal perspectives. The macro perspective takes the form of a structural equation analysis of the relationships between ICT use and travel behaviour across four countries: Canada, the United States, the United Kingdom, and Norway, with the data for the latter three obtained by pooling separate datasets on ICT use and travel behaviour. The micro perspective seeks to develop a microeconomic model of an individual maximising utility through joint choice of activities, including in-travel activities, ICT use, as well as the choice of travel mode, timing and route, with the decisions motivated by contribution towards satisfaction, productivity, and consumption. The model is subsequently tested in the empirical contexts of rail business travel time, business travel time valuation, and conceptualisation of the ICT and travel behaviour interaction scenarios reported elsewhere in the literature. The final, temporal perspective analyses the comparatively least explored topic of evolution in the relationships between ICT use and travel behaviour over time. This is achieved by analysing repeated cross-sectional data using structural equation modelling, and interpreted with reference to the theory of diffusion of innovations. The thesis also discusses a number of potential research, policy and industrial applications of its empirical and theoretical contributions.
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Chapter 1
INTRODUCTION

For as long as civilisations have existed, humans have been developing a means of acquiring, storing, processing, and transmitting information. From the early Babylonian abacus, Sumerian cuneiform, or Chinese paper, to modern digital storage, parallel processing, and telecommunication technologies, such inventions and advancements were designed to facilitate more efficient information handling and communication, and ultimately societies’ prosperity. Similar reasons have also motivated developments in how people and goods are moved around whereby modifications were sought so as to provide a means of transporting faster, at a greater distance, and ideally at lower costs.

Nevertheless, these domains have never evolved in complete separation, and their joint employment has proven to deliver synergetic effects already in ancient times. Such was the case of, the Royal Mail and Couriers in the Persian Empire under Cyrus the Elder in the 6th Century BC (Briant, 2006). The system enabled transferring important messages and orders by means of horse-mounted couriers who would relay their messages to subsequent couriers stationed in a network of posts built alongside the well-developed transport (road) network. By doing so, any potential lags in communication due to capacity limits of the transport means, i.e. need to rest by the horse or the courier could be avoided. This system achieved information transmission speeds hardly matched by other means available then. Nonetheless, Persians managed to push the communication capabilities frontier even further by employing aural (loud-speaking by specifically trained individuals) and visual signals in message relaying (Briant, 2006). In the latter case which relied on fire being lit on mountain tops, Persians were essentially making use of electromagnetic waves (light) to pass
meaningful information. Though limited in terms of the admissible content, the method could more easily overcome obstructions such as deep valleys or water barriers, which would have otherwise restricted horse-mounted carriers. In fact, modern telecommunication can be perhaps seen as having its roots in this ancient system of fire beacons.

![Figure 1.1 Global developments in ICT use](source)

*Estimates

**Figure 1.1 Global developments in ICT use**  
Source: ITU, 2013 (reproduced with permission – see Appendix 9)

More than 2,500 years later, in the last decades of the 20th and first of the 21st Century, both sophistication and penetration of what can collectively be termed information and communication technologies, or ICT (more detailed conceptual discussion of the term is presented in Chapter 2) reached levels unprecedented in the past (see Figure 1.1). These trends can also be seen as important driving forces behind people’s increasing participation in activities based in virtual reality. Some noteworthy examples of this trend are Facebook’s 1.23 billion active users, including 0.95 billion mobile users (Facebook, 2014), or the growing global online retails sales’ value, currently at a level of about $1.5 trillion (eMarketer, 2014). The other, darker side of this coin is the magnitude of disruptions achievable by means of ICT such as the 2007 cyber-attacks on Estonia which paralysed its government, media, and banking services (The Economist, 2010).

At the same time, transport systems have remained under continued stress to cope with multiple challenges. Temporally and spatially unbalanced levels of demand,
inadequate infrastructure together with limited resources for its maintenance (especially in the times of economic downturn), environmental pressures, or safety and security concerns are just a few among many. On the supply side, improvements in transport systems making use of ICT, i.e. intelligent transport systems (ITS) or transport telematics, have been increasingly perceived as remedies to those problems. On the demand side, growing participation of individuals in more sophisticated activities based in virtual reality is seen as novel way of fulfilling needs traditionally met through participation in physically-distant activities requiring travel. While this does not necessarily imply reduction in travel as will be shown in the subsequent chapters, the need to incorporate the effects of ICT in travel behaviour analysis has steadily grown over the past decades. Not surprisingly, ICT have become discussed in various policies and action plans around the world aimed at delivering a more prosperous future, e.g. London’s Smart London Plan (Smart London Board, 2014), Singapore’s Infocomm Media in 2025 (MCI, 2014), or the Indian State of Maharashtra’s Maharashtra IT/ITES Policy 2009 (Government of Maharashtra, 2009).

The research effort since at least 1970s has indeed contributed to growing understanding of the interactions between ICT and travel behaviour, but also led to new, further questions and challenges. Positioned in this possibly exceptional time of ongoing changes, this thesis can address only a limited set of these questions given the vastness and complexity characterising the field.

1.1 Aim and research objectives of the thesis

This thesis seeks to investigate a number of the comparatively less explored research areas of this field. In doing so, the contribution limits itself to the behavioural, i.e. demand side of the interactions, and passenger travel. This is motivated by the need to cope in a detailed manner and within the limited scope of the thesis, with an extensive field but consisting of numerous divergent insights. However, references to the supply side in the form ITS, or freight transport, e.g. in case of impacts of goods’ delivery, is made where deemed necessary for a more complete interpretation of the findings.

Therefore the overarching aim for the current study emerging from the previously discussed rationale (which is further elaborated in Chapter 2) is:
to develop novel understandings of the interactions between ICT and travel behaviour by means of applying and enhancing existing modelling paradigms and frameworks.

In order to translate this broad aim into more specific tasks, the following three research objectives (RO) representing distinctive perspectives on the topic are defined:

- **RO1: Macro (Cross-national) Perspective** in which variations across four countries: Canada, the United States, the United Kingdom, and Norway, in terms of the existing relationships between ICT use and travel behaviour are investigated. This is done in order to investigate cross-national differences and country-specific effects that could be linked to the socioeconomic and natural conditions. Additionally, due to lack of data which would simultaneously provide information on ICT use and travel behaviour, data pooling method is employed by means of which such information is be obtained from combining separate datasets on ICT use and travel behaviour.

- **RO2: Micro (Individual-level) Perspective** in which one of the topics recently re-emerging as a result of developments in ICT, especially mobile devices is explored, namely transformation of travel time experience and its productive use. In the process of doing so, a suitable microeconomic framework is developed and tested in an empirical context of rail business travel time. However, an even more fundamental reason for devising the microeconomic description stems from the need to develop a framework which could be extended beyond the context of travel time use, to conceptualise how different types of interactions between ICT and travel behaviour emerge as a result of the possibility to participate in activities based not only in physical, but also in ICT-enabled virtual reality. On the methodological grounds, such a result provide theoretical justification and possibly richer and novel application of a number of econometric techniques, including discrete choice and hazard-based models, as well as developments in transport investment appraisal methodologies.

- **RO3: Temporal (Pseudo-longitudinal) Perspective** in which the temporal aspect, i.e. changes in the relationships between ICT use and travel behaviour
over time, are analysed and interpreted with reference to the theory of innovation diffusion (Rogers, 2003). This research question remains important for attempting to infer about potential future trajectories that ICT and travel behaviour interactions may assume. As a result of the very fast developing pace, and thus changing nature of the ICT sector, the temporal perspective is inherently faced by behavioural, conceptual and methodological challenges, especially lack of longitudinal (panel) data that could provide opportunities for employing traditional longitudinal methods of analysis. In addressing this issue, an attempt to use repeated cross-sectional data is made. Consequently, the analysis is termed ‘pseudo-longitudinal’ given that such an approach does not follow a truly dynamic character, but rather takes advantage of comparative statics over time which, nonetheless, still leads to a number of novel insights.

Thus the common thread that links all the research objectives (see Figure 1.2 below) is the need to provide additional understandings in the field of interactions between ICT use and travel behaviour by means of application and further developments in the

![Figure 1.2 Schematic representation of the logical relationship between the aim and various research objectives](image-url)
modelling techniques, especially universal and transferable microeconomic framework. Thus whilst each of the research objectives could constitute a potent topic on its own both on empirical and methodological grounds, the microeconomic framework devised as part of the RO2 can be extended as theoretical basis for aggregated relationships investigated in RO1, as well as temporal changes explored in RO3, as described in Chapter 3 and Chapter 6 respectively.

1.2 Structure of the thesis

In addition to demonstrating the overall coherence of the study, Figure 1.2 can be translated into justifying the structure of the thesis. Thus Chapter 2 provides comprehensive discussion of the background literature relevant to the topic, dealing with both conceptual meanings as well as empirical and theoretical studies. A special focus is placed on the studies dealing with travel time use and productivity for which to date no comprehensive and organised systematic review has been provided.

Following from that, Chapter 3 addresses the RO1 by employing datasets from four countries: Canada, the United States, the United Kingdom, and Norway, to investigate cross-national differences in the relationships between ICT use and travel behaviour using structural equation modelling (SEM) with a common specification. Whereas a complete dataset for such purpose is available for Canada, an implicit data pooling technique based on the k-Nearest Neighbours (k-NN) algorithm is used for the remaining countries where only separate ICT use and travel behaviour datasets could be obtained.

The next step taken in Chapter 4 constitutes movement towards the micro-level perspective addressing the RO2 by developing a microeconomic framework, grounded in the concept of a utility-maximising individual seeking to allocate time and resources through choices of activity types and durations, travel modes and routes, and ICT use. The associated econometric specifications of the theoretical results are subsequently tested in the context of business rail travel-time. Further applications and extensions are elaborated on in Chapter 5 which demonstrates applicability of the model in the context of transport investment appraisal and presents theoretical discussion on how it could explain real-life scenarios of interactions between ICT and travel behaviour reported in other studies.
Addressing the RO3, Chapter 6 includes the analysis of five cross-sectional datasets from the 2000s United Kingdom focused on gaining insights into evolution of patterns of interaction between ICT use and travel behaviour have over time. This approach takes form of pooling independent cross-sections across time (PICSaT) together with multi-group SEM. The empirical results are further interpreted with reference to the innovation diffusion theory of Rogers (2003) suggesting some trends in in the ways that ICT use and travel behaviour have been interacting, and may interact in the future.

Finally, in Chapter 7 the results arising from the three objectives are brought together to provide a synthetic perspective on the contributions developed throughout the thesis. Hence the chapter demonstrates how the theoretical and empirical results of the current research translate into novel means of modelling and understanding of the interactions between physical and virtual realities, and in particular in terms of the implications for physical mobility of individuals. Moreover, potential areas of application of the results in further research efforts as well as policy-making and industry are highlighted together with the limitations that future studies in this area could address.

The thesis contains a number of further appendices attached at the end of the volume which include additional information that the reader may find useful for further apprehension of the analyses. For additional convenience, the very final Appendix 11 contains a glossary of acronyms used in throughout the thesis.
Chapter 2
LITERATURE REVIEW

The purpose of this chapter is two-fold. Firstly, it extends the contextual foundations of the thesis by discussing the prevailing understandings of the nature of the relationships between ICT and travel behaviour as reported in the literature. Given the sizeable body of knowledge on this topic, growing since at least late 1970s, the main scope of the present chapter is to focus on the major discourses, key findings as well as limitations and shortcomings predominating in this research area, rather than to explore each study in depth. In doing so, the chapter also provides robust rationale for the previously stated RO1.

The chapter is structured in the following way. A more conceptually-oriented section 2.1 introduces a number of working definitions of four key terms recurring throughout the thesis: ICT, tele-activities, multitasking and fragmentation, and productivity. Section 2.2 discusses typology of the relationships between ICT and travel behaviour while section 2.3 reflects on the main challenges pertinent to this research field. Discussion of the empirical studies begins in sections 2.4 and 2.5 which deal with the so-called first- (or lower-) and second- (higher-) order relationships between ICT and travel behaviour, yet which are largely limited to singular dimensions of interaction. More structural- and systemic-approaches are discussed in section 2.6 while studies discussed in section 2.7 are those which attempted to investigate evolution of the relationships over time. A more detailed discussion of the interactions of ICT and travel behaviour in the form of implications for travel time use and its productivity is taken in section 2.8. The motivation for such a distinct approach in the form of a comprehensive review of the studies stems from the absence, to the best of the author’s knowledge, of a systematic discussion of this particular research direction,
despite its growing importance in a number of policy-making and industrial contexts. Moreover, such a detailed treatment provides a comprehensive background for the subsequent development and estimation (in Chapter 4 and Chapter 5) of a modelling framework seeking to conceptualise and contribute to understanding of this particular instance of ICT and travel behaviour interaction. The final section 2.9 summarises the chapter.

2.1 Conceptual discussion

Throughout this thesis, four key terms are referred to on a number of occasions: information and communication technologies (ICT), tele-activities, multitasking and fragmentation, and productivity. Due to their far from unified meanings, it is desirable to establish working definitions for the subsequent analysis while also acknowledging their possible usages in the literature.

In doing so, a balance is sought between a very detailed but narrow definition, i.e. listing all the possible existing technologies, and a general and all-encompassing one. Whereas the former would easily enable delimitation of the scope of analysis, it could be limiting in the context of emerging and novel technologies, unknown at the time of establishing the definition. A more general definition can avoid this shortcoming, though may be not restrictive enough leading to vague and possibly confusing discussions and conclusions. Consequently, desirable definitions for the current context should be restrictive and selective, but at the same time flexible in accommodating new solutions.

2.1.1 ICT

The term information and communication technologies, or ICT, has remained in use since late 1980s, having evolved from the earlier concepts of computer, communication and information technologies, or IT, e.g. Benjamin et al. (1983). Popularisation of the acronym ‘ICT’ came with the so-called Stevenson’s report on the use of technology in British schools in the late 1990s in which the authors claimed to have added (The Independent ICT in Schools Commission, 1997, p. 12):

‘…“communications” to the more familiar “information technology” […]
to reflect the increasing role of both information and communication technologies in all aspects of society.’
Since then, the concept became an all-encompassing phrase used both in academic, and more general (media) use. Unsurprisingly, this widespread usage has led over time to a considerable ambiguity in its meaning. For instance, according to the Dictionary of Media and Communication (Chandler and Munday, 2012, p. 120), the meaning of ICT can be very broad:

‘An umbrella term for all of the various media employed in communicating information: for example, in an educational context ICT may include computers, the internet, television broadcasts, and even printed or handwritten notes.’

By following this definition, virtually anything capable of processing and transmitting information could be termed ICT, including a pen and a napkin. Such a general interpretation is, however, not particularly helpful in the context of investigating modern developments in technology. The International Telecommunication Union (ITU) associates the term with the penetration and use of telephony (fixed and mobile), broadband access to Internet (fixed and mobile), TV sets, radio, and computers (ITU, 2013). However, this strongly hardware-centric approach can fail to acknowledge changes occurring in the ‘softer’ layer of ICT, e.g. popularisation of cloud-based services, voice-over-Internet-protocol (VoIP), or social networking.

The most appealing definition from the current standpoint has been offered by OECD (2003, p. 3) to describe ICT goods [and services] as those:

‘...intended to fulfil the function of information processing and communication by electronic means, including transmission and display, or use electronic processing to detect, measure and/or record physical phenomena, or to control a physical process’.

Such definition is focused on functionalities and capabilities offered by ICT while also explicitly acknowledges the role of electronic means, excluding various non-electronic (‘pen and napkin’) information processing and communication possibilities. Finally, the definition emphasises the role of ICT as a means of interacting with the reality, in which case they can be interpreted as enablers of so-called tele-activities. In that sense, ICT would include:
- fixed and mobile telephony, including modern smartphones;
- computers, including desktop, portable (laptops, tablet);
- portable digital assistants (PDA);
- other communication-capable devices, e.g. TV and radio sets, music players;
- Internet, including technologies enabling its operation, i.e. data routing, and accessing, e.g. Wi-Fi, fixed broadband, mobile broadband;
- other networks, e.g. local area network (LAN), intranet;
- various sensing tools, e.g. closed-circuit television, satellite-based sensing, automatic traffic counters;
- software utilised by the aforementioned hardware
  - based on the devices, e.g. word processing or computer-aided design (CAD) software;
  - based on multiple devices held by the users, enabling co-ordination and co-operation between them, e.g. Internet communicators (Skype, Viber), peer-to-peer file exchange software;
  - based elsewhere, including cloud computing, file storage, media streaming, and online platforms allowing variety of activities to be undertaken, e.g. online shopping, social networking or news retrieval.

The list above is by no means exhaustive, but rather provides a workable reference point given the current conditions in the ICT sector. Thus throughout this thesis the meaning of ICT will be in the sense described above, with a particular focus on those technologies which enable participation in activities, i.e. demand side, rather than influence the provision (supply side) of transport, e.g. sensory capabilities, network management, or navigation which would be conventionally fall within the domain of ITS. Acknowledging, however, that such a distinction results more from convenience and different domains of origin, rather than tangible differences, wherever possible in this thesis links will be made between demand and supply side implications with the purpose of demonstrating the need for a more unified approach to the concept of ICT.

2.1.2 Tele-activities

The concept of tele-activity (also teleactivity) has remained in continued scientific use since at least 1970s. In the broadest sense it refers to an activity which is conducted remotely (from the Greek word tête meaning ‘far off’), usually by means of ICT. In
other words, in case of tele-activity an individual is physically present at a location different to that of the activity itself which can be either remote in physical sense, e.g. tele-conferencing with someone in another city, or in virtual, e.g. in ICT-enabled virtual reality. Clearly the definitions of ICT and tele-activity are in close relation to each other. While traditional physical-reality-based activities require, by definition, physical co-presence with the individual, tele-activities rely on the experience provided to the person by so-called ‘telepresence’ defined by Steuer (1992, p. 6) as:

‘…the experience of presence in an environment by means of a communication medium.’

Depending on the quality and purpose of such experience, ICT-enabled tele-activities can provide ways of enhancing activity participation, opening new opportunities for meeting various needs, or (which is perhaps a more conventional interpretation) becoming virtual counterparts of physical-reality activities in which individual participate through their digital representation, i.e. avatar. Thus tele-counterpart to physical-reality-based work is tele-work, tele-conferencing for conferencing (or more broadly human to human communication), tele-shopping for shopping, and so on.

Figure 2.1 Hägerstrand’s maximum daily prisms for walker, driver, and flyer
Source: Hägerstrand, 1970 (reproduced with permission – see Appendix 9)
A particular attribute of virtual reality-based activities is their relative independence of spatio-temporal constraints as well as greater flexibility in terms of capability, authority, and institutional constraints that define individual’s daily activity space-time, or maximum daily prism in Hägerstrand’s time geography as shown in Figure 2.1 (Hägerstrand, 1970). In this traditional representation, an individual present at a particular location at particular time can only participate in those activities, and at such times and locations which are attainable given the spatio-temporal and capability constraints (speed of travel) imposed by Newtonian mechanics, as well as coupling and authority constraints, e.g. hours of operation or participation permission. The emergence of tele-activities considerably alters this traditional perspective by allowing individuals to project themselves via tele-presence at the speed of an electromagnetic signal (perhaps delayed by the processing speed of ICT) either to places around the globe, e.g. to participate in a tele-conference, or into virtual reality.

A number of studies revisited Hägerstrand’s approach seeking incorporation of the aforementioned effects (Ma, 2011; Schwanen and Kwan, 2008) even though Hägerstrand himself noted that ‘telecommunication allows people to form bundles [of

![Figure 2.2](image)

*Figure 2.2* Light cone and its relationship to Hägerstrand’s maximum daily prism
individuals’ and resources’ space-time paths through daily prisms] without (or nearly without) loss of time in transportation’ (Hägerstrand, 1970, p. 15). Interestingly, in such a case the extension of the daily prism would coincide with what Einstein’s special theory of relativity would refer to as a ‘light cone’ (Hawking, 1998), i.e. set of all points in space-time attainable by light or in fact any other electromagnetic signal transmitting information, including tele-presence, as presented in Figure 2.2. Thus the light cone forms a theoretical (neglecting information processing delay) spatio-temporal boundary (constraint) governing participation in ICT-enabled tele-activities.

It is also worth noting that the capabilities of ICT can (and most likely will) extend beyond enabling tele-activity participation, possibly including creation of multiple replications of identities (avatars), enhancing physical capabilities of humans (and therefore their ease of participating in physical-reality activities), or indeed facilitating travel options through more advanced ITS. Nevertheless, ICT-enhanced (tele-)activity participation is far from being immune to problems. Firstly, quality of participation may not always match that of its physical counterpart and would also be strongly reliant on efficiency of ICT infrastructure just as physical reality participation is on transport system’s operation. The former, however, can be prone to overloading, imperfections (e.g. in software), as well as sabotage (cyber-terrorism) and abuses (data and identity thefts, credit card frauds) just as transport systems are. In that sense, increased digitisation does not lead to immunity from problems, but rather their evolution.

On the nomenclatural grounds, the concept of tele-activities has often been used interchangeably with activity-specific terms, e.g. tele-shopping versus e-shopping, online shopping or e-commerce. However, the former convention is preferred here as it ensures consistency with the research conducted since 1970s to date, despite some claims about its obsolescence. Secondly, the semantic root linked to the concept of remoteness indirectly emphasises the foremost importance of changes in activity-travel patterns, rather than techno-centrism, which is desirable in the current context.

2.1.3 Multitasking and fragmentation

Multitasking and activity fragmentation are time allocation phenomena that have been hypothesised as being enhanced by the previously discussed evolution in the constraints shaping daily activity space-times of individuals. In the case of
multitasking, Kenyon and Lyons provided a very insightful discussion on the concept in the context of the relationships between ICT and travel behaviour while at the same time offering a concise definition of the concept that can be conveniently referred to in this thesis (Kenyon and Lyons, 2007, p. 162):

‘[multitasking is] simultaneous conduct of two or more activities during a given time period.’

The concept of multitasking has been variously referred to in the existing literature, especially sociology and psychology oriented at time use research, as simultaneous activities, overlapping activities, concurrent activities, time-sharing activities, parallel activities, primary and secondary activities, or polychronicity (Circella et al., 2012; Floro and Miles, 2003; Gershuny and Sullivan, 1998; Harvey, 1993; Kenyon and Lyons, 2007). The concept of multitasking itself is sometimes used in the context of describing an ability of a person to be involved in different tasks such as research projects, without the requirement for actual temporal concurrence (Patanakul and Milosevic, 2008). While closely related to the definition of Kenyon and Lyons, it essentially refers to task management over time, which may not necessarily coincide with the temporally simultaneous participation in activities.

The importance of multitasking phenomenon lies in its potential to relax the conventional microeconomic time allocation theory assumption that the total duration of activities an individual can conduct during a specified period is fixed, e.g. 24 hours in a day (Jara-Díaz, 2007):

$$\sum_{\nu} \tau_{\nu} = \bar{\tau}$$

where $\tau_{\nu}$ denotes duration of a particular activity $\nu$ individual is engaged in during a fixed period $\bar{\tau}$. However, multitasking by definition allows concurrent participation in a number of activities. Pawlak and Polak (2010) modified the constraint 2.1 to allow for any arbitrary number of concurrent activities:

$$\sum_{\nu_1=1}^{J} \sum_{\nu_2=1}^{J} \ldots \sum_{\nu_K=1}^{J} \left( \frac{[\bar{\kappa} - \kappa_{\nu_1 \nu_2 \ldots \nu_K} + 1]}{\bar{\kappa}!} \right) \delta_{\nu_1 \nu_2 \ldots \nu_K} \tau_{\nu_1 \nu_2 \ldots \nu_K} = \bar{\tau} \quad \kappa_{\nu_1 \nu_2 \ldots \nu_K} \leq \bar{\kappa} \quad (2.2)$$
where $J$ denotes the universal choice set of activities, $\bar{\kappa}$ is the maximum number of activities that can be undertaken concurrently, $\kappa_{i_1i_2...i_\bar{\kappa}}$ is the number of activities undertaken concurrently for a particular combination of activities $v_1v_2...v_\bar{\kappa}$, $\delta_{v_1v_2...v_\bar{\kappa}}$ is an indicator variable equal to unity if a particular combination is feasible and null otherwise, $\tau_{v_1v_2...v_\bar{\kappa}}$ is the total duration of episodes of $v_1v_2...v_\bar{\kappa}$.

The constraint 2.2 can be understood as a summation of all elements of the $\bar{\kappa}$-dimensional symmetric tensor whose elements represent durations of particular combinations of activities undertaken simultaneously, i.e. sharing the same time interval. Since a particular combination of activities will appear more than once in a tensor due to the symmetry, an appropriate combinatorial adjustment is required to avoid double-counting. In the case of simultaneity, i.e. $\bar{\kappa} = 1$, the formulation 2.2 reduces to that of 2.1. An alternative approach is to redefine activities undertaken simultaneously as separate activity bundles which, however, would result in the universal set $J$ becoming the power set of the number of possible activities difficult to handle for analytical purposes.

However, as previously discussed developments in ICT have increasingly enabled participation in activities which are less (if at all) bound to physical locations, or which are enhanced and facilitated by technology. This property has been hypothesised to lead to increased opportunities for multitasking. However, there are two interlinked limitations to multitasking phenomenon: attention span and efficiency. Attention span refers to the ability of a person to devote their cognitive and physical abilities to activities he or she is engaged in at a particular time (Kenyon and Lyons, 2007), and also constitutes a Hägersträndian capability constraint. For example, talking to a person while walking is rather unproblematic, but browsing inbox on a smartphone while driving in congested conditions could prove more burden- and troublesome. Without reliance on replicated, perhaps augmented with artificial intelligence identities or brain-assistance technologies, attention span of a human is what ultimately limits the capability to multitask, though the actual limit would be largely individual-specific.

The attention span can also influence the efficiency of multitasking in terms of the output from an activity (satisfaction, productivity, quality among others) relative to a
case where activities are undertaken separately, i.e. monotasking (Circella et al., 2012). A simple example of synergetic effects for activities is listening to music while driving (or working for some individuals). On the other hand, negative (disruptive) effects could include working (or at least trying to) and being talked to by a colleague. In general, the actual effects would normally be strongly individual-, and situation-specific. In the particular context of travel behaviour, multitasking and its efficiency has gained interest due to potential implications for travel experience, time use and productivity, given the increasing possibility to undertake activities, especially ICT-enabled, while travelling. A more detailed discussion on these aspects is included in section 2.8 since it also constitutes an important aspect of the microeconomic model developed in Chapter 4 and Chapter 5.

Another phenomenon closely related to that of multitasking is that of activity fragmentation which describes relaxation of the traditional boundaries defining spaces and times characteristic to participation in certain activities (Couclelis, 2009, p. 1560):

‘Instead of occupying compact chunks inside the daily prism, ICT-aided activities tend to disintegrate into sets of discrete tasks which get spread out across places and over time.’

In other words, fragmentation refers to conditions in which conventional hours and locations typical for activities, e.g. work between 9 am and 6 pm in an office, become increasingly invalid as a result of ICT-enabled flexibility, effectively blurring boundaries between times and spaces reserved for particular types of (Lenz and Nobis, 2007). A particular manifestation of could include responding to e-mails at home in the evening, perhaps while watching TV with family, reflecting blurring between work and personal time-space. The empirical results presented by Lenz and Nobis (2007) provided evidence for existence of a population segment characterised by fragmented lifestyles, though noting that it still remained to be determined whether fragmentation was only a feature of particular sociodemographic group, or a trend spreading in the society due to the proliferation of ICT.

2.1.4 Productivity

The hypothesis of multitasking efficiency having implications for productivity naturally raises questions regarding what is meant by the latter, especially that its
meaning and use may vary depending on the context. This potential ambiguity calls for provision of a working definition, especially given the term’s subsequent importance in the subsequent analyses.

In the realm of classical economics, the term ‘productivity’ is used to describe the relationship between total output obtained in a particular production process, and the amount of inputs (also termed factors) to that process. Some of the simplest indicators of productivity include average and marginal products of an input, measuring the total output per unit of input and additional output obtained from employing additional unit of the input respectively (Varian, 2010). However, while at macro and meso scales, measures of productivity can be obtained in a reasonably straightforward manner through indicators such as gross domestic product and number of labour hours (Jones, 2002), the situation becomes much more cumbersome at a disaggregate, micro level of an individual worker. In an industry-focused, fordist economy of reasonably well-defined units of input (labour hours) and output (e.g. car components, tonnes of steel, number of trees cut), a measure of productivity at a very fine level and per specified unit of time can be estimated in a relatively straightforward manner (see e.g. Nicholls et al., 2004).

In the case of knowledge professionals, operating in a service-focused information economy, frequently as part of a larger team, measuring output per capita would unsurprisingly be much more challenging task. In such cases, wages would be used to serve as a long run approximation to individual’s productivity together with less conventional measures such as number and impact of publications, number of discoveries and patents, supervisors’ assessment, sales records, level of earnings, task sophistication, work-samples’ quality, marginal impact on firm’s value added, or even risk of losing job (Carayol and Mireille, 2006; Dodgson and Gann, 2010; Kellogg, 1986; Narin and Breitzman, 1995; Skirbekk, 2003). However, such measures neither fully recognise the diversity of tasks, nor always reflect short-term, e.g. hourly, fluctuations in workers’ performance which have been proved to exist by studies in engineering, economics, ergonomics, safety analysis and occupational medicine as a result of natural circadian rhythm, sleep amount, light exposure, and various other conditions of the surroundings surrounding amongst others (Bryson and Forth, 2007; Dawson et al., 2011; de Mello et al., 2008; Folkard and Tucher, 2003; Klerman and
Hilaire, 2007; Spencer, 1987; Van Dongen and Dinges, 2007; Wood and Magnello, 1992). The importance of taking into account such temporal variability arises from their potential significance in determining activity choice in conditions where individuals can more freely decide on their time and location of participation, i.e. the conditions facilitated by ICT-enabled tele-activities.

An alternative approach could be to rely on measures relative to a specific reference threshold which traces back to the method of stochastic frontier analysis developed in the 1970s as a means of investigating inefficiencies in production (Aigner et al., 1977). Such an approach found application also in the contexts where output may be difficult to measure, e.g. technology transfers (Siegel et al., 2003). On the other hand, studies dealing with flexible work arrangements tended to use traditional, office-based setting as a reference point to assess relative performance of the workers working in alternative locations such as home or transport modes (Dutcher, 2012; Fickling et al., 2008; Hensher, 1977). Such an approach is suitable also for the current research context where a reasonably universal indicator is required, and where a reference point can be intuitively defined as a traditional (physical) office setting. Thus the following operational definition of productivity is proposed, based on Hensher (1977) and Fickling et al. (2008):

‘The time requirement to achieve certain task at a reference (office) location at the usual conditions relative to the time needed to accomplish the same task at the currently prevailing conditions.’

An additional convenient aspect of the definition is that it allows the use of either objective (amount of inputs and outputs) or subjective (self-reported) measures of productivity. The latter strategy, whilst convenient from the point of view of data collection protocols, e.g. questionnaires as compared to controlled experimental setting, is subject to potential biases associated with whether individuals can and are willing to accurately estimate their productivity as a result of a moral-hazard-prone setting, Hawthorne effects, or impacts of variations in instantaneous well-being, mood, and feelings (Cervone et al., 1994; Foster and Rosenzweig, 1994; Westfall, 2004).
The final aspect concerns the impacts of ICT on productivity which, in the traditional theory of economic growth setting originating in the works of Solow, Swann, and Romer would be expressed in terms of changes to the way that labour and capital are combined, i.e. total factor productivity (TFP), or more efficient generation and application of ideas and innovations (Jones, 2002). These effects, on the other hand, would be argued to result from ICT-enabled exchange and dissemination of information as well as easier storage, navigation within, and creative manipulation of the existing stock of ideas (Dodgson et al., 2005). Thus the source of growth would come from what Dodgson et al. (2008) termed ‘think’ and ‘play’ phases before implementation of the initial ideas in the market environment, i.e. the ‘do’ step.

Nonetheless, whereas understanding and measuring the growth coming from expanding ICT industry (capital and labour) is straightforward, changes in TFP may be more difficult to detect and explain, especially at a very disaggregate level of a company or an individual worker. A number of researchers indicated changes in productivity resulting from introduction of ICT in companies amounting up to about 30% (Becchetti et al., 2003; Grimes et al., 2011; Maliranta and Rouvinen, 2006). Carayannis et al. (2013) discussed different ways in which smartphones can influence executives’ productivity, noting that such impacts encompass multiple dimensions, including ability to create and co-ordinate connections with social networks, maintaining work-life balance, or being able to react to unexpected situations, including ‘unexpected relevance’ (Carayannis et al., 2013, p. 468). Additionally, ICT could facilitate flexible working schemes, leading to reduced supervisory and administrative costs, and capitalising on better time allocation to work and non-work activities during the peak productivity periods though possibly at a risk of blurred boundaries between work and personal time and long-term implications for productivity and well-being (Golden, 2010; Hill et al., 1998). However, the results of an extensive review conducted a decade ago indicated inconclusiveness regarding the productivity impacts of such practices (Bailey and Kurland, 2002)

2.2 Typology of the relationships between ICT uses and travel behaviour

Given the complexity and extensiveness of the research field dealing with ICT and travel behaviour interactions (relationships), a systematic approach to discussion of
the existing discourses appears essential. This can be achieved by noting that each study conducted to date can be defined in terms of three dimensions characterising its scope and research design (see Figure 2.3 below):

- order (or level) of interaction of the relationships, which follows the distinction introduced by Salomon and Mokhtarian (Mokhtarian, 1990; Salomon, 1986) in terms of whether the investigated impacts were those that would influence activity-travel patterns directly (first/lower order), or via changes in other systems and sectors (second/higher order);
- singular versus structural approach, which describes whether the study dealt with a single, or a number of (structural) dimensions of ICT use and travel behaviour simultaneously;
- cross-sectional or temporal character, which describes whether the investigation was undertaken from a cross-sectional (atemporal) point of view, or longitudinal, i.e. seeking to explore changes to the interactions over time.

Whilst the distinction suggested in Figure 2.3 may not be complete in terms of other aspects which could distinguish approaches (e.g. qualitative versus quantitative, single or multiple samples), it is sufficient as a means of allocating the reviewed studies according to their relative positions across the three dimensions which should also provide efficient signposting in the discussion. A brief description of each of the

![Figure 2.3 Schematic representation of the approaches in the studies on ICT and travel behavioural interactions as described in the sections 2.4-2.7](image-url)
dimension is presented in order to clarify the scope of sections 2.4 to 2.7 (recall that section 2.8, while in principle falling within the scope of section 2.4, is treated differently due to its distinct character of a systematic literature review).

2.2.1 First (lower) versus Second (higher) order interactions

According to the taxonomy introduced by Salomon and Mokhtarian in late 1980s and early 1990s (Mokhtarian, 1990; Salomon, 1986), one which has remained remarkably stable over the years, interactions between ICT and travel behaviour can occur at different levels (Figure 2.4).

![Diagram showing First and Second-order interactions between ICT and travel behaviour]

**Figure 2.4** First- and Second-order interactions between ICT and travel behaviour

At the lower (first) level, interactions involve only direct changes in the existing activity-travel pattern. These relationships, include substitution, complementarity, modification, and neutrality, and have remained the theoretical cornerstone of the ICT and travel behaviour studies since the early 1990s.

Substitution takes place when an individual chooses to conduct activity by means of ICT, i.e. as a tele-activity, rather than in physical reality which reduces or even eliminates the need to travel. In its pure conceptual form, substitution should result from individual still undertaking an activity, but in its ICT-based form instead of travelling to a location where physical activity would have been undertaken. In practice, however, the research studies frequently identify net substitution as measured by a general reduction in the amount of travel. Given that substitution could in theory lead to reductions in traffic volumes and congestion, it tended to be overemphasised effect leading to initial perceptions of ICT as panacea to transport network overloading (Salomon, 2000, 1986).
An opposite effect to that of substitution is complementarity (also termed generation) in which case use of ICT is hypothesised to increase the amount of travel. Such situation is supposed to result from ICT-induced easier access to information and cheaper communication leading to increased awareness of various opportunities, also at more distant locations. Moreover, cheaper communication capabilities provide a means for maintaining larger social networks and the consequent increased exposure to social contacts, potentially translating into additional demand for meetings in physical reality and thus travel. Such effects could emerge at different scales, ranging from local leisure-related meetings to global professional networks and expansion into new markets with the consequent need for international business travel as will be discussed later in section 2.4.3.

While substitution and complementarity constitute extreme cases of interaction between ICT and travel behaviour, focusing on the sheer amount of travel, more subtle relationships modifying activity-travel patterns are also possible. They are usually defined in situations when a trip still takes place (or part of it) but as a result of ICT use its characteristics are changed in terms of:

- trip purpose(s) and/or destination(s);
- trip timing;
- route;
- mode(s) of travel;
- use of travel time (within the same mode), including its productivity.

While the first four cases constitute well-established components of traditional travel demand modelling frameworks, the last effect, i.e. travel time use and productivity, has only recently attracted renewed attention from transport researchers partly due to developments in ICT (Lyons and Urry, 2005). An additional feature characterising the modification effects is that it can co-exist with either substitution or complementarity, because it is not mutually exclusive with either of these effects. Hence, while ICT may lead to reduced travel amount, shifting in the trip timing is also possible. In fact, Hjorthol (2002) noted that such mixtures of effects would be predominantly observed in reality as opposed to the sheer changes in travel amount.

The final effect of neutrality can in fact be considered a limiting case of the other three types not existing. However, such a situation could also arise as a result of
substitution and complementarity cancelling each other resulting in net neutrality. Though possible in principle, evidence for such effects are usually more difficult to obtain as detailed information on pre- and post-ICT use activity-travel behaviour would be required to investigate rearrangements in time allocation and transport use patterns.

At the same time, higher order interactions involve ICT influencing other aspects of individual lifestyles (residential choice, mobility and time use preferences, car ownership) or even society and economy (social norms, urban form, smart infrastructure provision, market organisation) which can subsequently affect activity-travel patterns. Clearly, such higher order interactions would usually take longer time to take place than the first order interactions due to various rigidities including durations of rental contracts, investment time spans, regulations’ design, introduction and implementation, as well as habits, customs, and lack of trust for novel technologies among others. As such rigidities are rarely present in isolation, deeper understanding of how exactly higher order interactions take place has proved difficult on most occasions especially given the time span during which they take place, i.e. years, decades or even generations. Consequently, any study that deals with such interactions would most likely include a significant element of speculation with rigorous evidence for causality virtually impossible to establish given the complexity of simultaneous interactions, often of non-linear character, and dealing with concepts often difficult to quantify (trust, norms, or fashion)

It should be noted, however, that the two different levels of interaction are artificial constructs, and would normally be closely interconnected, e.g. long-term substitution of activity could only occur if its tele-counterpart is trusted. Nevertheless, the distinction has proved useful as a means of presenting the scope, and perhaps time horizon over which particular studies investigate the interactions.

2.2.2 Singular versus structural approaches

Another dimension along which the studies may be classified deals with whether the scope was limited to a single aspect of ICT use and travel behaviour interaction, or whether a wide, systemic (structural) understanding was sought. The former approach would conventionally consist of either estimating a single outcome variable model, or a narrow discussion of a specific instance of interaction. On the other hand, the latter
approach would seek to incorporate multiple components in a single framework, e.g. different uses of ICT and different aspects of travel behaviour as well as hypothesised relationships between them in an attempt to provide a holistic view on the system’s functioning, estimated by means of structural equation approaches or jointly estimated models. More qualitative approaches in these instances would perhaps deal with a higher level discussion of transformations in a society, norms, and economy identifying particular trends as indications for coherence (or its lack) of the proposed understanding.

2.2.3 Atemporal (cross-sectional) versus temporal (longitudinal) approaches

The third dimension concerns the role that time plays in the studies. Studies classified as atemporal would focus on a cross-sectional analysis of a sample collected at a particular point of time, and without explicit or implicit inclusion of time as a covariate. Temporal studies, on the other hand, would seek to explore changes and dynamics in the relationships, by either explicitly or implicitly incorporating time as a variable of potential impact.

2.3 Challenges associated with investigating the relationships between ICT and travel behaviour

Before commencing the discussion on the existing empirical studies, it appears essential to shed light on a number of challenges as well as possible caveats and limitations that researchers would be likely confront. A brief consideration of this kind appears especially important and justified given the numerous conceptual, empirical and methodological challenges that tend to be associated with this domain (Foss and Couclelis, 2009; Golob and Regan, 2001). While such challenges are usually interlinked, structuring the discussion around three broad themes, namely the nature of causalities, confounding with other processes, and context specificity, is believed to aid understanding the caveats the existing research contributions, including this thesis, are subject to.

2.3.1 The nature of ICT and travel behaviour causalities

Perhaps the most important issue which has received surprisingly little attention in the studies despite its fundamental importance concerns the actual direction of causality between ICT use and travel behaviour. Arguably, the early studies exploring such
interactions took as given, and were perhaps justified in doing so, the fact that emerging ICT could be taken as exogenous impacts that influencing some pre-established travel patterns, e.g. via substitution or modification of trips. However, over the years the domains have become increasingly interconnected in which case not only would physical mobility patterns be adjusted in response to acquisition and use of ICT, but technological innovation and adoption could be motivated by particular, perhaps not completely satisfactory activity-travel patterns. Thus in a simple example of ICT-enabled remote (tele-) work, a particular commuting pattern could be expected to change as a result of the individual adopting tele-work arrangement. However, it would be also possible to argue that introduction and adoption of such an arrangement was motivated by the existing travel conditions, in which case both ICT and travel behaviour would simultaneously determine each other. Such bi-directional causalities are hardly novel phenomena in travel behaviour domain, encountered for instance in the cases of interactions of activity-travel patterns with built environment and residential decisions (Mokhtarian and Cao, 2008), or vehicle utilisation (Hensher, 1985). Even though the issue has also been identified in the present domain, e.g. in the context of relationships between tele-shopping and retail accessibility (Cao, 2012, 2009; Cao et al., 2013), or in studies dealing with structural relationships (see section 2.6), surprisingly large number of studies have retained the implicit assumption of exogenous ICT influencing travel behaviour without even acknowledging its existence.

Yet as simple as it is to provide examples of different directions of causality between the two aspects of behaviour, it is much more challenging to establish or disprove their existence and magnitude. Perhaps the two main and closely entangled causes for this status quo arise from the dynamic nature of the ICT sector itself as well as lack of agreement regarding what aspects of ICT-related behaviour should be looked at from a longitudinal point of view. The former results from the very nature of the present pace of technological progress in which emergence of novel ICT and their uses sometimes exceeds time horizon over which necessary data could be collected and understandings formed. For example, a panel dataset collected over the course of the 2000s decade would see a transition from a limited to almost complete cellular phone penetration in the market, increasing broadband subscription, but also emergence and fast take-off of mobile broadband subscriptions (recall Figure 1.1).
Underlying these trends was, however, evolution in the capabilities well as emergence (or their introduction to the markets) of new forms of ICT, such as smartphones or tablet computers, as well as their novel uses, e.g. microblogging or social networking. A question that arises in light of this apparent quickly evolving technological sector is thus what aspects of ICT use (and also perhaps travel behaviour) should be measured to understand such patterns of evolutions? Among possible candidates that have been in use over the past decades are frequency of use, types and duration of activities, expenditure, types of devices, or even opinions though each of these indicators would suffer from possible limitations and criticisms. For instance richness and proficiency of use of particular ICT measured by duration could confound the actual high level of engagement with struggle to use or, in case of comparisons across time, changes in the processing capabilities.

Perhaps a step forward would be to move away from discussing ICT in terms of particular products and services, themselves very volatile, and think about ICT in terms of their more fundamental capabilities, such as relaxation of spatial and temporal constraints on participation in activities, or enhancement of the ability to simultaneously perform multiple tasks (or have them performed), along the lines outlines in the conceptual discussions of section 2.1. In addition, traditional data collection protocols such as activity and travel diaries may be insufficient to record activities conducted in virtual reality, as for instance switching from word processor to social networking website can happen virtually instantaneously, sometimes almost subconsciously. Recording such events in the era of increasing simultaneous use of time for multiple activities and at multiple places (multitasking and fragmentation) could be very burdensome for the respondent (Mokhtarian and Meenakshisundaram, 1999) thus putting into question the objectivity and even feasibility of such data collection techniques. Furthermore, it is possible that certain sample and self-selection biases could occur in the course of data collection as a result of ease of data collection among certain groups, willingness to reveal detailed information, or different levels of satisfaction experienced from particular ICT-travel interaction contexts (Mokhtarian and Salomon, 1996a). Hence, the lack of agreement on what aspects of ICT use are to be measured, perhaps fuelled by the interplay of limitations of the various indicators and feasibility of their use as well as the extent to which they could reflect the
evolving technological capabilities, may have contributed to a situation where longitudinal data collection efforts have been a rarity rather than a common practice.

The importance of gaining such consistent, longitudinal perspective stems from the fundamental property of causal relationships requiring the cause to precede the effect – a condition that is notoriously difficult, if at all possible, to robustly prove by purely econometric means based on non-experimental, cross-sectional data (Pearl, 2000). In fact, even in the experimental conditions, the fundamental problem of causal inference will ultimately limit the ability to prove causality since it is not possible to observe the treatment effect on the same unit at the same time (Holland, 1986). However, by assuming that similar units which are not exposed to a particular cause (treatment) can approximate the counterfactual history of the exposed units, it is possible to provide statistically measurable evidence for causality. However, for this purpose information on pre- and post-exposure attributes of the units, i.e. respondents, appears fundamental as emphasised in the analysis of causal inference summarised in the form of so-called Rubin’s causal model (Holland, 1986; Rubin, 1974).

Thus in the convenient case of availability of panel data, the traditional methods, such as Granger causal test and more general vector autoregressive models, could be employed to provide evidence for direction (or bi-direction) of the interactions (Dougherty, 2011; Wooldridge, 2013). In such cases, a record of variables for a set of individuals over time can help in establishing to what extent a particular difference between otherwise similar respondent is associated with differences in some other, response (outcome) variables.

On the other hand, when dealing with the cross-sectional datasets, pre- and post-exposure information of this kind is not available by definition. Thus ambiguous, possibly bi-directional nature of the causal relationships between ICT and travel behaviour, may require employment of other set of tools that either determine the direction, or attempt to control for the presence of reverse causality. Such tools include (Greene, 2012; Mokhtarian and Cao, 2008):

- Direct respondent questioning, which seeks to obtain as complete information about the postulated relationship as possible, including its directionality, by directly questioning the respondents. This approach requires either fortunate
presence of the suitable set of questions in the secondary survey, or the researcher's ability to obtain such information through follow-up survey.

- **Use of two-stage regression techniques and instrumental variables (IV)** with the IV required to be strongly correlated with ICT use and not travel behaviour, or vice versa. Consequently, the method would depend on the presence of suitable variables which could be justified to serve as instruments. However, such variables not only need to be present in the datasets (over which a researcher may not have control) but there must also be robust evidence on their appropriateness as instruments which could be difficult in the area of frequently contradictory results as well as the previously discussed prevalence of hypothetical, sometimes anecdotal relationships. This is especially important in light of the results presented by Mayston (2009) who argued that poor selection and performance of IV could in fact further increase bias in the subsequent analysis. As a result, the IV method appears to be applicable only in limited contexts, where at least some degree of consensus regarding the influence of various factors exists.

- **Emulation of an experimental environment** where a particular treatment has been assigned to an individual, in an effort to explore the hypothesis of its causal effect on the variables of interest. The conventional analysis of the treatment effects requires information on the respondents before and after the treatment has been assigned in order to infer about counterfactual history (outcome), i.e. what would have been the individual’s behaviour had it not received the treatment, such as adopting ICT. For such contexts, there are well-established methods such as difference-in-difference estimators. In the cross-sectional setting, such conditions could be emulated by means of propensity score matching or regression discontinuity design (Bryson et al., 2002; Greene, 2012). Nonetheless, such approaches would still require, in principle, a particular *a priori* belief in what in fact constitutes a treatment, be it a particular use, or a combination of uses of ICT, or a specific aspect of travel behaviour. Still, the actual decision determining the emulated design of the experiment would still lie in the hands of the researcher. Given the sheer number of potential combinations of ICT uses, or travel behaviour characteristics that could be interpreted as treatment effects, such approaches while making a bold attempt to provide evidence for causal
relationships, would still be prone to the criticisms regarding not considering other possible interpretations of the reality.

- **Model (re)structuring**, which attempts to address all possible simultaneous causal effects through their explicit incorporation in the modelling structure, e.g. using joint (choice) or structural equation models, depending on the character of the available variables. However, in the joint case where multiple aspects of ICT and travel behaviour are usually observed, the number of possible alternative behaviour patterns would become impractical to handle due to the sheer number of possible ICT-travel behaviour combinations. For example, in the relatively limited, 7 variables case of Chapter 6 (Table 6.2), the number of possible ICT-travel behaviour patterns an individual could adopt would already be prohibitively high, i.e. 1536 (4x4x6x2x2x2x2). In addition, the actual choice sets faced by individuals would not normally be observed in such cases, introducing further possible biases in the analysis. An alternative approach to the joint choice model would be structural equation modelling, in which the hypothesised relationships are specified, including (possibly) bi-directional causalities. Nevertheless, in its very flexibility, SEM can be used to capture various different patterns of interrelationships between the variables, and hence postulated causal structures. More precisely, SEM can yield results in which distinctly different postulated causal structures are empirically indistinguishable, as judged on the grounds of goodness-of-fit statistics. As a result, a strong theoretical and behavioural justification is always required for the presence of a particular relationship in the SEM, even contrary to statistical measures (Golob, 2003), as the SEM per se does not guarantee that the proposed specification represents accurately the true behavioural process. Rather than that, it provides a way of investigating the quality of the postulated theoretical model of reality which should provide a logic and coherent justification, and hence evidence for causal character of the relationships (Pearl, 2000). In the particular conditions of the ICT and travel behaviour interactions domain, however, the researchers may be comparing different possible specifications of SEM, yet their specifications will almost always be prone to criticisms on the grounds of some other evidence requiring a different model specification. While SEM could also accommodate some bi-directional relationships, by their very nature such relationships could lead to models being recursive in which case the specification’s identification
would not be assured (Golob, 2003). Such a situation would leave the researcher in a position of struggle for an estimation that is identifiable, but not necessarily reflecting the initially postulated representation of reality. Whether such practice is to any extent superior to an approach of non-recursive specification, representing a particular behavioural representation based on a number of clearly stated behavioural assumptions remains an open question, and possibly beyond the scope of this discussion.

If none of these methods is applicable, or does not completely eliminate the problem, it is the duty of the researcher to highlight potential consequences and caveats that the results will be subject to. In the ideal (and a very fortunate) case when the postulated specification does accurately represent the nature of the underlying behavioural process and its causal structure, no concern regarding the quality of the results is required. This would also be the case in a situation, when exogeneity of certain variables can be assumed in a given frame of reference, e.g. variables involving more long-term decisions, such as acquisition of ICT, as compared to the outcome variables such as immediate activity choice decisions.

Another level of severity of consequences would exist if the endogeneity problem concerned only a particular set of coefficients, in which case some of the factors would remain unbiased. More precisely, Mayston (2009) demonstrated that this would depend on the extent to which a postulated exogenous variable is correlated with other variables, especially those displaying the reverse causality problem. In the event of such a correlation being insignificant, the coefficient would remain unbiased, at least in the ordinary least squares case. Consequently, variables which would not be strongly linked with the potentially endogenous variables, should not be affected, whilst those affected would on average be biased upwards (Wooldridge, 2013, p. 536). In the most severe instance of endogeneity, the bias in parameters would affect all parameters, and therefore the overall quality of the specification putting into question the overall soundness of the model and its results.

The bottom line of this discussion is that models developed in constantly evolving and uncertain areas such as the ICT and travel behaviour field, are largely forced by the nature of the problems and the available data, to make certain assumptions regarding exo- and endogeneity of the relationships, and hence directions of causality. These
could be, in almost all instances, challenged with counter-arguments based either on other scientific studies, given the overall lack of consensus in the existing studies (which will be demonstrated in the following sections) or even on simple anecdotal evidence. As a consequence, contributions in such fields should in most cases be taken as possible realisations of behavioural mechanisms observed under specific circumstances, and not as definite and easily transferable explanations of process in the manner specific to natural sciences.

2.3.2 Concurrent processes

Another pertinent issue present in the current research domain concerns the possible presence of other, concurrent influences on the interactions between ICT and travel behaviour. Such influences could include the previously discussed evolution of technology, but also policies, demographic structure, preferences, norms, habits, or fashion amongst other things. The actual impacts of such processes can take place over longer temporal horizons, and hence may be confounded with other higher order interactions. For example, changes in travel behaviour patterns could result not only from impacts of ICT, but also from particular policies or fashion that emerged during the period of interest which, if not accounted for, could lead to biased conclusions about the nature of the relationships.

Moreover, ‘cohort/generation effects’ may become more profound in light of the fact that different generations would be raised being exposed to different levels of technological capabilities of ICT. Whilst one could claim that in the past it could be reasonably expected that with age and increased prosperity a typical (at least in the ‘Western’ sense) individual would aim to own a car and move to the suburbs - a chain of events equally valid in 1960s as in 1980s, such long-term stability of relationships may not be the case in the realm of ICT and travel behaviour interaction. For instance, significant interest has emerged in the willingness to give up personal information such as preferences, location, or current activities with some evidence that age may considerably affect attitudes and practices (for a detailed systematic review see Bélanger and Crossler, 2011). Perhaps only when the current generation reaches its adulthood, and assuming the suitable data is then available, will more complete insights into such phenomena be available.
2.3.3 Context specificity

The final caveat concerns the geographical and cultural context-dependence of the studies. Due to comparatively low number of cross-national studies (a gap which partially motivates RO1) and lack of harmonisation in data and methods employed, the observed results are rarely directly comparable (Mokhtarian et al., 1995). While it is justifiable to expect significant differences in terms of ICT use between various countries due to different levels of economic development, culture and attitudes (including attachment to car-based travel), as well as natural environment (Foss and Couclelis, 2009), more research towards establishing country- and region-specific effects on interaction between ICT and travel would appear warranted. Arguably, more research efforts towards this direction of inquiry could aid explaining some of the apparent contradictions in the estimated relationships, possible resulting from ignorance to specificity of particular group of individuals, time, location, or to other contextual factors.

2.4 Studies on the first (lower) order interactions

Studies exploring the first order interactions between ICT and travel behaviour tended to focus on particular functional areas defined in terms of the main (tele-)activity that the individuals would seek to participate in. As a result, the following sections 2.4.1 to 2.4.5 describe the cases of tele-work, tele-shopping, tele-activities involving interpersonal communication (tele-conferencing), tele-leisure, and tele-services with the latter being an umbrella term for tele-banking, tele-medicine, tele-government, and tele-education.

2.4.1 Tele-working

To date, studies dealing with the possibility of conducting work remotely have been the most abundant due to the large imprint of commuting-related travel. The coining of the phrases ‘tele-working’ and ‘tele-commuting’ are usually attributed to John (Jack) Nilles in 1970s though studies dealing with such work options have been conducted since at least early 1960s with the energy crisis of 1970s significantly contributing to popularisation of the topic (Bailey and Kurland, 2002; Haddon and Lewis, 1994; Mokhtarian, 2009).
Nonetheless, there exists a certain degree of conceptual confusion and vagueness in the meaning of *tele-commuting* and *tele-working* despite their seeming interchangeability. In discussing the issue, Mokhtarian noted that that the former concept carried implicit meaning of reduction or even elimination of physical commuting while the latter captured work-related activities which were not conducted in a specific, traditional workplace (Mokhtarian, 1991a). The two terms coincide in a situation of home-based work where commuting is eliminated and work is undertaken outside the office environment which appears to implicitly underlie studies discussing the commuting-related travel reduction due to ICT proliferation. In the current case, however, it is the tele-work as a more general concept that is the focus of scrutiny acknowledging the possibility of the consequent case of tele-commuting.

### Table 2.1 Potential chances and risks of tele-work adoption

<table>
<thead>
<tr>
<th>Effects</th>
<th>Employees</th>
<th>Organisation</th>
<th>Society</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive</strong></td>
<td>• work comfort</td>
<td>• <em>productivity</em></td>
<td>• global competitiveness</td>
</tr>
<tr>
<td></td>
<td>• work opportunities</td>
<td>• additional wage costs</td>
<td>• energy conservation</td>
</tr>
<tr>
<td></td>
<td>• <em>commuting cost (time, money, fatigue)</em></td>
<td>• reduction (e.g. social contributions)</td>
<td>• protection of the environment</td>
</tr>
<tr>
<td></td>
<td>• <em>individual organisation of time</em></td>
<td>• <em>security of location</em></td>
<td>• problematic issues</td>
</tr>
<tr>
<td></td>
<td>• <em>residential flexibility</em></td>
<td>• rationalisation (efficiency increase)</td>
<td>• <em>conurbation</em></td>
</tr>
<tr>
<td></td>
<td>• being more independent from the organisation</td>
<td>• workspace costs</td>
<td>• structural measures</td>
</tr>
<tr>
<td></td>
<td>• <em>flexible working hours</em></td>
<td>• compensation of work overload</td>
<td>• <em>traffic situation</em></td>
</tr>
<tr>
<td><strong>Ambiguous</strong></td>
<td>• family situation (work-life balance)</td>
<td>• wage costs</td>
<td>• self-employed/employed</td>
</tr>
<tr>
<td></td>
<td>• social security contributions</td>
<td>• workforce fluctuation</td>
<td>• demand behaviour</td>
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<tr>
<td></td>
<td>• wage</td>
<td></td>
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<tr>
<td></td>
<td>• qualifications</td>
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<td></td>
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<tr>
<td></td>
<td>• work contents (utilisation of skills)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Negative</strong></td>
<td>• contacts (social isolation)</td>
<td>• overheads</td>
<td>• occupational situation</td>
</tr>
<tr>
<td></td>
<td>• work safety</td>
<td>• control</td>
<td>• data protection</td>
</tr>
<tr>
<td></td>
<td>• career opportunities</td>
<td>• opportunities to obtain information</td>
<td>• parties involved in wage settlements</td>
</tr>
<tr>
<td></td>
<td>• control (motivation)</td>
<td>• organisational effort</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• monotonic environment</td>
<td>• selection of personnel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• interruptions from household members</td>
<td>• identification with the organisation</td>
<td></td>
</tr>
</tbody>
</table>

Note: italics indicate aspects directly associated with travel behaviour and implications for transport system
Tele-work has attracted significant attention from the research community which is reflected in the sheer number of literature reviews on the topic from fields of transport studies, human resource management and labour economics (Andreev et al., 2010; Bailey and Kurland, 2002; de Graaff, 2004; Golob and Regan, 2001; Haddon and Lewis, 1994; Konradt et al., 2000; Mayo et al., 2009; Salomon, 1986; Shin et al., 2000). The original interest in the topic came from labour economics due to potential implications of such arrangements for workers’ performance in terms of productivity, satisfaction and well-being. Over time, however, it became more apparent that such working arrangements would not only yield benefits to both the employers and employees as compared to traditional, non-tele-work labour organisation (Handy and Mokhtarian, 1996), but certain costs and issues could also emerge as summarised in Table 2.1. While a more detailed discussion of each of these aspects is left over (for more details see Haddon and Lewis, 1994; Konradt et al., 2000), inspection of the table reveals that travel- and transport-related issues constitute only a small part of the potential motivation for tele-work (Bailey and Kurland, 2002; Nossum and Hjorthol, 2007), in most instances not borne directly by the employer, unless productivity impacts are significant. Thus while an estimate of saving around 25 working days per year from tele-commuting arrangements was given in the Economist (2008), it did not appear to translate readily into companies’ practices on the grounds of not conforming to the workplace culture (Wilton et al., 2011) or due to concerns about social isolation, lower promotion opportunities and blurring of the boundaries between work and personal times and spaces (Nossum and Hjorthol, 2007; Salomon and Salomon, 1984). At the same time, employers seemed to be more willing to accept occasional tele-work arrangements as a back-up strategy to handle unforeseen circumstances such as travel disruptions due to mass events, industrial actions, or adverse weather conditions (BBC, 2012; Cools et al., 2010; Currie et al., 2014; Mokhtarian, 2009, 1991b).

Despite travel conditions not always underlying the motivation for tele-work, adoption of such a working regime results on most occasions in changes to travel behaviour which motivated travel-behaviour-oriented reviews of tele-work studies (Andreev et al., 2010; de Graaff, 2004; Golob and Regan, 2001; Salomon, 1986). In the first major analysis of this type Salomon (1986) indicated that the early studies had tended to make broad generalisations without actually testing many of the
suggested hypotheses which led to prevalence of the substitution hypothesis and its popularisation in policy-making and media mainly due to its attractiveness and radicalism. Furthermore, Salomon pointed out that even if the actual tele-commuting took place, the impact on travel for other, perhaps more discretionary purposes should not be neglected. He also suggested that for any tele-work effects to have significant impact on the overall transport system, tele-commuting would need to be a part of more general labour practice and hence overall made a cautious forecast that ‘travel patterns will be modified, not reduced’ as a result of tele-work (Salomon, 1986, p. 235). Almost two decades later, two further reviews largely re-confirmed the Salomon’s remarks regarding the need for wider adoption of tele-work as requirement for significant impacts on transport systems (de Graaff, 2004; Golob and Regan, 2001). Moreover, de Graaff found that the empirical results demonstrated on most occasions that commuting and tele-commuting are imperfect substitutes at best while complementarity effects would be a feature resulting confounding with fixed effects, such as income changes, labour market specialisation, housing market segmentation, diversification for travel purposes, increasing availability in the ICT, and not an effect per se (de Graaff, 2004). However, noting a caveat that majority of the empirical studies on which these conclusions were based, he also indicated that the patterns could differ in the contexts of the developing countries. At the same time, Golob and Regan pointed out that such relationships would strongly depend on the type of working arrangement, i.e. full-time, part-time, self-employment, or the need for mobile working, i.e. in-travel work (Golob and Regan, 2001).

In the most recent summary, Andreev et al. (2010) noted that majority of the studies conducted throughout 1990s and 2000s suggested substitution of the amount of commuting measured in vehicle-miles, person-miles, morning peak-hours, emissions or number of commuting trips when tele-work arrangement was implemented. Additionally, the impact on travel for other purposes, or by other members of the household in majority of studies was found either insignificant or weakly complementary.

A seminal piece of research on tele-work (tele-commuting) were three papers produced by Mokhtarian and Salomon (1996a, 1996b, 1993) in which they investigated adoption of tele-working from both conceptual and empirical
perspectives, and presented how various constraints, facilitators and drivers interacted to allow tele-work to enter people’s perceived choice set. In their empirical findings they reported ‘a large group of people for whom telecommuting is preferred though impossible alternative due to mainly lack of awareness of such alternative, job unsuitability, or lack of managerial support and/or approval (Mokhtarian and Salomon, 1996a, p. 1859) as well as provided evidence for the importance of ICT in terms of enabling tele-work options (Mokhtarian and Salomon, 1996b).

Other factors that were identified as important determinants of the strength and direction of the interaction between tele-work and travel behaviour included various sociodemographics. In case of gender, marital status, or dwelling type, there appears to be no overall conclusion regarding the direction or magnitude of relationships, while a stronger agreement emerged regarding age, education, and income in which cases mid-aged, highly-educated, and high-income individuals and households with more children were named as more likely to tele-work (de Graaff and Rietveld, 2007; de Graaff, 2004; Hjorthol and Gripsrud, 2009; Hjorthol, 2002; Lila and Anjaneyulu, 2013; Mokhtarian and Salomon, 1996b; Mokhtarian et al., 1995; Nossum and Hjorthol, 2007; Sener and Bhat, 2010; Singh et al., 2012). Not surprisingly professional and managerial, highly-skilled and knowledge-based occupations were found as more likely to engage in tele-work practices, as were people with flexible work arrangements and operating in companies focused on minimising employee-related costs and encouraging ICT-based contact both for internal and external communication though no impacts on travel behaviour would in such cases be seen as by-products only (de Graaff, 2004; Mokhtarian et al., 1995; Nossum and Hjorthol, 2007; Sener and Bhat, 2009; Sener and Reeder, 2012; Wilton et al., 2011).

Another set of factors included the use of ICT, including computer, Internet, fixed and mobile phones, among individuals which were usually seen as enablers of home-based working (de Graaff, 2004; Felstead et al., 2005; Lila and Anjaneyulu, 2013; Sener and Reeder, 2012) though not necessarily always associated with less travel as noted by Hjorthol (2002). Furthermore, commuting conditions in terms of distance, time, and congestion, were also mentioned as significant factors though the actual causality was show to be debatable due to the hypothesis of tele-commuters choosing a particular residential destination and lifestyle leading to increased travel (Handy et
al., 2005; Mokhtarian et al., 1995; Zhu, 2012). Nonetheless, there appears to be agreement that larger distance and longer commuting time would in general be positively associated with tele-work and tele-commuting (Hjorthol and Gripsrud, 2009). In addition, car availability and intra-household car-sharing were also found important for the frequency of tele-work (Sener and Bhat, 2010; Singh et al., 2012). Also built environment, especially urban and rural characteristics, density, land use, or possibility of non-motorised travel were reported significant in the studies though the overall direction of such impacts were context-dependent (Nossum and Hjorthol, 2007; Polydoropoulou and Tsirimpa, 2012; Singh et al., 2012). An interesting comment was made by Hjorthol (2002) who noted that availability of tele-work and the consequent shift towards travelling outside the peak hours (Mokhtarian et al., 1995; Pendyala et al., 1991) could make reliable and convenient public transport operation more costly due to reduced ridership.

An important theoretical contribution was offered by de Graaff and Rietveld (2007) who developed a consumer-theory based, microeconomic approach explaining the choice decisions in terms of allocating time between leisure, in-home (tele-work), and out-of-home work. In doing so, they not only provided evidence for ICT diminishing the wage penalty for in-home workers, but also demonstrated that home and out-of-home work were imperfect substitutes, noting also that high wage earners would be more willing to tele-work as they could also afford more leisure time.

2.4.2 Tele-shopping

Another stream of research has touched upon the case of tele-shopping, also referred to as online shopping, e-shopping or e-commerce. Similarly to tele-work, the idea of conducting shopping remotely and having the goods delivered has attracted the interest of researchers since at least 1970s (Gould and Golob, 1997) though most empirical studies started to emerge only in early 2000s following an unprecedented growth in this sector (Cao, 2009; Rotem-Mindali and Weltevreden, 2013). This observation is also consistent with Salomon (1986) who had reported low number of studies dealing with tele-shopping by mid-1980s, as well as by Golob and Regan who emphasised the role of business-to-business (b2b) trade noting that evolution in technology would lead to increase in tele-shopping, i.e. ‘from bricks to clicks’ (Golob and Regan, 2001, p. 14). The focus of tele-shopping studies tended to be on the
business-to-customer (b2c) mode, seemingly a direct translation of a traditional shop-customer situation and its relations with the activity-travel patterns. Nonetheless, additional interest emerged recently in terms of customer-to-customer (c2c) dealings, mainly due to the growth in various online auctioning and trading platforms (Rotem-Mindali and Weltevreden, 2013).

Andreev et al. (2010) noted that investigation of tele-shopping may be more difficult than tele-work due to the need to understand pre-purchase, purchase, and after-purchase behaviour and its relation to travel behaviour which was also consistent with the remarks made by Cao (2009) and Mokhtarian and Tang (2013). The latter authors provided empirical evidence for the link between these various elements supporting the concern that the conventional taxonomy, such as that presented in section 2.2.1 may not always suffice to completely capture the true nature of interactions between these aspects of shopping behaviour and travel.

Salomon (1986) noted in his review that a very challenging nature of tele-shopping-related research stems from its multifaceted role combining maintenance, leisure, and social purposes which was reiterated in the subsequent by subsequent researchers (Cao, 2009; Gould and Golob, 1997; Rotem-Mindali and Weltevreden, 2013). Consequently, Salomon correctly predicted that television- and catalogue-based shopping (themselves early forms of tele-shopping) would be the first segments overtaken by developments in ICT due to their already impersonal character and likely inferiority in terms of convenience and experience. The second prediction concerned higher potential to substitute unpleasant, maintenance-related (e.g. grocery, detergents), rather than leisure-oriented, ego-intensive shopping (jewellery, clothing).

The benefits of tele-shopping as compared to travel-requiring visit to a shop were initially assumed to derive from both reduced need of costly and fatiguing trip and utilisation of more efficiently operating fleets of delivery vehicles (Rotem-Mindali and Weltevreden, 2013). This standpoint was, however, criticised on a number of grounds such as the fact that shopping might be a part of an efficient trip, e.g. commuting, and its tele-substitution may result in additional trips if all products could not have been obtained online, or if the time saved is used for another, travel-inducing purposes. In addition, if non-motorised and active modes were used for shopping trips, tele-shopping would not reduce congestion, but possibly contribute to it by
inducing additional freight transport (Cao, 2012; Golob and Regan, 2001) though research on the latter effect has remained inconclusive (Rotem-Mindali and Weltevreden, 2013). Thirdly, greater use of tele-shopping could prompt individuals to undertake (longer) trips due to increased awareness of brands and more distant outlets.

Factors that were reported significant in determining the relationships between tele-shopping and travel behaviour included sociodemographics, with young and mid-aged, highly educated individuals more likely to tele-shop (Cao et al., 2013; Farag, 2006; McKeown and Brocca, 2009). Inconclusive results were reported in case of gender, or presence of children or elderly person in the household (Farag et al., 2002; Ferrell, 2004; Gould and Golob, 1997; Hjorthol and Gripsrud, 2009; McKeown and Brocca, 2009). Also the importance of accessibility of traditional retail outlets was noted though not conclusively in terms of the direction as positive association was reported by (Cao et al., 2013) and negative by (Ferrell, 2004) and (McKeown and Brocca, 2009). While the availability of vehicles to household remained unclear (Cao et al., 2013; Ferrell, 2004) there seemed to an agreement that positive attitude towards ICT would motivate tele-shopping adoption and increase its frequency (Farag, 2006; Farag et al., 2002; Ferrell, 2004; McKeown and Brocca, 2009; Mokhtarian and Tang, 2013) though with significant heterogeneities observed by Bhat et al. (2003).

Not surprisingly, the importance of type of product was also shown to be an important determinant of tele-shopping and travel behaviour interactions with (Hjorthol and Gripsrud, 2009) reporting the substitution in case of online for book, music, or tickets to events, but neutrality for holiday trips or clothes (though with a caveat that this could differ between sociodemographic groups). Similar conclusion was reached by Noce and McKeown (2008) who indicated young people’s preference to tele-shop for clothes or jewellery, and older for furniture. Finally, (Farag, 2006) noted that the size of influence on travel behaviour of tele-shopping would also be product-dependent as certain kinds of shopping (e.g. groceries) tended to be associated with more frequent trips conducted by a larger share of population, and thus travel behaviour impacts in such segments of retail would translate into more profound aggregate consequences for the transport systems.
To date, the most prevalent methods used in this research area included simple descriptive and categorical analyses (Hjorthol and Gripsrud, 2009), single and structural equation approach, as well as discrete choice models and 2-stage regressions (Andreev et al., 2010; Cao et al., 2013; Gould and Golob, 1997). Bhat et al. (2003) used a hazard-based duration model to investigate the impacts of mobile phone and computer use on shopping behaviour. Additionally, a number of researchers discussed the tele-shopping adoption mechanisms, referring to technology adoption or innovation diffusion models described in section 2.7 (Andreev et al., 2007; Cao et al., 2013).

Despite the progress to date, understanding of the relationships between tele-shopping and travel behaviour has continued to be far from complete. For instance Cao reported on studies producing seemingly contradictory results from analysing the same datasets (Cao, 2009). Such discrepancies may have their source in a number of areas including (Andreev et al., 2010; Cao, 2009; Farag, 2006; Rotem-Mindali and Weltevreden, 2013):

- definition and measurement methods of tele-shopping and travel behaviour (person versus household, duration versus frequency, searching versus actual purchase);
- time horizon (last week versus last month);
- sample composition (Internet users, online shoppers, general population);
- presence of confounding variables such as changes to income or built environment and their spatial distribution;
- different product types (food versus airline tickets, daily versus non-daily products) and consumer habits;
- methods of data collection, potentially influencing quality of subsequent analyses given that people tended to underreport their shopping activities en route to or from somewhere, or if not provided with clear examples;
- interactions with other activities and household members and obligations.

Consequently, while a significant amount of knowledge has been amassed to date, a number of significant limitations and discrepancies continue to exist.
2.4.3 Tele-activities for interpersonal communication

Another aspect of potential interactions between ICT use and travel behaviour involves the possibility of meeting other people without physical presence, usually termed tele-conferencing or videoconferencing. Whereas distant communication was already possible in the ancient times (recall the example of Persian couriers in Chapter 1), it was Alexander Graham Bell’s telephone together with the experiments conducted in 1930s involving multiple (more than two) parties communicating simultaneously that signalled the era of instantaneous, and intercontinental (or even beyond) capabilities of communication (Denstadli et al., 2013). Dodgson et al. (2008) provided a clear example of reduction in cost of a 3-minute telephone call between London and New York which fell from $300 to about $0.20 between 1930s and 2000s, i.e. by a factor of 1500. Moreover, the recent advancements in ICT have far exceeded the capabilities of plain voice exchange and now encompass services such as data exchange, interactive visualization, or graphical rich immersive technologies of virtual reality. Whilst the actual definition of tele-conferencing provided (Andreev et al., 2010, p. 9) is strongly work-related:

‘a live meeting of two to thousands participants within the same organisation or at different organisations conducted via a telephone or network connection’

the scope of this section is extended to include non-work related meetings especially in given the progress and proliferation of cheap or free communication software based on the concept of Voice-over-Internet-protocols, such as Skype or Viber, or virtual reality, e.g. SecondLife (Beaverstock and Budd, 2013).

In the case of company operation, the invoked potential application of tele-conferencing included co-ordination within the organisation, coping with the professional duties, and easier contact with its existing partners, as well as facilitation of establishment of new links with potential clients or suppliers, or in other words, expansion of business horizons (Aguilera, 2008; Storme et al., 2013). Other benefits could include time and cost savings due to reduced travel, increased training opportunities, reduced travel fatigue, and environmental friendliness (Denstadli, 2004). On the other hand, the most notable concern reported by the researchers was the ability (or its lack) to effectively substitute face-to-face meetings. Tele-
conferencing meetings were associated with generally colder contacts, difficulty to present certain products and concepts, as well as lower prestige not suitable for sensitive meetings, which may also carry a strong non-verbal component (Aguilera, 2008; Lu and Peeta, 2009; Roy and Filiatrault, 1998) Additionally, the contexts of a meeting may play a role, as the experimental results of Greiner et al. (2014) suggested higher co-operability between respondents working in the virtual environment of the Second Life though while others noted potential difficulties in ICT-relying distributed teams, especially if not led by an appropriately skilled manager case of co-operability between members of distributed teams relying on ICT-based contacts (Bailey et al., 2012; Lilian, 2014).

In terms of the relationships with travel behaviour, Salomon (1986) claimed that the actual decision of using tele-conferencing may be in the hands of the organisation rather than its employees. Thus, he argued, the most significant impacts from tele-conferencing would be expected in the segments of costly business trips as well as secondary impacts such as reduced use of car rental services or business-class lounges, both presumably used by business travellers. Additionally, Salomon indicated tendency of the studies to focus on substitution capabilities without considering travel generation possibility which may have been stimulated by the 1970s projections envisioning 50-60% reduction in business air travel due to tele-conferencing which, by 1990s, amounted to only 2-5% (Denstadli et al., 2013; Salomon, 1986). Partly explaining this discrepancy, Mokhtarian claimed that whereas initial potential for substitution of face-to-face contact with tele-conferencing was high, adoption based on the grounds of travel time and cost savings proved notably unsuccessful (Mokhtarian, 1988). Salomon et al. (1991), having compared costs between business travel and tele-conferencing for different combinations of number of participants, duration, and travel distances, indicated higher benefit-to-cost ratio for travel as compared to tele-conferencing for shorter distances and longer meetings (though it is worth noting that their calculations were based on the early 1990s conditions). Denstadli (2004), using data from Norway, reported limited impact of tele-conferencing in terms of substitution (below 5%) and also claimed that the evidence for travel generation was rather anecdotal with tele-conferencing serving as a supplementary communication channel. At the same time, Roy and Filiatrault provided evidence for significant substitution in their study in Canada where 25%
respondents claimed to travel less because of tele-conferencing (Roy and Filiatrault, 1998) while Arnfalk (2002) reported a very high substitution (64%) of business travel with tele-conferencing in a sample of companies.

As for the use of ICT-based communication for non-work (social) purposes, Gripsrud and Hjorthol found that people using chatting and discussion groups tended to make more visiting trips per day pointing towards complementarity effect (Hjorthol and Gripsrud, 2009). On the other hand, Kamargianni and Polydoropoulou (2013) found among Cypriot teenagers that those who spent between one and two hours, or more than four hours on social networking, i.e. what they termed ‘rational’ and ‘addicted’ usage, conducted more social-related. On the other hand, Van den Berg et al. (2014, 2008), having investigated the role of ICT communication in social contacts with the neighbours, found such modes used to maintain relationships with people from outside the immediate neighbourhoods, suggesting their role as an alternative to face-to-face meetings though without direct conclusions regarding travel behaviour impacts.

The most recent review by Andreev et al. (2010) appeared to confirm the general impression that tele-conferencing would not substitute travel, but rather either stimulate it or emerge as a supplementary channel. The latter may be perhaps used as a back-up in situations making travel prohibitively costly or dangerous. Denstadli (2004) provided example of disruptions to air travel in Norway following the 9/11 attacks, noting that videoconferencing worked rather as a short-run substitution (reported by 73% companies reported such effects) which lasted for approximately 5 months following the attacks. Some evidence was also reported in media regarding increased use of videoconferencing following the Icelandic volcano eruption in 2010 which resulted in major air traffic disruption (Reuters, 2010).

Factors that were reported as playing role can be broadly divided into four groups. The first one includes those associated with the characteristics of the meeting, such as its cost, sensitivity and character of participants (Lu and Peeta, 2009). The second group of factors include characteristics of the travel and face-to-face meeting alternative, with higher costs of such solutions being associated with more use of tele-conferencing. The third group of factors concerned the company characteristics, with number of years of experience in using tele-conferencing, the frequency of its use,
promotion of travel-cost reduction policy, and emphasis on the benefits of tele-conferencing associated with reduction in the number of business trips (Denstadli et al., 2013; Lu and Peeta, 2009; Roy and Filiatrault, 1998). The final group concerned the sociodemographics of individuals. In this context, whilst Roy and Filiatrault (1998) reported that sociodemographics did not play a significant role in the context of business travel, Denstadli et al. (2013) found older respondents possessing a university degree more likely to adopt tele-conferencing. At the same time, in the case of non-work-related interaction it was younger people belonging to smaller households located in areas of poor transport services who tended to maintain more distant relationships by means of ICT (Van den Berg et al., 2014, 2008). Hjorthol and Gripsrud (2009) also pointed towards greater use of ICT for social contacts among young people whereas Polydoropoulou and Tsirimpa (2012) found more diversified use of ICT (phone, Web, e-mail) for social contacts among urban residents.

Overall, the recent review by Andreev et al. (2010) indicated that rigorous studies dealing with the relationship between tele-conferencing and travel were rather sparse. Most approaches concentrated on either descriptive statistics with cross-tabulations, with some employing qualitative analyses of interviews and focus groups. Among the quantitative methods, single equation approaches were most prevalent including negative binomial and latent-class Poisson regression models.

**2.4.4 Tele-leisure**

The least well explored impacts include those concerning tele-leisure, despite leisure occupying most of the personal (non-work) time of individuals (Andreev et al., 2007). One of the particular reasons is the challenging nature of the ‘leisure’ concept itself which can encompass variety of aspects, sometimes hard to distinguish, and certainly strongly depending on subjective perception (for a more detailed conceptual exploration, see Mokhtarian et al., 2006). Furthermore, leisure purposes may be served by other activities such as social meetings or shopping thus blurring the boundaries between impacts of various tele-activities on particular elements of travel behaviour. Salomon suggested that leisure, serving less tangible purposes than work or shopping, may have higher potential of travel substitution with tele-leisure growing in importance as time budgets become tighter (Salomon, 1986).
The most comprehensive approach to investigating the impacts of tele-leisure was presented by Andreev et al. (2009) who proposed a taxonomy for leisure activities based on 5 needs that may be fulfilled, and provided ICT-related examples:

- **rest** – possibly fulfilled by surfing the Internet, listening to a concert or watching movie online;
- **action** – with activities such as Nintendo’s Wii-based games (tennis, bowling, boxing) or following online-based fitness courses;
- **play** – addressed by various sorts of online games;
- **social** – addressed with chats, online communicators, blogs, or social networking platforms;
- **intellectual** – with reading and learning new things from various online-based resources such as electronic libraries, or Wikis.

In the empirical research, the authors found that duration of ICT-based leisure activities did not directly influence travel duration or frequency, but by being linked with fewer non-ICT based activities (suggesting substitution), it was indirectly associated with lower travel demand. In other publications, the same authors claimed, however, that such effects were rather negligible, and in some cases complementarity occurred (Andreev et al., 2010, 2007).

Another approach was presented by Peng and Zhang (2008) who extended the microeconomic time allocation theory to model the choice between time allocation to virtual-reality based games. In doing so, the authors defined meta-utilities consisting of physiological, psychological, and monetary satisfaction. In their approach they argued that motivation for tele-leisure must come from psychological benefits exceeding the sum of physiological, psychological, and monetary satisfaction from leisure conducted in physical reality. Thus individuals spending significant time online appeared to fulfil some of their basic needs using online world for which they provided empirical evidence in a form of higher valuation by their respondents of online gaming as compared to real world activity. Whilst the authors did not provide any comment on the possible impacts of travel behaviour, the results of Hjorthol and Gripsrud (2009) indicated slightly fewer leisure-related trips for online gamers, themselves more likely to be males. On the other hand, in terms of the travel behaviour within the virtual world, Frei et al. demonstrated that people appeared to
synchronise their time and spatial patterns suggesting importance of the ‘virtual geography’ with people ‘closer’ to each other more likely to form partnerships (Frei et al., 2012).

2.4.5 Tele-services

Tele-services, or e-services, is an umbrella term including a relatively wide range of ICT-based activities falling outside the previously discussed categories, and including tele-banking, health care (tele-medicine), dealing with public authorities (tele-government) and education (tele-education) which accounted for 90% of research in this area (Arduini and Zanfei, 2014). At a general level, Reggi et al. (2014) provided a potential list of indicators that could be used to study the level of adoption of various tele-services while Golob and Regan noted that most of the studies reported either inconclusive results or indicated weak complementarity (Golob and Regan, 2001).

In case of tele-banking, also called e-banking or more generally e-commerce, Salomon (1986) named ATM one of the first realisations of such tele-activity suggesting also significant potential for travel substitution due to the fact that a visit to a bank would not usually provide any direct leisure-related qualities. However, the overall impact on the transport network would most likely be modest given that bank-related visits constituted only a small share of the overall travel demand. Hjorthol and Gripsrud (2009) noted very high penetration of tele-banking in Norway (92%), especially among highly-skilled respondents, as well as high and low income groups. They also found that adopters of tele-banking tended to have slightly more trips per day, especially using private cars. Polydoropoulou and Tsirimpa (2012) found the highest potential to increase use of tele-banking in case of lower ICT prices and worse travel conditions. They also reported on heterogeneity in the types of ICT used for such purposes with the urban residents relying on Web-based platforms, while rural and island communities using telephone-based banking. Lin et al. (2013) noted that pre-use trust is critical in adoption and satisfaction for subsequent use which would also drive the associated travel behaviour implications.

Regarding tele-medicine (also e-medicine, e-health) which includes ICT-based contact with health personnel and health information technology (HIT) for data management, including m-Health technologies (portable manipulation of digitised documentation) as well as various body-monitoring technologies (Nangalia et al.,
2010), the potential benefits would arise from easier contact with medical personnel in conditions of forbidding travel costs and conditions (Esser, 2011), as well as enhanced processing health-related information. On the other hand, Reis et al. (2013) pointed to the risks of heightened demand for remote diagnostics without attending the medicinal facility which may increase the likelihood of misdiagnosis. Furthermore, HIT use enabling analysis of medical records may also raise privacy concerns, especially if the purpose is beyond strictly public health and epidemiological purposes. In terms of the relationships with travel behaviour, Golob and Regan (2001) claimed that substitution may be significant in cases of looking for health-related information though its infrequent occurrence would limit potential impacts on travel behaviour to rather infrequent occasions which was confirmed in the review by Andreev et al. (2010). At the same time Arnfalk (2002) reported significant number of studies suggesting travel amount and cost reductions as a result of implementing such schemes. (Lewis et al., 2009) provided a clear example of reduction of car travel due to people's involvement in tele-medicine services which was also linked to more efficient use of staff time and reduction of the negative environmental impact.

Tele-government (or e-government, also including tele-justice) enabling use of ‘the Internet and the World Wide Web for delivering government information and services to citizens and firms’ (Arduini et al., 2013, p. 178) for obtaining information, downloading suitable forms, sending documents, or participation in elections became of interest not only to individuals or firms due to their convenience (reduced number of trips during the usual working hours) but also to the authorities increasingly seeing their benefits in terms of easier handling of the citizens’ issues. Arendsen et al. (2014) argued that tele-government services would lead to perceived reduced burden on companies, especially those of larger size and with significant number of specific ICT-personnel. Van der Wee et al. (2014) reported that switching from personal to electronic contact to tele-government services such as applying for licenses or income tax preparation could provide significant benefits to the citizens and firms. Based on their calculations using data from Belgium and the Netherlands, they estimated the values of such services to amount to about 30-60 euros annually per inhabitant, most of which (around 90%) would come from savings in travel time and costs.
Tele-education (also e-education, e-learning, distant learning, distributed learning, tele-mentoring, tele-apprenticeship) includes

‘institution-based, formal education where the learning group is separated, and where interactive telecommunications systems are used to connect learners, resources, and instructors’

some forms of which originated in Sweden somewhat 160 years ago, though without the use of actual ICT but post (Simonson et al., 2000, p. 32). Welsh et al. (2003) noted that today tele-education encompasses diversified set of forms, from simple downloadable notes to interactive and immersive environments. Tele-education proved useful for companies’ training programs having higher initial fixed, but subsequently lower operation costs especially for large groups of learners, potentially requiring travel (Bates, 2004; Miller, 1991; Welsh et al., 2003). Bates also mentioned an interesting case of m-learning (mobile learning) where employees would make use of their travel time to educate themselves for the benefit of the company though satisfactory effects of such initiatives would be strongly dependent on technological reliability (Bates, 2004). In addition, he reported that only a fraction (17%) of tele-education participants of his study was motivated by travel conditions and costs, while most of them were by other commitments, especially family. In addition tele-education was also reported to benefit in situations where not enough students could take part in particular course, or where the subject had very limited number of teachers/trainers, or where geographical conditions prevented other solutions, e.g. in case of sparsely populated island nations (Dede, 1996).

The remaining tele-services attracted considerably smaller attention from the researchers, possibly due to their unlikely major impacts on travel behaviour. Salomon (1986) reported an almost negligible impact on travel of early television-based news retrieval systems despite their high (85%) penetration. Hjorthol and Gripsrud (2009) reported slightly fewer shopping-related among individuals who retrieved news online, especially men and car owners. (Arduini and Zanfei, 2014) looked at various factors influencing adoption of e-procurement though potential travel impacts were not considered.
2.5 Studies on the second (higher) order interactions

The studies presented so far focused on the immediate relationships between activity-travel behaviour and ICT use. However, impacts of ICT extend beyond these first order interactions to phenomena which may influence people’s mobility patterns indirectly and/or over longer time horizons. While no consistent taxonomy similar to the one proposed by Salomon and Mokhtarian for the first level relationships has been proposed to date for the higher order interactions, the current section discusses five potentially relevant areas where such impacts may have arisen: land use and locational decisions, smart infrastructure, time use and social norms, mobility preferences, and market organisation and corporate culture. At the same time, it is worth noting that this selection is just one of multiple possible ways of dealing with these arguably more complex and less tangible interactions.

2.5.1 Land use (urban form) impacts and locational decisions

Potential changes to land use and urban form resulting from ICT adoption have been identified as one of the most essential areas requiring in-depth understanding from urban planning and regional science (Audirac, 2005). Audirac presented a rich summary and discussion of the main discourses and areas of concern in the context of ICT and urban form interaction (Audirac, 2005). She pointed out that from that perspective the key processes included ICT-based transportation logistics, regional and international outsourcing, ICT-induced travel, and ICT-intensive agglomerations. Consequently, understanding of these processes formed one of the key aspects to ensuring so-called smart growth of cities (Chourabi et al., 2012).

From a more travel behaviour-oriented perspective, a very intuitive and frequently referred to example (though largely unconfirmed empirically) has been that of tele-commuters moving away from the city centre in an effort to avoid the hazzles of living in congested urban areas, and in the process of doing so accelerating suburbanisation and re-shape urban forms (Salomon, 1986). In a simulation-based study, Rhee (2009) proposed a theoretical model of evolution of a city resulting from interaction between household decisions regarding work and commuting patterns (including tele-commuting) and business choices on location, production level and share of workforce employed via tele-commuting. In doing so, Rhee demonstrated that such decisions did not conform to the simple ICT-travel substitution
understanding but the overall outcome of such interaction would depend on the impact of tele-commuting on labour productivity, household incomes, agglomeration effects (workers working in proximity to each other), migrations as well effects on land values. Consequently, such interaction could result in either the city shrinking (in terms of size), or expanding (sprawling) which would be determined by the net effect of two opposing forces: centralising agglomeration and decentralising congestion/tele-commuting willingness.

The scarce empirical results indicated that tele-commuting may lead to longer commuting distances, though less frequent trips leading on average to 15% reduction in travel amount (Mokhtarian et al., 2003) and Zhu (2012) argued that that longer term tele-commuters would tend to choose more distance residential locations with longer commuting distances. The results of Kim (1997) re-confirmed the hypothesis of urban expansion, also noting effects in terms of decreased pollution in central parts of the city and slight increases in the suburban areas. On the other hand, Helsley and Zenou (2014) provided a model of interaction between residential location and position in a social network demonstrating that people who were more central in their networks tended to live closer to the geographical centre of interaction, suggesting that further developments in online social media platforms could be associated with the opposite phenomenon, i.e. migration from suburbs closer to inner city areas, and clustering of social network members.

Also the previously discussed studies by Cao (2009) and Cao et al. (2013) discussed potential changes to retail areas, resulting from proliferation of tele-shopping use. They suggested as a consequence possible further deterioration of retail prospects in areas already suffering from poorer shopping opportunities and further concentration of retail in the places already attractive for shopping. Such polarisation would also make the attractive shopping areas hubs for other social activities, especially if equipped with ICT-friendly infrastructure such as Wi-Fi or power sockets. Fernback and Shaffer (2010) noted that such considerations had only recently been acknowledged in urban planning aimed at creating mixed, liveable and ICT-friendly public spaces further stimulating economic opportunities and also improving the quality of life for the local residents.
2.5.2 Smart infrastructure

Another higher-order interaction between ICT and travel behaviour may be defined in terms of increasing ‘smartness’ of infrastructure, especially in relation to promoting more sustainable energy use. Among such solutions, modifications in the activity-travel patterns towards their greater environmental friendliness have frequently been invoked as one of the primary concerns to be tackled using various policies, often strongly reliant on increased ICT use (Bulu, 2013). For instance Kramers et al. (2014) explored the opportunities in which ICT could lead to reduced energy use through what the authors called dematerialisation, demobilisation, mass customisation, or intelligent operation applied to various aspects of life. Their examples included telecommuting (and more general notion of flexible work-place), live-streamed concerts, road pricing, vehicle and trip sharing services, electronic payment, visualisation of energy use, sensors for demand management, advanced metering, dynamic pricing of energy, micro-generation, remote healthcare.

On the other hand, Jung and Pawlowski (2014a, 2014b) demonstrated that consumption behaviour in virtual-reality environments tended to be more relaxed in terms of cultural, social, personal and structural constraints as virtual identity appeared to reduce inhibitions, preserve anonymity, as well as personal and physical constraints. Consequently, the process of smartness and dematerialisation may, at not necessarily lead to the expected and predictable behavioural (including mobility) responses, including the possibility of inducing behaviours appearing less desirable from the environmental point of view such as higher energy demands.

2.5.3 Time use and social norms

A number of researchers have indicated that adoption of ICT may have been important contributor to a more general evolution in social norms, time use preferences and habits, themselves directly translating into activity-travel behaviour patterns. Such changes have been hypothesised to come in various forms, including the previously discussed multitasking and activity fragmentation as well as increased spontaneity and changes to social interaction. An example of a high-level societal change can be the Castells’ notion of the ‘network society’ where activity-travel behaviour is organised around electronic, i.e. ICT-based, networks (Castells, 2000). Similarly, the Rheingold’s concept of ‘smart mob’, i.e. increasingly connected society
capable of coordination and spontaneity resulting from proliferation of individual Internet-capable mobile devices can be understood as wider change to societies that may have been re-shaping activity-travel behaviour (Rheingold, 2003).

An additional hypothesised effect related to the ICT-enhanced multitasking and fragmentation is redefinition in activity planning horizon (Hjorthol, 2008; Padayhag and Fukuda, 2009). Given that disintegrated character as well as greater spatiotemporal independence of ICT-enabled activities, individuals are no longer required to pre-plan to the extent required by physical, spatially-separated activities involving travel and sometimes also co-ordination with others, e.g. in terms of co-presence or vehicle use. The ability to co-ordinate with others in real time may also translate into increased willingness to alter pre-arranged schedules and adapt them to the constantly changing circumstances. Thus expansion of ‘on-the-spot’ choice set of (tele-) activities enabled by ICT may make the trips not only more spontaneous and unplanned, but also mean their constant evolution in terms of purpose and character. This is because individuals could try to accommodate additional emerging opportunities, hence forming long and frequently difficult to predict activity chains ‘on the go’. As such, the phenomenon appears to lead to increase in multi-purpose and non-home-based trips, perhaps requiring shift from transport modelling relying on the assumption of symmetrical, pre-planned, home-based trips as the building block of models, towards tele-activity- and multitasking-inclusive activity-based modelling.

Another aspect of higher-order ICT-induced changes related to time use included the increased use of time for multiple purposes simultaneously, i.e. multitasking. While the time use researcher grounded in sociology and psychology has for long acknowledged the possibility of such phenomenon, e.g. watching TV while making a phone call or (tele-)working while watching a child (Gershuny and Sullivan, 1998; Harvey, 1993), the concept received an increased interest from travel behaviour community in the context of travel time use and its productivity which is dealt with in more detail in section 2.8.

In terms of the research on activity fragmentation (Lenz and Nobis, 2007) reported on the existence of a segment of the population characterised by significantly fragmented lifestyles, though without providing evidence for the direct impacts of ICT. Similarly, Alexander et al. (2010) suggested existence of three distinctive patterns of
fragmentation: less spatially and more temporally fragmented, less temporally and more spatially fragmented, and spatially and temporally fragmented. They also provided evidence for ICT playing an important role in spatial and temporal fragmentation, reporting for instance that more frequent use of phone and e-mail for work-purposes outside working hours was associated with flexible work-schedule enabling work outside conventional hours. Such results could suggest that adoption of ICT may lead to higher flexibility in terms of timing of travel, possibly leading to flattening of travel demand peaks during a day. Nonetheless, the exact causality of such effects has remained undetermined so far and, in fact, Ben-Elia et al. (2014) demonstrated empirically that bi-directional causalities between ICT and activity fragmentation were prevalent. At the same time, Middleton and Cukier investigated possible negative impacts resulting from ICT’s prevalence in everyday life, including reduced driving safety, anti-social behaviour, distraction, and infringement as the core elements of the ‘dark side of mobility’ (Middleton and Cukier, 2006, p. 267).

Additionally, by enabling easier communication and information retrieval, ICT have been argued to lead to reduction in the time use planning horizons through easier rescheduling, adjustments, or learning about opportunities (Hjorthol, 2008; Padayhag and Fukuda, 2009). This effect has been argued to have implications in the form of erosion of fixity of schedules on one hand, but also the capability to adjust to unforeseen circumstances on the other (Line et al., 2011; Weight, 2008). For example Jain et al. (2011) provided example of females who made use of their mobile phones to alert about possible delays in picking up their children, or when meeting with other people implying that such behaviour have become more acceptable than before the arrival of ICT when late arrivals would not have been forewarned of. Hjorthol (2008) reported, on the other hand, that short planning horizon was positively correlated with mobile phone use. Padayhag and Fukuda (2009) observed a positive association between ICT use and pre-planning duration for social activities but they also indicated negative relationship between planning duration and the actual participation suggesting more frequent, on-sport decisions to take part in an activity. Nonetheless, the aforementioned studies reported on associations between ICT use and planning with the actual causal effects still to be proven.
Nyblom (2014) claimed that ICT were helping in accommodating uncertainty inherent to travel in congested conditions possibly making trips not only more spontaneous and unplanned, but also constantly evolving as individuals would continuously attempt to accommodate emerging circumstances and opportunities ‘on the go’. Such changes could possibly translate into more multi-purpose, non-home-based trips with implications for forecasting capabilities of the existing frameworks frequently relying on assumptions of symmetrical, pre-planned, home-based trips as the building blocks. In general, the aforementioned changes to time use patterns facilitated by portability and growing capabilities of ICT tended to be linked to greater ‘nomadism’ in people’s lifestyles with activities detached from places, times and contexts rearranged in novel and often unexpected ways (Axtell et al., 2008; Sørensen, 2002). Such changes could also have implications for the norms of social interaction, such as increased reliance on ICT in maintaining contact (Van den Berg et al., 2014, 2008) den Berg et al. (2008, 2014) though understanding of these long-term effects (e.g. on the whole generation) of social life virtualisation has only started to emerge.

2.5.4 Mobility preferences

A possible change to mobility patterns resulting from changes in the ICT characteristics, and use may also arise as a result of evolution in mobility-related preferences, e.g. in terms of modal preferences, driving license acquisition, or car ownership decisions. An example of such effect could be a relationship suggested by Sivak and Schoettle who argued for the effects of higher Internet usage on the reduced driving license acquisition rates, interpreting the results as a lower need for physical contact among people (Sivak and Schoettle, 2012) However, their actual empirical results were subsequently questioned on the methodological grounds indicating lack of robustness and thus misinterpretation (Le Vine et al., 2013). Another potential, higher order example of ICT influencing mobility could be the so-called ‘Peak Travel’ which describes relative deceleration or stagnation in the demand for travel in the developed economies, hypothesised to partly result from the growth in ICT use despite lack of empirical evidence to support such explanations (Kuhnimhof et al., 2012). Whereas the actual existence of such effects of ICT on changes in mobility preferences has to be, at least given the current state of the knowledge, taken with caution, the two examples demonstrate what could constitute a higher-order interaction between ICT and travel behaviour.
2.5.5 Market organisation and corporate culture

Yet another effect higher-level interaction discussed at least as early as in the Salomon’s review (Salomon, 1986) concerns implications for transport sector resulting from ICT impacting on market organisation and supply chains. For instance, globalisation of market exchange and service offshoring could alter people’s daily activity-travel patterns if the services they provide are determined by the demand profiles of places located in different time zones, such as in the case of call centres (Poster, 2007). In addition, Lilian (2014) argued that operation within geographically-distant teams may require certain novel leadership skills, such as ability to readily operate at any time of day, on any day of a week. In such cases, (Carayannis et al., 2013) reported, based on the sample of executives, the importance of smartphones as enablers of working anywhere, at any time, with virtually no geographical limits.

Additionally, ICT-related solutions for various industrial sectors, e.g. 3D printing capabilities, industrial automation, could alter freight transport patterns with the subsequent implications for traffic composition and hence travel conditions possibly to those resulting mass adoption of tele-shopping and increased number of commercial vehicles (Audirac, 2005; Cao et al., 2013). At the same time, ICT-enabled communication leading to further integration and globalisation of market could further stimulate more long-haul business travel (Beaverstock and Budd, 2013) despite the possibility of use of tele-conferencing as previously discussed in section 2.4.3. Nonetheless, the exact nature and causal directions between the different effects have not only been rigorously established to date, but may not ever be due to the complex interdependencies between other factors influencing developments in different sectors of economy.

2.6 Studies on the structural (systemic) relationships

Apart from studies dealing with specific, single aspects of ICT and travel behaviour interaction, a number of studies took a more aggregate, systemic perspective and attempted estimating mutual interdependencies between various dimensions of ICT use and travel behaviour. Such studies tended to rely either on structural equation modelling or categorical analysis.
Senbil and Kitamura reported that the use of telecommunications was significantly associated with the activity engagement and travel noting that the respondents appeared to take the advantage of ICT to participate in more leisure activities while cutting down on work-related ones (Senbil and Kitamura, 2003). Choo and Mokhtarian (2007) estimated a country-wide system of structural equations for the United States relating travel and telecommunication demands (measured in terms of telephone calls and vehicle-miles travelled respectively), infrastructure variables as well as land use and sociodemographics. They concluded that more telecommunications was associated with more travel and also noted that additional ICT infrastructure (telephone wires) was associated with higher demand for telephone calls. Due to this indirect mediation, the authors claimed that demand for telecommunications needed to be included in travel demand forecasting, while promotion of telecommunications together with travel reduction policies could be counteracting. A similar study in the context of Hong Kong (Wang and Law, 2007), and with more detailed information on ICT use (use of e-mail, Internet, videoconferencing and videophone) reinforced the case for ICT-travel complementarity since more use of ICT was associated with more time spent for out-of-home recreation as well as more travel (both in terms of travel time and number of trips).

On the other hand, Choo et al. (2005) using data on telecommunications and travel expenditures noted presence of both substitution and complementarity effects with the latter interaction dominant. Ren and Kwan (2009) supported this claim, indicating also possible differences in interactions depending on sociodemographic characteristics, in their particular case on the respondent’s gender. They also demonstrated how SEM-based decomposition of activity and travel patterns into more disaggregate categories could reveal otherwise hidden patterns, thus reinforcing the case for structural- as opposed to singular- approaches.

Yet another approach was followed by Wang and Li (2011) who employed a nested multiple discrete-continuous extreme value (NMDCEV) model of participation in physical and virtual activities, indicating that younger people valued participation in the latter more than older. As such, the authors provided an advanced means of modelling the interaction between physical and virtual activity participation.
However, the conceptual limitation of the study (as in fact of any conventional time allocation model) was in the implicit assumption of an individual pre-planning allocation of time to various activities over a certain time horizon. Such an assumption would not necessarily hold true under the conditions of increased spontaneity in participation, hypothesised by the growth in ICT. While focus of the paper was not specifically on travel behaviour, it is arguably one of the most advanced approaches in terms of a microeconomics-grounded model for understanding the time allocation decisions between physical and virtual reality.

Another, non-SEM approach was followed by Hjorthol (2002) who made use of a categorical analysis to compare the amount of travel for various purposes between users and non-users of personal computer in the late 1990s’ Norway. She reported no significant relationships in terms of total number of trips, but indicated differences in terms of composition of the total travel amount. More specifically, employed PC-owners in general reported fewer trips for work purposes while more for leisure and chauffeuring (escorting) trips which was in line with the findings of Senbil and Kitamura (2003). Furthermore, she noted that within the segment of PC-owners, more diversified use of ICT (in terms of number of activities) for non-communication activities such as word processing, numerical or graphical tasks was associated with higher number of work and business trips.

2.7 Studies on the temporal changes in the relationships

Among the first to explore the topic of interactions between ICT and travel behaviour were Hamer et al. (1991) who used experimental panel data of 30 households in which the respondents were allowed (with a consent from their employer) to telework. At the same time, changes to their travel behavior were monitored over five waves of data collection collected in approximately 3-monthly intervals between 1990 and 1991. The authors demonstrated that the number of trips by the tele-working respondents decreased quite quickly by approximately 20-30%, especially during peak hours, and for all modes of transport, though the distance travelled by car by other household members in general increased. The net result was, however, still a reduction in the total amount of travel per household although the results are hardly generalisable due to a very limited sample size.
Selvanathan and Selvanathan (1994) investigated the relationships between expenditures made by individuals on transport (public and private) and communications (telephone and postal services) in Australia and the UK for the period between 1960 and 1986. By estimating the cross-price elasticities, they found that during that period transport (both private and public) and communications appeared as substitutes, though the size of the elasticities were significantly different between the countries, i.e. 0.57 and 0.09 for private and public transport in the United Kingdom respectively, and 0.31 and 0.18 in Australia. This result further prompted a suggestion that certain country-specific factors and policies could have played a role in shaping the relationships.

Another approach was followed by Mokhtarian and Meenakshisundaram (1999) who employed SEM to estimate models of interaction between amounts of travel and various forms of communication (personal meetings, transfer of information-containing object, telephone, fax and e-mail) over two periods between 1994 and 1995. In doing so they found no support in terms of cross-sectional or longitudinal relationships between number of trips and amount of ICT-based communication (telephone, fax, e-mail). However, they noted importance of own-lagged effects of communication amount, i.e. higher amount of communication in the first period tended to be associated with more communication in the subsequent period, as well as some cross-effects, e.g. for instance in terms of number of trips and number of personal meetings. The only significant cross-impact involving ICT was in terms of more frequent fax use associated with less frequent information-containing object (e.g. letter, report) transfer which appears intuitive given the ability of fax to communicate such objects at much lower costs.

Nobis and Lenz (2009) also made use of two waves of data (2004 and 2007) to investigate the relationship between mobile phone use and travel behaviour. They noted that while the former increased significantly, the latter remained relatively stable, thus rejecting the substitution hypothesis, and instead pointing towards complementarity between the two. However, the sole focus of the study on mobile phone use based on only two waves of data did not provide very detailed insight into temporal dynamics of the overall ICT-travel behaviour interaction at a disaggregate level.
Zhu (2012), based on cross-sectional data from 2001 and 2009, suggested that the impact of tele-work grew over the years in terms of increased daily total commuting distance and reduced frequency of such trips. Moreover, telecommuters tended to have longer, more distant and more frequent non-work-related trips, though the strength of the relationship decreased slightly over the period. Both effects were attributed to more general changes in lifestyles, including general travel behaviour patterns as well as (more speculative) residential location. The author concluded that if such trends were to continue, further promotion of tele-work could be leading towards higher travel demand in the future both for work and non-work purposes.

2.7.1 Studies related to innovation adoption theories

Another related stream of research looked into the process of adopting ICT and tele-activities, conceptually drawing on the technology adoption theories such as technology acceptance model (TAM) or innovation diffusion theory (Andreev et al., 2010; Cao et al., 2013; Davis, 1989; Rogers, 2003). The TAM approach (see Figure 2.5) is principally oriented at investigating the interplay between perception of usefulness, intention to use, and the actual usage as well as factors that influence each of these components (Legris et al., 2003). Thus for instance, in investigating the adoption of mobile banking, Lin et al. (2013) indicated the importance of trust, as even the pre-use trust could influence the long-term decision on using (or not), even after an initial attempt to adopt a particular innovation. This result was also consistent with the findings of Beaudry and Pinsonneault (2010) who emphasised the importance of subjective factors such as emotions in adoption and continuing use of technology.

Other studies put stronger focus on identifying factors associated with earlier adoption of particular innovations, and in doing so were conceptually closer to the innovation
diffusion theory of Rogers (2003). In his original formulation, Rogers identified certain segments of potential adopters, i.e. ‘innovators’, ‘early adopters’, ‘early majority’, ‘late majority’, and ‘laggards’ which were defined based on the normal distribution curve and standard deviations from the mean adoption time (see Figure 2.6). Moore (1991) noted, however, that some innovations may never become adopted by majority of the population and thus identified a ‘chasm’ between the segments of early adopters and early majority. Thus it could be hypothesised, as is done in the analysis in Chapter 6, that while certain tele-activities such as tele-banking or mobile phones may eventually be adopted by virtually the whole population, other services such as tele-work could remain restricted to only certain segments of the population. Consequently, the scale of impacts of ICT on travel behaviour could be argued, to depend not only on the magnitude of such impacts, but also on the share of population they would apply to.

An example of application of the Rogers’ theory in the current context included modelling factors influencing adoption of Internet use in Canada using binary logistic regression (Noce and McKeown, 2008). They found that high income, university-educated, young, male, urban, English-speaking individuals belonging to households without children individuals had higher probability of using the Internet. A similar method was used in analysing adoption of tele-shopping (for a summary see Cao,
whereby the adoption was found to take place sooner in urban areas. This phenomenon was suggested to results from greater exposure to novelties in such areas leading to knowledge spill-overs and encouraging adoption of new technologies. However, Cao also noted that an alternative and to some extent a contradictory efficiency hypothesis, had been supported in other similar contexts where tele-shopping was associated with the higher relative benefit experienced in non-urban, low-shopping-accessibility areas (Cao, 2009; Cao et al., 2013). Nonetheless, this seemingly contradictory result appeared to emphasise that adoption of certain innovation, such as tele-shopping, may be influenced by its attributes, among them relative advantages and observability (the other being compatibility, complexity, and triability) indicated by Rogers (2003, p. 265).

Nevertheless, a significant proportion of studies conducted in this research area tended to rely on single, usually binary variable, describing adoption of particular innovation. Arduini and Zanfei (2014) suggested the use of continuous measures which they constructed as composite indices of use of various ICT services while Reggi et al. (2014) provided a list of potential indicators that could be used to study the level of adoption of various tele-services. Moreover, a number of the reported results relied on single, cross-sectional datasets which may have not fully captured the temporal character (dynamics) of the diffusion process given its non-ergodic character. Furthermore, the adoption studies focused on technologies rather than behavioural changes, or in other words, adoption of ICT and its use per se, and not change in travel behaviour that would result from ICT adoption. It is the latter phenomenon that is of interest in the current research context, and that motivates the analysis in Chapter 6. For this purpose, however, the theory of innovation diffusion can still be applied as a theoretical basis and a consistent and more universally applicable explanation for the temporal evolutions the interactions between ICT and travel behaviour.

2.8 Studies on the relationships between ICT use and in-travel time use and experience

One of the possible ways in which ICT have been increasingly seen interacting with travel behaviour is in the area of in-travel time use, and its relative productivity. Possibly interpreted as a particular realisation of the modification effect described in
section 2.2, the phenomenon has recently received a renewed interest from researchers as a result of the ICT-caused relaxation in spatiotemporal constraints on activities leading to increased opportunities of active time use whilst travelling. This is to emphasise that the travel time per se has not been empty before the advent of ICT with thinking, talking, reading, playing, or even dancing (in case of ocean liners) occupying travellers. Making use of travel time has usually come as natural, though in some contexts may have played a crucial role, e.g. in maintaining high morale more on long exploratory voyages as noted by the polar explorers Ernest Shackleton or Roald Amundsen (Shackleton, 2012). However, it was the emergence, and subsequent growth in sophistication and portability of ICT that has been continuously transforming travel experience and in-travel time use. Not surprisingly, in a recent report on automotive industry KPMG identified the possibility of taking part in an increased range of activities while travelling as one of the most important features resulting from increased automatisation of private vehicles (KPMG, 2012).

Given that to the best of the author’s knowledge, the research area has not yet been provided with a comprehensive and systematic review, the present section seeks to contribute by discussing 91 studies, all in English (see Appendix 1) relevant to the topic and compiled using a combination of search engine results and cross-referencing (‘snowballing’). Most studies were peer-reviewed (journal and conference papers, books, and book chapters) though also items such as business reports or government documents were included on the grounds of offering interesting and cutting-edge insights into the topic. The extensive character of the review is further motivated by the need for a deep and detailed understanding of the topic required for the subsequent development and application of a microeconomic description of the phenomenon as part of the RO2 undertaken in Chapter 4 and Chapter 5.

No temporal restrictions were placed on the publication dates and bibliometric analysis of the number of publications by years (see Figure 2.7 on the next page) revealed that the topic started to received attention as early as in 1970s and 1980s, though studies conducted at that time were largely conceptual. Late 1990s and early 2000s were the periods where the topic started to gain increased attention which also coincided with the emergence and proliferation of mobile, Internet-capable ICT.
2.8.1 Visual representation of the domain

In order to facilitate the discussion of the relevant studies which originate from a number of heterogeneous research domains, a visual representation of the research domain is proposed based on the idea of co-authorship on a publication, itself drawing upon co-citation analysis methods (White and McCain, 1998). The is to facilitate

Figure 2.7 Number of studies on in-travel time use and productivity published between 1977 and 2014
Note: No relevant studies were identified in the years 1978-1980, 1982-1985, 1987-1993, and 1996.

devices. Subsequently, the peak around 2007 was associated with a series of conceptual academic publications as well as empirical findings from a large-scale dataset in the UK, i.e. National Rail Passenger Survey (Lyons et al., 2007). Re-emergence of the topic since 2012 was due to a recurring debate on the extent to which the phenomenon requires incorporation in travel time valuation procedures. In addition, the growing concern about safety implications for automobile users of mobile phones propelled the number of safety-related publications during that period.
Figure 2.8 Visual representation of the co-authorship in the productive use of travel time research domain
analysis of the existing literature as well as identify potential gaps in the knowledge. In the current case, this was achieved by creation of a database containing meta-data on the publications and subsequently converting it, by means of a purpose-specific script implemented in Python language, into an input file for network-drawing software PAJEK (Batagelj and Mrvar, 2010) which generated the suitable graphical representation (see Appendix 1 for the sample of pre-coded meta-data and the database-convertsing script). The results of the network analysis are shown in Figure 2.8 where each nod represents a particular individual while a line reflects co-authorship on at least one publication. In order to place a suitable structure on the reviewed body of knowledge, the existing studies were divided into 5 thematic areas based on their objectives and approach:

- **Quantitative modelling studies** which included those making use of quantitative methods to analyse larger datasets, often also proposing modelling structures for measuring the impacts of certain factors on in-travel time use.
- **Qualitative studies** which explored behavioural aspects of in-travel time use by employing more qualitative techniques such as interviews or focus groups to analyse smaller samples of respondents.
- **Conceptual studies** which explored and advanced the theoretical and conceptual understandings of the topic.
- **Value of time studies** which addressed the hypothesised implications of the in-travel time use for travel time (savings) valuation.
- **Safety studies** which explored implications of engaging in in-travel activities for safety.

Each of these themes is represented in Figure 2.8 as a coloured region including authors who co-authored at least one study belonging to that subject area. An author can be simultaneously present in multiple areas (hence their overlapping) if co-authored studies falling into multiple regions, or working on a study that touched upon multiple thematic areas. Such a particular classification certainly included a significant degree of subjectivity, though at the benefit of enabling visual and thus arguably more approachable representation of the domain. Moreover, inspection of Figure 2.8 immediately enables identifying the relative separation of the studies dealing with safety implications, as well as limited extent to which the area of overlap
between conceptual, quantitative, and value of time studies were explored especially when compared to the richer region of interaction between them. Moreover, studies that would simultaneously deal with safety and conceptual issues, or qualitative approach and value of time were also not identified and thus represented potential areas for further inquiry.

Based on the visual representation, the upcoming discussion of the existing studies in the five upcoming sections (2.8.2 to 2.8.6) follows the path indicated by the dashed line in Figure 2.8, commencing with discussion of the (purely) conceptual studies in section 2.8.2. The existing qualitative contributions are discussed subsequently in section 2.8.3. Following that section 2.8.4 deals with quantitative modelling studies whereas 2.8.5 discusses value of time studies. The final discussion on safety-related studies is included in section 2.8.6.

2.8.2 Conceptual studies

From the conceptual perspective, the interest in travel time activities has re-emerged as a result of the capabilities of ICT in terms of enabling tele-activities, and possibly leading to increased fragmentation, multitasking, modern nomadism, and possibly even changes to the urban space itself (Aguiléra et al., 2012; Sørensen, 2002; Townsend, 2000). Consequently, the researchers started to discuss possible changes to utilities associated with particular transport modes, demand for travel itself and possibly in an extreme case making travel a desired end on its own rather than a necessity derived from destination activities (Mokhtarian and Salomon, 2001; Mokhtarian, 2005; Niles, 1994). In a useful conceptual systematisation, Mokhtarian and Salomon defined the utility associated with travel as consisting of three elements: utility derived from destination activities, utility derived from in-travel activities, and utility derived from the act of travelling itself (Mokhtarian and Salomon, 2001), though Handy et al. (2005) noted these may be hard to separate. A very insightful conceptual discussion was provided by Lyons and Urry (2005) who, amongst other things, hypothesised how different modal characteristics may translate into productivity impacts and relative attractiveness of those who participate in in-travel activities.

Additionally, apart from the journey time itself, Gerdes (2013) claimed that certain architectural changes may be required to the (railway) stations, or more broadly in-
transit facilities (Cairns et al., 2014) to meet the needs of travellers increasingly perceiving travel time as useful and productive. Vincent-Geslin et al. (2012) noted that such perception would be influenced by three types of factors: material (e.g. characteristics of the means of transport, available material artefacts and infrastructure), personal (e.g. sociodemographics and preferences), and situational (e.g. presence of a companion or purpose of the journey). The extent to which each of these factors influence the travel experience and in-travel time use were in fact subject of the studies discussed in section 2.8.3 and section 2.8.4. Given the possibility of such profound changes to motivations behind travel, a number of researchers began to emphasise the need to incorporate this phenomenon, and the wider idea of multitasking in the existing modelling paradigms and policies (Kwan et al., 2007; Rasouli and Timmermans, 2014a).

In addition to claiming that the growth in ICT influences participation in in-travel activities, some studies argued that also changes in the existing social norms were observed, such as (lack of) acceptance of noisy telephone talks or constant availability (Gant and Kiesler, 2002; Julsrud and Gjerdåker, 2013; Murtagh, 2002; Sherry and Salvador, 2002; Zerubavel, 1981). Such changes to the established social norms and routine are, however, not new as for instance Schivelbusch (1980) described the concerns emerging in 19th century Europe as a result of people switching from stage coaches to railway. The new conditions of travel, i.e. compartments, were claimed to discourage conversations and thus compromise the quality of social life and travel experience. Moreover, the experience of in-travel time was argued to evolve from interaction with the landscape and external conditions towards preoccupation with the immediate surroundings and activities (Ross, 1995). While such experience was traditionally associated with the use of private cars (Bull, 2004), portable ICT (including personal music players) made individuals increasingly in control of their immediate surroundings not only in terms of activity participation, but also sensory, audio-visual experience regardless of the place (Bull, 2000; Du Gay et al., 1997).

2.8.3 Qualitative studies

Another group of studies sought to employ various qualitative methods such as interviews and focus groups as a means of exploring motivations and mechanisms driving the in-travel time use decisions. In doing so, it was claimed that people
converted travel time from a previously undefined period into a personalised and useful experience (Watts and Urry, 2008; Weight, 2008), itself possibly being source of positive utility potentially leading to excess travel (Handy et al., 2005; Mokhtarian and Salomon, 2001).

Kenyon and Lyons (2007) observed in their empirical study that one of the most important roles of ICT during travel time was that of communication. This re-confirmed earlier findings of Jain and Lyons (2008) who reported, based on the focus groups, that travel time was usually perceived as a period where individuals could freely decide what they wanted to do. As such, a frequently named activity turned out to be that of contacting people who would otherwise not be contacted which was a result similar to that reported by Bull (2004). Additionally, Line et al. (2011) indicated the importance of in-travel communication capabilities for easier re-configuration and re-arrangement of subsequent activities. Interestingly, within the same study the authors found that people used the ICT to maintain sense of security when walking alone in the evenings and talking on the phone.

An additional perspective on the topic was offered by Brown and O’Hara (2003) who reported that in-travel work was yet another reflection of shift towards employees operating more frequently in the conditions of detachment from desks and offices. Such hybrid worker-traveller employees would make use of combinations of various equipment including ICT and stationery, to fulfil some of the needs of travel purpose while travelling (Brown and O’Hara, 2003; O’Hara et al., 2002). While such behaviour was also possible in the past, the growing ICT capabilities enabled taking advantage of the ability to remotely access materials that would have been otherwise either carried or inaccessible. This reliance on ICT meant also increased need for reliability, including connection availability and stability, or development of contingencies such as possession of backup devices (Churchill and Wakeford, 2002; Oulasvirta and Sumari, 2007; Puuronen and Savolainen, 1997) At the same time, Middleton and Cukier (2006) indicated a number of possible negative impacts and undesirability of the omnipresent connectivity while Weight (2008) reported on individuals using ICT disruptions as excuses for inaccessibility. Such findings should not come as a surprise as some travellers were found to perceive their travel time as that of relative freedom between work-related and household duties (Sipress, 1999).
Interestingly, as reported by Laurier (2002) simultaneous uses of various pieces of equipment, including ICT, were not only limited to public means of transport, but also included private modes such as cars where travellers’ attention is required for their safe operation (more on the safety implications are discussed in section 2.8.6. Sherry and Salvador (2002) summarised such behaviour as an attempt to (re-)create certain work-place microenvironment, also termed a ‘hybrid workspace’ (Haynes, 2010) in an interplay between improvisation (given the conditions faced) and harmonisation (given the preference for certain microenvironment of work). The importance of the capability of means of transport to provide such re-configuration opportunities and adjustment of personal space to ones preferences and purposes was confirmed in other studies (Oulasvirta and Sumari, 2007; Watts and Urry, 2008). At the same time, Perry et al. (2001) argued that not only in-travel conditions mattered, but also the design of ICT which had to reflect the need for portable operability in combining lightweight with flexibility of use in various conditions.

A slightly different perspective was offered by Price and Matthews (2013) who investigated the meaning of travel time for parents travelling with young children discovering the importance of inherent modal characteristics for in-travel time experience. For instance, time spent on train tended to be perceived positively by enabling the individuals and their children to spend time actively playing and chatting which would not be possible in case of car driving. At the same time, the respondents noted that such positive experiences made it easier to convince children to travel. These results were also in support of the findings of Hagen (2009) who identified segments of travellers with specific needs and preferences translating into certain requirements and attitudes towards in-travel time use.

2.8.4 Quantitative modelling studies

As a complement to usually smaller in scale, respondent-intensive methods of behaviour analysis offered by the qualitative studies, the quantitative studies provided ways of analysing larger, often more representative samples. Such approaches sought to estimate the magnitudes and direction of impacts of various factors on in-travel time use and experience. Such approaches appeared particularly important in light of such environments increasingly serving as activity spaces, frequently for work purposes (Alexander et al., 2010; Felstead et al., 2005; Hislop and Axtell, 2007).
In terms of investigating in-travel activities, to date the largest analysis in terms of the sample size was that of Kenyon and Lyons (2007) and (Holley et al., 2008) using the UK’s National Rail Passenger Survey 2006. Based on the sample of more than 26,000 travellers, they managed to establish that almost 70% of the respondents indicated some positive utility associated with participation in in-travel activities, with their actual combination depending on the journey purpose and whether the leg was outward or return. Additionally, they established that ICT played a prominent role in making time better spent which was later re-confirmed in the analysis of the subsequent wave of data collected in 2010 (Susilo et al., 2012). This subsequent analysis also re-emphasised the importance of contextual factors reporting for instance that business travellers appeared to like longer journeys more as compared to non-business travellers. They also noted the impacts of then-emerging ICT devices such as portable DVD players or e-book readers. At the same time, they reported that impacts of ICT varied depending on what activity individuals participated in as well as on how they perceived their participation. For instance, the use of ICT for social networking and personal calls was perceived positively by the commuters, but negatively by the business travellers while the opposite was found for Internet browsing. As such, the findings provided evidence for significant heterogeneities in terms of the ICT impacts as well as interaction of ICT-related factors with other features, especially attitude and the amount and quality of the available space.

Nonetheless, the results of Ophir et al. (2009) suggested that even the appropriate environment may not always be enough to ensure high productivity providing evidence that people who appeared better at handling multiple sources of information (and thus ICT in general) simultaneously, were less efficient at tasks requiring focused attention, and thus demonstrated that the actual on-board tasks should be suited to the conditions (including ICT) as well as personal characteristics.

Furthermore, Lyons et al. (2007) suggested existence of the threshold of 15 minutes of journey duration below which individuals appeared less likely to engage in more absorbing activities. However, they also noted that for such short journeys ICT seemed to play a role of ‘gap fillers’. Investigating such shorter journeys, yet in the context of the London underground, Gamberini et al. (2012) noted that travel time in such contexts was more organised and filled with in-travel activities as compared to
the railway context which they attributed to developments in small, portable ICT which also conformed to the qualitative findings of Perry et al. (2001).

The importance of ICT for in-travel time use, especially work, was also investigated in the Norwegian context where Gripsrud and Hjorthol (2009) reported that ICT use seemed to serve as an adaptation strategy of individuals who sought to make their journey more worthwhile. They found that almost 90% of their respondent claimed to follow such behaviour while also noting that 27% of the commuters had their commuting time approved at least partially as work time by the employers.

A number of other studies employed field observations to collect data on patterns of in-travel activities (Timmermans and Van der Waerden, 2008; Van der Waerden et al., 2009). These studies advocated a more sceptical view on the prevalence of multitasking and in-travel time use and questioned the need for further changes and investments in the on-board environment. At the same time, their data collection protocols did not provide means of investigating mental activities (planning, thinking), motivations and obstructions leading to particular behaviours. Furthermore, the types of activities and features characterising individuals were recorded subjectively by the observer, potentially biasing the results. However, also Ettema et al. (2010) found that the fraction of respondents using ICT for in-travel activities was relatively small. At the same time, having looked at different modes of transport and noting different activity patterns, they provided empirical evidence for inter-modal differences in productivity distributions hypothesised by Lyons and Urry (2005).

In addition to work-related productivity impacts, Wener and Evans (2011) reported that car users experienced more stress which may have been linked to the limited opportunities for using travel time. In a different study Ettema et al. (2012) looked at the travellers’ satisfaction from public transport use and reported lack of robust evidence for in-travel activities increasing satisfaction of travel time. Interestingly, they mentioned that ICT use was sometimes associated with lower satisfaction of travel which could simply indicate adaptation to the otherwise even less bearable travel conditions. Such behaviour would also arise from the utility-maximising framework introduced by Rasouli and Timmermans (2014). In another study Ory and Mokhtarian (2005) argued that the liking of travel would be very strongly dependent on personal characteristics as well as attitude which could explain the patterns
observed by Ettema et al. (2012). On the other hand, recent evidence reported by Mokhtarian et al. (2013) estimated that Wi-Fi provision on the Californian Amtrak railway may have increased its ridership by 2.7%, possibly as a result of people switching from modes not allowing in-travel time use or access to online resources, e.g. cars or planes. As such, the results provided further empirical support for the claim that in-travel activity-enabling ICT may increase of rail as compared to cars (Lyons and Urry, 2005; Rhee et al., 2013).

Taking an even more extreme point of view, Salomon and Mokhtarian noted that an increase in the quality of travel experience, partially due to improvements in in-travel environment may even lead to increased and excess amount of travel (Mokhtarian and Salomon, 2001; Salomon and Mokhtarian, 1998). However, the prevalence of such behaviour was rather marginal with the service reliability in terms of travel time and conditions predictability rather than the possibility of using time productively identified as the most important determinants of travel time satisfaction (De Oña et al., 2014; Rhee et al., 2013). This is not to say, however, that individuals would seek to reduce their travel time to null as Redmond and Mokhtarian (2001) found in their survey that the ideal, desired travel time averaged at around 16 minutes with individuals indicating that this allowed ‘shifting’ between activities. Similar conclusions were reached by Fraszczyk and Mulley (2012) who investigated the extent to which teleportation would be desirable as a substitute to travel. As such, both studies provided evidence that travel was a desirable period for adjustment and not necessarily a quantity to be completely minimised, but possibly transformed to ensure high quality, and personalised experience.

While the studies discussed above constituted approaches concentrated on analysing particular datasets, a number of approaches sought to develop suitable microeconomic interpretations of in-travel time use. From that point of view, the most comprehensive approach was offered by (Hu, 2009). Focused on in-travel virtual activities in the form of mobile commerce and drawing on microeconomic time allocation models as well as goods-leisure paradigms (Becker, 1965; Jara-Díaz, 2007; Train and McFadden, 1978), she developed utility-maximisation framework that demonstrated how the possibility of in-travel time use could impact the utility of travel, and more generally activity-travel patterns. The model was operationalised by means of discrete
choice theory estimated using stated preference data, though she did not specifically address in-travel time allocation and productivity implications resulting from the on-board use of various ICT.

On the other hand, the utility-maximising framework of Zhang and Timmermans (2010) addressed the in-travel activity choice problem by employing skewed-logit (scobit) model to formulate probabilities of engaging in particular activities. As such, the framework provided valuable contribution linking microeconomic theory and in-travel time allocation decisions though without incorporating the possibility of differences in quality of activity participation, e.g. in terms of productivity. Moreover, their model considered only activity choice decisions at specified intervals and thus the actual durations turned out to be only by-products of the approach. Acknowledging that limitation, they called for simultaneous treatment of these two aspects as well as for more inclusion of ICT effects in such studies which largely coincidental with the model presented in Chapter 4. Finally, also the study of Rasouli and Timmermans (2014) provided a microeconomic link between in-travel activity participation and satisfaction from travel, demonstrating that such approach could offer previously unattainable insights into behavioural implications of ICT use. In particular, they indicated that the use of Internet positively influenced the experience of travel, but its attractiveness would tend to diminish quickly with its duration.

While not dealing explicitly with in-travel time use, Cheng et al. (2014) discussed possible infrastructural implications resulting from increased reliance on ICT in the context of in-travel time use. They noted that the consequent increase in demand for connectivity and bandwidth would require developments of ‘offloading’ methods to ensure continued reliability of the services. Yet another perspective on in-travel time use was that of Song et al. (2009) who investigated exposure to particle pollution in buses. They concluded that higher crowding levels tended to be associated with higher exposure to pollution due to more activities and thus movements of the passengers.

2.8.5 Value of travel time studies

A distinct, yet closely-related to the quantitative studies, is the group of studies that dealt with the implications of in-travel time use for valuation of time, and travel time savings (VTTS). While a more detailed discussion on the underlying microeconomics,
operationalisation and estimation procedures is presented in Chapter 5, this section seeks to highlight the major conceptual and empirical contributions to date.

As early as in 1970s Hensher acknowledged that the possibility to use travel time productively may influence the way travel time should be perceived and valued (Hensher, 1977). In doing so, he incorporated this effect in his framework for valuation of business travel time savings of airline passengers which has remained surprisingly robust, still constituting an alternative, benchmark specification incorporating the effects of ICT on in-travel time use and productivity (Batley et al., 2012; Mackie et al., 2003). Additionally, Gasparini (1995) noted that more attention may be required to transformations in the ways waiting time is perceived and valued in the era of increasingly capable ICT.

To date a number of studies have been undertaken in order to investigate the degree to which productive travel time was prevalent as well as to investigate the need to include such effects in the VTTS estimation methodologies (DfT, 2012; Fickling et al., 2008; Kirby et al., 2007; Richardson, 2003; Worsley and Hyman, 2012). The studies reported high prevalence and possibly profound implications for transport investment appraisal practices due to resulting from downward pressure on the currently assumed values of travel time savings used for benefit estimation, partially resulting from increasing ICT capabilities and increased comfort of travel. As a consequence, an intense discussion emerged on the need to re-visit the existing appraisal practices, though so far no clear consensus has emerged (Batley et al., 2012). A step towards that direction was taken by Hultkrantz (2013) who provided a microeconomics-grounded model for travel time savings estimation which accounted for the possibility of productive use of travel time. What he noted was that explicit incorporation of the in-travel productivity effects was not required, at least if the conventional rule-of-a-half approach was followed, since the underlying appreciation for the usefulness of travel time would be already captured by larger welfare gains and more significant growth in ridership if travel time was reduced.

Another possible manifestation of the impacts of in-travel activities on valuation of travel time savings came in the form of hypothesis of existence of travellers with zero or negative value of travel time reduction. Such findings were usually based on the results obtained from discrete choice models, given their well-established link to
microeconomic models of time and resource allocation (Bates, 1987; Hensher and Truong, 1985). Given the microeconomic theory, values obtained in this way would normally be negative with travellers seeking to reduce their travel time and use the freed-up time for alternative (leisure, work) purposes. However, the researchers noted that by employing mixing distributions in discrete choice distributions it was possible to obtain estimates of VTTS that are zero, or even negative (Cirillo and Axhausen, 2006). While zero values were also reported by Richardson (2003), existence of the negative values was interpreted as an artefact of the assumed mixing, unbounded distribution for the taste parameters rather than a reflection of true and very irrational in an economic sense nature of the respondents’ behaviour (Hess et al., 2005). At the same time, Verschuren and Ettema (2007) demonstrated empirically that in-travel time activities and productivity could be an effect, rather than a cause, of the underlying, inherently higher valuation of time (time-pressure) and the consequent need to spend travel time productively. This conclusion would imply that estimating the extent to which in-travel activities influence VTTS would require also data on more general time use patterns and subjective perception of time pressure in order to disentangle different components of VTTS.

2.8.6 Safety studies

The final group of studies approaches the phenomenon of in-travel time use, especially in terms of ICT use, by exploring its potential impacts on transport safety. Such studies tended to focus on instances where the travellers were actively participating in the operation of the transport modes, i.e. car driving and cycling.

Arguably the most important instance concerns that of the disruptive nature of the use of portable ICT, especially mobile phones, while driving. In fact, there appears to exist a relatively well-established consensus regarding the negative impact of using mobile phone when driving (Bellinger et al., 2009; Lim and Chi, 2013). White et al. (2010) noted that the prevalence of unsafe practices was high despite awareness of the negative safety implications and concluded that only hard measures such as fines could diminish such behaviour. At the same time, Hislop (2012) noted that the mobile phone use behaviour was heterogeneous and attempted to distinguish various segments of population differing in their perception of the severity of attention conflict when driving and talking on the phone. Similar results regarding mobile
phone disruption were noted among cyclists by de Waard et al. (2011) who found association between mobile phone use and reduction in speed and longer braking times as well as reduced response to auditory stimuli. On the other hand, Bruyas et al. (2009) demonstrated that possible mitigation measures against the attention conflicts could be asynchronous capabilities such as voicemails or text messages, which would put the driver back in control of their attention allocation. Other possible solutions could be better suited mobile-phone designs, though neither hands-free capabilities, nor touchscreens were proven to unambiguously and significantly reduce severity of the attention disruption (Reimer et al., 2014; White et al., 2010).

Yet another possible mitigation measure against attention disruption was suggested to come from developments in driving assistance and autonomous driving technologies (Jamson et al., 2013; Lee, 2007). However, until these technologies are proven to perform completely reliably without the need for human intervention and alertness, such solutions may not lead to the desired improvements in safety. This is because the traveller’s awareness of the autonomy of the system was found to further reduce people’s attention and thus increase the risk of accident in case the system fails in way similar to the well-known automation-induced complacency observed among airplane pilots (Parasuraman et al., 1993). Interestingly, (Welki and Zlatoper, 2014) noted that mobile phone use (or at least possession) could also have positive, though secondary consequences for safety enabling easier access to medical assistance potentially reducing the number of fatalities following an accident. Finally, a number of researchers explored safety implications resulting from listening to the music, in which case the results were less consistent across transport modes. As regards car drivers, listening to the music, though at moderate loudness, was associated with better reaction times, and in general better performance in the driving simulators, possibly due to enhanced arousal (Bellinger et al., 2009; Ünal et al., 2013). On the other hand, too loud music could obstruct reception of auditory signals which was observed among cyclist, though only those with inner-ear plugs on both ears (de Waard et al., 2011).

2.9 Summary
This aim of this chapter was to provide an extensive background to the current study, demonstrate the existent discourses and highlight areas for potential exploration. In
doing so, the key conceptual terms of ICT, tele-activities, multitasking and fragmentation, as well as productivity were discussed. Subsequently, a typology for the relationships between ICT and travel behaviour was presented, drawing upon the existing taxonomies and proposing new ones. Following that, the main challenges associated with research in this field were discussed, especially in terms of the issues regarding causality, together with their possible consequences and mitigation measures. It was also shown that such problems may be prevalent to the extent that virtually any attempt seeking to abstract the reality to the level of a tractable model will encounter similar issues which, however, need to be acknowledged and taken into account when providing interpretations of the estimated results.

In terms of the empirical studies, a large number of contributions were reviewed in terms of the first- and second-order interactions between ICT and travel behaviour. In addition, studies taking more structural (systemic) approaches were looked at as well as those that took a longitudinal approach seeking to understand evolutions in the relationships between digital behaviour and physical mobility. Nevertheless, most of the studies were found to deal with single contexts, be empirically driven and not attempting to provide a coherent theory for explaining sometimes contradictory results observed across the literature. Finally, an extensive systematic review of the studies dealing with the in-travel time use, drawing from multiple disciplines, demonstrated the re-emerging interest in the topic as well as growing acknowledgment of the importance of this particular form of interaction between ICT and travel behaviour.

At the same time, it was demonstrated that despite significant research effort to date, few long-standing consensuses could be identified. At the same time, the extensiveness of potential impacts of the developments in ICT on travel behaviour, be them due to simple substitution of a trip to a bank or more far-reaching societal consequences with implications for policy-making and investment appraisal, means that the topic requires further elaboration.

More importantly, however, the research field appears to require certain reconciliations and more universal approaches to understanding the behavioural mechanisms leading to emergence to the observed patterns of interaction between ICT and travel behaviour. Realisation of the RO1 defined in Chapter 1 is believed to
provide a means towards increased understanding of some of the identified underexplored areas such as cross-national analyses, mechanisms of obtaining richer datasets through data pooling, developments of microeconomic models and their application, as well as investigation of temporal changes and their interpretation in reference to the existing theories of technological change.
Chapter 3
RO1: MACRO PERSPECTIVE

As demonstrated in the previous Chapter 2, cross-national studies of the relationships between ICT and travel behaviour have been relatively uncommon despite their potential to provide insights into the roles of various country-specific factors, including regulations and policies, natural conditions, attitudes and traditions, or general level of material prosperity. One of the major obstructions to conducting analyses of this kind has remained relative lack of comparable (harmonised) data sources which would simultaneously include information on respondents’ use of ICT, or digital lifestyles, and physical mobility, or travel behaviour. Even if such data sources exist, they are not usually collected at the same points of time in different countries, and do not usually include directly comparable sets of variables, or not easily accessible for the purpose of comparative studies.

At the same time, a number of data collection entities have traditionally gathered data including information on either ICT use (such as Internet use surveys), or travel behaviour (such as traditional travel or time use surveys). However, a common feature

![Figure 3.1 Conceptual representation of the data pooling (grafting) process in the current context](image)
in both datasets is usually a set of variables which describe socio-demographic characteristics and socio-economic situation of the respondents and their households. Given that such characteristics are important determinants of both ICT use and travel behaviour, the natural question arises whether this combination of common presence and explanatory strength could be explored for drawing valid inferences about the relationships between ICT use and travel behaviour. Figure 3.1 depicts such a situation conceptually. An ICT dataset (e.g. Internet use survey) would contain only ICT use variables and a number of sociodemographic variables, $X_{1_{ICT}}$ and $X_{2_{ICT}}$ respectively. A travel dataset (e.g. travel survey) would also contain sociodemographic variables ($X_{2_{TS}}$) as well as travel behaviour variables ($X_{3_{TS}}$).

Assuming that the ICT dataset is the target dataset (i.e. receiving imputed values) while travel behaviour dataset is the training (donor) one (i.e. providing information on the relationship between common variables and to-be-imputed variables), the task is to make use of the relationships between the variables observed in both datasets ($X_{2}$) and travel behaviour variables, to impute travel variables in the target dataset ($X_{3_{ICT}}$). Naturally, the process of imputing $X_{1_{TS}}$ is possible by following a similar logic, and the actual choice of the approach would normally depend on characteristics of the datasets and variables they contain, interdependencies between the variables, as well as the subsequent methods of analysing the combined data.

It turns out that this research problem can be approached using the techniques of data pooling, also termed fusion, or grafting, and also closely related to statistical matching (see Saporta, 2002, for a conceptual discussion) which under certain assumptions discussed later in the chapter, can yield approximately valid inferences about relationships between pooled variables, i.e. $X_{1_{ICT}}$ (ICT use) and $X_{3_{ICT}}$ (travel behaviour). While similar techniques have found application in various other disciplines, including transport studies, e.g. to combine multiple sensory data sources (Han, 2011), to the best of the author’s knowledge the approach has not yet been attempted in the context of modelling relationships between ICT and travel behaviour. Consequently, the objective of the present analysis, one that is very experimental in nature, is to explore the extent to which such approach can be employed in combating the aforementioned data deficiencies present in this research field. At the same time, the cross-national context of the analysis should prove fruitful in terms of exploring for existence of differences in such relationships across countries. A caveat to the
latter outcome is that such comparisons are only possible to the extent allowed by the characteristics of the available data, especially in terms of their collection year and aspects of digital and travel behaviour measured. Interestingly, such differences in terms of how individual behaviour is measured (e.g. frequency, duration, number of activities) can also provide valuable methodological results. More precisely, it will be shown that similar model structures yet estimated with different data sources may lead to different, sometimes contradictory inferences about the observed relationships. While clearly intuitive, following a common specification for all countries has an additional motivation of demonstrating yet another possible reason for existence of some of the contradictions reported in the research field. Naturally, as the use will be made of structural equation modelling, a number of a priori assumptions will be required regarding the implied correlation structure and causation directions with the possible consequences such as those discussed in section 2.3, elaborated more on in the context of SEM in section 3.3.

Given that the actual data pooling design will be strongly determined by the characteristics of the available data, section 3.1 presents the employed datasets so as to establish the ground for further discussion. Afterwards, section 3.2 deals with technical aspects of data pooling methodology in order to justify the subsequent use of implicit pooling using the $k$-nearest neighbour ($k$-NN) algorithm. Furthermore, the section discusses ways of quantifying the degree of uncertainty resulting from analysing pooled datasets. As the current analysis is aimed at modelling simultaneous relationships between various aspects of digital lifestyle and travel physical mobility, section 3.3 describes briefly the structural equation modelling methodology employed to achieve this aim. Section 3.4 presents the findings, including a number of methodological results thus providing not only insights into the behavioural aspects of ICT and travel behaviour interaction, but also into the extent to which data pooling methods appears applicable in similar contexts. Section 3.5 summarises the results highlighting their limitations and suggesting potential avenues for further exploration.

### 3.1 Datasets analysed

The datasets used in this analysis come from 4 countries: Canada, the United States, the United Kingdom, and Norway, and their characteristics are summarised in Table 3.1. The most complete and up-to-date source is the Canadian General Social Survey.
2010 (Statistics Canada, 2011) being not only very recent but also including both sets of variables of interest, i.e. ICT use and travel behaviour, relevant to the objective of this analysis. As for the remaining countries, a combination of two datasets together with appropriate data pooling mechanism have to be used to obtain a complete dataset relating digital behaviour and physical mobility. While the UK’s ONS General Lifestyle Survey contains a number of variables describing travel behaviour, the fact which is explored for the purposes of longitudinal analysis in Chapter 6, these variables are not comparable with travel behaviour variables in the remaining countries. Consequently, the dataset in the context of the present chapter is treated as containing only ICT-related variables and therefore subject of data pooling procedure.

As different characteristics, i.e. the type, format and temporal horizon of the variables present in the datasets make cross-national comparison limited at best, in order to

| Table 3.1 Summary of the datasets used in the RO1 analysis |
|-------------|----------------|----------------|
| **Country** | **ICT use (Year; Size)** | **Travel behaviour (Year; Size)** |
| Canada      | aGeneralised Social Survey (2010; 15 390) |  |
| USA         | bPEW Internet Survey (2007; 2 200) | cAmerican Time Use Survey (2007; 12 248) |
| UK          | dONS General Lifestyle Survey (2010; 1 003) | eNational Travel Survey (2010; 18 356) |
| Norway      | fICT and Holiday Survey (2005; 1 235) | gNorwegian Travel Survey (2005; 17 514) |


| Table 3.2 Characteristics of the aggregate ICT and travel behaviour variables |
|----------------|-------------|-------------|-------------|
| **Variable**   | **Country** |             |             |
| **ICT use**    |             |             |             |
| Communication  |             |             |             |
| Social         |             |             |             |
| Shopping       | Total time spent on the related activities on the survey day | Number of the related activities individual has ever participated in | Number of related activities individual participated in during the previous 3 months |
| Leisure        |             |             |             |
| Services       |             |             |             |
| **Travel**     |             |             |             |
| Work           | Total time spent on the trips on the survey day | Total time spent on the trips on the survey day | Frequency of trips during the survey week |
| Social         |             |             |             |
| Shopping       |             |             |             |
| Leisure        |             |             |             |
| Other          |             |             |             |
provide at least some degree of comparability between the countries, aggregate composite indices have been constructed on the basis of dataset-specific information. These aggregate constructs measure ICT use for a variety of purposes, i.e. communication, social, shopping, leisure, and services, as well as travel amount for the purposes of work, social, shopping, leisure, and all other. Table 3.2 summarises characteristics of these aggregate variables characteristics with a more detailed description provided in Appendix 3. The idea behind using such variables is to reflect richness of digital lifestyle in various dimensions on one hand, as well as typical aspects of travel behaviour patterns on the other. At the same time, their formation is driven by trade-off between information available in the datasets, their format and response rate on the one hand, and the breadth of the subsequent analysis, estimation limitations and categorisation consistency on the other. Nevertheless, being derived from essentially different measures of behaviour, i.e. range of activities, their daily durations, or frequencies, the aggregate variables are likely to lead to different patterns of interrelations. Awareness of this challenge underlies the previously stated caveat that the current analysis ought to be perceived as strongly methodologically exploratory with potentially interesting behavioural interpretations regarding relationships between ICT use and travel behaviour across the countries.

3.2 Methodology of data pooling approach

The process of pooling datasets can be framed as an extreme case of data missingness in which no respondents provided information on certain aspects of their lifestyles (Aluja-Banet et al., 2007). In particular, respondents in the ICT use datasets did not report on their travel behaviour while those in the travel behaviour datasets on their ICT use which is clearly problematic from the point of view of analysing relationships between the two behavioural aspects. However, the complete missingness means also that the non-response mechanism is in principle known, i.e. no questions were asked to the respondents which is also unrelated to the respondent characteristics and can be deemed missing completely at random (MCAR) given also that the datasets were collected so as to ensure representativity of the populations. This information is important in establishing that there is no concern in regards of possible biases due to certain groups being more or less likely to reveal particular information (D’Orazio et al., 2006).
At the same time, given the relative sizes of the datasets (Table 3.1), it is more desirable to treat the smaller ICT datasets as consisting of respondents with travel behaviour variables MCAR, i.e. as target datasets. At the same time, the more sizeable travel behaviour datasets containing richer, and thus more diversified samples of observations can serve as donor (or training) observations containing auxiliary data for imputation of the missing variables (D’Ambrosio et al., 2007). The crucial feature is that both datasets share a number of common variables which in the current context describe socio-demographic (e.g. gender, age, education, household size) and situational (e.g. car ownership, dwelling type) characteristics of the respondents and their households. Whereas the logic above applies to data pooling methodology in general, there are multiple ways with by specific strengths and limitations, in which the technique can be implemented (D’Orazio et al., 2006; Smit, 2011).

The first decision to be made involves the level at which the missing data is to be imputed. This can be either micro (person, household, company, or organisation) level in which case variable values for individual units are imputed, or macro in which case aggregate parameters describing the entire sample (population) are imputed. Under ideal conditions the two approaches should align so that values imputed following the micro approach would lead to population parameters that would arise in the macro approach. In most cases, the macro approach would be simpler to implement (and thus may be preferred if providing enough insights for the given research context) on the grounds that specific values of population statistics may be associated with multiple possible combinations of values observed in unit-level responses, i.e. different compositions of the underlying populations, as determined by the number of degrees of freedom. Consequently, while the successful macro approach will provide the right aggregate statistic, the additional challenge encountered in micro approaches would be in accurately characterising the combination of the underlying values as defined by the respective degrees of freedom.

Once the decision on micro or macro approach is made, the choice of type of imputation mechanism must be made which can be either explicit or implicit. In the former case, also termed parametric, the imputed values for the target dataset are inferred using an explicit statistical model such as linear regression, discrete choice, or any other parametric posterior Bayesian distribution with the parameters estimated
using the training data. The implicit (non-parametric) techniques are, on the other hand, implemented in an attempt to avoid reliance on any particular modelling structure and possibly any *a priori* distributional assumptions. Instead, they seek to measure similarity between each respondent in the target dataset and any respondent in the training (donor) dataset, with the most similar respondent in the latter donating the missing value to the target individual (Aluja-Banet et al., 2007; Saporta, 2002; Sivakumar and Polak, 2013). In most instances, implicit approach takes form of a statistical matching procedure, usually variants of so-called hot-deck matching, in which the most similar respondent is sought on the basis of the minimum value of a distance metric constructed using variables shared by the datasets, i.e. $X^2$.

The main advantage of the explicit approaches lies in their capability of quantifying the degree of bias and precision of the imputed values using various goodness-of-fit statistics which can also help in deciding about the preferred specification. Nevertheless, this will clearly require assumptions regarding the underlying modelling structure which may not necessarily be an accurate one, or may induce various undesirable statistical phenomena in subsequent analysis of the synthesised complete dataset, including reduced variance or multicollinearity. Moreover, an accurate imputation of a set of variables simultaneously, such as daily travel durations for different travel purposes, may require accurate capturing of the underlying correlation structure to ensure consistency between variables (Saporta, 2002) such as avoiding imputation of daily travel durations exceeding 24 hours. In such a case, structural equation modelling could prove helpful, though it is not usually and easily applicable for inferential purpose and, being in principle of linear nature (despite existent of more complex non-linear approaches), it could induce multicollinearity in the subsequent analysis of the full, synthesised dataset.

Regardless of whether the imputed values are derived by means of a parametric or non-parametric method, *restrictions* may be placed on the range of values assigned to particular units in the target dataset. This is usually done in order to ensure consistency between variables such as non-zero frequency of car trips as a driver among individuals without driving licence. Conversely, if no particular constraints are placed on the imputed values, the imputation is equivalent to unconstrained data
pooling, and can take place, for example, when total time devoted for leisure purposes during a day is imputed.

Following decisions on the aspects above, the preferred imputation mechanism can be implemented. Nevertheless, imputing single values derived from either an explicit regression-based model or from matching the closest observation, and treating the pooled dataset as complete will not normally account for additional uncertainty in the estimation resulting from the pooled nature of the dataset. This shortcoming may translate into higher risk of the type 1 error (incorrect rejection of a true null hypothesis, i.e. not rejecting lack of association between ICT use and travel behaviour). However, this deficiency can be controlled under certain assumptions through adding a degree of randomisation in the imputation by obtaining multiple possible realisations of the imputed values. In the explicit imputation this may be done either through multiple draws from the estimated distribution, or by adding randomly drawn error component in case of explicit approaches. In the implicit case inference based on multiple most similar donors (so-called nearest neighbours) can be performed. In either case, the procedure would seek to construct appropriately adjusted confidence intervals taking into account both sampling- and imputation (pooling)-related uncertainty.

A comprehensive theoretical underpinning for the multiple imputation method was developed by Rubin (1987) in the context of non-response in surveys. In doing so, Rubin has demonstrated that if an appropriate Bayesian posterior predictive distribution(s) of variable(s) containing missing values can be estimated on the basis of the observed values, draws from such a distribution can be used to create multiple datasets which can be used to make approximately valid inferences about the estimated parameters following a set of simple rules. The Rubin’s approach seeks to calculate the between-imputation variance \( \sigma_M^2 \) using estimates of the desired parameters \( \mu_m \) obtained in each of the \( M \) imputations as well as their arithmetic mean \( \bar{\mu}_M \):

\[
\sigma_M^2 = \frac{1}{M} \sum_{m=1}^{M} (\mu_m - \bar{\mu}_M)^2
\]  

(3.1)
Subsequently, the between-imputation variance $\sigma_M^2$ can be combined with the mean within-imputation variance $\bar{\sigma}_\mu^2$ (calculated as the arithmetic mean of the squared standard errors obtained during the $M$ repetitions of the imputation) using the formula:

$$\bar{\sigma}_\mu^2 = \bar{\sigma}_\mu^2 + (1 + M^{-1})\sigma_M^2$$

Thus equation 3.2 is an expression for the final variance $\bar{\sigma}_\mu^2$ of the estimated parameter $\mu$ which takes into account both sources of uncertainty. While the simplicity and neatness of the Rubin’s method are attractive, a caveat should be made that inferences based on equations 3.1 and 3.2 are valid only if the multiple imputation procedure is ‘proper’ in Rubin’s terms (Rubin, 1987: 118). This is equivalent to having the missing variables determined by means of an explicit Bayesian model, as well as having the final, multiple-imputation-based estimates tending towards their true values with the associated between-imputation variance smaller than the within imputation variance (for a more formal statement, see Rubin, 1987, p. 118). As a result, the method is only applicable to certain instances of imputation problems based on parametric approaches, while in the context of implicit, metric-matching imputations it could lead to biased (underestimated) results.

An alternative approach to Rubin’s multiple imputations framework which is far less reliant on parametric assumptions involves bootstrap-based estimation of variance and confidence intervals (Andridge and Little, 2010; Shao and Sitter, 1996). As the current analysis will employ an implicit approach, the actual bootstrap method is described in more detail in the subsequent section 3.2.1. In the end, the trade-off between single and multiple imputation approaches is that between a method of greater computational simplicity but with potentially naïve (underestimated) variance, and a more computationally demanding but possibly correcting for that shortcoming approach. Nevertheless, multiple imputations procedures themselves have also specific methodological caveats which need to be taken into account when attempting to quantify the uncertainty due to imputation and thus data pooling procedures.

The final aspect, in fact sometimes overlooked in studies dealing with data pooling despite its critical importance, concerns the issue of identifiability of the hypothesized
joint distribution of the pooled variables under conditions when such variables are not simultaneously (jointly) observed (Gilula et al., 2004; Smit, 2011). Recalling that the underlying logic for data pooling approach is to explore common presence of certain variables, the method seeks to mimic a situation where all variables of interest, i.e. $X_1$ and $X_3$ (recall the notation from Figure 3.1) are observed jointly in a single dataset $D$. Under such idealised scenario, it would be possible to define a joint probability distribution of the variables given specific parameters $\theta$ describing the distribution (Gilula et al., 2004):

$$p(X_1, X_3|D) = \int p(X_1, X_3|D, \theta)p(\theta|D) \, d\theta$$

(3.3)

However, $p(X_1, X_3|D, \theta)$ is not directly observable and therefore a link between this joint distribution and conditional distributions which are directly observed in the data, i.e. that of $X_1$ and $X_3$ give $X_2$, are needed. Note that equation 3.3 can be rewritten in terms of the conditional expectations of $X_1$ and $X_3$ given $X_2$:

$$p(X_1, X_3|D) = \int \int p(X_1, X_3|X_2, \theta)p(X_2)p(\theta|D) \, dX_2 \, d\theta$$

(3.4)

Unfortunately, $p(X_1, X_3|X_2, \theta)$ is not directly observed either and the only available information that can be drawn from the datasets includes marginal distributions of $X_1$ and $X_2$ (ICT dataset), and $X_2$ and $X_3$ (travel behaviour dataset). If one imposes the assumption of conditional independence (CIA) between $X_1$ and $X_3$ given $X_2$, i.e.:

$$p(X_1, X_3|X_2, \theta) = p(X_1|X_2, \theta)p(X_3|X_2, \theta)$$

(3.5)

the joint distribution of $X_1$ and $X_3$ can be completely identified from the available information, i.e.:

$$p(X_1, X_3|D) = \int \int p(X_1|X_2, \theta)p(X_3|X_2, \theta)p(X_2)p(\theta|D) \, dX_2 \, d\theta$$

(3.6)
The requirement for CIA is dictated by the fact that for any given marginal distributions of $X_1$ and $X_2$, and $X_2$ and $X_3$, there can be many forms of consistent joint distributions of $X_1$, $X_2$, and $X_3$. The CIA imposes constraints on the dependence between variables ensuring identifiability of the joint distribution of $X_1$ and $X_3$. At the same time, the assumption is effectively equivalent to declaring that the vector of common variables $X_2$ is rich enough that after conditioning on it, no further dependence would exist between $X_1$ and $X_3$. While this limitation is not always clearly stated in data fusion studies, it underlies most of the techniques, both explicit and implicit. Unfortunately, testing for validity of this assumption in particular instances is only possible with auxiliary information in a form of jointly observed values of $X_1$, $X_2$, and $X_3$. Alternative approaches ensuring that the joint distribution is identifiable given the observed marginal distributions include pairwise independence assumption or finite mixture models introducing additional latent variables to condition upon (Smit, 2011), though these techniques are not only far less frequently applied, but their validity can also only be established by means of additional auxiliary data. Nevertheless, Gilula et al. claimed that in situations where a rich array of shared variables is available, conditional independence assumption may be a reasonable approximation (Gilula et al., 2004).

3.2.1 Data pooling approach in the current context: hot-deck matching using the $k$-NN algorithm and a proper bootstrap

Facing the methodological considerations discussed in the previous section, a number of approaches are in principle feasible in the current research context. A feature that needs to be borne in mind is the subsequent SEM character of the analysis which requires consistency between the imputed variables and for this purpose implicit hot-deck procedure appears the most suitable as, by its definition, whole set of variables observed with the donor respondent is transferred to the target respondent (Aluja-Banet et al., 2007). Moreover the approach’s ‘efficient in keeping covariance structure and avoiding incoherencies’ (Saporta, 2002, p. 471) which is important when dealing with SEM which relies on maximising the fit between observed and implied covariance structures.

A possible alternative could be to develop regression-based models in which travel behaviour variables are regressed on the shared variables though in such a case
ensuring the consistency between the imputed variables would be difficult to achieve. Moreover, a number of distributional and structural assumptions would be required which could be difficult to meet especially when facing mixed categorical and continuous variables. For these purposes, direct donation of the values as in the hot-deck approach emerges as more suitable.

When choosing between the level of imputation, the micro approach is more desirable as implementation of implicit procedures are rarely undertaken at macro levels (Smit, 2011). Furthermore, implementing the hot-deck procedure by means of the $k$-NN algorithm (see next section 3.2.2 for a more detailed overview) naturally generates multiple candidate donor records in the form of a set of nearest neighbours, thereby facilitating the possibility of capturing the pooling-related uncertainty in estimation by means of a proper bootstrap (also to be described in the following section 3.2.2). Additionally, from the exploratory perspective, investigating the micro approach should prove more fruitful given that micro-data can be used for a wider range of modelling structures.

Regarding restrictions placed on the imputed values, the travel variables can be imputed in principle without any as individuals would in general be able to travel for any of the investigated travel purposes, including work as the samples involves teenage or older respondents. When it comes to the issue of identifiability, being in no possession of any auxiliary information about the joint distribution of variables of interest (which is in fact part of motivation for the current analysis), it is necessary to assume that the conditional independence assumption holds on the basis of richness in the socio-demographic and situational variables shared by the respective ICT and travel behaviour datasets.

### 3.2.2 Design and implementation of the data pooling procedure

In the current context, the main idea behind the pooling approach is to find, for each respondent in the target dataset (ICT use), a similar respondent (or a set of $k$ most similar respondents, or nearest neighbours) in the training (travel behaviour) dataset and assign his/her values of the variables of interest, i.e. travel behaviour characteristics. This assumption of ‘twins behaving similarly’ is also justifiable on the statistical grounds. More precisely, if smoothness of the joint probability distribution
of the shared and travel variables $p(X_2, X_3|\theta)$ is assumed, the regression function $X_3_l = f(X_2_l)$, i.e. an explicit model, expressing the expectation $E(X_3|X_2)$ for a particular respondent $l$ can be approximated by values observed for individuals $l'$ located in the local neighbourhood $L$ of the respondent $l$ (Aluja-Banut et al., 2007):

$$E(X_3_l|X_2_l) = f(X_2_l) \approx g[f(X_2_{l'}), l' \in L(l)]$$

(3.7)

where $g$ denotes a function transforming the values derived from the local neighbours into a suitable value for the respondent $l$ which usually takes form of an arithmetic mean. Consequently, the k-NN method may serve as a means of obtaining draws and conditional expectations which are essential to data pooling method as shown in equation 3.6. Due to implicit character of the approach, no assumptions need to be made regarding the actual functional form of $f(X_2_l)$. Instead, the imputations are obtained more directly by combining the values observed with the closest training observations (local neighbourhood), e.g. by averaging over them, which is expressed by the function $g$. This process is summarised in equation 3.7. In case of an explicit model, the purpose would be to define actual functional form of $f(X_2_l)$ estimated using the training set. Obviously, assumptions would be required regarding the nature of such relationship and modelling structure, which is not required in the k-NN approach. The implicit price of this flexibility is the assumption that the formulation 3.7 provides a reasonable approximation for $f(X_2_l)$, which is why larger datasets, providing denser coverage of the feature space are preferred as training datasets.

An important aspect of the $k$-NN approach involves the choice of the measure of similarity between the respondents which needs to make use of the variables shared by the pooled datasets, i.e. $X_2$. In contexts where data pooling technique is a pre-planned strategy rather than a means of handling lack of complete datasets, such variables would be selected so as to ensure compliance with the conditional independence assumption. However, in the current context where no control over the datasets is available, the choice of such variables is strongly data-driven. Additionally, while it may be intuitive to assume that more shared variables would always lead to superior performance of the algorithm by enabling more accurate comparisons between the respondents (just as more explanatory variables would be hoped to
provide superior fit in case of regression-based models), this is not necessarily the case for finite-size samples. This arises from the so-called curse of dimensionality.

**Figure 3.2** Schematic representation of the curse of dimensionality

which describes a condition where ‘irrelevant attributes in the feature vector dominate the distance metric, reducing the influence of relevant attributes on the distance metric’ (Robinson and Polak, 2005, p. 8). Consider a simplified representation of the issue in Figure 3.2. In the left panel the most similar observation to the target observation $l$ (green cross) in terms of the feature dimension $X_{2x}$ is $l_1$, since clearly $d^{1D}_1 < d^{1D}_2$. However, if additional dimension $X_{2y}$ is introduced, it is observation $l_1$ that becomes the closest match since $d^{2D}_2 < d^{2D}_1$ (while $d^{1D}_1 < d^{1D}_2$ still holds) though the difference is clearly less profound. Introducing additional dimension of matching may be desirable if both $X_{2x}$ and $X_{2y}$ matter in terms of the matching quality. However, further increase in the number of dimensions may lead to blurring of the differences and similarities just as in the Figure 3.2 where significant difference ($\ll$) became less pronounced ($<$) as a result of the reduced density of data points in the local neighbourhood of $l$. In such cases, possible donor respondents become more or less equidistant to the target observation. Furthermore, if $X_{2y}$ happens to describe either irrelevant feature or captures the same kind of similarity as a different variable, it may reduce the impact of relevant features and impair the overall matching quality. A possible way to mitigate this effect is to introduce weighting of the matching variables with the weights derived on the basis of
explanatory power using e.g. simple linear regressions, including locally estimated weights (Wang et al., 2005). The curse of dimensionality would not be an issue in principle in case of an infinite number of heterogeneous observations which would ensure that the region in the proximity of the target observation is dense enough regardless of the number of dimensions. However, this condition is virtually impossible to meet when dealing with human respondents, though may be more feasible in case of passively derived ‘big data’. Additionally, the respondents should be randomly distributed in the feature space to ensure accurate coverage of the local neighbourhood for any respondent.

As a consequence, construction of an appropriate vector of matching variables will need to reflect a balance between the requirements posed by the conditional independence assumption in terms of comprehensive transmission of the relationships between pooled variables, and parsimony required to avoid the curse of dimensionality. In order to achieve this result, it is customary to investigate the vector of common variables for possible dimension reductions without compromising the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country nominal (N)/ordinal (O)*, number of response categories</td>
<td>USA (13)</td>
</tr>
<tr>
<td>Gender</td>
<td>N, 2</td>
</tr>
<tr>
<td>Age</td>
<td>O, 100</td>
</tr>
<tr>
<td>Marital status</td>
<td>N, 5</td>
</tr>
<tr>
<td>Household size</td>
<td>-</td>
</tr>
<tr>
<td>Number of children in the household</td>
<td>N, 10</td>
</tr>
<tr>
<td>Household structure</td>
<td>-</td>
</tr>
<tr>
<td>Highest level of education obtained</td>
<td>O, 7</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>N, 5</td>
</tr>
<tr>
<td>Hispanic background</td>
<td>N, 2</td>
</tr>
<tr>
<td>Region/state of residence</td>
<td>N, 56</td>
</tr>
<tr>
<td>Urban/rural resident</td>
<td>N, 2</td>
</tr>
<tr>
<td>Type of tenure</td>
<td>-</td>
</tr>
<tr>
<td>Full-/part-time employment status</td>
<td>N, 2</td>
</tr>
<tr>
<td>Self-employment status</td>
<td>-</td>
</tr>
<tr>
<td>Full-/part-time student status</td>
<td>N, 3</td>
</tr>
<tr>
<td>Number of work-hours in a typical week</td>
<td>-</td>
</tr>
<tr>
<td>Supervisory duties at work</td>
<td>-</td>
</tr>
<tr>
<td>Personal income</td>
<td>-</td>
</tr>
<tr>
<td>Household income</td>
<td>O, 8</td>
</tr>
<tr>
<td>Computer and/or Internet user</td>
<td>N, 2</td>
</tr>
<tr>
<td>The most frequent travel purpose</td>
<td>-</td>
</tr>
<tr>
<td>Number of cars available to the household</td>
<td>-</td>
</tr>
<tr>
<td>Frequency of travel by bus</td>
<td>-</td>
</tr>
</tbody>
</table>

* Included also continuous variables to facilitate the use of symbolic covariance-based Mahalanobis distance
explanatory power through employment of statistical techniques such as factor analytic methods or regression techniques as well as the analysts' informed (e.g. on the basis of literature) judgment. The lists of variables used for constructing the measure of similarity between respondents in the datasets which was decided upon through employment of these techniques are summarised in Table 3.3.

Once the vector of matching variables is defined, the decision regarding functional form of the distance metric must be made to enable conversion of the shared characteristics into a single, scalar measure. In the present analysis, the use is made of Mahalanobis distance which has been deemed optimal for the k-NN approach (Enas and Choi, 1986; Fukunaga and Hostetler, 1973; McCane and Albert, 2008; Robinson and Polak, 2005) and also remained the most widely used to date. The Mahalanobis distance $d_{l-l'}$ measuring the degree of similarity between respondents $l$ and $l'$ in terms of the characteristics described by vectors of $X_2_l$ and $X_2_{l'}$ respectively is given by:

$$d_{l-l'}(X_2_l, X_2_{l'}) = \sqrt{\delta(X_2_l, X_2_{l'})^T \Sigma^{-1}_{sym} \delta(X_2_l, X_2_{l'})}$$

(3.8)

where $\delta(X_2_l, X_2_{l'})$ is a function attaching numerical value to particular differences in features (e.g. in gender or income group) and $\Sigma^{-1}_{sym}$ is the inverse of symbolic covariance matrix (McCane and Albert, 2008) which ensures both unit-free comparison and accounts for the possible dependence between the variables. The use of symbolic covariance in the current case is motivated by the fact that while calculation of the Mahalanobis distance is straightforward for continuous variables, it becomes much more cumbersome in the presence of mixed, discrete ordinal and categorical variables. In such a case, not only the question is how to represent numerically the difference between nominal categories such as genders or marital statuses, but also how to appropriately capture the underlying correlation (covariance) structure. While complex modifications of Mahalanobis distance have been devised to enable inclusion of mixed data (e.g. Leon and Carrière, 2005), McCane and Albert (2008) demonstrated that the use of so-called symbolic covariance matrix can be more efficient and practical at the cost of possible moderate deterioration in the quality of performance.
The main difference between the traditional concept of covariance matrix and its symbolic counterpart lies in the interpretation of deviations from the mean value. Instead of obtaining algebraic differences between the values and the mean, the symbolic covariance matrix defines a function $\delta$ which attaches numerical value to differences between the categories of response. A simple example in case of a binary variable would be to evaluate to unity if the encountered categories are different, and to null if they are the same. It is worth noting that if the variables are continuous and $\delta$ is defined as algebraic difference between the actual numerical values, the concept of symbolic variance collapses to the usual covariance matrix, and thus the latter can be seen as simply a specific realisation of the symbolic case.

In this study, the following rules (based on the suggestions of McCane and Albert, 2008) for $\delta$ are assumed for assigning numerical values when the function is evaluated for individuals $l$ and $l'$ over the response values, $X_{2_l}^q$ and $X_{2_l'}^q$, respectively, of a variable $X_2^q$ belonging to the vector of $Q$ shared variables $X_2$:

- if $X_{2_l}^q = X_{2_l'}^q$, $\delta \left(X_{2_l}^q, X_{2_l'}^q\right) = 0$;
- if either $X_{2_l}^q$ or $X_{2_l'}^q$ contains a missing value, $\delta \left(X_{2_l}^q, X_{2_l'}^q\right) = 0$;
- if $X_{2_l}^q \neq X_{2_l'}^q$ and $q$ is nominal (categorical), e.g. gender, $\delta \left(X_{2_l}^q, X_{2_l'}^q\right) = 1$
- if $X_{2_l}^q \neq X_{2_l'}^q$ and $q$ is ordinal, e.g. income level:
  - $\delta \left(X_{2_l}^q, X_{2_l'}^q\right) = 1$ for extreme categories (e.g. lowest and highest income groups)
  - if either category is not extreme, the difference would be is proportional to the number of categories in the variable, i.e:

$$\delta \left(X_{2_l}^q, X_{2_l'}^q\right) = \frac{C(X_{2_l}^q, X_{2_l'}^q) + 1}{C(X_{2_l}^q) - 1} \quad (3.9)$$

where $C(X_{2_l}^q, X_{2_l'}^q)$ is a number of categories separating $X_{2_l}^q$ and $X_{2_l'}^q$ and $C(X_{2_l}^q)$ is total number of categories in the variable $X_{2_l}^q$. This rule can be visualised by means of the following Toeplitz matrix (3.10), elements of which provide values for $\delta$ for any combination of the ordinal categories. The appropriate values can be found by assuming that the lowest category conforms to the row/column index of 1, one category higher to 2, and so on:
Thus for instance in case of a 4 category ordinal variable $X_{2q}$ ($C(X_{2q}) = 5$), the value which the function $\delta$ would evaluate to over 1st and 3rd categories (counting from the lowest) is given by by equation 3.9 is:

\[
\delta(X_{2q}^l = 1, X_{2q}^{l'} = 3|C(X_{2q}) = 5) = \frac{C(X_{2q}^l, X_{2q}^{l'}) + 1}{C(X_{2q}) - 1} = \frac{1 + 1}{5 - 1} = \frac{1}{2} \tag{3.11}
\]

The same result can be obtained by looking for an element in 1st row and 3rd column (or 3rd row and 1st column due to the symmetric character of the matrix 3.10):

\[
\delta(X_{2q}^l = 1, X_{2q}^{l'} = 3|C(X_{2q}) = 5) = \frac{2}{C(X_{2q}) - 1} = \frac{2}{5 - 1} = \frac{1}{2} \tag{3.12}
\]

The intuition behind the rules above is that the difference between the most distant ordinal categories would be valued similarly to a difference between any nominal variables with the intermediate values located proportionally in-between following the advice by McCane and Albert (2008) to capture ordering of the values. This is to reflect the fact that the order of categories carries additional information about differences between the respondents that should be reflected in the distance metric, e.g. people of medium and high income are more similar than low and high income. In order to in order to conform to the rules outlined above, some variables that would
normally be treated as continuous, e.g. age, household size, had to be effectively
discretised into ordinal variables. Nevertheless, in the process of doing so the
maximum feasible level of granularity has been retained by forming as many response
categories as the potential integer values observed which, together with the distinctive
treatment of ordinal variables, ensures efficient use of information contained in such
variables. Finally, regardless of whether a variable is nominal or ordinal, if any of the
compared values is missing, $\delta$ function evaluates to unity which is a conservative
approach hedging against yet additional uncertainty that could be introduced in
additional imputation at this level.

By following the approach outlined above, it is possible to calculate Mahalanobis
distances between any pair of respondents in the target and training datasets. This
enables finding, for each respondent in the ICT dataset, $k$ most similar respondents
(nearest neighbours) in the travel behaviour (training) dataset as characterised by the
shared variables. The actual choice of the value of $k$ (or alternatively a cut-off
distance which is, however, a rarely followed approach) in relation to the sample size
$N$ should make use of the property which ensures consistency in approximation of the
probability density function in the feature space hypersphere of the local
neighbourhood of the target respondent (Ghosh, 2006):

$$\lim_{{k \to \infty}} \frac{k}{N} = 0$$

(3.13)

If the condition 3.13 holds while $k \to \infty$ and $N \to \infty$, the error rate of the nearest
neighbour approach will tend to the Bayes’ error rate, i.e. that of a loss-minimising
(Bayes) estimator which is, by definition, the maximum achievable performance. In
the case of a single nearest neighbour, i.e. $k = 1$, the risk will tend to twice the Bayes’
error (Dudani, 1976; Elkan, 2011). At the same time, increasing the value of $k$ will in
general lead to increased bias in the in the estimated quantities as more and more
distant neighbours’ are based upon to impute the value for the target respondent
though with the benefit of reduced variance in the estimate (Enas and Choi, 1986;
Hand and Vinciotti, 2003). Dudani (1976) demonstrated, however, that the bias of
larger $k$ can be reduced by reflecting the degree of similarity within the nearest
neighbours, not just the mere fact of belonging to that set. This would transform the expression 3.7 to take explicit account of the distance between the respondents $d_{l-l'}$:

$$E(X3_l|X2_l) = f(X2_l) \approx g[f(X2_{l'}), d_{l-l'}(X2_l, X2_{l'}) \ l' \in k(l)]$$  \hspace{1cm} (3.14)

A simple example of implementation of the rule 3.14 would be to use weighted average of the values with the weights inversely proportional to the distance of a particular nearest neighbour to the target respondent (McRoberts et al., 2011). The actual choice of an optimal value for $k$ would mean attempting to conform to these different challenges, and hence unsurprisingly a large body of literature has emerged around the topic though still without a definite theoretical guideline (Ghosh, 2006; Hall et al., 2008). While the recommended method would be to attempt cross-validating different possible values of $k$, such approaches are usually computationally very demanding and therefore frequently impractical. Furthermore, they would not only require defining appropriate criteria for optimality (see for instance Wang et al., 2005), but may also lead to multiple competing optimal values which will also be context- (i.e. distribution-) specific. A more universal result was obtained by Fukunaga and Hostetler (1973) who approached the issue of finding the optimal value $k^*$ by attempting to minimise the mean square error (difference) of the estimated density as compared to the actual one (Robinson and Polak, 2005). Nevertheless, the actual calculation of the value of $k^*$ would still require making parametric assumptions about the underlying mixture distribution which may be challenging in case of mixed- and multi-dimensional matching vectors.

| Table 3.4 Enas and Choi rule for choosing $k^*$ given sample size $N$ |
|-----------------|-----------------|
| Difference in sizes between target and training datasets | Small | Large |
| Difference in between covariance matrices (shared variables) | Small | $k^* = N^3_8$ | $k^* = N^2_8$ |
| | Large | $k^* = N^2_8$ | $k^* = N^3_8$ |

Source: adopted from Enas and Choi, 1986

Enas and Choi (1986) tested by means of a Monte Carlo experiment 5 different values of $k$ related to the sample size in a way conforming to the condition 3.13, i.e. $k = \{N^1_8, N^2_8, N^3_8, N^4_8, N^5_8\}$. Their study resulted in a simple rule for choosing $k^*$ which is summarised in Table 3.4. Based on the differences in covariance matrices observed
for target and training datasets, as well as relative sample sizes, the results of Enai and
Choi provide guide for an actual value of $k^*$. In the current context, it turns out that all
countries display large differences in terms of the sample sizes (as can be seen from
Table 3.1) and the differences in the covariance matrices of the matching variables are
significant (see Appendix 4 for a non-parametric test supporting this conclusion).
What follows from that result is the actual value for $k^*$ for each country (Table 3.5).

<table>
<thead>
<tr>
<th>Heuristic</th>
<th>Country</th>
<th>USA</th>
<th>UK</th>
<th>Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k^* = \frac{N}{3}$</td>
<td></td>
<td>34</td>
<td>40</td>
<td>39</td>
</tr>
<tr>
<td>(Enas and Choi, 1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$k^* = \frac{N}{2}$</td>
<td></td>
<td>11</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>(Enas and Choi, 1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$k^* = \sqrt{N}$</td>
<td></td>
<td>111</td>
<td>135</td>
<td>132</td>
</tr>
<tr>
<td>(Loftsgaarden and Quesenberry, 1965)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$k^* = \arg\min_{\text{RMSE}}$ under multivariate normality</td>
<td></td>
<td>12</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>(Fukunaga and Hostetler, 1973)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: shading indicates the preferred approach and thus values of $k^*$ for each country

Clearly, the resulting values fall between what other approaches suggest, and are
significantly larger than what appears to be the lower-bound suggestion. This may be
indication for possible biases in the imputed values if no distance-based weighting is
applied, and thus justifies the need for such way of deriving the estimates in the
current context.

In the current process, there are two ways enabling distance-based weighted estimates
of the imputed values. The first one involves explicit calculation of the weighted
average of the imputed variables, and estimation of the subsequent model based on a
single dataset consisting of the averages. The other technique follows a similar
procedure, though in an implicit manner, by obtaining a large number of datasets
constructed by means of imputing values for the individuals from their set of nearest
neighbours using Monte Carlo draws. Subsequently, estimation of the desired models
is carried out, and unweighted averages of the estimated parameters are calculated
(see Figure 3.3 on the next page). Whereas both methods would lead to equivalent
results due to linear character of the subsequent SEM, the Monte Carlo approach is
preferred as demonstrating more general applicability of the overall data pooling method at a cost of moderately higher computational effort. In order to obtain the probability of donating values to individual $l$ by a donor respondent $l'$ belonging to $l$’s set of nearest neighbours $k_l^*$, the distance $d_{l-l'}$ between the two can be converted by using a multinomial logit transformation:

$$p(l'|d_{l-l'}, k_l^*) = \frac{e^{-d_{l-l'}}}{\sum_{l'' \in k_l^*} e^{-d_{l-l''}}}$$  \hspace{1cm} (3.15)

Given that equation 3.15 leads to higher probability of being drawn for more similar observations, additional confidence can be placed in the result following from the conclusions Dudani (1976) who demonstrated lower error rates for distance-based weighting.

At the same time, to enable inferences regarding significance of the estimated parameters (and hence relationships) between the variables, a suitable measure of combining sampling variance (i.e. the usual standard error) as well as variance due to data pooling is necessary. While there exists parametric methods which enable drawing approximately valid inferences, with the previously discussed Rubin’s multiple imputation framework being the most widely applicable, these approaches may not be appropriate for implicit, k-NN-based imputations. This is especially the case given reliance of the current analysis on non-standard, symbolic covariance.
matrix approach. An attractive alternative in such a situation is offered by resampling-based approaches, in particular bootstrap-based and jackknife-based estimators of variance (Ene et al., 2013; McRoberts et al., 2011; Shao and Sitter, 1996) which are less reliant on parametric assumptions, and also less prone to misspecification of the underlying imputation models (Andridge and Little, 2010; Cordeiro et al., 2010).

![Figure 3.4 Schematic representation of bootstrap variance and confidence intervals estimation](image)

Nevertheless, the standard (naïve) bootstrap in which the imputed dataset is resampled for bootstrapping as if it was a complete dataset would normally lead to biased results, most importantly underestimated variance and hence size of the confidence intervals (Shao and Sitter, 1996). Consequently, it is crucial that the imputation procedure is reflected at each resampling level ensuring propagation of the additional uncertainty (Andridge and Little, 2010; Shao and Sitter, 1996). Such a procedure, shown in Figure 3.4, would start from creating a large (usually 1000) number of datasets by resampling (with replacement) from the target (ICT) dataset. Subsequently, values for the resampled datasets are imputed by Monte Carlo draws according to the previously defined imputation procedure which leads to the method of proper bootstrap.

It should be noted that each respondent in the resampled dataset would have its value assigned independently which means that even those observations which happen to be resampled more than once in the same dataset may have different values imputed (though from the same set of nearest neighbours). Subsequently, the actual analysis can be run to obtain the actual estimates of the desired parameters to produce 1000 (or other assumed large number) of such estimates. These estimates can be used to
directly construct the appropriate confidence intervals by selecting 2.5 and 97.5 percentiles as the respective cut-off points. Thus the procedure outlined above mimics and draws upon the procedures of approximate Bayesian bootstrap (Rubin, 1987) and bootstrap aggregating, or ‘bagging’ (Breiman, 1996) though in those contexts draws are made from the same dataset in order handle the missing data problem rather than quantify uncertainty in the data pooling procedure.

### 3.3 Methodology of Structural Equation Modelling

Structural Equation Modelling (SEM) has been an important modelling methodology in travel behaviour research for more than three decades (Golob, 2003). Whereas it is beyond the scope of this analysis to present in detail the SEM methodology which is well described in a number of other studies (Golob, 2003; Senbil and Kitamura, 2003) some technical information required to interpret the results of SEM analysis in the current context is essential, especially in light of the subsequent reliance on that method also in the Chapter 6.

A typical structural equation can be framed as consisting of vectors of endogenous and exogenous vectors, $Y$ and $X$ respectively, both of which can be defined as latent variables, the associated matrices of parameters $B_Y$ and $B_X$ as well as vector of the error terms $\varepsilon$:

$$Y = B_YY + B_XX + \varepsilon \quad (3.16)$$

Given that formulation is linear in character, it is possible to derive the model-implied covariance matrices which can be fitted to the observed (sample-based) covariance matrices assuming that certain identifiability conditions hold (see Golob, 2003, for a general and Greene, 2012, for a technical discussion). Additionally, the structural equation approach enables identifying two sorts of effects of an exogenous variable: direct and indirect (mediation). While direct effects are captured by the $B_X$ parameters, indirect effects account for the possibility of transmission of that effect through other endogenous variables in which case the indirect effect is defined as the product of appropriate elements of $B_Y$ and $B_X$. The sum of such effects provides indication of the size and direction of total effect of certain exogenous factor on an endogenous variable.
If no latent variables are present, as is the case in the current analysis, the task is reduced to constructing a structural model as compared to a measurement model, another subclass of SEM. This is in principle equivalent to estimating parameters of a number of simultaneously interrelated multivariate linear equations which can be achieved by various methods including normal theory maximum likelihood, generalised least squares, and different forms of weighted least squares being the most frequently used (Golob, 2003). In the current study, use is made of so-called asymptotically distribution-free diagonally-weighted least squares (ADF-DWLS) approach whose main shortcoming of large sample size requirement, i.e. at least 1000 observations is fulfilled (Golob, 2003). The advantage of the approach lies in its robustness to deviations from normal theory distributional properties of the datasets, and accuracy in the presence of ordinal data (Jöreskog, 2005; Mîndrilă, 2010).

Inherently, however, sizes of the estimated parameters would be unit-dependent. Due to the cross-national character of the study and the use of a number of very different datasets, for a better comparability between the countries it is desirable to standardise the estimated parameters. Such standardised parameters are either Pearson product-moment correlation coefficients in case of continuous variables, or polychoric correlation coefficients for discrete ordinal variables (Jöreskog, 2005). While the product-moment correlation coefficient is a well-established concept, the polychoric correlation coefficient, also attributed to Karl Pearson, has remained lesser known. The idea behind it is to assume that the analysed discrete ordinal variable is in fact only a result of discretisation of the underlying normal distribution of a continuous variable (Jöreskog, 1994). Such an assumption enables estimation of thresholds of the bins (categories) into which such a variable would have to be discretised in order to remain consistent with the observed distribution of the discrete values. Using pairs of such variables, now assumed to be jointly normally distributed, an attempt is made to estimate an asymptotic covariance matrix providing the best fit to the data observed in the sample, and thus obtain a polychoric correlation coefficient (Jöreskog, 2005, 1994). There is some disagreement on the overall quality of such a procedure (Ekström, 2011) yet studies have reported that it performs no worse, and frequently better than the product-moment coefficient, in the contexts involving use of discrete variables (Holgado–Tello et al., 2008; O’Brien and Homer, 1987) and is thus the recommended procedure (Jöreskog, 2005). Nevertheless, the polychoric correlation
coefficient can be applied only to endogenous variables, and therefore is not used in the current analysis, but is employed in the context of RO3 investigation in Chapter 6.

When specifying a structural equation model, the objective of the researcher should be to perform confirmatory analysis of the hypothesised interrelationships between the variables (Golob, 2003). For that purpose, a number of goodness-of-fit measures are used to test the quality of fit of the implied covariance structure as compared to the observed one (a more technical discussion is provided by Byrne, 1994). Such indices include:

- Chi-square test, which relates the discrepancy function (e.g. likelihood or sum of normalised least-square residuals) to the chi-square distribution to infer about the significance of the discrepancy between the observed and implied covariance structures. Nevertheless, the index tends to be overly inflated for models with many parameters, and even more so for large samples, in which cases its high value may bias judgment about the model quality;
- Rot mean square error (RMSE) which measures the mean difference between the observed and model-implied covariance structure;
- Comparative indices, including goodness-of-fit (GFI), comparative (CFI), and normed (NFI) indices which measure the relative fit of the hypothesised and observed covariance structures by investigating changes in the discrepancy function (GFI), and possibly adjusting it for sample size and number of factors investigated (NFI and CFI);
- Information criteria, e.g. Akaike (AIC) or Bayesian (BIC) which serve as tools for comparing model specifications to ensure high explanatory power and parsimonious character.

Nevertheless, multiple different hypothetical specifications can be fitted to the same underlying dataset, and still yield significant result and similar goodness-of-fit measures. Whereas improvements in the models can be sought by inspecting so-called modification indices, i.e. changes in the fit (chi-square values) due to inclusion of additional links between variables, these measures are based on purely statistical grounds (difference in chi-square statistic). Consequently, they should serve as advice rather than absolute indication for inclusion of an additional relationship, especially if no sensible interpretation can be provided. Thus in the present analysis, the focus is
given on devising, based on the literature, and testing a suitable specification together with investigating whether the data pooling approach can lead to informative results about the relationships between ICT use and travel behaviour.

3.3.1 SEM specification for the cross-national analysis of RO1

In the current study, the assumed *a priori* specification (see Figure 3.5 on the next page) is that where ICT use for a particular purpose is hypothesised to impact travel behaviour that arises from the need to participate in an activity fulfilling similar needs, e.g. tele-shopping is hypothesised to influence travel for shopping purposes. Such a formulation is motivated by the possibility of existence of various first order interactions between ICT and travel behaviour as discussed in sections 2.2 and 2.4, in terms of substitution, complementarity, modification, or neither. Note that ICT use for communication purposes is assumed to be linked with both work-related and social-related travel since the available datasets do not consistently distinguish the character of such ICT use. In addition, travel for work-related purposes, being the least flexible due to restrictions and rigidities resulting from employment obligations and labour organisation, is assumed to influence travel for other purposes due to limited time and monetary budget. Moreover, as the ICT use variables are effectively assumed exogenous, interactions between them can be captured through correlations in the error terms reflecting unobserved higher or lower propensities of joint ICT uses. Naturally, the ICT exogeneity could be challenged on the grounds discussed in 2.3 with the potential consequences described there, especially in terms of bi-directional causality and endogeneity. This is equivalent of saying that it would be possible in principle to argue for travel behaviour playing a role in determining ICT use, though in the current analysis the assumption is that individuals would seek to adopt ICT-based activities first, and depending on their usefulness, choose only subsequently to modify (or not) their activity-travel behaviour. This is similar to the assumption expressed by Wang and Law (2007, p. 518) that ‘travel is derived from activity participation [and] ICT-induced changes in time allocation for activities may lead to changes in travel behavior’. Furthermore, given that other means of handling simultaneity in the current context, e.g. IV or direct questioning are not possible, a strongly theory-supported SEM specification capturing the possible interactions in the most complete and justifiable manner constitutes a reasonable solution while ensuring identifiability of the system due to its non-recursive character (Golob, 2003).
Figure 3.5 Cross-national comparison of the relationships between ICT use and travel behaviour (standardised)
*significant at 90% level **significant at 95% level
The SEM estimation was performed using the lavaan 0.5.16 package implemented in R environment together with bootstrapping of standard error and confidence intervals thereof (Rosseel, 2012). The data pooling and resampling based on the k-NN algorithm was carried out by means of purpose-specific script implemented in Ox 6.20 (Doornik, 2011) with the selected number of draws assumed at the conventionally used level of 1000.

### 3.4 Findings

The first finding concerns performance of the of k-NN procedure which can be measured in terms of the extent to which the algorithm is able to correctly re-identify a respondent as its own closest neighbour by knowing only values of the shared variables and thus the distance metric. This procedure is similar to the concept of confusion matrix in which observed and implied values are compared against each other in a contingency table to assess the degree of accuracy of the model. Whereas the fraction of correct matches, i.e. hit rate, would tend to unity in the case of unique combination of matching values for each respondent, it could also be lower than that in case of non-uniqueness of such combinations or/and presence of missing values in the matching variables. The hit rates obtained in the current analysis for each country are shown in Figure 3.6.

**Figure 3.6** Quality measures of the k-NN data pooling process
are presented in Figure 3.6. The most consistent matching is observed in the case of UK dataset, reaching the value of almost 90% of correct predictions. This performance can be attributed to both high number of matching variables, convenient distribution of the respondents in the feature space, as well low rate of value missingness in the matching variables. Lower hot rates values have been obtained for the remaining datasets. In those cases, despite lower data missingness and more information-rich ordinal variables, the result for Norway is not as good as in the case of the US which has more matching variables in total, perhaps providing more unique identification information.

In terms of the fit of SEM for each country, a number of goodness-of-fit indices are reported in Table 3.6. The challenging nature of reporting fit indices in the present analysis results from the fact of dealing with pooled datasets (except Canada) in which cases mean values of the fit indices obtained from 1000 estimations using datasets pooled by means of distance-weighted MC draws from $k^*$ are reported.

<table>
<thead>
<tr>
<th>Fit measure</th>
<th>Country</th>
<th>^USA</th>
<th>^UK</th>
<th>^Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>p-value (&lt;0.001)</td>
<td>0.027</td>
<td>0.003</td>
<td>0.008</td>
<td>0.001</td>
</tr>
<tr>
<td>p-value (H0: RMSE=0)</td>
<td>&lt;0.001</td>
<td>0.999</td>
<td>0.998</td>
<td>0.999</td>
</tr>
<tr>
<td>95% Conf. interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower bound</td>
<td>0.024</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Upper bound</td>
<td>0.031</td>
<td>0.018</td>
<td>0.024</td>
<td>0.014</td>
</tr>
<tr>
<td>Goodness-of-fit index (GFI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Benchmark: &gt;0.90)</td>
<td>0.912</td>
<td>0.999</td>
<td>0.998</td>
<td>0.998</td>
</tr>
<tr>
<td>95% Conf. interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower bound</td>
<td>-</td>
<td>0.997</td>
<td>0.996</td>
<td>0.997</td>
</tr>
<tr>
<td>Upper bound</td>
<td>-</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>Comparative fit index (CFI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Benchmark: &gt;0.93)</td>
<td>0.852</td>
<td>0.995</td>
<td>0.992</td>
<td>0.999</td>
</tr>
<tr>
<td>95% Conf. interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower bound</td>
<td>-</td>
<td>0.964</td>
<td>0.960</td>
<td>0.987</td>
</tr>
<tr>
<td>Upper bound</td>
<td>-</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>Normed fit index (NFI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Benchmark: &gt;0.90)</td>
<td>0.852</td>
<td>0.954</td>
<td>0.936</td>
<td>0.960</td>
</tr>
<tr>
<td>95% Conf. interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower bound</td>
<td>-</td>
<td>0.920</td>
<td>0.897</td>
<td>0.932</td>
</tr>
<tr>
<td>Upper bound</td>
<td>-</td>
<td>0.980</td>
<td>0.961</td>
<td>0.981</td>
</tr>
<tr>
<td>Sample size</td>
<td>15 390</td>
<td>2 200</td>
<td>1003</td>
<td>1235</td>
</tr>
<tr>
<td>$k^*$</td>
<td>-</td>
<td>32</td>
<td>37</td>
<td>39</td>
</tr>
</tbody>
</table>

Table 3.6 Fit indices for the SEM for different countries

Estimation method: ADF-DWLS

^Benchmark values based on Byrne (1994) and Golob (2003); ^Mean values based on the distance-weighted means, confidence intervals constructed using the percentile method form the proper bootstrapping approach.
together with confidence intervals obtained from the bootstrap-based percentile method.

As for the chi-square values, the hypothesised structures appear to yield good fit to the data apart from the Canadian case where, however, the large sample size may have been responsible for inflating the value. As for the RMSE, all models achieve performance of below the benchmark value of 0.05 which indicates acceptable level of mean discrepancy between the implied and observed covariance matrices. This result seems to be also confirmed for the pooled datasets when observing the relative fit indices which are all well above the benchmark values suggesting improvement in the fit as compared to an independent model (assuming no correlations between the variables). Surprisingly, only in the Canadian case the relative goodness-of-fit was noticeably lower which may indicate interaction of the large sample size and, subject to the validity of the data pooling mechanism, the fact that relationships between durations of ICT-based activities and travel may be influenced by additional factors, as compared to relationships involving number of ICT activities participated in.

3.4.1 Relationships between ICT and travel behaviour across countries

The specification and results presented in Figure 3.5 support the overall hypothesis regarding existence of complex pattern of interactions between ICT use and travel behaviour in various countries. While the arrows in the figure may suggest directionality of relationships, given the well-known difficulties in reliably inferring causation from cross-sectional data requiring a number of sometimes difficult to sustain assumptions (Mebane, 1990), such interpretations are limited only to instances where strong behavioural explanation may be provided. An example of such an instance may be seen in the case of significant and consistent across countries negative relationship between travel for work purposes and travel for the remaining purposes even when measured using different indices (duration, frequency). As work-related travel amount is usually less freely chosen than that for other reasons, it is justified to interpret it as causal relationship, especially that such a relationship has been reported by researchers in other contexts, including the currently analysed countries (e.g. Konduri and Pendyala, 2009).

When it comes to the relationships between ICT use and travel behaviour, ICT-based communication is seen as negatively associated with travel for work purposes in case
of Canada, but positively in the cases of the UK and Norway. Given the ways in which the variables were measured, the results may be interpreted as evidence for temporal substitution (in Canada) on one hand, but also (for the other two countries) complementarity in terms of more types of communication activities among those who travel more for work. Nevertheless, these results may mask heterogeneity within the populations as discussed in Chapter 2, e.g. highly skilled and also very mobile people are usually associated with more frequent use of communication tools, though Noce and McKeown (2008) noted that also those living in rural areas with a generally poorer access to advanced ICT may travel more frequently.

No evidence is present for any significant relationships between ICT use for communication and travel for social purposes which suggests that pure communication capabilities may not be sufficient to fulfil individuals’ social needs. On the other hand, time spent in the virtual activities whose functionalities are oriented at social needs such as social networking or blogging is negatively correlated with travel for such purposes in the Canadian case. Given that this dataset is not only the most complete one (as compared to the pooled ones) but also comparatively recent (2010), it already captures emergence of social media (Facebook, Twitter) in the late 2000s. This result may suggest therefore that in the most recent Canadian case a degree of substitution between ICT-based social activities and travel for social reasons is indeed supported. However, this outcome may also include a degree of Canadian specificity in these relationships when compared against other countries as well as results reported elsewhere in the literature, reporting positive relationship between participation in social media and social-related travel (Hjorthol and Gripsrud, 2009; Kamargianni and Polydoropoulou, 2013).

As for tele-shopping and shopping-related travel, positive correlation can be observed in the Canadian case which is also is consistent with the report by McKeown and Brocca (2009) suggesting that Canadians tend to search for products and compare their prices online (which would nonetheless be coded as ‘shopping online’), but eventually buy the items from traditional stores. At the same time, a negative relationship is noted in case of the UK dataset which, when interpreted in light of the ICT variable for that country capturing the range of goods bought online, suggests that more comprehensive use of tele-shopping is associated with reduced shopping-
related travel. Lack of significant result in the case of the US may be resulting from the poor information regarding online shopping behaviour (i.e. only in terms of using unsolicited e-mails for shopping) whereas in the Norwegian case the result indicates no relationship to daily frequency of travel-related trips.

Regarding leisure, North Americans tend to have their duration (Canada) and range (US) of ICT-based activities negatively correlated with the durations of travel for such purposes. At the same time, the relationship is of the opposite direction in the European cases (UK, Norway). In the Canadian case, longer participation in ICT-based leisure may force individuals to reduce travel for leisure-related activities due to time constraints whereas in the case of the US richer participation in terms of online leisure appears to discourage other forms of leisure and the associated travel. As for the UK and Norway, more digital leisure activities can be perhaps linked to more leisure-related travel and possibly presence of leisure-oriented lifestyles in general.

Last but not least, in case of ICT use for various tele-services and its relationship with all other travel, a positive and significant relationship is seen in Canada but a negative one in the context of the US with no definite relation in the UK and Norwegian contexts. In case of Canada, this may be interpreted as supplementary interaction of virtual and physical participation in other activities, including education, personal care, or civic services. The negative relationship in the case of the US suggests that

<table>
<thead>
<tr>
<th>Travel purpose</th>
<th>Country</th>
<th>bUSA</th>
<th>bUK</th>
<th>bNorway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indirect effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>0.005**</td>
<td>0.004</td>
<td>-0.006</td>
<td>-0.013**</td>
</tr>
<tr>
<td>Shopping</td>
<td>0.005**</td>
<td>0.004</td>
<td>-0.023**</td>
<td>-0.012**</td>
</tr>
<tr>
<td>Leisure</td>
<td>0.004**</td>
<td>0.001</td>
<td>-0.029**</td>
<td>-0.013**</td>
</tr>
<tr>
<td>Other</td>
<td>0.004**</td>
<td>0.004</td>
<td>-0.007</td>
<td>-0.010**</td>
</tr>
<tr>
<td><strong>Total effects</strong></td>
<td>-0.006</td>
<td>-0.018</td>
<td>0.002</td>
<td>-0.016</td>
</tr>
</tbody>
</table>

**significant at 95% level

such virtual participation can also be associated with travel for such purposes as a substitute which could potentially indicate dataset- and country-specificity but more consistent way of measuring these aspects would be required for a robust justification of this conclusion.
Given that use of ICT for communication is related to travel for social purposes both directly and indirectly via work-related travel, Table 3.7 presents the results of a mediation analysis for these cases. These results indicate that in addition to the previously reported direct effects, communication in the Canadian case, by being associated with lower amount of travel is also correlated with more time for travel social, shopping, leisure, and all other purposes. Interestingly, opposite results can be reported in the UK and Norwegian cases due to a different nature of the relationship between ICT-based communication and work-related travel. What can be concluded from this analysis is that there appears to exists evidence for the fact that direct effects may not provide a complete enough picture to infer about the net interactions with travel amount, emphasising the complexity of such relationships, and that evidence for such relationship may be different due to the dataset and context specificities.

At the same time, a significant degree of homogeneity in the populations appears to exist in terms of propensity to engage in various ICT-based activities simultaneously as suggested by the positive residual correlations between the ICT variables (Table 3.8). Given that the ICT data for the US, UK, and Norway were all recorded in terms of the range of activities or online-shopped goods, the results suggest that advancement of the digital lifestyle would tend to be observed as increased use of ICT for different purposes simultaneously. In the Canadian case as the variables represent durations of participation in ICT activities, lower level of correlation may result from the fact that duration per se may not be an accurate measure on the actual level of proficiency and advancement in terms of ICT use. In fact, more time spent on activity can be interpreted as resulting from higher level of engagement and advancement on one hand, but also as a struggle in participation on the other. Nevertheless, the results

<table>
<thead>
<tr>
<th>ICT Use Variables</th>
<th>Country</th>
<th>Canada</th>
<th>USA</th>
<th>UK</th>
<th>Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>Social</td>
<td>0.006</td>
<td>0.368**</td>
<td>0.476**</td>
<td>0.521**</td>
</tr>
<tr>
<td>Communication</td>
<td>Shopping</td>
<td>-0.005</td>
<td>0.109**</td>
<td>0.611**</td>
<td>0.585**</td>
</tr>
<tr>
<td>Communication</td>
<td>Services</td>
<td>0.025**</td>
<td>0.730**</td>
<td>0.699**</td>
<td>0.659**</td>
</tr>
<tr>
<td>Communication</td>
<td>Leisure</td>
<td>0.006**</td>
<td>0.685**</td>
<td>0.592**</td>
<td>0.495**</td>
</tr>
<tr>
<td>Social</td>
<td>Shopping</td>
<td>-0.006</td>
<td>0.110*</td>
<td>0.410**</td>
<td>0.488**</td>
</tr>
<tr>
<td>Social</td>
<td>Services</td>
<td>0.008</td>
<td>0.444**</td>
<td>0.429**</td>
<td>0.486**</td>
</tr>
<tr>
<td>Social</td>
<td>Leisure</td>
<td>0.020</td>
<td>0.489**</td>
<td>0.534**</td>
<td>0.531**</td>
</tr>
<tr>
<td>Shopping</td>
<td>Services</td>
<td>0.002</td>
<td>0.150**</td>
<td>0.783**</td>
<td>0.742**</td>
</tr>
<tr>
<td>Shopping</td>
<td>Leisure</td>
<td>0.000</td>
<td>0.147**</td>
<td>0.586**</td>
<td>0.499**</td>
</tr>
<tr>
<td>Services</td>
<td>Leisure</td>
<td>0.023**</td>
<td>0.721**</td>
<td>0.666**</td>
<td>0.503**</td>
</tr>
</tbody>
</table>

*significant at 90% level **significant at 95% level
reported in Table 3.8 appear to be in support of existence of segment of population with particularly rich ICT-based lifestyles.

Table 3.9 Cross-national comparison of the relationships between travel behaviour for individuals with rich digital lifestyles

<table>
<thead>
<tr>
<th>Country</th>
<th>Features of digital lifestyle</th>
<th>Digital lifestyle segments</th>
<th>Travel Behaviour: amount of travel for different purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High level of participation in a variety of different online activities</td>
<td>Shopping lovers, Internet explorers, Fearful browsers, Fun seekers</td>
<td>Work: Less Social: Uncertain Shopping: More Leisure: More Other: More</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td>Influencers, Communicators</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>High level of participation in a variety of different online activities</td>
<td>Shopping lovers, Internet explorers, Fearful browsers, Fun seekers</td>
<td>Work: Uncertain Social: Uncertain Shopping: Uncertain Leisure: Less Other: Less</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>High level of participation in a variety of different online activities</td>
<td>Shopping lovers, Internet explorers, Fearful browsers, Fun seekers</td>
<td>Work: More Social: Less Shopping: Less Leisure: Uncertain Other: Uncertain</td>
</tr>
<tr>
<td>Norway</td>
<td>High level of participation in a variety of different online activities</td>
<td>Shopping lovers, Business users, Fearful browsers, Internet explorers</td>
<td>Work: More Social: Less Shopping: Less Leisure: Uncertain Other: Less</td>
</tr>
</tbody>
</table>

This finding in terms of existence of individuals whose digital lifestyles are particularly rich can be compared with the segments of digital behaviour reported in other studies (Brengman et al., 2005; TNS Global, 2010) as shown in Table 3.9. When both direct and indirect relationships between ICT and travel variables reported in Figure 3.6 are taken into account, it is possible to assign particular characteristics of travel behaviour to the digital lifestyle segments. By doing so and assuming, perhaps somewhat speculatively, that the assumption of causality between ICT and travel behaviour holds, it is possible to assess how increase in ICT use for different dimensions simultaneously may translate into travel behaviour. Thus in the case of Canadian individuals, it would be possible to expect less work-related travel and more travel for shopping and other purposes with uncertain implications for social and leisure travel. In the US context, reduction in leisure and travel for other purposes may be expected, whereas changes to travel for work, social, or shopping would be unclear. In case of the UK and Norway, some similarities can be observed in terms of increased expected travel for work-related purposes and less travel for social and
shopping. Whilst in both cases impact on leisure-related travel would be uncertain, travel for any other purpose would be expected to fall in Norway while in the UK this would remain uncertain. Whereas clearly depending on the untested causality assumption, this discussion demonstrates despite certain similarities in terms of ICT use observed across countries, these may not necessarily translate into similar relationships with travel behaviour, and hence implications for transport systems.

3.4.2 Methodological findings

Apart from the behavioural aspect of the study, the current analysis provides an opportunity for investigating methodological results arising from the novel character of applying $k$-NN-based data pooling approach in this context. Table 3.10 presents the degree of bias in the estimated parameters when comparing distance-weighted estimates ($\theta_{k^*}$), standard (naïve) bootstrap estimates ($\theta_{BT}$), and proper bootstrap estimates ($\theta_{BTk^*}$) taking into account the imputation process. The distance-weighted and proper bootstrap approaches, calculated only for the US, UK, and Norway, were calculated in reference to the case where $k = 1$. Inspection of the Table 3.10 reveals that in all naïve bootstrap cases, the bias is almost negligible (especially for statistically significant parameters) which is consistent with the random resampling and averaging procedure. A higher degree of bias can be observed in where inferences are based on multiple nearest neighbours which is in line with the previously.

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Outcome variable</th>
<th>Country</th>
<th>Canada</th>
<th>USA</th>
<th>UK</th>
<th>Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\theta_{BT}$</td>
<td>$\theta_{BT}^{k^*}$</td>
<td>$\theta_{BTk^*}$</td>
<td>$\theta_{BT}$</td>
<td>$\theta_{BT}^{k^*}$</td>
</tr>
<tr>
<td>ICT use</td>
<td>Travel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commun.</td>
<td>Work</td>
<td>4%</td>
<td>5226%</td>
<td>1%</td>
<td>-19%</td>
<td>-1%</td>
</tr>
<tr>
<td>Commun.</td>
<td>Social</td>
<td>10%</td>
<td>5777%</td>
<td>-1%</td>
<td>-77%</td>
<td>6%</td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td>&lt;1%</td>
<td>15%</td>
<td>&gt;1%</td>
<td>31%</td>
<td>14%</td>
</tr>
<tr>
<td>Shopping</td>
<td>Shopping</td>
<td>&lt;1%</td>
<td>1201%</td>
<td>-1%</td>
<td>1256%</td>
<td>9%</td>
</tr>
<tr>
<td>Leisure</td>
<td>Leisure</td>
<td>1%</td>
<td>36%</td>
<td>&lt;1%</td>
<td>39%</td>
<td>10%</td>
</tr>
<tr>
<td>Services</td>
<td>Other</td>
<td>-4%</td>
<td>-37%</td>
<td>&lt;1%</td>
<td>-36%</td>
<td>-39%</td>
</tr>
<tr>
<td>Travel</td>
<td>Travel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>Social</td>
<td>&lt;1%</td>
<td>-9%</td>
<td>&lt;1%</td>
<td>-9%</td>
<td>9%</td>
</tr>
<tr>
<td>Work</td>
<td>Shopping</td>
<td>&gt;1%</td>
<td>&gt;-8%</td>
<td>&lt;1%</td>
<td>-8%</td>
<td>-5%</td>
</tr>
<tr>
<td>Work</td>
<td>Leisure</td>
<td>&gt;1%</td>
<td>&gt;-3%</td>
<td>&lt;1%</td>
<td>-4%</td>
<td>-19%</td>
</tr>
<tr>
<td>Work</td>
<td>Other</td>
<td>&gt;1%</td>
<td>&gt;-3%</td>
<td>&lt;1%</td>
<td>-3%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Note: Bold indicates cases where the actual estimated parameter was found significant at 95% level

a For the US, the UK, and Norway this is based on a singly imputed dataset with $k^* = 1$
Table 3.11 Relative 95% bootstrap-based confidence interval size as compared to parametric estimates

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Outcome Variable</th>
<th>Country</th>
<th>( \theta_{BT} )</th>
<th>( \theta_{BT}^{+} )</th>
<th>( \theta_{BT^{k}} )</th>
<th>( \theta_{BT} )</th>
<th>( \theta_{BT^{k}}^{+} )</th>
<th>( \theta_{BT^{k}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT use</td>
<td>Travel</td>
<td>Canada</td>
<td>101%</td>
<td>107%</td>
<td>116%</td>
<td>112%</td>
<td>116%</td>
<td>118%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USA</td>
<td>104%</td>
<td>107%</td>
<td>116%</td>
<td>112%</td>
<td>116%</td>
<td>118%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UK</td>
<td>107%</td>
<td>116%</td>
<td>107%</td>
<td>112%</td>
<td>116%</td>
<td>118%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Norway</td>
<td>85%</td>
<td>95%</td>
<td>85%</td>
<td>83%</td>
<td>85%</td>
<td>83%</td>
</tr>
<tr>
<td>Communication</td>
<td>Work</td>
<td>83%</td>
<td>90%</td>
<td>80%</td>
<td>80%</td>
<td>84%</td>
<td>86%</td>
<td>86%</td>
</tr>
<tr>
<td>Communication</td>
<td>Social</td>
<td>101%</td>
<td>104%</td>
<td>107%</td>
<td>116%</td>
<td>112%</td>
<td>116%</td>
<td>118%</td>
</tr>
<tr>
<td>Social</td>
<td>Social</td>
<td>100%</td>
<td>107%</td>
<td>123%</td>
<td>166%</td>
<td>166%</td>
<td>158%</td>
<td>158%</td>
</tr>
<tr>
<td>Social</td>
<td>Shopping</td>
<td>116%</td>
<td>107%</td>
<td>123%</td>
<td>166%</td>
<td>166%</td>
<td>158%</td>
<td>158%</td>
</tr>
<tr>
<td>Shopping</td>
<td>Leisure</td>
<td>100%</td>
<td>162%</td>
<td>226%</td>
<td>155%</td>
<td>158%</td>
<td>164%</td>
<td>166%</td>
</tr>
<tr>
<td>Leisure</td>
<td>Other</td>
<td>84%</td>
<td>181%</td>
<td>150%</td>
<td>168%</td>
<td>173%</td>
<td>176%</td>
<td>156%</td>
</tr>
<tr>
<td>Services</td>
<td>Other</td>
<td>83%</td>
<td>80%</td>
<td>78%</td>
<td>100%</td>
<td>98%</td>
<td>90%</td>
<td>91%</td>
</tr>
<tr>
<td>Travel</td>
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<td>86%</td>
<td>76%</td>
<td>99%</td>
<td>180%</td>
<td>158%</td>
</tr>
<tr>
<td>Work</td>
<td>Social</td>
<td>84%</td>
<td>93%</td>
<td>132%</td>
<td>77%</td>
<td>90%</td>
<td>164%</td>
<td>166%</td>
</tr>
<tr>
<td>Work</td>
<td>Shopping</td>
<td>86%</td>
<td>75%</td>
<td>86%</td>
<td>76%</td>
<td>99%</td>
<td>180%</td>
<td>158%</td>
</tr>
<tr>
<td>Work</td>
<td>Leisure</td>
<td>90%</td>
<td>85%</td>
<td>75%</td>
<td>93%</td>
<td>98%</td>
<td>108%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Note: Bold indicates cases where the actual estimated parameter was found significant at 95% level

*For the US, the UK, and Norway this is based on a singly imputed dataset with \( k^{*}=1 \)
discussed theoretical and empirical findings (Enas and Choi, 1986; Hand and Vinciotti, 2003). Interestingly, the bias observed for the UK case as compared to the US and Norwegian cases is smaller in general, i.e. in the range of 10% rather than 30%, which can also be confronted with the previously discussed performance of the k-NN algorithm (recall Figure 3.6). It appears that the results are closely linked, i.e. higher hit rates would tend to be associated with more stable predictions though more analysis would be required to confirm this finding.

Additionally, the proper bootstrap method enabled construction of percentile-based confidence intervals which can be compared in terms of their relative coverage (sizes) to parametric (in the Canadian case) and naïve bootstrap based on single or multiple nearest neighbours (Table 3.11). In the case of Canadian dataset, the relative sizes of confidence intervals for parameters describing the relationships ICT use and travel behaviour variables remain quite similar to those estimated by parametric means, and slightly smaller for intra-travel-behaviour parameters. Given the relative robustness of bootstrap-based approaches to violations of underlying distributional assumptions, it appears that the normal-theory based confidence intervals slightly overestimate the variance due to sampling observed for these parameters.

In the remaining cases, whereas the naïve and proper bootstrap are largely in agreement in terms of the direction and magnitude of change in the confidence intervals, hardly any persistent trend across the datasets can be identified. A possible

![Figure 3.7 Schematic representation of the impact of imputation process and number of nearest neighbours on the variance of estimates and confidence intervals](image)

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explanation for this effect which follows from the previously discussed features of the $k$-NN-based pooling approach is that two counter-acting sources of impacts on variance and confidence interval sizes are present (Figure 3.7). On one hand, incorporation of the imputation process in the estimation of variability and confidence intervals leads to larger variability and confidence intervals. At the same time, higher number of nearest neighbours to estimate the variance in estimated reduces variance in the estimate (Enas and Choi, 1986; Hand and Vinciotti, 2003). Consequently, the net effect of those two impacts may be uncertain, although their disentanglement is not required for drawing approximately valid inferences about significance of the relationships.

3.5 Summary

The picture that emerges from the current analysis confirms the presence of complex interactions between digital lifestyle and physical mobility as discussed by various studies reported in the literature discussed in Chapter 2. The two main objectives of this chapter were to confront the challenges linked to lack of cross-national comparisons in the studies dealing with ICT and travel behaviour, as well as deficiencies in terms of suitable datasets.

From the behavioural point of view, the results of the current analysis support the existence of individuals who are increasingly making use of ICT for multiple purposes. The question persistent in the existing body of knowledge has been whether there are any cross-national commonalities in terms of possible characteristics of travel behaviour implications for such individuals, especially given that growing sophistication and proliferation of ICT. Some cautious answers to this question may be suggested by the results obtained in this chapter. For instance, whereas in the Canadian context those using more ICT could be expected to travel less for work- and more for shopping-related purposes, the expected trend is opposite in the case of the UK or Norway. Deeper understanding of such differences, however, calls for more cross-national comparative studies that could provide further insights into the dynamics of such processes, but even more importantly the role of country-specific factors, including regulations, natural conditions, or culture.
On the other hand, the limited availability of sufficiently detailed data remains a significant obstacle in conducting such research. As a result, the current analysis investigated whether data pooling (fusion, grafting) techniques employed in other domains as well as sub-fields of transport studies, can serve as an alternative to costly collection of surveys. Given very restricted control over the data characteristics and quality, the data pooling approach performed surprisingly well yielding a number of significant results suggesting potential wider applicability in the field, though still requiring more extensive studies on its performance as compared to complete-data analysis. Such an alternative may become, however, even more important not only due to budgetary reasons, but also amidst growing concerns regarding personal data privacy and potential misuse which both make it a moot point whether full data on linked physical and digital behaviour will, or should ever be available on a large scale.

There are clearly inherent limitations to the study resulting from its research design. Firstly, a caveat that should be made in reference to the results for the US, UK, and Norway, is that the interpretations remain subject to the validity of the data pooling method. Whereas formal methodology was adhered to in terms of the use of the k-NN method as well as subsequent inference of parameters significance, in the end the results can only be as good as the available data. In doing so, perhaps the most crucial aspect to be investigated more formally concerns the validity of conditional independence assumption and, in the event of its disproval, provision of an alternative approach. The second main limitation of the study results from the use of datasets which only encompassed different years, but also had both ICT and travel behaviour represented in terms of variables of different type and measurement level. As a consequence, direct comparison between the relationships was not always possible, and further data collection efforts in these domains should address the issue of data harmonisation facilitating comparative studies. The third limitation of the analysis lies in its relative simplicity in terms of the proposed SEM specification which does not directly capture factors such as multi-purpose trips, use of travel time, or more complex patterns of interactions such as simultaneous impacts of ICT on travel and vice versa. In the future, more comprehensive and purpose-specific datasets could be collected enabling addressing such issues more systematically.
While the current data does not permit it, future research could also aim at developing a predictive tool, capable of forecasting the impacts of various digital behaviour policies such as investment in broadband infrastructure, promotion of tele- and other flexible work practices, or development of tele-government services, on travel behaviour. Such an initiative would require not only more evidence for causality between various relationships discussed above, but also an econometrically robust tool to make credible predictions. A cross-national perspective in such a context could prove valuable in terms of observing differences in performance of different policy scenarios across specific cultural, legal, or and geographical countries. An aspect which is, however, going to be explored further in the following Chapter 4 and Chapter 5 is that of attempting to provide a microeconomically-grounded model of individual behaviour seeking to explain the interaction between ICT and travel behaviour. Such an approach can provide a means for more universal understanding of the interaction between digital lifestyles and physical mobility.
Chapter 4
RO2: MICRO PERSPECTIVE I

It was shown in Chapter 2, and in particular in section 2.8 that ICT have been increasingly recognised as important factors influencing the processes of spatiotemporal flexibility and fragmentation of activities, as well as simultaneous use of time for multiple activities, i.e. multitasking. A particular instance of such impacts concerns facilitation of travel time activities together with implications for in-travel productivity. The current chapter presents a microeconomic framework for conceptualising such behaviour as well as, by means of an appropriate econometric translation its application in the context of modelling business rail travel time and productivity.

A more detailed derivation and presentation of the framework is presented in section 4.1 which results in a number of theoretical conditions driving the choice and duration of in-travel activities and linking them to the notion of productivity. Section 4.2 provides econometric specification which enables testing of the model using empirical data in the context of rail business travel time while section 4.3 presents and discusses the findings. Section 4.4 performs a simple cross-validation procedure as means of exploring robustness of the approach for inferential and forecasting purposes while section 4.5 summarises the chapter.

4.1 Microeconomic framework

In the current context of in-travel time use, it is assumed that an individual operates in a reference period delimited by the start and end times, $t_0$ and $t_E$ respectively (see Figure 4.1 on the next page) which is similar to the concept of ‘activity envelope’
developed by Rasouli and Timmermans (2014a, p. 70). At the beginning of this period, the individual is involved in an activity $A$ which he chooses to finish at time $t_1$ when he or she decides on transport mode $i$ and travels on route $j$ for mode-, route-, and time-of-day-specific travel duration $r_{ij}(t_1)$ which reflects the dependence on modal characteristics and daily variations in the prevailing travel conditions on the transport network. Following the journey, an individual engages in activity $B$ from time $t_1 + r_{ij}(t_1)$ which finishes at the end of the reference period $t_E$. Clearly, $t_0$ and $t_E$ could be interpreted as the limiting cases of departure from activity $A$ location, and latest possible arrival to location of activity $B$ respectively. For instance, $t_0$ could mark the earliest possible departure from work, while $t_E$ the latest arrival to a

**Figure 4.1** Conceptual framework for modelling in-travel time use

![Conceptual framework for modelling in-travel time use](image)

**Figure 4.2** Conceptual representation of the dynamic process of activity choice and productivity assessment

![Conceptual representation of the dynamic process of activity choice and productivity assessment](image)
spectacle. Additionally, while travelling (i.e. between $t_1$ and $t_1 + r_{ij}(t_1)$) individual can engage in $K$ spells of in-travel activities $T_1, T_2, ..., T_K$ switching between them at times $t_2, t_3, ..., t_K$, just as in the conceptual model of Zhang and Timmermans (2010).

Another way of understanding, at least from the analyst’s perspective, the behavioural process in a more dynamic sense, is to decompose the situation depicted above into a 3-step process (Figure 4.2). An individual present at a certain initial location at a particular time chooses to travel by a specific mode. At the beginning of the journey, he or she chooses an initial in-travel activity. For the remainder of the journey time, he or she re-evaluates continuously (perhaps to some extent subconsciously) whether staying engaged in the current activity is the most beneficial way of spending time as compared to participation in any other activity, depending on how productive in terms of that participation he or she is feeling (assuming that individual is capable of making such assessment). The precise meaning of the term ‘beneficial’ depends on what drives the activity choice decisions, and as such will be discussed in the next section. Once the journey is over, an individual should be able to assess the degree to which his or her in-travel mean work-related productivity was similar, better, or worse to a specific benchmark level, the typical office conditions being perhaps the most convenient in the current context due to a number of reasons (recall the discussion from section 2.1.4). It is worth noting that the activity choice, and thus time allocation decisions, as well as the in-travel activity productivity (and hence the satisfaction derived thereof) are in general assumed to depend on the person’s characteristics, attitude, the journey context and conditions as well as ICT use in order to realise the objective of linking these different components in a single, unified framework.

The actual model is based on the concept of time-specific marginal utility of an activity the roots of which can be traced to the Winston’s time-specific analysis of household activities (Winston, 1987, 1982). It has previously been applied in a number of modelling contexts such as activity choice, scheduling and duration, or road pricing (Ashiru et al., 2003; Ettema and Timmermans, 2003; Ettema et al., 2007; Hu, 2009; Polak and Jones, 1994). Following Winston’s convention, the model formulates total utility $U_L$ an individual derives from being engaged in an activity $L$ from time $t_{L0}$ till time $t_{L1}$ as:
\[ U_L = \int_{t_{L0}}^{t_{L1}} u_L(z_L(t, \theta)) \, dt \] (4.1)

where \( u_L \) denotes an instantaneous utility derived from participating in activity \( L \) with intensity \( z_L \) expressing how much more utility a person would gain from participating marginally longer in activity \( L \). The concept of activity intensity proposed by Winston is a variational equivalent of the concept of household commodity proposed by Becker in his household production theory (Becker, 1965; Winston, 1982). Intuitively, it can be understood as the ‘level of engagement’ in a specific activity and is assumed to be influenced by time \( t \) which can, depending on the context, be either clock time (i.e. expressing time of day), or time since the activity commenced, i.e. its duration so far. Furthermore, \( z_L \) can be influenced by other factors, collectively denoted as \( \theta \), potentially including possession of specific equipment (including ICT), presence of a companion(s), socio-demographics, participation in previous activities, or in fact anything that could impact the quality of participation in an activity. Taking as an example eating a breakfast, the intensity will depend on whether it is eaten during conventional breakfast time, as well as on the presence and quality of food, possibly also a companion, and perhaps specific ambience. The main convenience of such conceptualisation lies in its natural link to the instantaneous concepts, allowing subsequent statement of dynamic conditions for activity choice, which will be shown later. However, while Winston assumed that higher intensity of an activity would lead to its higher utility, this approach appears unnecessarily limiting as, for instance, a high-intensity walk could be attractive to a physical-activity-keen individual, but could also be disliked by someone with walking difficulties. Thus in the current context, the assumption is not required.

In line with equation 4.1, the utility \( U \) of participating in in-travel activity \( T1 \) on mode \( i \) can be formulated as:

\[ U_{T1i} = \int_{t_1}^{t_2} u_{T1}(z_{T1i}(t, \psi_{T1i}, \theta_{T1i}), z_{xT1i}(x_{T1i})) \, dt \] (4.2)
Similarly to the original Winston’s formulation, it is assumed that the intensity of the activity depend on time $t$, in this case time since the activity started. This enables quantifying the impact of how the duration of participation so far on the instantaneous satisfaction derived from it. Additionally, for in-travel activities the intensity would also depend on the selected mode of transport $i$ to reflect (in)compatibility of certain activities with some inherent characteristics of travelling by certain modes, an example of such is virtual impossibility to work on a laptop while cycling. $\psi$ denotes a discrete bundle of ICT use, e.g. a smartphone and a laptop while $\theta$ indicates other variables potentially important, including the time of day (clock time), sociodemographic characteristics, presence of a companion, or journey conditions.

However, the difference between the equation 4.2 and the original Winston’s formulation is that the consumption $x_{T1ij}$ is assumed to enter the utility via a separable consumption-related intensity component $z_{xT1ij}$ which though limiting in terms of interaction possibilities with other factors, enables analytical manipulation and solution of the utility-maximisation problem (more details on the meaning and implications of this assumption are presented below). The consumption variable itself in the current context may be interpreted in terms of a composite consumption good reflecting the generalised level of consumption of an individual, rather than a particular set of products. Obviously, the utility derived from participating in origin and destination activities $A$ and $B$ would be formulated in a similar manner, though without dependence on travel modes. Finally, it is possible that the act of travelling itself can induce experience which has some intrinsic utility for individuals (Mokhtarian, 2005). This could be either positive, e.g. for joyriders in beautiful scenery, or negative, e.g. people suffering from motion sickness on a winding route. This intrinsic utility is denoted as $u_{Ti}$, and depends on the mode-, and route-specific intensity of travel $z_{Ti}$ itself assumed independent of consumption.

Following the logic outlines above, the total utility $U$ derived by an individual in the whole reference period is can be denoted as:
\[ U = \int_{t_0}^{t_1} u_A(z_A, z_{x_A}) \, dt + \int_{t_1}^{t_2} u_{T_1}(z_{T_1ij}, z_{xT_1ij}) \, dt + \ldots + \]
\[ + \int_{t_1}^{t_{t_1+\tau_{ij}(t_1)}} u_{T_K}(z_{T_Kij}, z_{xT_Kij}) \, dt + \int_{t_1}^{t_{t_1+\tau_{ij}(t_1)}} u_{T_i}(z_{T_{1i}}) \, dt \]
\[ + \int_{t_{t_1+\tau_{ij}(t_1)}}^{t_E} u_B(z_B, z_{xB}) \, dt \]  

(4.3)

However, without a constraint placed on the amount of consumption \( x \), an individual would be able to increase their utility indefinitely by arbitrarily increasing their consumption. To avoid such cases, a budget constraint is required. It is proposed to assume for this purpose that the non-consumption related intensity of an arbitrary activity \( z_L \) is interpreted as a proxy measure of productivity (productive output) which individual is paid for according to their activity-specific wage \( w_A \). Note that this is a general notation, and in case of most leisure activities, this wage would be equal to zero, e.g. as one is unlikely to receive payment for sleeping. Such income can be used to pay for consumption \( x \) priced at an assumed market price level \( p \), and for the cost of using ICT \( c_{\psi} \).

As individuals do not always work productively while travelling, yet can still consume using income earned elsewhere, external transfers \( I \) are included in the constraint. This is also to reflect the fact that expenditure and earnings in the reference period will rarely match each other exactly which needs to be balanced either by making savings from the reference period, or using money earned elsewhere, e.g. during office-work which would also capture the case of a fixed-salary worker. It is assumed that in the current context this term is exogenous which means that an individual has a fixed sum, either positive, or negative when facing the decision process outlined above. In empirical contexts, this could be interpreted as having a certain maximum travel expenditure allowance (for business travellers), having a fraction of monthly disposable proportional to the duration of the episode, or aiming for certain savings from the period (in case \( I \) is negative). It is also assumed that the available income is exhausted so that the constraint is of an equality form. Nonetheless, it should be noted that \( I \) can in principle be formulated as an endogenous
variable with an additional utility term expressing utility from carrying over income to outside the reference period. Such external transfers would also be present in situations when optimisation is performed over multiple reference periods as discussed in more detail later in this chapter. However, in the present formulation exogeneity of the term is assumed for the purpose of simplicity and tractability which can be interpreted along the lines outlined above.

Furthermore, since the travel is also costly, a mode- and route- (e.g. road toll) specific cost term $c_{ij}$ dependent on travel duration is included. Following the familiar integral notation, the monetary constraint placed on the consumption in the reference period is:

$$
 w_A \int_{t_0}^{t_1} z_A \, dt + w_{T1} \int_{t_1}^{t_2} z_{T1ij} \, dt + \cdots + w_{TK} \int_{t_K}^{t_{1+r_{ij}(t_1)}} z_{TKij} \, dt + \\
 + w_B \int_{t_{1+r_{ij}(t_1)}}^{t_E} z_B \, dt + l = p \int_{t_0}^{t_1} x_A \, dt + p \int_{t_1}^{t_2} x_{T1i} \, dt + \cdots + (4.4)
$$

$$
 \int_{t_K}^{t_{1+r_{ij}(t_1)}} x_{TKij} \, dt + p \int_{t_{1+r_{ij}(t_1)}}^{t_E} x_B \, dt + c_\phi + c_{ij}
$$

Given the dependence of earnings on productivity, it should be clear that an implicit assumption made here is that of the prevailing long-run equilibrium in labour market. In other words, the marginal product of labour ($z$ in this case) is values at its marginal cost, i.e. wage. In the current context, the meaning of such assumption is that one’s wage reflects the need to work while travelling which is frequently the case as people of higher wages are usually also expected to perform more, or more difficult and perhaps time-consuming duties. Another assumption is that the individuals are aware of their time-specific variability in productivity, and as such know how to optimally allocate their time. This is justifiable on the grounds of the results obtained in a number of studies which demonstrated people’s awareness of temporal variations in productivity and ability to allocate time accordingly (recall section the discussion in section 2.1.4). Furthermore, the integral-based formulation implicitly incorporates the
time constraints defining activity participation durations through appropriate definition of the limits of integration.

In order to make the model analytically tractable, a number of simplifying assumptions are required which, nonetheless, do not impair the insight into the mechanism driving in-travel time allocation decisions. Firstly, which has already been partially introduced when discussing equation (4.2), instead of \( x \) denoting the level of consumption of a particular good in a particular activity, it is assumed to reflect a generalised level of consumption of goods, identical for all activities, i.e. \( v \in \{A, B, T_1, ..., T_K\} \). More formally:

\[
x = x_v \quad \forall v
\]  

(4.5)

Furthermore, additive separability between the consumption component of the intensity \( z_{xv} \) and other impacts, i.e. \( z_v \), as well as separability of the utility function is assumed:

\[
u_v(z_v(t, x_v, \psi_v, \theta_v)) = u_v(z_v(t, \psi_v, \theta_v)) + u_v(z_{xv}(x_v)) \quad \forall v
\]  

(4.6)

Finally, consumption utility is assumed to be a linear function of the level of activity intensity, itself a linear function of consumption level with \( b \) denoting the (constant) instantaneous marginal utility of consumption. In other words:

\[
u_v(z_{xv}(x_v)) = bx \quad \forall v
\]  

(4.7)

The meaning of additive separability is such that changes to either of the components, such as increase in consumption, will not be influenced by the level, or changes in the other components (Gorman, 1968). In addition, such assumption implies relative ease of substitution between the consumption and non-consumption components of the utility while the linear formulation in equation (4.7) means proportional increase in satisfaction resulting from a proportional increase in consumption level, without any degree of satiation (concavity). Both assumptions, whereas debatable, can be interpreted as a first-order approximation to the actual role of consumption, and should not constitute a strong limitation given a fairly short time horizon considered. In fact, such approach has been applied in other time allocation studies to provide
analytically tractable solutions to time allocation problems (Jara-Díaz, 2007). It is also assumed in the equation 4.7 that the utility derived from consumption would have the same functional form for all activities. As a result, the formulation 4.6 reduces to:

$$u_v(z_v(t, x_v, \psi_v, \theta_v)) = u_v(z_v(t, \psi_v)) + bx \quad \forall v$$

(4.8)

An additional assumption is that of having a discrete measure of ICT use $\psi$ in place of assuming different ICT bundles for each activity. This assumption’s role is to reduce the dimensionality of the subsequent maximisation problem in which $\psi$ would be taken as representing the selected propensity to make use of ICT.

$$\psi = \psi_v \quad \forall v$$

(4.9)

Following the assumptions, above it is possible to define a microeconomic framework in which an individual seeks to maximise their utility $U$ over the whole reference period from $t_0$ to $t_E$. He or she does so by appropriately choosing (over a continuous scale) level of consumption $x$, departure time $t_1$, time of switching between the in-travel activities $t_2, t_3, ..., t_K$ as well as (discrete variables) origin and destination activities, $A$ and $B$ respectively, in-travel activities $T_1, ..., T_K$, transport mode $i$, route $j$, and ICT bundle $\psi$. Using equations 4.3 and 4.4 in conjunction with 4.8 and 4.9 it is possible to formalise the constrained utility maximisation problem:

$$\max_{x, t_1, t_2, ..., t_K, A, B, T_1, ..., T_K, i, j, \psi} U = \int_{t_0}^{t_1} (u_A(z_A) + bx) dt + \int_{t_1}^{t_2} (u_{T1}(z_{T1i}) + bx) dt + \cdots +$$

$$+ \int_{t_K}^{t_{1+r_{ij}(t_1)}} (u_{TK}(z_{TKij}) + bx) dt + \int_{t_1}^{t_{1+r_{ij}(t_1)}} (u_{TI}(z_{TI}) dt +$$

$$+ \int_{t_1+r_{ij}(t_1)}^{t_E} (u_B(z_B) + bx) dt$$

(4.10)

subject to the budget constraint:
Note that equation (4.11) can be expressed in real terms by dividing the expression by the generalised price of consumption goods $p$. Furthermore, the expressions for the total consumption level, itself assumed time invariant, can be simplified resulting in:

$$\frac{w_A}{p} \int_{t_0}^{t_1} z_A dt + \frac{w_{T1}}{p} \int_{t_1}^{t_2} z_{T1ij} dt + \cdots + \frac{w_{TK}}{p} \int_{t_K}^{t_{1+r_{ij(t_1)}}} z_{TKij} dt +$$

$$+ \frac{w_B}{p} \int_{t_{1+r_{ij(t_1)}}}^{t_E} z_B dt + \frac{l}{p} = p \int_{t_0}^{t_1} x dt + p \int_{t_1}^{t_2} x dt + \cdots +$$

$$\left(4.11\right)$$

$$\int_{t_K}^{t_{1+r_{ij(t_1)}}} x dt + p \int_{t_{1+r_{ij(t_1)}}}^{t_E} x dt + \frac{c_\psi + c_{ij}}{p}$$

In other words, the total real value of the consumption expenditure must be equal to the total (in real terms) earnings and transfers from the external source of income net of the costs of ICT and travel. On the other hand, isolating the consumption-related utility components from equation (4.10) yields a transformed expression for the utility $U$ derived by an individual during the reference period:

$$U = \int_{t_0}^{t_1} \left( u_A(z_A) \right) dt + \int_{t_1}^{t_2} \left( u_{T1}(z_{T1ij}) \right) dt + \cdots +$$

$$\left(4.13\right)$$

$$\int_{t_K}^{t_{1+r_{ij(t_1)}}} \left( u_{TK}(z_{TKij}) \right) dt + \int_{t_1}^{t_{1+r_{ij(t_1)}}} \left( u_{Ti}(z_{Ti}) \right) dt +$$

$$+ \int_{t_{1+r_{ij(t_1)}}}^{t_E} \left( u_B(z_B) \right) dt + bx(t_E - t_0)$$

Clearly, expressions (4.12) and (4.13) can be combined into a single one using term $bx(t_E - t_0)$ as a pivot resulting in the following expression for the utility derived
during the reference period, and taking into account the budget constraints, for clarity denoted as $\bar{U}$:

$$
\bar{U} = \int_{t_0}^{t_1} u_A(z_A) \, dt + \int_{t_1}^{t_2} u_{T_1}(z_{T_1ij}) \, dt + \cdots +
$$

$$
+ \int_{t_1+r_{ij}(t_1)}^{t_1+r_{ij}(t_1)+r_{ij}(t_1)} u_{TR}(z_{TRij}) \, dt + \int_{t_1}^{t_1+r_{ij}(t_1)+r_{ij}(t_1)} u_{TI}(z_{TIj}) \, dt
$$

$$
+ \int_{t_1+r_{ij}(t_1)+r_{ij}(t_1)}^{t_E} u_B(z_B) \, dt + \frac{bw_A}{p} \int_{t_0}^{t_1} z_A \, dt + \cdots + \frac{bw_{TR}}{p} \int_{t_K}^{t_1+r_{ij}(t_1)+r_{ij}(t_1)} z_{TRij} \, dt
$$

$$
+ \frac{bw_{T_1}}{p} \int_{t_1}^{t_2} z_{T_1ij} \, dt + \frac{bw_B}{p} \int_{t_1+r_{ij}(t_1)}^{t_E} z_B \, dt + \frac{b_l}{p} - \frac{bc_\psi}{p} - \frac{bc_{ij}}{p}
$$

(4.14)

By removing the consumption terms, the dimension of the maximisation problem is reduced while retaining its initial properties. Naturally, the utility maximisation philosophy itself rests on a number of assumptions that are carried implicitly in this procedure, and which has been subject of continuing criticism since at least 1980s (Boland, 1981; McFadden, 2013). Nonetheless, its idealised assumptions are still followed in the current context as a means of providing a consistent microeconomic interpretation and linking it to an econometric translation and empirical application. Obviously, future reflections on the present contribution could attempt to address some of the shortcomings raised in the criticisms of traditional utility maximisation procedure, but this remains beyond the scope of the present analysis.

Since the current prime area of interest involves the behaviour mechanism driving in-travel activity choice, the most important parameters are in-travel activity switching times $t_2, t_3, \ldots, t_K$ and the associated first order conditions:

$$
\frac{\partial \bar{U}}{\partial t_k} = 0 \quad \forall k \in \{2, 3, \ldots, k\}
$$

(4.15)

Using equations (4.14) and (4.15), and invoking the fundamental theorem of calculus, it is possible to obtain the condition that is met when an individual switches between the $(k - 1)$th and $k$th activities:
\[ u_{Tk-1}(z_{Tk-1ij}) + \frac{bw_{Tk-1}}{p}z_{Tk-1ij} = u_{Tk}(z_{Tki}) + \frac{bw_{Tk}}{p}z_{Tki} \]
\[ \forall k \in \{2,3,\ldots,K\} \]
\[ Tk \in \{1,2,3,\ldots,J\} \]

(4.16)

where \( J \) denotes all possible in-travel activity types individual can be involved in, i.e. the activity choice set. Equation (4.16) expresses the condition driving activity engagement during travel according to which an individual would always engage in the most beneficial activity, i.e. one that which provides the highest utility arising from participating at a particular instant and contribution to the consumption through the productivity and positive wage. If one denotes the marginal benefit \( V_{Tki} \) from participating in an activity \( T_k \) while travelling on mode \( i \):

\[ V_{Tki} = u_{Tk}(z_{Tki}) + \frac{bw_{Tk}}{p}z_{Tki} \]

(4.17)

Than the formal decision rule to follow when allocating in-travel time given the mode \( i \) and route \( j \) is to seek in-travel activity \( T_v \) maximising \( V_{T_v} \) at each particular instant of travel:

\[ \max_{T_v} V_{T_v}|_{t,i,j} = u_{T_v}(z_{T_v}(t,\psi,\theta_{T_v})) + \frac{bw_{T_v}}{p}z_{T_v}(t,\psi,\theta_{T_v}) \]

(4.18)

\[ \forall t, t_1 \leq t \leq t_1 + r_{ij}(t_1) \]

In fact equation (4.18) is consistent with the Winston’s general rule for activity choice requiring ‘to spend time, always, in the activity which time has the most value’ (Winston, 1982, p. 172) as well as consistent with the results obtained in other time allocation models where the marginal utility from consumption is equal to marginal utility of leisure. It is also clear that the choice will not only be motivated by duration of the activity, but also by ICT use \( \psi \), marginal contribution of the activity to the consumption utility, and also by other factors \( \theta_{T_v} \) as well as the characteristics of travel mode \( i \) and route \( j \). In this sense, the framework achieves the requirement of linking the ICT use with the in-travel activity choice. A point to note is that according to the rule (4.18), activities can be switched without any additional cost (monetary or temporal) which does not appear to be a strong assumption in the current context.
Note also that (4.18) is a choice rule for initial activity with the following underpinning logic. If an activity not yielding the highest utility is chosen at first, the individual can be made better off by instantaneously switching to a different activity which follows from (4.18). However, by virtue of statement (4.10), the individual is seeking to maximise their utility at every moment which means that the initial activity choice cannot be other than utility-maximising, i.e. following the rule (4.18) as it otherwise would lead to a logical contradiction.

In terms of the choice of departure time \( t_1 \), differentiating expression (4.14) with respect \( t_1 \) to yields the following first order condition:

\[
\begin{align*}
u_A(z_A(t_1^*)) + bw_A z_A(t_1^*) &= u_B(z_B(t_1^* + r_{ij}|t_1^*)) + bw_B z_B(t_1^* + r_{ij}|t_1^*) + \\
+u_{T1}(z_{T1ij}(t_1^*)) + bw_{T1} z_{T1ij}(t_1^*) - u_{TK}(z_{TKij}(t_1^* + r_{ij}|t_1^*)) - \\
-bw_{TK} z_{TKij}(t_1^* + r_{ij}|t_1^*) + u_T(z_{Tij}(t_1^*)) - u_T(z_{Tij}(t_1^* + r_{ij}|t_1^*)) + \\
+ \left( \frac{dr_{ij}}{dt_1} \right)_{t_1^*} \left[ u_B(z_B(t_1^* + r_{ij}|t_1^*)) + bw_B z_B(t_1^* + r_{ij}|t_1^*) - b \frac{dc_{ij}}{dr_{ij}} \frac{dr_{ij}}{dt_1} \right]_{t_1^*} \\
- u_{TK}(z_{TKij}(t_1^* + r_{ij}|t_1^*)) - bw_{TK} z_{TKij}(t_1^* + r_{ij}|t_1^*) - u_T(z_{Tij}(t_1^* + r_{ij}|t_1^*))\right]
\]

(4.19)

where \( t_1^* \) is optimal departure time satisfying condition 4.14. For the purpose of clarity, consider first a situation where change in the departure time does not influence travel duration, such as a commuter train operating in accordance with the schedule, i.e. without delays. Under such conditions, the term \( \frac{dr_{ij}}{dt_1} \) reduces to zero. Thus the overall utility derived from change in departure time and hence infinitesimal change in duration of activity \( A \) (from both satisfaction and consumption contribution) will be exactly equal to a corresponding infinitesimal change in activity \( B \) together with changes in utilities induced by changed timing of in-travel activities and travel itself. This could be illustrate with an example of an individual departing at 9:05 AM instead of 9:00 AM and hence arriving at the destination at 10:05 AM instead of 10:00 AM (assuming that 5 minutes approximates an infinitesimal change). Condition (4.19)
states that that such individual must derive higher utility from participating in activity $A$ during those 5 minutes than would have derived from participation in activity $B$ between 10:00 AM and 10:05 AM together with any changes in in-travel activities (e.g. checking e-mail at 9:06 instead of 9:01, finishing coffee at 10:05 and not 10:00, etc.) as well as changes in travel conditions, e.g. weather, congestion or crowding. It is worth noting that in case of tele-activities for which, by definition travel duration $r_{ij}$ is fixed at zero and no in-travel activities take place, condition 4.19 reduces to one similar to 4.16. In other words, a minute longer participation in activity $A$ is associated with the minute-long opportunity cost (change in utility) associated with not participating in tele-activity $B$ at the same time.

In reality, however, change in the departure time is usually associated with changes in travel duration, i.e. $\left. \frac{dr_{ij}}{dT_1} \right|_{T_1^*} \neq 0$, as circumstances on the network vary due to traffic congestion, weather conditions, or frequency of service. In such a situation, depending on the direction of change of $r_{ij}$, the effects resulting from shorter (longer) duration of post-travel activity $B$ discounted by longer (shorter) participation in the final in-travel activity as well travel itself would have to be taken into account. Moreover, the in-travel time use could also change as a consequence which would depend on how in-travel intensity depends on the clock time. Furthermore, as travel time in certain contexts (modes, routes) may not always be completely predictable, $r_{ij}$ could be framed as a random variable with the degree of uncertainty possibly influenced by the use of ICT providing access to real-time travel information. On the other hand, aversion to such uncertainty could enter the model via inherent travel utility term $u_T(z_{Tij})$. Thus the formulation could also link to various studies on the effect of travel time variability and uncertainty on travel behaviour decisions, as well as those which incorporate the effects of intelligent transport systems (Bates et al., 2001).

Furthermore, the present formulation also provides a consistent relationship between the activity choice decisions and work-related productivity. Let it be assumed that an activity $v$ for which the associated wage rate is non-zero is termed ‘work activity’, and also that it belongs to a set $W$ of all work activities:
For such activities, it is assumed that the intensity $z_c$ serves as a proxy reflecting the instantaneous productivity, i.e. work-related output at a particular instant. In such a case, the mean in-travel relative productivity $\zeta_{ij}$ of an individual on a particular transport mode $i$ and route $j$, a quantity easiest to report in such conditions, can be formally defined as the total work-related output from all $k$ spells of in-travel work-related activities $T_{uv}$ divided by the total duration of those activities:

$$
\zeta_{ij} = \frac{\sum_{T_{uv} \in W} \int_{t_{T_{uv}k}}^{t_{T_{uv}k+1}} z_{T_{uv}ij}(t, \psi, \theta_{T_{uv}ij}) dt}{\sum_{T_{uv} \in W} (t_{T_{uv}k+1} - t_{T_{uv}k})}
$$

Thus equation 4.21 demonstrates a consistent link between the in-travel time allocation decisions, and what can be termed work-related productivity. The latter is dependent on the interplay between work-spell durations (and also possibly non-work episodes), ICT use, transport mode characteristics as well as other factors, such as occupation or presence of a companion. In addition, formulation (4.21) is flexible enough so as to incorporate various measures of this productivity (recall the discussion in section 2.1.4), including those relative to an assumed reference point, e.g. usual office conditions. In this sense, this is rather a measure of efficiency of work, though allowing for the possibility of super-efficiency exceeding unity. The relative productivity is easier for a respondent to report reasonably objectively, without any units, and for the current purposes appears very convenient.

A number of points regarding the framework developed above are worth noting. Firstly, while it is useful to assume that the intensity of an activity is a non-negative number, its relationship with the utility does not need to be limited to any particular direction. Such approach is especially convenient for work activities, i.e. productivity can be reasonably assumed non-negative unless one actually starts to destroy the previous output.

Secondly, the framework can also be extended to situations in which an individual would change transport modes. In this case activity $B$ could be interpreted as changing, or waiting time while $t_E$ (the end of the reference period), the latest
possible departure time for the subsequent journey leg. Interestingly, if the travel conditions are forbidding, e.g. travel duration \( r \) is very long for all modes, the framework can capture a situation when an individual chooses not to travel at all and engage in a tele-activity. In this limiting case, \( t_1 \) would denote time of commencing participation in such a tele-activity. This feature has an interesting interpretation in the particular case of tele-working, since \( z_B \) would reflect relative productivity of working at the home as compared to the office conditions, possibly influenced by factors such as ICT use or sociodemographics captured by the variables \( \psi \) and \( \theta_{T,ij} \) respectively.

Finally, there is nothing prohibiting the framework to be extended to multiple periods. In such a case, the overall utility \( \bar{U} \) to be maximised over the desired number of periods \( \Omega \):

\[
\bar{U} = U_1 \otimes U_2 \otimes \ldots \otimes U_\Omega
\]

(4.22)

where \( \otimes \) denotes a combination operator with the property that the overall utility \( \bar{U} \) is increasing in all the components such as addition, multiplication, or exponentiation, or in more general all operations fulfilling the property:

\[
\frac{\partial \bar{U}}{\partial U_\omega} > 0 \ \forall \omega, \omega \in \{1, 2, 3, \ldots, \Omega\}
\]

(4.23)

In such a case, the utility components could be also assumed to interact with each other, e.g. impact of duration of work in the previous reference period influencing propensity to work in the current one, or the requirement to balance the budget over multiple periods. This is also to acknowledge the awareness of the fact that expression (4.10) represents only a limited picture of the respondent’s life, one with a ‘memoryless’ utility function, i.e. not influenced by earlier reference periods. However, in its simplicity and tractability, it provides a means of understanding intra-travel time allocation, implications for in-travel productivity, and the role of various factors including information and communication technologies. In order to link the proposed theory with the empirical data, the subsequent chapter provides an econometric specification which enables investigating and testing the hypothesised impacts using real world information.
4.2 Econometric specification and estimation

The next step in linking the theoretical framework presented in the previous section to the empirical data involves developing an appropriate econometric specification for the theoretical results of the decision rule for in-travel activities (4.18), and the definition of the in-travel productivity (4.21). In the current case, the dataset comes from the United Kingdom’s Study of the Productive Use of Rail Travel-time 2008 (SPURT, DfT, 2009) which is described in more detail in the next section. It should be noted that whilst the data includes only information on whether the respondent was involved in work or non-work activity, it will be demonstrated that the econometric specification can be extended to multiple types of activities while travelling, e.g. work, sleeping, reading, talking, or engaging in different tele-activities. In this sense, the framework also captures the hypothesised effects of fragmentation and multitasking.

Based on these theoretical results, the following sections provide formalisation of the how to estimate the effects of various variables on initial activity choice (section 4.2.2), in-travel time allocation (section 4.2.3), and in-travel productivity (section 4.2.4) as previously described in Figure 4.2. As a result, estimation enables investigation of a number of behavioural implications suggested by the framework:

- the extent to which the choice of initial activity is consistent with the subsequent activity-switch rule;
- the effect of the duration of being engaged in an activity on the chances of interrupting it, i.e. is it the case that an individual engaged in an activity becomes more focused and, or rather experiences fatigue and weariness;
- the effects of various covariates on different components of the model, including the specific effects of ICT on activity choice, duration, and productivity;
- the accuracy of the overall microeconomic description of the phenomenon.

As the final model specification is estimated using maximum likelihood approach, the sections 4.2.2 to 4.2.4 below defines partial likelihoods associated with the specific components, while section 4.2.5 describes the estimation procedure.
4.2.1 Data

The data employed in the current estimation comes from the 2008 Study of the Productive Use of Rail Travel-time which surveyed 1660 rail travellers on various routes in the United Kingdom in March and April 2008. The survey was conducted in order to ‘obtain evidence on the productive use of travel time during the course of work and to assess its impact on the work value of marginal travel time savings’ (DfT 2009: 1-1). As such, it involved business travellers (distinguished from non-business by asking if their journey was related to their employment, excluding commuting) filling and subsequently posting back the questionnaires (see Appendix 5 for a sample questionnaire). A detailed description of the data collection process is can be found in the official report produced from the study (DfT, 2009). Briefly speaking, the survey asked questions about the following aspects of travel:

- trip characteristics: journey duration, purpose, origin and destination, time of departure (origin and station) and arrival (station and final destination), outward/ return leg, transport modes to and from the station, presence of companion;
- ticket type (single, return, season), price, whether the costs were covered by the employer;
- seating availability: proportion of journey when seating available, class of travel, availability of table, power socket, and Wi-Fi;
- crowdedness: average, minimum and maximum proportion of seats occupied and number of people standing, whether crowding changing during the journey, whether one had to finish tasks not accomplished during the journey later;
- activities on the train: type of activities undertaken before and during and the journey, proportion of travel spent on them, use of ICT (laptop, mobile phone, smartphone predecessor, i.e. PDA), actual time allocation between work and non-work activities, time requirement to accomplish the same work output in the office conditions, changes to time allocation if journey lasting shorter/longer, stated impact on daily work duration if the journey time reduced;
• respondent characteristics and attitude: employment status, occupation, car ownership, gender, personal and household income, attitude towards working on the train;
• stated preference exercise with various scenarios of the journey (not used in the current analysis).

In terms of the actual time allocation to activities, the respondents were asked to use a grid consisting of 10 equal cells corresponding to deciles (10%-long sections) of the journey to mark periods of work and non-work related activities. While convenient from the perspective of data collection, this way of coding may bias estimates due to the fact that such deciles were, by definition longer for longer journey durations leading to heteroscedasticity which needs to be accounted for in the model specification. Furthermore, this way of reporting relied on the respondents remembering accurately their in-travel time use. However, the main advantage of the self-reporting protocol was, apart from convenience, that the individuals could more easily distinguish between what constituted work-related activity even if such was not directly observable, e.g. in case of cognitive processes masked by apparent ‘idleness’.

Additionally, the respondents were asked whether, and if so by how much, would the duration of work activity differ to achieve the same output as during the travel. Using that piece of information, it is possible to derive a measure of relative productivity as defined in equation 4.21. In terms of the ICT use, the only available information allows to investigate whether the use of ICT in general, i.e. not specified when or for what purpose, is related to time allocation and productivity.

<table>
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<tr>
<th>Table 4.1 Comparison of sample composition (%)</th>
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<td><strong>Leg</strong></td>
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<td><strong>Journey time</strong></td>
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<td><strong>Size</strong></td>
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Business travellers only (see DfT, 2009, Appendix D)
Source: DfT, 2009
While the initial sample size available in the data amounted to 1660 respondents, only 940 provided complete enough information on their in-travel time allocation, productivity, and ICT use. Applying imputation techniques in this case to obtain more complete sample would be undesirable due to the fact that the imputed quantities would be dependent variables with high percentage (43%) of missing values. Consequently, incomplete cases had been deleted from the analysis and the final size of the sample included 940 individuals. The distribution within the sample in terms of the main variables is virtually no different to the complete SPURT dataset (Table 4.1), though it is different to the nationally representative National Rail Passenger Survey 2007. At the same time, the empirical distribution of the productivity values (Figure 4.3) is strongly leptokurtic revealing very strong clustering of the subjective productivity assessment around unity (i.e. productivity similar to that experienced in the usual office conditions).

Figure 4.3 Histogram of the empirical distribution of productivity

While the initial sample size available in the data amounted to 1660 respondents, only 940 provided complete enough information on their in-travel time allocation, productivity, and ICT use. Applying imputation techniques in this case to obtain more complete sample would be undesirable due to the fact that the imputed quantities would be dependent variables with high percentage (43%) of missing values. Consequently, incomplete cases had been deleted from the analysis and the final size of the sample included 940 individuals. The distribution within the sample in terms of the main variables is virtually no different to the complete SPURT dataset (Table 4.1), though it is different to the nationally representative National Rail Passenger Survey 2007. At the same time, the empirical distribution of the productivity values (Figure 4.3) is strongly leptokurtic revealing very strong clustering of the subjective productivity assessment around unity (i.e. productivity similar to that experienced in the usual office conditions).
4.2.2 Initial activity choice

As has been demonstrated in section 4.1 above, the choice of initial activity is driven by the desire to maximise the overall utility, as expressed in condition (4.18). If it is assumed that $V_{T_1}$ is a deterministic component of the utility of participating in an activity $T_1$ given mode $i$ (this subscript is dropped for easier notation), while $\varepsilon_{T_1}$ is an associated error term, the probability $P_{\text{Init},T_1}$ that an individual will engage in $T_1$ as a first in-travel activity, i.e. at $t_1$, and not any other activity $T_u$ can be expressed as:

$$P_{\text{Init},T_1} = P(V_{T_1}|t_1 + \varepsilon_{T_1} > V_{T_j}|t_1 + \varepsilon_{T_j}) \quad \forall T_u, T_u \in \{2,3,\ldots,J\}$$ (4.24)

Rearranging equation 4.24 yields the following result:

$$P_{\text{Init},T_1} = P(V_{T_1}|t_1 - V_{T_u}|t_1 > \varepsilon_{T_j} - \varepsilon_{T_1}) \quad \forall T_u, T_u \in \{2,3,\ldots,J\}$$ (4.25)

If appropriate assumptions are made on the character of the joint distribution on the error terms, equation (4.25) provides a direct and general link to the discrete choice models. For instance, in the case where the error terms are distributed identically and independently distributed according to the Gumbel distribution, formulation (4.25) would result in a multinomial logit model (Ben-Akiva and Lerman, 1985).

Since the current data contains only information on whether individual was involved in a work- or non-work-related activity, equation (4.25) reduces to a binary decision whether or not to starting the journey working. In other words, the probability of choosing to work as an initial activity $P_{\text{Init},T_W}$ rather than not to work, which for better intuition is termed leisure denoted by $T_L$, can be expressed as:

$$P_{\text{Init},T_W} = P(V_{T_W}|t_1 - V_{T_L}|t_1 > \varepsilon_{T_L} - \varepsilon_{T_W}) \sim \text{Weibull}(\frac{1}{\lambda}, \rho)$$ (4.26)

where $\lambda$ and $\rho$ are scale and shape parameters respectively, both non-negative. The choice of the Weibull distribution has been dictated by the need for consistency with the subsequent model of in-travel activity choice and duration which is based on the Weibull distribution (see section 4.2.2 for justification). Thus following equation (4.27), the model of initial activity choice results in the following expression for the probability of an individual of engaging in work as initial in-travel activity:
\[ P_{\text{Init}_T, W} = 1 - e^{-\left(e^{\nu_{T_W|t_1} - \nu_{T_L|t_1}}\right)^{\rho_{\text{Init}}}} \] (4.27)

Conversely, not choosing to work as an initial activity, i.e. choosing leisure, is given by the complementary probability:

\[ P_{\text{Init}_T, L} = 1 - P_{\text{Init}_T, W} = e^{-\left(e^{\nu_{T_W|t_1} - \nu_{T_L|t_1}}\right)^{\rho_{\text{Init}}}} \] (4.28)

It is worth noting that expressions (4.27) and (4.28) are consistent with the assumed theory. In other words, the higher the benefit of participating in work \( V_{T_W} \), the higher the probability of engaging in it which also results from the first derivative of expression 4.27 with respect to \( V_{T_W} \) (note that \( \rho_{\text{Init}} \) is assumed non-negative):

\[ \frac{\partial P_{\text{Init}_T, W}}{\partial V_{T_W}|_{t_1}} = \rho_{\text{Init}} e^{-\left(e^{\nu_{T_W|t_1} - \nu_{T_L|t_1}}\right)^{\rho_{\text{Init}}}} \left(e^{\nu_{T_W|t_1} - \nu_{T_L|t_1}}\right)^{\rho_{\text{Init}}} > 0 \] (4.29)

On the other hand, by virtue of equation (4.28), the probability of engaging in leisure would fall. A similar logic can be applied to prove the existence of similar relationship between the benefit from leisure \( V_{T_L|t_1} \) and the probability of engaging in leisure. For the estimation purposes it is assumed that the difference in the deterministic components of the utility \( V_{T_W|t_1} - V_{T_L|t_1} \) can be expressed as the following function:

\[ V_{T_W|t_1} - V_{T_L|t_1} = \lambda_{\text{Init}} \left(\beta_{T_W}^{\text{I}} \bar{X}\right) \] (4.30)

where \( \bar{X} \) is a vector of covariates including both ICT-related variables \( \psi \) and all other factors \( \theta \), and \( \beta_{T_W}^{\text{I}} \) is the vectors of parameters to be estimated. Moreover, \( \beta_{T_W}^{\text{I}} \) represents parameters that are also present in the subsequent specification of the in-travel time allocation component scaled appropriately by \( \lambda_{\text{Init}} \). In other words, the significance of \( \lambda_{\text{Init}} \) indicates the degree of consistency between the initial choice of activity and the subsequent activity choices, i.e. to what extent these are driven by the same factors. Note also that the value of scaling parameter would be expected negative since higher attractiveness of work will increase probability of working initially, but decrease probability of its interruption, as shall be expressed by appropriate hazard function.

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As a result, combining equations (4.28), (4.29) and (4.30) enables construction of the partial likelihood function $L_{\text{Init}}$ for the sample of $n$ individuals:

$$L_{\text{Init}} = \prod_{l=1}^{n} \left[ 1 - e^{-e^{-\lambda_{\text{Init}} \beta_{TW} \bar{X}_l}^{\rho_{\text{Init}}}} \right] \delta_{l \text{Init}}^{\rho_{\text{Init}}} \left[ e^{-e^{-\lambda_{\text{Init}} \beta_{TW} \bar{X}_l}^{\rho_{\text{Init}}}} \right]^{1-\delta_{l \text{Init}}^{\rho_{\text{Init}}}}$$  

(4.31)

$$\delta_{l \text{Init}}^{\rho_{\text{Init}}} = \begin{cases} 1 & \text{ if } T_{1l} \in \mathbf{W} \\ 0 & \text{ otherwise} \end{cases}$$

This expression can be subsequently used, together with other partial likelihood functions, to form a full likelihood expression enabling estimation of the parameters of interest.

**4.2.3 In-travel time allocation**

Following the initial choice of activity, an individual would participate in it until switching to another activity becomes more worthwhile as defined by condition (4.18). In other words, it is possible at each moment $t$ to define the probability $P_{T_{u,k}}$ that an individual *interrupts* the current spell $k$ of an activity $T_u$ and engage in another activity $T_{u'}$:

$$P_{T_{u,k}}(t) = P(\exists T_{u'}: [T_{u'} \in \{1,2,3, \ldots, J\}\setminus\{T_u\}] \land [V_{T_{u'}}|t + \varepsilon_{T_{u'}} > V_{T_u}|t + \varepsilon_{T_u}]|t)$$  

(4.32)

Thus in order to interrupt the current activity there has to be another activity which yields a greater benefit at the time of interruption. Considering work activity, in the current two-activity case, i.e. $J = \{W, L\}$ this would reduce to probability of interrupting the $k^{th}$ spell of work $P_{W,k}$ given an individual remained engaged in work for the duration $t$ which can be formally stated as:

$$P_{T_{W,k}} = P(\left(V_{T_L}|t - V_{T_W}|t > \varepsilon_{T_W} - \varepsilon_{T_L}\right)|t)$$  

(4.33)

In fact, both equations 4.32 and 4.33 are conceptually closely related to the concept of hazard function which can be defined in the following way (Hamerle, 1989; Hensher and Mannering, 1994). Let there be a cumulative probability distribution function $F$ and its corresponding density function $f$ of a random variable, e.g. time $T$. Thus a probability that an event whose occurrence can be described by $T$ will happen before $t$ can be defined in terms of the cumulative distribution function:
\[ P(T < t) = F(t) \]  \hspace{1cm} (4.34)

Also, by definition:
\[
f(t) = \frac{dF(t)}{dt} = \lim_{\Delta t \to 0} \frac{P(t \leq T \leq t + \Delta t)}{\Delta t}
\]  \hspace{1cm} (4.35)

On the other hand, the complementary probability to expression (4.34), i.e. the probability that the event will not occur until \( t \) defines the survivor function \( S(t) \):
\[
S(t) = P(T \geq t) = 1 - F(t)
\]  \hspace{1cm} (4.36)

Thus the ratio between (4.35) and (4.36) would describe the hazard function \( h(t) \), i.e. the probability that an event happens exactly at \( t \) given it has not happened until \( t \):
\[
h(t) = \frac{f(t)}{S(t)} = \lim_{\Delta t \to 0} \frac{P(t \leq T \leq t + \Delta t | T \geq t)}{\Delta t}
\]  \hspace{1cm} (4.37)

In other words, equation (4.37) describes the instantaneous chances that an event which lasted for duration \( t \) will be interrupted. This is precisely the relationship described in equation (4.33), i.e. what are the chances that an individual interrupts their work and switches to leisure, given his participation in work for the duration \( t \).

Thus equations (4.33) and (4.37) provide link between the theoretical result arising from the model, and its econometric specification in terms of a hazard model. In fact, this class of models has previously been applied in similar contexts of modelling activity duration (Bhat, 1996a, 1996b; Ettema et al., 1995), but also a range of different ones, e.g. unemployment duration, mortality rates, or fatigue in materials (Sobczyk, 1987; Wilson, 1994).

The class of a hazard model is defined by distributional assumptions placed on the probability density function which also defines the duration dependence in terms of how hazard varies with time. In particular, hazard can be monotonically increasing with time (the longer the duration, the higher the relative risk of the event occurring), constant (hazard remains constant regardless of duration), or decreasing with time (hazard of an event becomes lower as the duration increases). However, it is also possible to obtain non-monotonic hazard functions, e.g. bell-shaped, and the choice of the desired distribution would usually depend on the behavioural assumptions regarding the modelled phenomenon (Ettema et al., 1995). A good discussion of the
most widely used hazard functions as well as the transport-related contexts of their application can be found in Hensher and Mannering (1994) and Bhat (2000).

Arguably the most flexible formulation involves generalised gamma probability density function, as it does not restrict the direction or monotonicity of the hazard function which is dependent on the estimable parameters. The main drawback involves its higher computational complexity and requirement for larger samples. Also in the current context, this demanding nature led to inability to obtain consistent estimates and abandonment of this distribution.

A number of other distributions provide greater simplicity and ease of application at the price of reduced flexibility. Log-normal and log-logistic distributions allow for the possibility of non-monotonic, bell-shaped, but are still quite cumbersome to compute, and do not allow for monotonically-increasing hazard. The last limitation appears particularly restrictive in the context of activity duration modelling as it is possible that the risk of interrupting activity increases with its duration, e.g. due to fatigue or boredom. A Weibull distribution assumes monotonicity, yet without further limits on the directionality of the hazard change with time, and thus in the current context appears to be the most appealing alternative. The hazard function associated with the Weibull distribution can is given by:

\[ h(t) = e^{\lambda \beta X} \rho (e^{\lambda \beta X} t)^{\rho - 1} \]  \hspace{1cm} (4.38)

with \( \lambda \) and \( \rho \) being scale and shape parameters, \( X \) the vector of covariates and \( \beta \) the vector of associated parameters. The shape parameter \( \rho \) is of particular importance in the hazard analysis, describing the duration dependence, i.e.:

\[
\begin{align*}
0 < \rho < 1 & \quad \text{hazard decreases with time} \\
\rho = 1 & \quad \text{hazard is constant} \\
\rho > 1 & \quad \text{hazard increases with time}
\end{align*}
\]  \hspace{1cm} (4.39)

In such a case, the hazard function \( h_{TW\,k} \) for interrupting the \( k \)th spell of work given its duration \( t \) is defined by:

\[ h_{TW\,k}(t) = P((V_{TL\,t} - V_{TW\,t}) > \varepsilon_{TW} - \varepsilon_{TL})|t) = \\
= e^{\beta_{TW\,X} X_{TW\,k}} (e^{\rho_{TW\,k} t})^{\rho_{TW\,k} - 1} \]  \hspace{1cm} (4.40)

in which case it is evident that the difference in benefit derived from engaging in particular activities \( V_{TL\,t} - V_{TW\,t} \) is described by the linear-in-parameters
function $\beta_{TW} X$. However, due to the potential risk of heteroscedasticity resulting from the decile-based recording protocol for activity duration, it is necessary to account for the possible dependence of the shape parameter on journey duration $X_{JD}$ which can affect the variance in activity durations. For this purpose, Hsieh demonstrated such outcome can be achieved by parameterising the shape parameters in terms of the possible variable inducing heteroscedasticity while also ensuring non-negativity of the parameter (Hsieh, 2001; Wu et al., 2002). As a result the shape parameter the $k$th spell of work $\rho_{TW,k}$ can be defined in terms of a linear combination of spell-specific constant $\beta_{TWJD,k}$ and impact due to journey duration $X_{JD}$ and its associated parameter $\beta_{TWJD}$:

$$\rho_{TW,k} = e^{\beta_{TWJD,k} + \beta_{TWJD}X_{JD}}$$  \hspace{1cm} (4.41)

while for leisure spells:

$$\rho_{TL,k} = e^{\beta_{TLJD,k} + \beta_{TLJD}X_{JD}}$$  \hspace{1cm} (4.42)

Clearly, in case where no heteroscedasticity is observed, the parameters associated with journey duration would be equal to zero, and formulation would reduce to a case of homoscedasticity. Consequently, the corresponding hazard function for interrupting the $k$th spell of leisure given its duration $t$ can be defined by $h_{TL,k}$:

$$h_{TL,k}(t) = P\left(\left(V_{TW} | t - V_{TL} | t > \varepsilon_{TL} - \varepsilon_{TW}\right) | t\right) = e^{\beta_{TL,X} \rho_{TL,k}(e^{\beta_{TW,X} t})^{\rho_{TL,k}}}$$  \hspace{1cm} (4.43)

It is worth noting that whilst equations (4.40) and (4.43) represent special cases in which only one possible event is possible (switch to leisure in case of being engaged in work, and switch to work if engaged in leisure), it is possible to extend the current methodology to the general case where different alternative activities, or indeed tele-activities, are possible. In this case expression 4.32 could be translated into competing risk hazard model (Ettema et al., 1995) which under further distributional assumptions could be framed as a discrete choice model, e.g. multinomial logit. Hence the framework above can be also interpreted as theoretical and behavioural justification for using discrete choice models when analysing choice of in-travel activities (Pawlak and Polak, 2010; Susilo et al., 2012).
A number of points should be noted about equations (4.40) and (4.43). Firstly, as the in-travel activities can involve multiple switching between activities, the formulation needs to be constructed as a multi-spell hazard duration model (Hamerle, 1989). Secondly, given that the impact of duration of activity may vary between the consecutive spells, also the shape parameters $\rho_{T_{wk}}$ and $\rho_{T_{lk}}$ are allowed to vary between the activity spells. Moreover, in the current case the scaling parameter $\lambda$ is arbitrarily fixed to unity to allow unambiguous estimation of $\beta$ parameters.

In case of travel activities, however, it is possible that the interruption occurred not as a result of activity choice rule, but as a result of the trip end. Estimating the parameters without appropriate acknowledgment of such a possibility could introduce bias as an activity would have continued if the journey had lasted longer (an exceptional case where the journey end and activity switch exactly coincide seem unlikely to prevail in general). Within the realm of hazard models it is possible to account for such effects through right-censoring (Bhat, 2000; Hamerle, 1989) in which case an appropriate indicator variable is used to distinguish between spells interrupted according to the endogenous decision rule (4.18), and those interrupted due to the exogenous factors, i.e. journey end.

Estimating the suitable parameters involves constructing the suitable likelihood function $L_{Haz}$ considering all individuals $n$ with their total number of activity spells $K_l$, by means of fitting the probability distribution function (for the spells that were interrupted endogenously due to the decision rule) and survivor function for the exogenously interrupted spells. Furthermore, as some covariates may be spell-dependent, e.g. duration of the previous spells of the same activity, while others remain constant throughout the journey. Let the following notation be assumed for clarity:

$$
\beta_{T_{w}}X_i = \beta_{T_{w}}'X_i + \beta_{T_{w}}''X_{T_{wi}}
$$

(4.44)

$$
\beta_{T_{l}}X_i = \beta_{T_{l}}'X_i + \beta_{T_{l}}''X_{T_{li}}
$$

where $X_i$ indicates all covariates characterising individual $l$. These include variables which are known at time of choosing the initial activity $\bar{X}_i$, e.g. time of day or gender, those that are not known when initial activity is chosen, but are learnt subsequently, e.g. actual ICT use, denoted by $X_i$, those that are activity- and spell-specific, e.g.
duration of previous similar spells so far, denoted by $X_{T_{Wlk}}$ for work and $X_{T_{Llk}}$ for work and leisure spells respectively. All these variables have associated parameters $\beta$ to be estimated (note also that $\beta'_T$ is the same term that after scaling entered equation (4.30)). This yields the following expression for the partial likelihood function:

$$L_{Haz} = \prod_{i=1}^{n} \prod_{k=1}^{K_l} \left[ \left( e^{\beta_{T_{W}} X_{t} \rho_{T_{W}} k} (te^{\beta_{T_{W}} X_{t} k})^{\rho_{T_{W}} k - 1} e^{-\left(te^{\beta_{T_{W}} X_{t} k}\right)^{\rho_{T_{W}} k}}\right)^{1 - \delta_{T_{Wlk}}} \left(e^{-\left(te^{\beta_{T_{W}} X_{t} k}\right)^{\rho_{T_{W}} k}}\right)^{\delta_{T_{Wlk}}} \right]$$

$$\left[ \left( e^{\beta_{T_{L}} X_{t} \rho_{T_{L}} k} (te^{\beta_{T_{L}} X_{t} k})^{\rho_{T_{L}} k - 1} e^{-\left(te^{\beta_{T_{L}} X_{t} k}\right)^{\rho_{T_{L}} k}}\right)^{1 - \delta_{T_{Llk}}} \left(e^{-\left(te^{\beta_{T_{L}} X_{t} k}\right)^{\rho_{T_{L}} k}}\right)^{\delta_{T_{Llk}}} \right]^{1 - \delta_{T_{Wlk}}}$$

(4.45)

$$\delta_{T_{Wlk}} = \begin{cases} 1 & \iff T_{Wlk} \in \mathbb{W} \\ 0 & \text{Otherwise} \end{cases}$$

$$\delta_{T_{Wlk}}^c = \begin{cases} 1 & \iff k = K_l \text{ i.e. } T_{Wlk} \text{ is right censored} \\ 0 & \text{Otherwise} \end{cases}$$

$$\delta_{T_{Llk}}^c = \begin{cases} 1 & \iff k = K_l \text{ i.e. } T_{Llk} \text{ is right censored} \\ 0 & \text{Otherwise} \end{cases}$$

$X_k$ is the vector of covariates characterising the $n$th individual on $k$th spell of in-travel, $\beta_{T_{W}}$ and $\beta_{T_{L}}$ are associated parameters for work and leisure activities respectively, $\rho_{T_{Wk}}$ and $\rho_{T_{Lk}}$ are shape (duration dependence parameters) for $k$th spells of work and leisure activities respectively. It is also worth reminding that parameters $\beta'_T$ enter both equations (4.31) and (4.45) enabling joint estimation of the parameters driving initial activity choice, as well as the subsequent activity decisions.

### 4.2.4 Productivity

The final component of the framework concerns the in-travel productivity as defined by equation (4.21). In the current empirical context, the available data includes
information on how much more/less time a respondent would require in the usual office conditions to accomplish the same work-related activity (or task) as the activity (task) accomplished during the travel. Thus the ratio of the hypothetical office-time requirement $t_{WO}^{off}$ and the actual in-travel work duration $\sum_{T_{ij},k \in W} (t_{ij,k+1} - t_{ij,k})$ can constitute a proxy measure of the in-travel, algebraically defined as:

$$\zeta = \frac{t_{WO}^{off}}{\sum_{T_{ij},k \in W} (t_{ij,k+1} - t_{ij,k})} \equiv \zeta_{ij}$$  \hspace{1cm} (4.46)

Thus expression (4.46) provides a link between the presented microeconomic framework and the available empirical data. The values above unity (office work would require more time for the same activity) indicate higher productivity, while lower productivity would result in a value below unity.

Given the non-negative and stochastic nature of productivity, gamma distribution appears as one meeting the necessary requirements while retaining high degree of flexibility with a reasonable degree of complexity (Forbes et al., 2011):

$$\zeta \sim \Gamma(\theta_{\zeta 1}, \theta_{\zeta 2}) \hspace{1cm} \theta_{\zeta 1}, \theta_{\zeta 2} > 0$$  \hspace{1cm} (4.47)

where $\theta_{\zeta 1}$ and $\theta_{\zeta 2}$ are the distribution’s shape and scale parameters respectively. Let the shape parameter $\theta_{\zeta 1}$ be parameterised as a linear-in-parameters exponential function which enables incorporation of the covariates while maintaining the positivity assumption:

$$\theta_{\zeta 1} = e^{\beta_{\zeta} x_1}$$  \hspace{1cm} (4.48)

Where $\beta_{\zeta}$ denotes the parameters associated with productivity component to be estimated. Consequently, the associated likelihood function for the sample of $n$ individuals with a common scaling parameter $\theta_{\zeta 2}$ is:

$$L_{\zeta} = \prod_{i=1}^{n} \frac{\zeta_i^{\beta_{\zeta} x_i - 1} e^{-\frac{\zeta_i}{\theta_{\zeta 2}}}}{\Gamma(e^{\beta_{\zeta} x_i}) \theta_{\zeta 2}^{\beta_{\zeta} x_i}}$$  \hspace{1cm} (4.49)

However, since equation (4.49) is to be maximised, a maximum likelihood estimator of $\theta_{\zeta 2}$ can be obtained by taking logarithm of equation (4.49) and subsequently differentiating it with respect to the scale parameter and equating to zero (first order condition for maximisation) yielding:
\[ \theta_{\zeta 2} = \frac{\sum_{l=1}^{n} \zeta_l}{\sum_{l=1}^{n} e^{\beta \xi x_l}} \]  

(4.50)

As a result, substituting result (4.50) into equation (4.49) results in an expression for productivity component partial likelihood function dependent only on the location parameter defined in equation (4.48):

\[ L_{\zeta} = \prod_{l=1}^{n} \frac{\zeta_l e^{\beta \xi x_l - 1}}{\Gamma(e^{\beta \xi x_l}) \left( \frac{\sum_{l=1}^{n} \zeta_l}{\sum_{l=1}^{n} e^{\beta \xi x_l}} \right)^{\sum_{l=1}^{n} \zeta_l} e^{\beta \xi x_l}} \]  

(4.51)

The additional benefit from conceptualising the intensity as work-related productivity comes from enabling investigation of the relationship between the productivity and time allocation decisions. Using equation (4.43), the derivative of the hazard of work interruption with respect to the work-related productivity \( \zeta_i \) can be decomposed as:

\[ \frac{\partial h_{T Wi}}{\partial \zeta} = \frac{\partial h_{T Wi}}{\partial (V_{T L} - V_{T W})} \frac{\partial (V_{T L} - V_{T W})}{\partial z_{T W}} \bigg|_{T W'} \frac{\partial z_{T W}}{\partial \zeta} \]  

(4.52)

where \( t_{T W'} \) denotes an arbitrary instant of a work activity. Thus equation (4.52) describes change in the hazard of work interruption (relative risk of work interruption) with respect to the mean reported work-related productivity. Regarding the first term \( \frac{\partial h_{T Wi}}{\partial (V_{T L} - V_{T W})} \), it can be shown using (4.40) that (dropping \( k \) index for clarity):

\[ h_{T W} = e^{V_{T L} - V_{T W}} \rho_{T W}(e^{V_{T L} - V_{T W}} t)^{\rho_{T W}-1} \]  

(4.53)

Taking natural logarithms (‘\( \ln \)’) of both sides (a positive monotonic transformation preserving ordering and signs, noting that both sides by definition are non-negative) simplifies the analysis:

\[ \ln(h_{T W}) = (V_{T L} - V_{T W}) + \ln(\rho_{T W}) + (\rho_{T W} - 1)[(V_{T L} - V_{T W}) + \ln t] \]  

(4.54)

Consequently:

\[ \frac{\partial \ln(h_{T W})}{\partial (V_{T L} - V_{T W})} = -\rho_{T W} \]  

(4.55)

Since \( \rho \) is a non-negative shape parameter, it follows that:

\[ \frac{\partial h_{T W}}{\partial (V_{T L} - V_{T W})} = \rho_{T W} h_{T W} > 0 \]  

(4.56)
In other words, the more attractive leisure appears as compared to work, the more likely is an individual to interrupt work, \textit{ceteris paribus}. Turning back to equation (4.52) and taking the rightmost term together with equations (4.21) and (4.46) yields:

\[
\frac{\partial \zeta}{\partial z_{TW}'} = \frac{1}{\sum_{j \in W} (t_{j+1} - t_j)} \sum_{j, k \in W} \frac{\partial \int_{t_j}^{t_{j+1}} z_{Tji}(t, \psi, \theta_{Tji}) dt}{\partial z_{TW}'}
\]

(4.57)

Note that by definition of an antiderivative:

\[
\frac{\partial}{\partial z_{Tji}} \int_{t_j}^{t_{j+1}} z_{Tji}(t, \psi, \theta_{Tji}) dt = z_{Tji}(t, \psi, \theta_{Tji})
\]

(4.58)

which (assuming strictly positive instantaneous productivity \(z_{TW}\) leads to:

\[
\frac{\partial \zeta}{\partial z_{TW}'} = \begin{cases} 
\frac{z_{TW}'}{\sum_{j \in W} (t_{j+1} - t_j)} & t_j \leq t_{TW}' \leq t_{j+1} \\
0 & \text{Otherwise}
\end{cases}
\]

(4.59)

In other words an increase in instantaneous work productivity will lead to a positive change in the overall mean value of the productivity, equal to that change ‘spread over’ the whole duration of all work activities. Consequently:

\[
\left(\frac{\partial \zeta}{\partial z_{TW}'}\right)^{-1} > 0 \leftrightarrow t_j \leq t_{TW}' \leq t_{j+1}
\]

(4.60)

Finally, the middle term can be further decomposed:

\[
\frac{\partial (V_{TL} - V_{TW})}{\partial z_{TW}'} = \frac{\partial V_{TL}}{\partial z_{TW}'} - \frac{\partial V_{TW}}{\partial z_{TW}'}
\]

(4.61)

which describes the impact of intensity of work on the benefit from participating in leisure or work. However, the nature of equation (4.61) is troublesome as its unambiguous sign (direction) could only be observed if either of the right-hand-side terms was null, or if they held opposite signs. Unfortunately, different arguments can be made regarding the sign and size of the terms. Consider people for whom higher intensity (productivity) of work is associated with higher satisfaction and monetary (and thus consumption) reward, but could greater tiredness and thus attractiveness of leisure. This description is especially accurate for situations with no strict (e.g. legal) requirement to work during travel and people choosing to do so only during their productive periods (Golden, 2010). This could be a case of creativity bursts for those
for whom in-travel environment provides stimulating milieu similar to anecdotal rituals of Balzac’s strong, black coffee, or Hemingway’s pencil sharpening (Kellogg, 1986). In such a case, both terms would be positive, and the overall direction of change in equation of 4.61 would depend on their relative sizes i.e. how quickly one becomes tired, and how that influences propensity to keep on working.

On the other hand, it is also possible that some people, perhaps time-pressured with numerous duties as described by Verschuren and Ettema (2007) are required to accomplish self- or exogenously-imposed tasks, but experience low productivity (Jain and Lyons, 2008). Such people would have higher propensity to work despite low productivity (slower progress), as well as lower propensity to engage in leisure (due to the work pressure). In such a case, both terms would be negative, leading again to ambiguity of the net effect resulting from the relationship (4.61). It is worth noting that such ambiguity would not only be individual specific, but possibly spell-specific, e.g. depending on the progress in task accomplishment. Consequently:

\[
\frac{\partial h_{TWk}}{\partial \zeta} = \frac{\partial h_{TWk}}{\partial (V_{T_L} - V_{TW})} \frac{\partial (V_{T_L} - V_{TW})}{\partial z_{TW}|_{t_{TW}'}} \frac{\partial z_{TW}|_{t_{TW}'} \partial \zeta}{\partial z_{TW}|_{t_{TW}'} \partial \zeta} \tag{4.62}
\]

As a result, change in the relationship between mean work productivity and the hazard of work interruption is closely related to the relationship between instantaneous productivity and relative benefits from participating in work and leisure. Finally, it is possible that the results could be biased due to moral-hazard-prone situation, as the respondents could freely underreport their working conditions in hope of influencing better service provision (‘My productivity would have been better with a free Wi-Fi’). Such misreporting of work effort and output (productivity) is not uncommon in labour and contract economics but is difficult to resolve without a more objective ways of monitoring and measuring productivity (Foster and Rosenzweig, 1994). Thus, the extent to which these interpretations are accurate in the current context is cumbersome to state using the current, self-reported data alone.

Whereas the present dataset does not contain enough information for such a purpose, it is in principle possible to determine the sizes of the two effects observed in expression (4.61). A simplest solution could be to directly question respondents on their in-travel work requirement or/and motivation. Another solution could include
specifying directly the intensity and utility functions, and hence $V_{TL}$ and $V_{TW}$, and designing a stated-choice exercise investigating the sensitivities of choices of activities at different stages of the journey depending on the experienced intensity (productivity). If the specifications for $V_{TL}$ and $V_{TW}$ was linear in $z_{TW} | t_{TW}$, equation (4.62) could be estimated using the difference in respective taste-parameters estimated in a simple discrete choice model, especially given the well-established link between such models and hazard-based formulation (Ettema et al., 1995). In such a case, covariates from expression (4.44) would, after appropriate scaling, enter the productivity equation directly, with all three components (initial activity choice, in-travel time allocation, and productivity) estimated jointly. However, as the current dataset does not include enough information on motivation for in-travel work, the productivity component has to be estimated independently from the time allocation components. An accidental benefit is, however, that this independent estimation isolates the activity choice component of the framework from any biases possibly resulting from subjectivity of self-reported productivity indicators.

4.2.5 Estimation procedure

Before the estimation, the available data was cleaned (including minor ad-hoc imputations for some explanatory variables) and re-coded to conform to the estimation procedure. The latter involved maximising the likelihood function $L$ consisting of the partial likelihoods from equations (4.31), (4.45), and (4.49):

$$L(\lambda, \beta, \rho | X) = L_{Init}L_{Haz}L_\zeta$$  

(4.63)

where $\lambda, \beta, \rho$ denote collectively parameters to be estimated, and $X$ values are the covariates. $L$ can be used to obtain estimates of the parameters together with their standard errors by using sequential quadratic programming package implemented in Ox 6.20 (Doornik, 2011). Note that whereas the partial likelihood associated with productivity $L_\zeta$ is independent of the remaining components, for specification-searching convenience all components were still estimated simultaneously. The optimal specification was sought using significance criterion at 90 and 95% levels and likelihood-ratio tests. Furthermore, reference to Akaike Information Criterion ensured that the model remained parsimonious, and the final specification included parameters either statistically significant, or those retained for controlling.
<table>
<thead>
<tr>
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<th>Module:</th>
<th>Work as initial activity (scaled)</th>
<th>Hazard of work interruption</th>
<th>Hazard of leisure interruption</th>
<th>Productivity</th>
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<td>s.e.</td>
<td>Value</td>
<td>s.e.</td>
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<td>-0.003</td>
<td>0.020</td>
<td>0.009</td>
<td>0.059</td>
</tr>
<tr>
<td>Trip duration: 91 to 150 minutes</td>
<td></td>
<td>0.010</td>
<td>0.026</td>
<td>-0.030</td>
<td>0.074</td>
</tr>
<tr>
<td>Trip duration: 151 minutes or more</td>
<td></td>
<td>-0.019</td>
<td>0.031</td>
<td>0.058</td>
<td>0.088</td>
</tr>
<tr>
<td>Presence of a companion</td>
<td></td>
<td>-0.017</td>
<td>0.026</td>
<td>0.051</td>
<td>0.074</td>
</tr>
<tr>
<td>Presence of a table</td>
<td></td>
<td>-0.017</td>
<td>0.026</td>
<td>0.051</td>
<td>0.074</td>
</tr>
<tr>
<td>Purpose of travel: business meeting</td>
<td></td>
<td>-0.018</td>
<td>0.012</td>
<td>0.055*</td>
<td>0.032</td>
</tr>
<tr>
<td>Mode of travel to the station: bus</td>
<td></td>
<td>0.026</td>
<td>0.024</td>
<td>-0.078</td>
<td>0.068</td>
</tr>
<tr>
<td>Mode of travel to the station: bicycle</td>
<td></td>
<td>.</td>
<td>.</td>
<td>-0.090*</td>
<td>0.047</td>
</tr>
<tr>
<td>Mode of travel from the station: train</td>
<td></td>
<td>.</td>
<td>.</td>
<td>-0.028</td>
<td>0.044</td>
</tr>
<tr>
<td>Mode of travel from the station: car or motorbike</td>
<td></td>
<td>.</td>
<td>.</td>
<td>0.003</td>
<td>0.166</td>
</tr>
<tr>
<td>Work-related destination</td>
<td></td>
<td>-0.003</td>
<td>0.013</td>
<td>0.009</td>
<td>0.036</td>
</tr>
<tr>
<td>Worked just before the journey</td>
<td></td>
<td>0.050</td>
<td>0.046</td>
<td>-0.151</td>
<td>0.128</td>
</tr>
<tr>
<td>Held a phone conversation before the journey</td>
<td></td>
<td>-0.019</td>
<td>0.028</td>
<td>0.057</td>
<td>0.080</td>
</tr>
<tr>
<td>Interaction: worked before the journey and used laptop later</td>
<td></td>
<td>.</td>
<td>.</td>
<td>0.030</td>
<td>0.177</td>
</tr>
<tr>
<td>Interaction: worked before the journey and used PDA later</td>
<td></td>
<td>.</td>
<td>.</td>
<td>-0.276</td>
<td>0.193</td>
</tr>
<tr>
<td>Interaction: worked before the journey and used mobile phone later</td>
<td></td>
<td>.</td>
<td>.</td>
<td>0.146</td>
<td>0.170</td>
</tr>
<tr>
<td>Interaction: female with a companion</td>
<td></td>
<td>0.079*</td>
<td>0.041</td>
<td>-0.237**</td>
<td>0.099</td>
</tr>
</tbody>
</table>

**Note:** The table shows the results of the model estimation for various variables, including work as initial activity, hazard of work interruption, hazard of leisure interruption, and productivity. The values represent coefficients with standard errors (s.e.). Significant levels are indicated by **.
Table 4.2 Results of the model estimation

<table>
<thead>
<tr>
<th>Variables:</th>
<th>Module: Work as initial activity (scaled)</th>
<th>Hazard of work interruption</th>
<th>Hazard of leisure interruption</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sociodemographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High household income (&gt;£75k p.a.)</td>
<td>0.032*</td>
<td>0.018</td>
<td>-0.096**</td>
<td>0.044</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td>-0.050**</td>
</tr>
<tr>
<td>&gt;45 years</td>
<td>0.029**</td>
<td>0.014</td>
<td>-0.088**</td>
<td>0.034</td>
</tr>
<tr>
<td>Employed regularly</td>
<td>0.039**</td>
<td>0.018</td>
<td>-0.117**</td>
<td>0.042</td>
</tr>
<tr>
<td>Senior managerial occupation</td>
<td>0.139**</td>
<td>0.052</td>
<td>-0.181**</td>
<td>0.053</td>
</tr>
<tr>
<td><strong>Attitudinal factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Considered crowding level disruptive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure intention</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valuing in-travel working opportunity</td>
<td>0.030*</td>
<td>0.018</td>
<td>-0.090**</td>
<td>0.045</td>
</tr>
<tr>
<td>Would not reduce the amount of work if the journey was shorter</td>
<td>-0.043**</td>
<td>0.017</td>
<td>0.131**</td>
<td>0.036</td>
</tr>
<tr>
<td><strong>ICT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wi-Fi available</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used laptop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used PDA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used mobile phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric socket available</td>
<td>0.003</td>
<td>0.014</td>
<td>-0.010</td>
<td>0.040</td>
</tr>
<tr>
<td>Interaction: laptop use and Wi-Fi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: laptop use and table presence</td>
<td></td>
<td></td>
<td></td>
<td>-0.021</td>
</tr>
<tr>
<td>Interaction: laptop use and senior manager</td>
<td>0.167</td>
<td>0.149</td>
<td>0.604**</td>
<td>0.259</td>
</tr>
<tr>
<td>Interaction: laptop use, senior manager, no companion</td>
<td></td>
<td></td>
<td></td>
<td>-0.142</td>
</tr>
<tr>
<td>Interaction: PDA use and Wi-Fi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: mobile phone use and Wi-Fi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: mobile phone use and female</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: PDA use and high income</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: PDA use and senior manager</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Previous spells of activities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of similar previous episodes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.2 Results of the model estimation

<table>
<thead>
<tr>
<th>Variables:</th>
<th>Module: Work as initial activity (scaled)</th>
<th>Hazard of work interruption</th>
<th>Hazard of leisure interruption</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of other previous episodes</td>
<td>.</td>
<td>.</td>
<td>0.708**</td>
<td>0.322</td>
</tr>
<tr>
<td>Remaining journey time</td>
<td>.</td>
<td>.</td>
<td>-0.102**</td>
<td>0.021</td>
</tr>
</tbody>
</table>

**Structural parameters**

| Constant | -0.733** | 0.081 | 0.813** | 0.227 | 0.456 | 0.428 | 2.311** | 0.142 |
| Scaling factors | -0.332** | 0.093 | 1.000 | . | 1.000 | . | . | . |
| Shape: episode 1 (spell 1) constant | 1.000 | . | 1.866** | 0.122 | 1.895** | 0.115 | . | . |
| Shape: episode 2 (spell 1) constant | . | . | 2.279** | 0.139 | 1.417** | 0.135 | . | . |
| Shape: episode 3 (spell 2) constant | . | . | 1.854** | 0.239 | 1.408** | 0.126 | . | . |
| Shape: episode 4 (spell 2) constant | . | . | 2.190** | 0.231 | 1.769** | 0.411 | . | . |
| Shape: episode 5+ (spell 3 onwards) constant | . | . | 1.971** | 0.663 | 1.647** | 0.275 | . | . |
| bShape: impact of journey duration (in hrs) | . | . | -0.009 | 0.030 | -0.178** | 0.031 | . | . |

**Model fit**

<table>
<thead>
<tr>
<th>Component:</th>
<th>Overall</th>
<th>Initial activity choice and duration</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$LL$ with constants only</td>
<td>-2161.221</td>
<td>-1969.139</td>
<td>-192.082</td>
</tr>
<tr>
<td>$LL$ at convergence</td>
<td>-1303.620</td>
<td>-1147.151</td>
<td>-156.469</td>
</tr>
<tr>
<td>Number of parameters</td>
<td>149</td>
<td>107</td>
<td>42</td>
</tr>
<tr>
<td>$\rho^2$</td>
<td>0.397</td>
<td>0.417</td>
<td>0.247</td>
</tr>
</tbody>
</table>

**Excluded variables**

- Ticket type (single/return/season)
- Interregional train
- Train to/from London
- Afternoon (past 4 pm) trip
- Purpose: meeting with a customer
- Activity before the journey: talking to the companion
- Non-home-based trip
- Transport mode(s) used to get/from the station: train, metro, car or motorbike, walk only, taxi
- Transport mode(s) used to travel from the station: metro, bus, walk only, taxi

*significant at 90% level  **significant at 95% level.

Fixed to enable estimation.

Natural logarithm of – recall equations 4.41 and 4.42.
4.3 Findings

The estimation results are presented in Table 4.2. Overall, the final specification fits the data well as indicated by the high $\rho^2$ value of 0.397. In terms of the partial likelihoods which can be investigated given the independence of activity-choice and productivity components, it can be seen that the fit is better in case of the former ($\rho^2=0.417$) as compared to the latter ($\rho^2=0.247$). This is also consistent with the number of significant parameters capturing effects of the covariates itself possibly linked to the relative small variability in the productivity values (recall Figure 4.3). The scaling variable associated with the initial activity choice module was found statistically significant and, as expected, negative. This finding demonstrates consistency of rule (4.18) which drives both initial activity choice, and in-travel activity switching, by showing that if work appears beneficial, probability of choosing it initially is higher while subsequent chances for its interruption are lower.

4.3.1 Duration dependence

In terms of the shape parameters, the one associated with initial activity choice had to be arbitrarily fixed (to unity) to enable model identification. As for the hazard functions, the shape parameters describe the effect of activity duration (duration dependence) on the hazard of their interruption, controlling for all other covariates’ effects (Bhat, 2000) as explained in equation (4.39). It turns out that the dependence of shape parameters on journey duration, introduced in equations (4.41) and (4.42) was significant in case of leisure activities, i.e. the longer the duration, the less likely individuals were likely to interrupt leisure activities once engaged which can have either behavioural, or technical (heteroscedasticity due to decile-based recording) roots. This can also be observed in Figure 4.4 (see next page) where hazard profiles observed in the case of longer journeys (solid lines) tended to be lower, more concave or even convex. Such effect was less profound in the case of work activities which can be interpreted as individuals reporting relatively longer work spells as compared to leisure on shorter trips possibly reflecting existence of a minimum requirement for absolute duration of a work-related activity which will naturally occupy higher proportion of travel time for shorter journeys.

The estimated shape parameters indicated monotonically increasing hazard of leisure interruption (episodes from 5 onwards were binned together due to small number of
observations) apart from the second episode (first spell) of leisure in the upper and third episode (second spell) of leisure in the lower panel. In other words, the risk of activity interruption increased with its duration, in line with some other hazard-based models of activity duration, e.g. Bhat (1996b) or Lee and Timmermans (2007). The two exceptions when leisure followed the first spell of work-activity displayed hazard reducing with time, i.e. people being less keen on interrupting leisure and switching back to work. In addition, the hazard for work activities being in general higher than for leisure could support the claim that work was in general less enjoyable and preferred to leisure, ceteris paribus.
Additionally, the results suggested that, apart from the two convex hazard cases, the marginal benefit from participating in an activity was diminishing with duration which could be interpreted as reflection of convex preferences for duration of participation in the activities (Varian, 2010). In even more behavioural terms, this would mean that longer engagement in an activity would be associated with increasing tiredness and poorer concentration (in case of work), or boredom and idleness in the case of leisure. Judging from the duration dependence alone, a traveller who engaged in working activity right after the journey began (upper part of Figure 4.4) benefitted from work-related hazard profiles below those of an individual engaging in leisure at first. However, in either case an individual would, following the first spell work, engage in leisure activity whose risk of interruption would be decreasing with its duration, possibly reflecting their willingness to rest once their work was done, i.e. to get things done and relax for the rest of the journey thereafter.

4.3.2 Effects of the journey characteristics and previous activities

In addition to duration dependence, a number of factors were identified as significant determinants of activity choice as reported in Table 4.2 and Figure 4.5-Figure 4.8 on the next pages. Their meaning is such that the positive parameters are associated with increased probability of engaging in work initially, easier interruption work or leisure (note that the parameters are already scaled), or higher mean in-travel productivity.

In case of the trip duration, apart from the previously discussed impact on shape parameters, longer trips were also and the episodes of activities (both work and leisure) were more likely to last longer. This result can be interpreted as showing the respondents’ greater inertia in switching between activities facing longer travel have. As such, the finding did not confirm that of Gamberini et al. (2012) who reported no significant impacts of journey length on activity duration, though their research involved much shorter (below 15 minutes) journeys. On the other hand, the journey duration did not significantly influence productivity of individuals.

It was also found that the respondents were less likely to interrupt work with more remaining journey time, while an opposite effect was observed in the case of leisure activities. A possible interpretation could be that the respondents preferred to accomplish work first and be able to relax during the rest of the trip, or in the case of leisure activities, felt they still would have enough time to accomplish their tasks.
Figure 4.5 Comparison of the impact of various covariates (excluding ICT) on work and leisure duration (bars indicate standard errors)
Figure 4.6 Comparison of the impact of various ICT covariates on work and leisure duration (bars indicate standard errors)
Figure 4.7 Comparison of the impact of various covariates (excluding ICT) on in-travel productivity (bars indicate standard errors)
Figure 4.8 Comparison of the impact of various ICT covariates on in-travel productivity (bars indicate standard errors)
In addition, leisure activities would be less likely to interrupt with longer previous durations of other spells, possibly due to either fatigue resulting from earlier work episodes, or numbness increasing with longer spells of non-work activity. At the same time, the risk of work interruption increased with duration of both types of previous spells, indicating that latter episodes of work tended to be shorter than the first ones.

Furthermore, people on a return leg were less likely to start with work-related activity, more likely to interrupt work, as well as experience lower productivity. This result appears consistent with that of Lyons et al. (2007) who reported lower propensity to engage in work by business travellers on the return leg, claiming that this may be due to its more relaxed nature, often taking place outside the office hours.

Whilst the effect of first class travel was that of discouraging leisure, the higher ticket price was associated with longer participation in leisure alike, possibly due to longer journeys having longer spells of activities. Similarly, the findings for seating availability encouraging longer work spells could be explained in terms of providing better work-enhancing conditions.

As for the presence of a table (of any kind), there was no link to the activity choice and time allocation, though the factor turned out to be associated with higher reported productivity. This finding supports results reported by of O’Hara et al. (2002) regarding business travellers’ ‘juggling’ between paper documents and ICT, for which working space such as table of appropriate size is critical (Axtell et al., 2008).

As for the presence of a companion, the effect was found to be that of lowering the propensity to interrupt leisure, though the effect was less profound for females in which case higher engagement in work was observed. Thus co-travellers appeared to be a strong incentive for leisure-related interaction, such as personal matters or commenting on a football match, rather than stimulant for work-related discussions. Nonetheless, more information regarding the number of co-travellers well as the type of relationship (personal and/or professional) with the respondents could shed more light on this effect.

Regarding the purpose of travel, a business meeting or work-related slightly increased the propensity to interrupt work, as well as leisure (in the latter case only). On the other hand, working just before the journey was not found to have any significant
effect thus not providing support for the notion of work being carried over to the train. In terms of the effects of transport modes used to travel to the station, increased chances of leisure interruption were noted following a bus trip to the station, or higher productivity among those who cycled instead. In terms of the trips from the station (assumed to be pre-planned), train use was associated with more work engagement, while the use of car, motorbike, or bicycle with increased leisure interruption perhaps to ensure that the work-related tasks are accomplished before using transport modes with no possibility of undertaking work-related activities.

4.3.3 Sociodemographics and attitude

In terms of sociodemographics, factors such as regular employment, being a male, age above 45, annual household income above £75k and senior managerial position were found to make travellers stay engaged in work longer. Thus regular employment would be associated with more stable duties and higher expectations from the employer whereas older respondents could perceive the travel time as a period between busy and disruptive office and home duties, as discussed by Churchill and Wakeford (2002) or Ettema et al. (2010). Similar explanation could lie behind respondents of senior managerial position reporting such effects. In terms of gender effects, females were found to more likely interrupt work which is only partially supported in the literature as (Timmermans and Van der Waerden, 2008) found females to be more talkative (though not noting whether the talk was work- or leisure-related) while Gamberini et al. (2012) did not found any gender effects. As for high income the finding largely follows that of Ettema et al. (2010) who indicated low and high income groups’ higher propensity to work (though not in case of business travellers only).

Regarding attitudinal factors, people intending to spend travel in leisure were less likely to start the journey working or interrupt leisure as well as more likely to interrupt spells of work episodes which suggests significant role of pre-planning of activities. At the same time, valuing in travel work opportunity was found associated with higher engagement in work and lower in leisure. A more unexpected was the sign of the parameter associated with individuals who stated they would not reduce the amount of work if the journey was shorter. While one would expect that such people being more likely to stay engaged in working, the opposite effect of easier
interruption was noted. A possible explanation could be that the output of such people was already low and involved low profile tasks, e.g. inbox cleaning, or news reading, which are frequently interspersed with leisure anyway. More detailed insight into this effect could be perhaps obtained if more was known about the type of tasks or output of the respondents. Last but not least, some evidence was found in terms of perception of disruptive character of crowding on productivity, possibly reflecting struggle to accomplish work while being disturbed by noise and less pleasant atmosphere in general, both reported in other studies (Ettema et al., 2012; Van der Waerden et al., 2009).

4.3.4 Effects of ICT

The hypothesised impacts of ICT on travel time use and productivity constituted the main motivation for developing the current framework. Given the sheer number of significant ICT-related parameters observed in Table 4.2, it appears that the general case of ICT use being important determinants in the travel time use and productivity context is supported. This is also consistent with the earlier large scale studies (Lyons et al., 2007; Watts and Urry, 2008) with Susilo et al. having demonstrated that the importance of ICT in the context of in-travel time use have been increasing over the recent years (Susilo et al., 2012).

The use of laptop was found to be associated with lower productivity, though the effect was less profound for senior managers, or if a table was available in which case no significant effect would exist. This appears to be in line with the qualitative findings describing the important role of laptop in creating a microenvironment of office (Brown and O’Hara, 2003; Sherry and Salvador, 2002) which can be linked to the notion of ICT-enhanced activity fragmentation (Alexander et al., 2010). Interestingly, while the positive effect of table and laptop use on productivity was noted, there was no impact from electricity sockets which can be argued to result from pre-planning involving charging ICT devices. Additionally, Axtell et al. (2008) noted that travellers may not be willing to use their laptop on shorter journeys as this would involve too much effort as compared to the duration of use. Arguably, this niche may have already been addressed by the emergence and proliferation of tablet computers or smartphones – an effect which would not have been captured by the available data coming from 2008 (the first iPad was introduced commercially in 2010).
Interestingly, the effect of laptop use in the presence of Wi-Fi coverage made respondents less likely to interrupt their leisure activities (no effect concerning hazard of work interruption was found). The result is somewhat similar to that of Rasouli and Timmermans (2014) who indicated that the utility of Internet for work activities diminished very quickly perhaps indicating higher attractiveness of that ICT combination for leisure activities. This finding may also point towards existence of Internet-based procrastination, i.e. prolonged involvement in non-work activities such as social networking, or gaming. The focus groups-based analysis by Jain and Lyons (2008) indicating that when people use laptop, they use it for both leisure and work, could to some extent support that interpretation.

Nonetheless, the results are likely to mask a more complex picture. First of all, the Wi-Fi coverage was reported only by 8.3% of the respondents, though this figure might only reflect those who sought it while a number of respondents might possibly not even aware of its availability (or not). At the same time, the presence of Wi-Fi coverage on its own did not have any effect, perhaps due to the fact that its usefulness comes only with the use of an ICT device. Secondly, no information regarding the cost of Wi-Fi use was available while this characteristic would likely be important determinant of its actual use. Thirdly, already in 2008 the mobile phones were capable of tethering Internet connection to the laptops and so the presence of Wi-Fi itself would not be completely informative in terms of the actual Internet access and use. Last but not least, the reliability of the service is crucial if one wants to engage in an important, online based activity (Puuronen and Savolainen, 1997) even though and Churchill and Wakeford reported on individuals developing contingencies to cope with the risk of disruption, e.g. by pre-typing e-mail in offline mode and sending it only when the connection is fairly stable (Churchill and Wakeford, 2002; Holley et al., 2008). On the other hand Axtell et al. demonstrated that poor coverage, both of mobile phone and Wi-Fi, can be used as an excuse to ‘escape’ ICT-based communication (Axtell et al., 2008). Nonetheless, assuming that Wi-Fi coverage is reliable and correlated with the actual use of Internet, it could increase individuals’ capabilities to manage duties enabling greater range of communication channels (e-mail, social networking, perhaps even video-conferencing), activities (including tele-activities) as well as access to resources such as documents or news (Brown and O’Hara, 2003; O’Hara et al., 2002). Not surprisingly Gripsrud and Hjorthol found
Internet access to be a very important facility for business travellers (Gripsrud and Hjorthol, 2009) and (Gamberini et al., 2012) suggested that Internet provision on the underground may stimulate further use of ICT devices. Furthermore, the importance of Wi-Fi was confirmed in ever-increasing provision of wireless links in transport hubs and modes including planes, stimulating business of Wi-Fi provision, e.g. GoGo In-Flight Internet (GoGoAir, 2013) or Virgin Wi-Fi on the London Underground (Virgin Media, 2013).

At the same time, access to multiple media sources offered by the Internet could be distracting as suggested by the experimental results of Ophir et al. who found ability to multitask undesirable when facing several potential distractors, as it was associated with lower ability to focus and process information (Ophir et al., 2009). However, until more detailed information on the type of activities, especially online, undertaken using laptop is available, further conclusions regarding the impact of Internet on in-travel time use or productivity would be rather speculative. Nonetheless, given the aforementioned potential of Internet access, further data collection designs should address this deficiency as one of the priorities.

The use of mobile handheld devices such as mobile phone or PDA was also found important in the current context which confirmed the findings reported elsewhere in the literature (Lyons et al., 2007; Susilo et al., 2012; Timmermans and Van der Waerden, 2008). The use of PDA was found to increase productivity, especially among high income users, possibly reflecting the capability of receiving a work-related call, message, or e-mail, as well as engaging in other activities such as co-ordination or rescheduling (Churchill and Wakeford, 2002; O’Hara et al., 2002; Weight, 2008). In fact, such productivity-enhancing capabilities can be seen as one of the drivers of proliferation of smartphones which are in essence descendants of PDA.

However, the results also indicated that mobile phones could be disruptive for both work- and leisure-oriented activities possibly delivering unwanted and unpredicted calls and/or messages, prompting particular behavioural responses (Gant and Kiesler, 2002). This is in line with the results of Axtell et al. and Susilo et al. who reported on respondents claiming that the periods without mobile phone and thus interruptions from personal calls tended to be more productive (Axtell et al., 2008; Susilo et al., 2012). This finding suggests that mobile phone serves not only as activity-enabling
device, but may also increase expectations of constant accessibility, itself not always desirable (Sherry and Salvador, 2002; Weight, 2008). While the disruptive nature of a mobile phone is not as critical in the context of rail travel as in car-driving where it can compromise safety (Bellinger et al., 2009; Lee, 2007), it can still influence the quality of other passengers’ travel (Murtagh, 2002). Interestingly, the effect of mobile phone was less profound for females which may suggest that females could be better at managing their travel time use in relation to possible ICT-induced disruptions, or used their phones for work-related purpose. On the other hand, PDA-using senior managers tended to report lower levels of productivity unless they also were in higher income groups which could be attributed to the disruptive nature of ICT, especially to individuals holding key posts in companies though managers with as well as the capability, both psychological and organisational, of resisting such disruptions.

Finally, participating in a work activity before the journey together with a subsequent use of a laptop was not found significant, while the use of PDA would lower the risk of leisure interruption. This could be interpreted as respondents attempting to deal with all business-related matters before boarding the train, and using PDA for more personal reasons once travelling which could be supported by findings in other studies indicating that travel time may be a good opportunity to catch up with people who could not be contacted otherwise (Bull, 2004; Jain and Lyons, 2008). Given that the respondents were on business trips, this result may reflect a wider trend towards blurring of space between work and non-work (Vincent-Geslin et al., 2012; Zerubavel, 1981) even though an attempt to divide time between pre-journey work and in-travel leisure was made. More information regarding the type of activates, people contacted, and subject of discussion (work vs. non-work) could again provide further insight and justification for such an interpretation.

### 4.3.5 Excluded variables

While constructing the optimal specification of the model, a number of variables were found neither significant, nor essential as controlling or policy variables. The most surprising was lack of effect observed for non-home-based trip or meeting with a customer destination. Neither was the effect of time of day found significant (travelling in the afternoon or later), though this could be influenced by non-observed individual characteristics with some people preferring to work in the mornings, and
others in the afternoons, or evenings. Travel modes used to travel to or from station were found only partially significant and more detailed information on the conditions of use of such modes such as cost, duration, seating availability, or weather conditions could shed more light on this result. No additional effect was found regarding the effect of ticket type (single, return, or season), or travelling on an interregional train, or to and from London.

Additionally, the specification of the model tested for various interactions between the use of ICT and sociodemographics as well as ICT in bundles, e.g. laptop and mobile phone use. However, apart from the ones discussed in the previous sections, such effects turned out to be insignificant. As such, the results did not supporting findings suggesting very strong age-specific effects of ICT use, though some evidence for occupation-specific (senior manager) impacts were found (Gripsrud and Hjorthol, 2009; O’Hara et al., 2002; Van der Waerden et al., 2009). Neither was there much support for co-ordinated use of various ICT equipment (Brown and O’Hara, 2003; Laurier, 2002; Oulasvirta and Sumari, 2007). Nonetheless, the issue of how and for what purpose ICT were used remains somewhat unanswerable using the current data only though the framework could still be applied for more detailed data should such emerge in the future.

### 4.4 Cross-validation

The final stage of the investigation involved attempting to measure the extent to which the presented formulation would be capable of inferring the values of work duration and productivity change. In doing so, the cross-validation procedure in a form of a k-fold hold-out sample method was used (Kohavi, 1995). The method assumes partitioning the sample into random complementary subsamples consisting of approximately 80% and 20% observations. The former subsample was used to re-estimate the parameters of the model, which were subsequently used to simulate work durations and productivity changes for the remaining 20% (hold-out) sample by means of a microsimulation, for which a purpose-specific script was created in Ox 6.20 (Doornik, 2011). Ten repetitions (folds) of the procedure were assumed as suggested by the results of Kohavi (1995). The method was deemed a reasonable trade-off between robustness and computational demands, the latter being possibly of an issue given the model’s complexity (Kohavi, 1995).
The process of simulating the values followed the logic presented in Figure 4.2. Firstly, the probability of work as initial activity was calculated, and a random draw was used to simulate the actual choice, depending whether the value was above or below the calculated threshold probability. Hence the outcome would be either work or leisure as an initial activity, also defining the hazard profile (recall Figure 4.4) of an individual on that particular journey. Subsequently, durations of spells of activities were simulated using inverse of the survival function (4.36) depending on the values of shape parameters and covariates. Naturally, if the sum of the activity durations for a particular individual exceeded the journey duration, the final activity was censored to ensure consistency with the journey duration. On the other hand, productivity experienced by an individual was derived as the expected value of the assumed gamma distribution with the scale and location parameters appropriately modified to reflect the impact of respondent’s characteristics and conditions faced. In order to obtain stable estimates of the quantities of interest, 1000 simulations were performed.

| Table 4.3 Hold-out validation results (fold no.1) (n = 188, 1000 simulations) |
|-----------------|-----------------|
|                  | Observed        | Simulated       |
| **Work Duration** |                 |                 |
| Mean (s.e.) [in minutes] | 56.754 (2.825) | 60.858 (2.873) |
| Paired sample t-test (p-value) | 1.774 (0.078) | 1.774 (0.078) |
| Wilcoxon Signed-Rank Z (p-value) | 0.893 (0.373) | 0.144 (0.037) |
| Kolmogorov-Smirnov D (p-value) | 0.144 (0.037) | 0.144 (0.037) |
| Root-mean-square Error (RMSE) [in minutes] | 31.908 | 31.908 |
| %age correctly predicted | 94.7% | 94.7% |
| Linear regression constant (s.e., t-statistic, $H_0$: constant equal to zero) | 0.277 (0.065, 4.292) | 0.277 (0.065, 4.292) |
| slope (s.e., t-statistic for $H_0$: slope equal to unity) | 0.659 (0.054, 6.315) | 0.659 (0.054, 6.315) |
| $R^2$ | 0.449 | 0.449 |
| **Productivity** |                 |                 |
| Mean (s.e.) [in minutes] | 0.966 (0.020) | 0.998 (0.008) |
| Paired sample t-test (p-value) | 1.448 (0.149) | 1.448 (0.149) |
| Wilcoxon Signed-Rank Z (p-value) | 2.379 (0.017) | 2.379 (0.017) |
| Kolmogorov-Smirnov D (p-value) | 0.442 (<0.001) | 0.442 (<0.001) |
| Root-mean-square Error (RMSE) | 0.302 | 0.302 |
| Linear regression constant (s.e., t-statistic, $H_0$: constant equal to zero) | 0.997 (0.186, 5.354) | 0.997 (0.186, 5.354) |
| slope (s.e., t-statistic for $H_0$: slope equal to unity) | -0.031 (0.185, 5.573) | -0.031 (0.185, 5.573) |
| $R^2$ | 0.001 | 0.001 |
| 3 categories |                 |                 |
| Lower ($\zeta \leq 0.950$) | 42 | 54 |
| Same ($0.950 < \zeta < 1.050$) | 126 | 81 |
| Higher ($\zeta \geq 1.050$) | 20 | 53 |
| $\chi^2_{2,\alpha\ell}$ (p-value) | 26.200 (<0.001) | 26.200 (<0.001) |
| 2 categories |                 |                 |
| Low ($\zeta \leq 0.950$) | 42 | 54 |
| Same or Higher ($\zeta > 0.950$) | 146 | 134 |
| Fisher exact test (p-value) | 0.193 | 0.193 |

*within 95% confidence interval*  
*As compared to usual office conditions, frequencies calculated using*
for each of the hold-out sample and the mean simulated duration was used as an estimate. In case of simulation of productivity values, by definition only a single estimate was obtained using the expected value.

Table 4.3 presents the results of comparing the observed and simulated values of the major quantities of interest, i.e. duration of in-travel work and mean in-travel productivity for an exemplar realisation of the validation with the remaining realisations (folds) presented in Appendix 6 displaying similar quality of fit. Regarding the in-travel work duration, the mean of the observed values was found to lie closely to the simulated value, with the paired sample t-test indicating no significant difference at 95% level. Similarly, the Wilcoxon Signed Rank and Kolmogorov-Smirnov tests provided evidence at 95% and 99% respectively for the similarity between the values’ distributions. In terms of accuracy of individual predictions, in 178 out of 188 cases (approximately 94.7%), the simulated values and their associated 95% confidence intervals included the observed values, though the RMSE value of around 32 minutes suggested the confidence intervals, constructed by means percentile methods, were comparatively wide.

Finally, the linear regression results indicated that the best inferential accuracy was achieved for durations of work around 50 minutes (i.e. region where the best-fit line crossed 45-degree line). A possible explanation of such a pattern may be interaction of two effects. The first one is overestimation of work engagement for the respondents who reported zero, or close to zero work duration. Such conditions could also emerge in the process of simulation, but under very specific and comparatively unlikely conditions of initial participation in leisure and its uninterrupted lasting for the entirety of the journey, both occurring in each of the 1000 simulations. The second reason for the observed pattern of discrepancy observed in the case of linear regression test would result from existence of leverage points, i.e. respondents on longer journeys for whom the discrepancy between observed and simulated work durations would be larger in absolute terms, and not necessarily as expressed in terms of the proportion of total journey duration. Such points would have a stronger impact (leverage) on the best-fit-line parameters resulting in their bias. Future efforts in mitigating these effects could include explicit account of the cases of zero work duration, e.g. as an additional possibility in initial choice component, thighb this would
inevitably increase the number of parameters in the already complex model. In terms of the second effect, a method of duration recording which does not rely on decile-coding (itself by definition less accurate for the longer journeys and durations of work), could prove effective step towards obtaining more reliable estimates of activity durations.

In terms of the quality of simulation of mean in-travel productivity, the main obstruction was the strongly leptokurtic empirical distribution of the values with strong clustering of the observed values around unity (recall Figure 4.3). Despite this fact, the framework provided satisfactory result in terms of insignificant difference in the mean value as indicated by the paired sample $t$-test or RMSE value of 0.302. The Wilcoxon Signed-Rank and Kolmogorov-Smirnov tests indicated significant difference between the observed and simulated distributions (though at 95% degree only in the former case) which was also confirmed by the linear regression results. This finding is unsurprising given the very leptokurtic nature of the empirical distribution, possibly difficult to replicate even by a distribution as flexible as gamma.

Another way of investigating the inferential performance of the model in terms of the productivity was to perform categorical analysis of the results. By grouping the observed and simulated productivity values into three categories (low, similar, and higher than in the typical office conditions), it was possible to test for the similarity of distributions using Pearson Chi-square test. In such a case the results were significantly different with the main discrepancy resulting from overestimation of ‘High’ productivity category at the expense of ‘Same’. If these categories, however, were merged into a common ‘Same or Higher’ category, the difference became insignificant at 95% significance level as indicated by the Fisher’s exact test. Hence the accuracy provided by the framework as a microsimulation-based inferential tool was promising in terms of forecasting whether travel time was perceived as productive or not. In this context, the ability to distinguish between negative impacts versus no or positive impact was more crucial though further efforts towards collecting less subjective measures of productivity should shed more light on the extent to which it was more productive than time that would have been spent in the office.
As the effects of travel time spent productively have been increasingly part of the debate regarding transport investment appraisal methodology (see Batley et al., 2012), the framework developed in this chapter, despite limitations in terms of its inferential capabilities, could form a step towards designing more efficient appraisal tools, and ultimately policies. Such attempt is made in the subsequent Chapter 5 where the cross-validation results obtained above are applied in the context of valuation of employers’ value of business travel time savings using elements of the so-called Hensher’s approach in an effort demonstrating a possible avenue towards incorporation of the ICT effects on in-travel time use and productivity (Batley et al., 2012; Hensher, 1977; Mackie et al., 2003).

4.5 Summary

This chapter presented an important contribution to understanding how the relationship between ICT and travel behaviour can be framed and understood in terms of a microeconomic model. In doing so, a novel approach to the issue of travel time use and productivity was demonstrated, with theoretical rules driving people’s choice of activities and time allocation as well as their link to productivity. In fact, possible extensions to accommodate wider range of situations of ICT-travel interaction are possible, and these are discussed in the subsequent chapter.

The empirical part of the chapter demonstrated how the proposed theory could be translated into an estimable, econometric specification, and applied it in the context of modelling the impacts of ICT on in-travel time use and productivity. The results confirmed important role of ICT-related factors in this context, together with their interaction with respondent- and journey-specific characteristics. These results were also confronted with the prevailing discourses to find that the impacts of various factors explored in the current study were found in certain cases different from the findings of other researchers. Possible sources of such discrepancies might have included specificity of the sample and approach, as well as the dynamic evolution of ICT sector between the periods of studies. What was also been demonstrated was that ICT did not necessarily lead to increase in in-travel work and higher productivity, but the impacts were heterogeneous, and frequently context-dependent, e.g. sociodemographic-specific. From that point of view, the findings support the notorious complexity of the possible interrelations between different factors also
emphasizing the need for theory-building as a means of better understanding of such complexities.

Finally, the model was also tested in terms of its inferential capabilities. In doing so, the predictions were shown to reasonably align with the observed values with a number of cases indicating no significant different between the simulated and observed values. Future improvements in the could concentrate on data collection efforts, especially in terms of establishing more objective measures of in-travel productivity, time allocation records not relying on decile-based indicators, and more detailed ICT-use information. Larger samples could also facilitate model-building by enabling use of more data-demanding hazard distributions such as generalised gamma, or randomly-distributed coefficients. Additionally, comparison with other modes of transport, especially those with established ICT infrastructure such as airplanes, coaches or ferries, could indicate the role of in-travel time use possibilities on mode’s attractiveness. In a similar spirit, more detailed information on types of activities (especially those ICT-based) would further facilitate understanding of how technologies have been influencing the perception of travel time and productivity, especially given that the method presented above was shown to possibly accommodate such extended datasets, both theoretically and empirically.
Chapter 5
RO2: MICRO PERSPECTIVE II

The previous chapter introduced a theoretical and econometric framework for modelling in-travel time use and productivity based on number of factors, including ICT use, socio-demographics, attitude, and journey characteristics. Building on these developments, the objective of this chapter is to demonstrate further applications of the framework. In doing so, sections 5.1 and 5.2 present application of the model to the context of valuation of business travel time savings, firstly by presenting its relation to the theoretical developments in this area, and secondly by means of microsimulation making use of the SPURT data used in the previous chapter. On the other hand, sections 5.3 and 5.4 deal with further theoretical developments. In particular, section the former presents a link with the discrete choice modelling domain as well as means of valuing various qualities characterising travel behaviour and ICT choice. Additionally, by means of three hypothetical activity-travel scenarios, the conceptual applicability of the approach to various cases of interaction between ICT and travel behaviour is presented in section 5.4. Section 5.5 summarises the results of the chapter.

5.1 Microsimulation-based valuation of employer’s business travel time savings

The valuation of travel time savings has been an important component of transport investment appraisal and public policy analysis since the early 1950s (Cherlow, 1981). In the UK, for example, travel time savings typically account for about 80% of the monetised benefits within the cost benefit analysis of major road schemes (Mackie et al., 2003). In the most recent (October 2013) economic case for one of the UK’s largest transport investments in decades, High Speed 2 (HS2) rail line from London to
Birmingham, almost half of the expected benefits to transport users (£24.6bn) are derived from travel time savings, most of which is due to savings in the business travel time, i.e. £7.9bn or 28.2% of the total benefits (HS2, 2013). Given such a prominence, it is of no surprise that the estimation of parameters that enable the calculation of travel time savings has remained important, often controversial, research field for decades (AHCG, 1996; MVA et al., 1987).

At the same time, transport scheme appraisal relies heavily on the assumption that travel time is unproductive and wasted. However, as was demonstrated in Chapter 2 and Chapter 4, this assumption has become increasingly questioned, especially in light of proliferation, and growing capabilities and portability of ICT. At the same time, the microeconomic framework presented in Chapter 4, especially the promising validation results, in conjunction with the so-called Hensher’s approach (Hensher, 1977), described in more detail in the next section can provide means of incorporating in-travel time productivity effects in business travel time valuation.

What should be made explicit is that engagement with the on-going debate regarding the appropriateness and revision of the existing valuation methodologies (Batley et al., 2012) does not constitute a direct objective of this contribution. Rather than that the focus is on demonstrating technical applicability of the previously developed model to operationalisation of the Hensher’s approach.

5.1.1 Theoretical foundations of business travel time savings

The current understanding of the concept of value of time ($VOT$) and value of travel time savings ($VTTS$) can be traced to the seminal work of Becker (1965) which defined the roots of modern microeconomic time allocation theory. Becker assumed two sources of utility: consumption and leisure, and claimed that a rational individual would seek to maximise his or her utility by allocating time between income-generating work (enabling subsequent consumption) and leisure activities, subject to time and budget constraints. A number of researchers revisited the theory subsequently, extending and enhancing it (see Jara-Diaz, 2007 for a review) though it was DeSerpa's (1971) contribution that introduced additional constraints reflecting minimal expenditure and time requirements characterising participation in certain activities. An example of such an activity is travel with its duration and costs usually...
pre-determined by infrastructural, physical, and physiological factors, also reflected in the Hägerstrand’s prisms (recall Figure 2.1).

The existence of time, budget, and minimum duration and expenditure constraints means that the individual faces trade-offs when making time- and resource-allocating decisions. At the same time relaxing these constraints will on most occasions lead to higher utility levels which, if expressed in money terms, would give rise to different theoretical constructs for valuing different aspects of time.

The value of saving time in a particular activity (e.g. value of travel time savings) is based on technical constraints on the minimum amount of time that must be allocated to particular activities (e.g. minimum time for a trip, though this is a constraint that could be relaxed to account for activities such as telecommuting). This value can be expressed as a ratio of Lagrangean multipliers associated with the minimum time requirement and budget constraint. Equivalently, it could be defined as an algebraic value of the difference between the value of time assigned to an alternative use (such as the value of leisure) and the value of time as a commodity (Bates, 1987; Jara-Díaz, 2007). Algebraically this can be expressed as:

\[
\frac{K_v}{\lambda} = \frac{\mu}{\lambda} \frac{\partial U}{\partial \tau_v} \tag{5.1}
\]

where \(K_v\), \(\lambda\), \(\mu\) are Lagrangean multipliers associated with the minimum time requirement constraint for activity \(v\), the budget constraint, and total time constraint respectively while \(U\) is utility derived from the overall time allocation process (just as it was in the framework of Chapter 4) and \(\tau_v\) is duration of particular activity \(v\).

The resource \(VOT\), i.e. the first term on the right hand-side of the equation (5.1), is represented by the ratio of the marginal utility of total time to the marginal utility of income, or between the respective multipliers in Lagrangean constrained optimisation. As such it describes the value attached by an individual to time as a result of its fixity, and possibly scarcity in a given period, e.g. 24 hours in a day, 7 days in a week etc. On the other hand, the previously discussed concept of multitasking, i.e. concurrent (simultaneous) participation in multiple activities could be interpreted as partial relaxation of that constraint as previously discussed in section 2.1.3. As a consequence, resource \(VOT\) would be reduced. Nonetheless, the empirical estimation
of such effects has proved cumbersome so far as higher value of time tends to be also associated with higher propensity to multitask, resulting in a self-selection bias with the previously discussed results of Verschuren and Ettema (2007) confirming this hypothesis.

The rightmost term in equation (5.1) is that of the $VOT$ as a commodity in which case time itself is viewed as potential source of utility and not just as a factor contributing to the production of other goods. The value is derived as the rate of substitution between the activity that time is spent on and money, and would be equal to the resource value of time only if the individual assigns more time to the activity than the minimum required, i.e. only for leisure activities.

Several researchers have also demonstrated the link between these theories of time allocation and the discrete choice modelling framework (Bates, 1987; Hensher and Truong, 1985) through formulation of an indirect utility functions in models of travel behaviour. These contributions provided link between the aforementioned theoretical constructs and empirical means of estimation from observed (revealed preference) data and/or data from stated choice experiments. The $VOT$ in these models is implicit and is extracted from the observed sensitivities of individuals to travel times and costs. In the simplest case of linear-in-parameters utility functions, the $VOT$ is given by the ratio of parameters associated with travel time and cost and has been employed by researchers in various modal- and geographical contexts (Brownstone and Small, 2005; Brownstone et al., 2003; Hess et al., 2005). In fact, similar reasoning is applied in following section 5.3 where indirect function is derived based on the utility maximisation problem from Chapter 4.

However, the theory of time allocation discussed above places in the centre of decision-making process an individual who seeks to maximise their own, personal utility. While applicable in wide range of contexts, this conceptualisation may not appropriately capture the situation of business travellers travelling in the course of work. In such a case, travel time of an employee constitutes his or her work time, itself employer’s resource sought to be utilised in the most efficient manner. In the current context it is the ‘briefcase travellers’, i.e. ‘employees travelling in the course of business’ (Mackie et al., 2003, p. 5) that are of main interest, and thus the case of professional (commercial) drivers is excluded. At the same time, a caveat should be
made that in conditions of the knowledge economy and increased blurring of work-
and non-work spaces and times, binary business- versus non-business trip distinction
may not always be adequate to capture situations where leisure activities are
undertaken on business trips, and some work activities during leisure trips.

While it is possible in principle to infer about employers’ willingness to pay for
reduced travel time by their employers on the business trips using discrete choice
models, such approach yields a ‘danger of confounding two sources of money saving
related to reduced travel times – those related to the cost of the employee […]], and
those to vehicle operating cost’ (Mackie et al., 2003, p. 7). Thus the main conceptual,
and to some extent competing approaches to business travel time valuation have
traditionally been those of cost-saving approach, and Hensher’s approach (Mackie et
al., 2003) which are introduced below.

5.1.2 Cost-saving approach

The idea behind the cost-saving approach rests on the assumption of classical
microeconomics that an employer (firm) would employ labour up to the point where
the marginal cost of adding another unit of labour, i.e. wage rate plus overheads (so-
called ‘wage plus’) would equal the marginal product of that unit of labour. Consequently, assuming that travel time is indeed unproductive, the cost born by the
employer would be approximately equal to the cost of employing a similar unit of
labour to compensate for that ‘lost in travel’ unit. Alternatively, the additional unit of
labour could be released and re-hired in the labour market which may not always be a
realistic assumption for certain occupations, or in general in conditions of economic
downturn (Mackie et al., 2003).

While clearly parsimonious and well-grounded in the economic theory, the approach
is based on a number of assumptions which would only hold under very restrictive
conditions such as (Batley et al., 2012; Mackie et al., 2003):

- competitive conditions in the goods and labour markets;
- no indivisibilities in the use of time for production, i.e. so every minute is equally
  valuable;
- the frequency of business trips is independent of total business travel time;
- all released travel time goes into work, not leisure;
• travel time is totally unproductive in terms of work;
• the employee’s disutility of travel during working hours is equal to their disutility of working.

While seemingly restrictive, the approach has been advocated on the grounds that in the long run, the above effects would in general cancel out while the employee’s disutility resulting from the need to frequently travel could be accounted for in their wage rate (Fowkes, 2001; Mackie et al., 2003). Hence, incorporating any in-travel productivity effects in VTTS estimation has been argued to carry the risk of double-counting. At the same time, the approach has been seen as controversial on the grounds that in its disaggregate form it could favour investments beneficial to higher income groups due to the use of income as a proxy for work-related output. Consequently, investments in transport infrastructure with high proportion of high-income individuals would inflate the VTTS and hence the total value of the investment benefits.

5.1.3 Hensher’s Approach

Relaxing some of the assumptions introduced above, Hensher (1977) provided an alternative approach to how to value travel time savings, more specifically value of savings in business travel time (VBTT). While criticised on the demanding nature in terms of the introduced concepts, data requirements and thus applicability (Batley et al., 2012), it still offers more detailed insight into elements that constitute VBTT.

The basic idea underlying Hensher approach stems from acknowledging the existence of two components forming the overall VBTT: ‘the intrinsic VTTS for the traveller on that trip [VBTT_{EE}], and the consequences for the employer in respect of lost productive time [VBTT_{ER}]’ (Gunn, 2000). Based on the Hensher’s contribution, Fowkes et al. formalised his approach in the following algebraic expression for VBTT (Fowkes et al., 1986; Mackie et al., 2003):

\[
VBTT = \frac{[(1 - R) - PQ]MP + MPF}{VBTT_{ER}} + \frac{[(1 - R)VW + RVL]}{VBTT_{EE}}
\]  \hspace{1cm} (5.2)

where:

\[ VBTT \] – value of savings in business travel time;
\[ VBTT_{ER} \] – employer’s value of savings in business travel time;
The intuition behind expression (5.2) is very straightforward. The benefits resulting from reducing duration of a business trip can be decomposed into those accrued by the employer and by the employee. As regards the employer, the gain is equal to the marginal product of labour $MP$ less fraction of the saved (reduced) time devoted to non-work activities $R$ (since not all saved may be spent on work), and less the productive output $PQ$ resulting from in-travel work that would have been generated in the reduced journey time. An additional effect would be that of the extra output due to reduced fatigue $MPF$ of the employee. It can be observed that under the conditions discussed in the previous sections, i.e. $R, P, Q$ constrained to zero, and with workers not attaching any utilitarian value to work, i.e. $VW = 0$, Hensher approach reduces to simple cost-saving approach.

At the same time, the benefit to the employee is that of a weighted (by the fraction $R$) average of the gain (or loss) in the utility from work and leisure activities relative to travel time, $VW$ and $VL$ respectively, that are undertaken during the saved travel time. While not addressed in the frameworks, it should be noted that these utilities should be measured in reference to the utility of travel time per se as well as that of in-travel activities.

An interesting theoretical consequence of the Hensher’s approach is that $VBTT_{EE}$, and $VBTT_{ER}$, and hence also $VBTT$ can yield negative values, i.e. travel time reduction yielding losses rather than benefits. In the case of an employee, i.e. $VBTT_{EE}$, its negative value would simply reflect experiencing higher satisfaction of spending time on board rather than in office or house making $VW$ and/or $VL$ negative. The
qualitative findings in terms of people reporting enjoyment of travel time due to it providing an opportunity for a free time, in-between hassles of office and household duties, as discussed by some of the studies in section 2.8 can be taken at least as partial evidence for real-world existence of such situations under specific conditions.

From the employer’s perspective, negative $V_{BT_{ER}}$ could result from simultaneously high values of $R$ and $PQ$. In other words, if the employee spends high proportion ($P$) of travel time on very productive ($Q$) work, time which he or she would otherwise not devote to work but leisure ($R \rightarrow 1$), the value of travel time reduction from the employer’s perspective is negative. This is because there could be a loss in terms of work-related output generated during travel time without an adequate compensation from work undertaken during the saved time. While somewhat counterintuitive at first, some of the qualitative evidence reported in section 2.8 regarding origin- and destination-related hassles, with their consequent implications for the actual productivity, may mean that not all time would be spent working, and possibly not as efficiently as in potentially work-enhancing on-board environment. Lastly, while travel time is usually associated with an additional fatigue with potential implications for productivity translating into positive $MPF$ value, it is possible to imagine situations where comfortable travel conditions, such as sleeper carriages, could reduce tiredness and contribute towards productivity resulting in negative $MPF$.

Clearly, the Hensher approach represents a more comprehensive treatment of various effects that can possibly influence value of travel time savings of business travellers. In that sense it provides much greater degree of flexibility in terms of differentiating between work- and non-work-related effects in the process of valuation. This capability may appear particularly useful in the conditions of increasingly fragmented activity-travel patterns of individuals operating in the conditions of knowledge economy where the distinction between work-, leisure-, and travel-times may become increasingly difficult to discern.

At the same time, however, extensiveness and demanding nature in terms of input data requirements made application of the Hensher’s framework cumbersome and limited to date. More specifically, the Hensher’s approach requires either disaggregate data on, or almost a separate modelling framework for in-travel time use, productivity, and fatigue effects, as well as time allocation models (to investigate
relative utilities of other activities). At the same time, the cost-saving approach requires only knowledge about the (forecasted) distribution of gross wages and overheads which can be obtained in a relatively straightforward manner by means of labour force surveys and income growth models. Given the conditions described in section 5.1.2 the Hensher’s framework reduces to cost saving approach, it has not been unusual for the researchers and policy-making to assume that ‘deviations from [those] conditions are generally self-cancelling’ (Mackie et al., 2003, p. 99). At the same time, significant body of empirical research discussed in section 2.8 has increasingly questioned such self-cancelling assumptions, especially in conditions of growing ICT sophistication and prevalence.

It is proposed that the theoretical and empirical results obtained in the previous chapter suggest a means by which the Hensher approach could be more readily operationalised. Given the available empirical data, the focus was placed on the employer’s value of savings in business travel time, net of fatigue effects:

\[
VEBTT = VBTTER - MPF = (1 - R - PQ) MP
\]  \hspace{1cm} (5.3)

Moreover, an additional assumption that has to be made is that the proportions of saved time used for work, as well as its relative productivity can be approximated by the observed proportion of work duration in the overall journey, and experienced productivity throughout the journey. While certain empirical studies suggested that such assumptions may not hold (Fickling et al., 2008), it is argued that they are sufficient to demonstrate how a disaggregate model of in-travel time use could serve the purpose of more detailed, and perhaps accurate, valuation of travel time savings. Given that the previous chapter found the use of ICT playing important role in that processes, the present application demonstrates means by which the impacts of ICT in terms of changing in-travel conditions and influencing fragmentation of work activities and productivity could be incorporated into transport investments appraisal.

5.1.4 Benefits calculation methodologies

In order to calculate the actual values of the travel time savings based on the empirical data, and in the process of doing so test the applicability of the previously developed framework, use can be made of the validation subsample from Chapter 4. In doing so,
the results of validation process (see section 4.4) can be employed, i.e. the parameters estimated using the 80% subsample can be used to infer about in-travel time use and productivity for the remaining 20% validation subsample. This method is supposed to emulate a situation in which an unknown population would be investigated for travel time savings valuation.

In particular, the following paragraphs present the ways of calculating the values of travel time savings in the course of business travel for the following approaches:

- cost-saving (wage plus) approach based on Department of Transport Web Transport Analysis Guidance (WebTAG) values;
- cost-saving (wage plus) approach with the values inferred from the validation sample;
- the Hensher’s approach with the values inferred directly from the validation sample;
- the Hensher’s approach using values inferred by means of microsimulation runs based on the characteristics of the validation sample and parameters estimated from 80% estimation subsample in Chapter 4.

However, given that the approaches described above rely on a known value of marginal product of labour, it was necessary to maintain the assumption of its equivalence to the sum of personal wage and overhead costs, reflected by multiplying the wage rate by a factor of 1.212 as advised by the UK Web Transport Analysis Guidance Unit 3.5.6 (DfT, 2013). Given that the assumption is carried throughout various methods of benefits calculation, it should not lead to biases in comparing different approaches to business VTTS estimation. Additionally, due to the fact that a number of respondents reported only information on their household income, as opposed to the required personal income, it was essential to reduce the sample for analysis from the initial 188 to 166 respondents. Some further information regarding sample composition is given in Appendix 8.

The cost-saving approach in the current context is straightforward and involves estimating the cost of employing a unit of labour for each individual. In terms of the WebTAG values, unit 3.5.6 advises on the values to be used for investment appraisal in the context of travelling in the course of work (DfT, 2013). The reference value for
the year 2010 was £39.65 for rail passengers in the course of business which can be converted to 2008 values (to ensure comparability with the empirical data collected in that year) using appropriate growth rates also advised by the module (−4.98% for the period 2009-2010, and −1.77% for 2008-2010). Moreover, as the income variable is of discrete, ordinal type, the central value for each category was chosen while for the extreme categories, i.e. below £10k or above £100k, £7.5k and £150k were assumed respectively. Following this approach, the value of £43.06 per hour was obtained as a cost-saving value of savings in the business time $V_{BTT}^{CS,WebTAG}$ identical for every individual $l$:

$$V_{BTT}^{CS,WebTAG} = £43.06/h \quad \forall l \quad (5.4)$$

On the other hand, in case of the sample values, estimation involved converting the annual personal income dividing the average assumed number of working hours in a year, i.e. 1755, to obtain to personal hourly wage $w_l^P$ which is an approach assumed in other UK investment appraisal methods (Fickling et al., 2008). This value was increased by a factor of 1.212 to reflect any overhead costs borne by employers which yields the sample based cost-saving value of savings in the business time $V_{BTT}^{CS,Sample}$:

$$V_{BTT}^{CS,Sample} = MP_l = 1.212w_l^P \quad (5.5)$$

Thus equation (5.5) provides a means of calculating respective values for individuals which can be subsequently averaged to obtain an aggregate and comparable value to that provided by the WebTAG.

In terms of operationalisation of the Hensher’s approach, the focus is on employer’s perspective and net of travel fatigue implications, defined by equation (5.2). As such, the values of interest are the proportion of travel time saved used for leisure $(R)$, proportion of travel time saved at the expense of work done while travelling/proportion of travel time devoted to work activity $(P)$, and relative productivity of work done while travelling relative to at workplace $(Q)$. The marginal product of labour can be calculated as in the cost-saving approach equation (5.5).

Parameters $P$ and $Q$ can be obtained directly from the sample in a straightforward manner, as both in-travel time duration and the relative productivity were reported by
the respondents (recall that in-travel proportions are assumed to approximate values that would be observed during the changes/reductions in travel time).

As for the parameter $R$, the only information available in the dataset concerned whether an individual would spend the saved travel time on work or leisure as a binary variable and not the actual proportion. In order to obtain a realistic value based on the available data, it is assumed that the probability of engaging in leisure reflects the latent proportion of reduced travel time spent in leisure. As a result, an ad-hoc binary logistic model of choosing to engage in leisure in the saved travel time can estimated, given certain observed covariates $X_R$ and in-travel time use pattern either observed directly from the sample or simulated, and denoted $X_R^{Sample}$ and $X_R^{Sim}$. This model can be used to calculate the respective probability $P_L$ of engaging in leisure which is treated as a proxy for the actual proportion $R$ spent on leisure:

$$R_{L,t}^{Sample} \approx P_L(X_R, \hat{X}_R^{Sample}) \quad (5.6)$$

$$R_{L,t}^{Sim} \approx P_L(X_R, \hat{X}_R^{Sim}) \quad (5.7)$$

In other words, $R$ is treated as a latent variable approximated by the probability of engaging in leisure during the saved time. While a simplified approach, it appears to provide better approximation of the reality than using the actual binary values which could polarise the resulting estimates of travel time savings. The estimated values of binary logistic model are presented in Table 5.1 on the next page.

A brief inspection of the results reveals that it is the proportion of journey spent working that is associated with the strongest (and negative) effect on proportion of saved time that would be spent on leisure. In other words, high fraction of travel time allocated to work time would also mean that travel time reduction would be more likely spent on work perhaps to accomplish tasks that would have been accomplished on the train otherwise. No direct impact from the absolute duration of work or trip, or productivity was found.

Not surprisingly, non-work-related destination was found to be strongly associated with higher probability of engaging in leisure, as was travelling to the station by train (which could have been used earlier to accomplish various tasks) and female
travelling with a companion. At the same time, high household income was associated with lower leisure probability, perhaps to reflect more duties and tasks faced by higher earners, more likely to be senior (though the impact of senior managerial position was not found significant). In terms of the attitudes, only attaching value to in-travel productive opportunities was found significant and associated with lower propensity to engage in leisure. This perhaps reflects travel playing an important role as work-related time and its reduction would mean that some work would have to be undertaken anyway. In case of the ICT impacts, only the use of mobile phone was associated with lower proportion of changes in travel time spent in leisure.

Table 5.1 Logistic regression model for saved time that would have been spent on work (n=752, optimal specification using n=940)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>s.e.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-travel time use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-travel work duration [in hours]</td>
<td>0.468</td>
<td>0.312</td>
<td>0.133</td>
</tr>
<tr>
<td>Proportion of journey spent working</td>
<td>-2.188</td>
<td>0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean in-travel productivity</td>
<td>0.110</td>
<td>0.240</td>
<td>0.646</td>
</tr>
<tr>
<td><strong>Journey characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln(trip duration, hours)</td>
<td>-0.171</td>
<td>0.306</td>
<td>0.575</td>
</tr>
<tr>
<td>Non-work-related destination</td>
<td>1.015</td>
<td>0.164</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Travelled to the origin station by train</td>
<td>0.535</td>
<td>0.221</td>
<td>0.016</td>
</tr>
<tr>
<td>Interaction: female with companion</td>
<td>1.007</td>
<td>0.493</td>
<td>0.041</td>
</tr>
<tr>
<td><strong>Sociodemographics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High household income (&gt;£75k p.a.)</td>
<td>-0.605</td>
<td>0.242</td>
<td>0.012</td>
</tr>
<tr>
<td>Female</td>
<td>0.033</td>
<td>0.199</td>
<td>0.868</td>
</tr>
<tr>
<td>&gt;45 years</td>
<td>0.152</td>
<td>0.169</td>
<td>0.368</td>
</tr>
<tr>
<td>Employed regularly</td>
<td>-0.112</td>
<td>0.213</td>
<td>0.598</td>
</tr>
<tr>
<td><strong>Attitudinal factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Considered crowding level disruptive</td>
<td>-0.186</td>
<td>0.211</td>
<td>0.377</td>
</tr>
<tr>
<td>Leisure intention</td>
<td>0.224</td>
<td>0.211</td>
<td>0.298</td>
</tr>
<tr>
<td>Valuing in-travel working opportunity</td>
<td>-0.593</td>
<td>0.246</td>
<td>0.016</td>
</tr>
<tr>
<td>Would not reduce the amount of work if the journey was shorter</td>
<td>0.065</td>
<td>0.188</td>
<td></td>
</tr>
<tr>
<td><strong>ICT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wi-Fi available</td>
<td>0.124</td>
<td>0.590</td>
<td>0.834</td>
</tr>
<tr>
<td>Used laptop</td>
<td>-0.380</td>
<td>0.221</td>
<td>0.086</td>
</tr>
<tr>
<td>Used PDA</td>
<td>-0.193</td>
<td>0.197</td>
<td>0.329</td>
</tr>
<tr>
<td>Used mobile phone</td>
<td>-0.395</td>
<td>0.179</td>
<td>0.027</td>
</tr>
<tr>
<td>Interaction: laptop use and Wi-Fi</td>
<td>-0.428</td>
<td>0.599</td>
<td>0.475</td>
</tr>
<tr>
<td>Interaction: PDA use of Wi-Fi</td>
<td>0.197</td>
<td>0.648</td>
<td>0.760</td>
</tr>
<tr>
<td>Interaction: mobile phone use and Wi-Fi</td>
<td>0.471</td>
<td>0.611</td>
<td>0.440</td>
</tr>
<tr>
<td>Interaction: laptop use and high household income</td>
<td>0.529</td>
<td>0.376</td>
<td>0.159</td>
</tr>
<tr>
<td><strong>Structural parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.293</td>
<td>0.526</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Model fit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL with constants only</td>
<td>-516.768</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL at convergence</td>
<td>-449.506</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of parameters</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{\rho}^2$</td>
<td>0.130</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\log_e$
In order to calculate the values of savings in business travel time using the Hensher’s approach $VEBTTHen,Sample$, and based on the directly observed values, the following expression was used, based on equation (5.2):

$$VEBTTHen,Sample = (1 - R_{Sample}^l - Q_{Sample}^l P_{Sample}^l)MP \quad \forall l$$

(5.8)

with marginal product of labour defined as previously in equation (5.5). In the case of the microsimulation-based values, the following formula can be used by employing parameters obtained in the process of model validation outlined in section 4.4.

$$VEBTTHen,Sim = (1 - R_{Sim}^l - Q_{Sim}^l P_{Sim}^l)MP \quad \forall l$$

(5.9)

Both methods for obtaining Hensher’s approach-based values of travel time savings, together with the cost-saving approach-based values were comparatively analysed, the results of which are provided in the following section.

5.2 Findings

The results of calculating $VEBTT$ using the two approaches are presented in Table 5.2 and Figure 5.1. The cost-saving approach values derived from the sample were found similar (in terms of average and median) to the value recommended by the WebTAG. This spread of values observed in the sample, and yet largely consistent with the aggregate WebTAG value emphasizes the existence and extent of the heterogeneity in the valuation of travel time. As for the $VEBTT$ values, the formal statistical tests indicated a significant discrepancy between the observed and inferred estimates. As a result, the results presented here may only be interpreted as demonstration of how the developments along the theoretical and empirical directions outlined in the previous chapter could enable operationalisation of more sophisticated approaches to investment appraisal, e.g. Hensher’s approach (or its elements), rather than as a ready-for-implementation tool. Observing Figure 5.1 it can also be noticed that the $VEBTT$ values for the Hensher’s approach were found significantly lower than the cost-saving values. This is because the latter constitutes the former’s upper limit under the conditions outline previously in section 5.1.3, i.e. unproductive travel time, and a complete allocation of travel time savings to work. In addition, while the central values for the Hensher’s approach remained above zero, a number of observations were found to fall below it. These cases represented the previously discussed situation in which, from the employer’s perspective, travel time reduction may not be desirable.
### Table 5.2 Comparison of observed and simulated input values for VEBTT calculation (n = 166, 1000 simulations)

<table>
<thead>
<tr>
<th></th>
<th>Proportion of travel time spent working $P$</th>
<th>Proportion of saved time spent in leisure $R$</th>
<th>VEBTT$^{10ea}$ (2008 GBP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity $Q$</strong></td>
<td>Observed ($n$)</td>
<td>Simulated ($n$)</td>
<td>Observed ($n$)</td>
</tr>
<tr>
<td>Mean (s.e.)</td>
<td>0.955 (0.019)</td>
<td>1.007 (0.009)</td>
<td>0.598 (0.022)</td>
</tr>
<tr>
<td>Median</td>
<td>1.000</td>
<td>1.001</td>
<td>0.600</td>
</tr>
<tr>
<td>Paired sample $t$-test (p-value)</td>
<td>2.545 (0.012)</td>
<td>1.230 (0.220)</td>
<td>3.881 (&lt;0.001)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank $Z$ (p-value)</td>
<td>3.125 (0.002)</td>
<td>0.687 (0.492)</td>
<td>2.642 (0.001)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov $D$ (p-value)</td>
<td>0.464 (&lt;0.001)</td>
<td>0.313 (&lt;0.001)</td>
<td>0.115 (0.213)</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.267</td>
<td>0.247</td>
<td>0.054</td>
</tr>
<tr>
<td>$b$Linear regression</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant (s.e., $H_0$ p-value)</td>
<td>0.923 (0.169, &lt;0.001)</td>
<td>-0.114</td>
<td>0.013</td>
</tr>
<tr>
<td>(0.109, 0.294)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slope (s.e., $H_0$ p-value)</td>
<td>0.031 (0.167, &lt;0.001)</td>
<td>1.146</td>
<td>1.038</td>
</tr>
<tr>
<td>(0.172, 0.198)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.001</td>
<td>0.213</td>
<td>0.449</td>
</tr>
</tbody>
</table>

$^a$As compared to usual office conditions, frequencies calculated using enumeration $^bH_0$: constant equal to zero, slope equal to unity
as more productive output is generated during the travel than outside of it. as expected. A significant spread of the values can also be noted in the case of $\text{VEBTT}$ values (see Table 5.3 below) though not as high as in the case of cost-saving approach which may result from various combinations of in-travel work, productivity, and the use of travel time savings for non-work purposes dampening the otherwise extreme observations. Nonetheless, it must be noted that the actual extent to which such

![Box-plot comparison between the results of different VEBTT calculation approaches](image)

**Figure 5.1** Box-plot comparison between the results of different VEBTT calculation approaches (in 2008 GBP, n=166)

<table>
<thead>
<tr>
<th></th>
<th>Wage plus (WebTAG)</th>
<th>Wage plus (Sample)</th>
<th>$\text{VEBTT}$ (Sample)</th>
<th>$\text{VEBTT}$ (Simulation)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>43.060</td>
<td>48.706</td>
<td>16.657</td>
<td>14.251</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>0</td>
<td>29.727</td>
<td>13.679</td>
<td>11.401</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>43.060</td>
<td>43.162</td>
<td>13.679</td>
<td>11.401</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>43.060</td>
<td>10.360</td>
<td>-28.080</td>
<td>-3.930</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>43.060</td>
<td>103.590</td>
<td>83.860</td>
<td>51.380</td>
</tr>
<tr>
<td><strong>Interquartile range (IQR)</strong></td>
<td>0</td>
<td>31.077</td>
<td>19.186</td>
<td>10.793</td>
</tr>
</tbody>
</table>
effects apply (and hence determine the spread of values) would normally depend on the actual values of \( Q \), \( P \), and \( R \) during travel time saved while the current analysis used the parameters observed during the whole journey as a proxy.

At the same time, the simulated values were characterised by a similar distribution in terms of the centrality, but slightly more leptokurtic as can be observed in Table 5.3. This finding is to a certain extent confirmed by the results reported earlier in Table 5.2 where the moments of observed and simulated distributions of the values were reasonably close to each other (in some cases even passing formal tests), accurate predictions for particular individuals were much more difficult to obtain. The main discrepancy would result from imperfect predictions in productivity and proportion of saved time spent in leisure. Consequently, the prediction capabilities for inferring the \( VEBTT \) values associated with particular individuals were found to be limited in the current context (see Figure 5.2) though the formal statistics indicated rejection of the

![Figure 5.2 Comparison between observed and simulated VEBTT values (in 2008 GBP, 45-degree dashed line added for reference)](image)
null hypotheses (in case of Wilcoxon Signed-Rank and Kolmogorov-Smirnov tests) only at the 95% level, and not 99%.

The analysis above provided further evidence for significant discrepancy between the prevailing cost-saving values, both derived from the sample and based on the WebTAG, and the Hensher’s VEBTT. In the latter case, if the approach was ever to be considered for use in VTTs estimation, the current microsimulation framework could offer a means of deriving aggregate, average value for investment appraisal though inference regarding individual values would still require refinements towards which further research and data collection efforts should be directed.

5.2.1 Towards a cost-saving approach adjusted for in-travel productivity

While the Hensher’s approach provides more comprehensive, and detailed treatment of the VBTT calculation, its direct application ‘introduces other theoretical issues and practical implications’ thus raising doubts regarding ‘feasibility and robustness’ of its implementation (Batley et al., 2012, p. 8), including length of the time horizon over which cost and benefits should be assessed, or robust estimation or inference of the parameters $P$, $Q$, and $R$. The latter remark is also consistent with the fact that even the operationalisation presented in the previous section was applicable only to a part of the Hensher’s approach and was based on the assumption that the actual proportion of travel time spent working and in-travel productivity can approximate such parameters observed during travel time changes. Otherwise, stated preference questionnaire would need to be adopted to infer such parameters which in reality, however, can be influenced by a range of unpredictable factors, such as household responsibilities or conditions on the carriage. Addressing some of these concerns while reviewing the value of time assumptions for business travellers on HS2, Batley et al. called for ‘an “adjusted” cost saving approach that appeals to the productivity argument, but does not go as far as the Hensher approach’ (Batley et al., 2012, p. 8).

It is worth noting that both cost-saving approach and Hensher’s approach are rather focused on the idea of reducing losses due to travel time, be it a marginal product of labour or fatigue, rather than dealing with potential gains due to travel time productivity. Thus a desirable solution combining both approaches would be the one which reduces wasted time and resources. However, let it is assumed that the
The objective of transport investment is to reduce travel time by amount $\Delta r$ but also to enhance the productive output of the remaining travel time $r - \Delta r$ by increasing its actual (observed) proportion spent working $P'$ and average productivity $Q'$. In such a case (assuming constant marginal product of labour), the benefit from investment in transport associated with a particular business traveller $l$ can be described by the expression:

$$TB_l = [\Delta r_l + (r_l - \Delta r_l)(P'_l \Delta Q'_l + Q'_l \Delta P'_l)]MP_l$$  \hspace{1cm} (5.10)

Equation (5.10) enables a novel way of approaching transport investments while building upon the existing cost-saving and Hensher's approaches. In fact, in a situation where pure travel time change is the focus of investment, and no changes to in-travel environment, and thus proportion of travel spent on work, or its productivity are taking place, expression 5.10 would reduce to a simple cost-saving approach.

On the other hand, if changes to in-travel time use (in terms of work) or productivity were expected as a result of, e.g. investments in improvements in the conditions of travel or provision of ICT infrastructure with no changes in travel duration ($\Delta r_l = 0$), equation (5.10) would describe the value of benefits due to changes to productive output of travel time. Obviously, if the objective of investment is thorough modernisation which includes both effects, the benefits would depend not only on how much people reduce their travel time, but also on how in-travel environment is improved. In fact, the two effects would normally interact with each other as lengthy journeys in comfortable conditions can be tiring, just as short journeys with poor in-travel environment can. As a result the proposed approach while acknowledging that business travellers and their employees may seek faster travel, also recognises that they could also look for conditions enabling more readily translation of travel time into productive output.

Another feature that makes the proposed approach attractive is the fact that the parameters used in the expression (5.23) are all related to the microeconomic framework presented in the previous chapter. Consequently, the framework and its operationalisation provide a method for inferring values for $P'_l$ and $Q'_l$ as well as their changes, by means of microsimulation making use of the fact that both in-travel work duration and productivity were inferred as part of the cross validation process in section 4.4:
\[ P'_l = \sum_{T_{ijk}} W(t_{T_{ijk}+1} - t_{T_{ijk}}) \]

And (recalling equation 4.46):

\[ Q'_l = \zeta_l \]  

It should be noted that the expressions 5.11 and 5.12 allow for various work-related activities with different levels of productivity. Hence the approach is flexible enough to account for certain tasks being undertaken more easily than other while travelling, e.g. reviewing a report as compared to conducting business negotiations. Thus quality of inference of productive in-travel output \( Y_l \) for each individual \( l \), defined as:

\[ Y_l = MP_l P'_l Q'_l \]

is shown in Table 5.4 and Figure 5.3. Clearly, the estimated values are on average significantly above zero. In term of the discrepancy between the observed values and those obtained by means of microsimulation, the results of various tests indicate rejection of the null hypothesis at 95% level of significance though the linear regression test, as well as inspection of Figure 5.3 indicates reasonable alignment between the simulated and observed values along the 45-degree line. Thus the proposed approach to valuation of business travel time savings could be operationalised by making use of the previously developed framework for in-travel time use and productivity. Moreover, in the process of doing so, it would directly account for the ongoing developments in ICT providing the previously discussed flexibility in undertaking productive tasks while travelling as well as provide economic justification for investments in productivity-enhancing in-travel facilities.

| Table 5.4 Comparison of observed and simulated values of productive in-travel output (n = 166, 1000 simulations) |
|-------------------------------------------------|-------------------------------------------------|
| **Observed** | **Simulation** |
| Mean (s.d.) | 27.903 (1.814) | 31.130 (1.654) |
| Paired sample t-test (p-value) | 2.561 (0.011) |
| Wilcoxon Signed-Rank Z (p-value) | 2.416 (0.016) |
| Kolmogorov-Smirnov D (p-value) | 0.163 (0.022) |
| Root-mean-square Error (RMSE) | 16.500 |
| Linear regression constant (s.e., \( H_0 \) p-value) | 2.641 (2.172, 0.226) |
| slope (s.e., \( H_0 \) p-value) | 0.812 (0.058, (<0.001)) |
| \( R^2 \) | 0.547 |

*\( H_0 \): constant equal to zero, slope equal to unity
As a result, the approach could perhaps form a step towards the adjusted approach called for by Batley et al. (2012), and in doing so contribute towards development of an investment appraisal methodology which would treat possible ICT developments more inclusively.

**Figure 5.3** Comparison between observed and simulated productive output values (in 2008 GBP, 45-degree dashed line added for reference)
5.3 Application to modelling the joint choice of ICT and travel behaviour

In addition to conceptualising in-travel time use and productivity impacts on valuation of travel time (and its reduction) for business travellers demonstrated in the previous sections, the proposed theoretical framework can be applied more widely to model the impacts of ICT as enablers of tele-activities, with consequent implications for travel behaviour. The purpose of this section is to explore such further applications.

5.3.1 Indirect utility function for the joint choice of ICT and travel behaviour

Recall the first order conditions (4.16) and (4.19), and assume for simplicity (though without loss in generality) that only two in-travel activities, \( T1 \) and \( T2 \) take place. In such a case, the first order conditions are given by:

\[
 u_{T1}(z_{T1ij}(t^*_i)) + \frac{bw_{T1}}{p} z_{T1ij} = u_{T2}(z_{T2ij}(t^*_i)) + \frac{bw_{T2}}{p} z_{T2ij} \tag{5.14}
\]

and

\[
 u_A(z_A(t^*_i)) + bw_A z_A(t^*_i) = u_B(z_B(t^*_i + r_{ij}|t^*_i)) + bw_B z_B(t^*_i + r_{ij}|t^*_i) +
\]

\[
 +u_{T1}(z_{T1ij}(t^*_i)) + bw_{T1} z_{T1ij}(t^*_i) - u_{T2}(z_{T2ij}(t^*_i + r_{ij}|t^*_i)) -
\]

\[
 - bw_{T2} z_{T2ij}(t^*_i + r_{ij}|t^*_i) + u_T(z_{Tij}(t^*_i)) - u_T(z_{Tij}(t^*_i + r_{ij}|t^*_i))
\]

\[
 + \left( \frac{dr_{ij}}{dt_i} \right) \left[ u_B(z_B(t^*_i + r_{ij}|t^*_i)) + bw_B z_B(t^*_i + r_{ij}|t^*_i) \right]
\]

\[
 - u_{T2}(z_{T2ij}(t^*_i + r_{ij}|t^*_i)) - bw_{T2} z_{T2ij}(t^*_i + r_{ij}|t^*_i) - b \frac{dc_{ij}}{dr_{ij}} \frac{dr_{ij}}{dt_i} \left|_{t^*_i} \right.
\]

\[
 - u_T(z_{Tij}(t^*_i + r_{ij}|t^*_i)) \right]
\]

Where \( t^*_i \) and \( t^*_i \) are optimal in-travel activity switching and journey departure times respectively, defined by meeting the conditions above. Using equations (5.14) and (5.15) in conjunction with the equation (4.14) it is possible to derive expression for truncated (i.e. void of elements unaffected by the choice variables) indirect utility
function for the joint choice of activities pre- and in- and post-travel activities, as well as mode $i$, route $j$, and ICT bundle $\psi$, conditional on the optimal timings $t_i^*$ and $t_i^*$:

$$V_{A,B,T1,T2,i,j,\psi}|_{t_i^*,t_i^*} =$$

$$= \int_{t_o}^{t_i^*} (u_A(z_A) + bw_Az_A) \, dt + \int_{t_i^*}^{t_i^*} (u_T1(z_{T1ij}) + bw_{T1}z_{T1ij}) \, dt +$$

$$+ \int_{t_i^*}^{t_i^*+r_{ij}(t_i^*)} (u_T2(z_{T2ij}) + bw_{T2}z_{T2ij}) \, dt + \int_{t_i^*}^{t_i^*+r_{ij}(t_i^*)} u_T(z_{Tij}) \, dt +$$

$$+ \int_{t_i^*+r_{ij}(t_i^*)}^{t_E} (u_B(z_B)dt + bw_Bz_B) \, dt - bc_{\psi} - bc_{ij} (r_{ij}(t_i^*))$$

(5.16)

where $M$-terms denote total gains in the utilities obtained from particular activities (both due to time-specific intensity as well as contribution to consumption) in the reference period. It should be noted that in presence of more than two in-travel activities, the corresponding first order conditions and optimal timings would resemble equation (5.14) and consequently, working with the two activities case provides enough generality while retaining algebraic simplicity.

Expression (5.16) provides a microeconomics-grounded interpretation for systematic component of the utility function in a discrete choice model of an individual operating in the reference situation described earlier in Figure 4.1. This unified treatment of time allocation and consumption (budgetary) decisions leading to the systematic component of utility function which can enter discrete choice models is based on the approach of Train and McFadden in their goods-leisure framework (Train and McFadden, 1978). In the current formulation, a discrete alternative would thus be defined as a particular combination of pre-, in-, and post-travel activities ($A, T1, T2, B$), mode $i$, route $j$, and ICT bundle $\psi$. Additionally, making use of such indirect utility function for valuation of qualities of alternatives (see below) is rooted in the contributions of Bates (1987), Hensher and Truong (1985), and Jara-Díaz (2007).
The interpretation of formulation (5.16) follows the intuition that the highest utility-yielding alternative will be that which maximises the sum of aggregate utilities (i.e. integrated utilities derived from time-specific intensity and contribution to consumption) of pre-, in-, and post-journey activities less the reduction in consumption due to the expenditure on using the ICT bundle and particular transport mode on a particular route. While conceptually simple, expression (5.16) is comprehensive in incorporating any combination of activities, including tele-activities, and their associated time- and context-specific characteristics (individual experience of participation, productivity, companionship, equipment possession etc.), compatibility of in-travel activities with transport mode and route, or impacts from changes in transport network conditions. Interestingly, the expression (5.16) allows for the possibility of ICT inhibiting the pace of proliferation of tele-activities (understood as substitution of physical activity and travel with virtual reality) if they lead to better travel conditions, i.e. expanded opportunities to make use of travel time or more reliable travel time prediction due to developments in transport telematics.

These interactions between various components of the utility function (5.16) demonstrate that perceiving the problem of tele-activity choice as simply an efficiency choice problem (‘Am I more efficient when working at home? Or in the office?’), or a ‘to travel or not-to travel’ problem alone may be erroneous as both factors should be considered jointly. This logic is also consistent with the empirical results by Ndubisi and Kahraman (2005) who warned of perceiving tele-activities in an overly simplistic manner. Additionally, these analytical results emphasise that in a world of tele-activities enabling higher spatial but also temporal flexibility, it appears essential to relate the activity choice and time allocation decisions to the inherent preferences for particular activity timings, among other factors resulting from individual’s circadian rhythm. Being a highly individual-specific issue, such timing preferences could offer an opportunity to explain more of individual variations in activity/travel decisions which happen to constitute a large unexplained component of such choice problems (Makoto et al., 2009).

5.3.2 Subjective valuation of the qualities of travel and ICT choices

Additionally, the indirect utility function (5.16) provides a means of obtaining estimates of the subjective values of the qualities of an alternative. Assuming that a
particular combination $A, B, T_1, T_2, i, j, \psi$ is characterised by certain quality $\beta$ and its respective cost $c_\beta$, the subjective value of $\beta$ is defined as (Jara-Díaz, 2007):

$$SV_\beta = - \frac{\partial c_\beta}{\partial \beta} = - \frac{\frac{\partial V_{A,B,T_1,T_2,i,j,\psi}}{\partial \beta}}{\frac{\partial V_{A,B,T_1,T_2,i,j,\psi}}{\partial c_\beta}}$$

(5.17)

Equation (5.17) provides a means of attaching values to changes in qualities characterising the chosen discrete alternative such as travel time, seating availability, or broadband speed and reliability. For instance, in the case of travel time $r_{ij}$ reduction, and noting that there is no minus sign in front of the expression as negative change is investigated, the subjective value $SV_{r_{ij}}$ in real terms which can be converted to monetary terms by multiplication by the price index $p$ (see Appendix 8 for the exact derivation of $SV_{r_{ij}}$):

$$SV_{r_{ij}} = \frac{\frac{\partial V_{A,B,T_1,T_2,i,j,\psi}}{\partial r_{ij}}}{\frac{\partial V_{A,B,T_1,T_2,i,j,\psi}}{\partial c_{ij}}} =$$

$$= \frac{d c_{ij}}{d r_{ij}} + \frac{-u_T(z_{T2ij}) - u_T(z_{Tij}) + u_B(z_B)dt}{b} - w_T z_{T2ij} + w_B z_B$$

(5.18)

Expression (5.18) indicates that the value of reduction in travel time consists of the sum of change to direct cost of travel $c_{ij}$ and the value of longer participation in activity $B$ less the value due to shorter duration of the final in-travel activity $T2$ (note that dividing by $b$ converts utility into monetary value in real terms). Consequently, expression (5.18) follows the similar intuition to that provided by the Hensher’s method for valuing the savings of business travel time reduction, which incorporated not only the benefit of longer post-activity participation, but also the cost from reduced in-travel time use with potentially different-to-office productivity (Hensher, 1977). Given that formulation (5.18) depends on the characteristics of the ICT bundle (via intensities/productivities $z$), it also provides a microeconomic justification for inclusion of ICT use in the context of travel time savings valuation. Following a similar logic, the subjective value $SV_{\beta_\psi}$ of a quality $\beta_\psi$ characterising the ICT bundle,
such as bandwidth, connection reliability and quality, can be expressed in real terms as (see Appendix 8 for the detailed derivation):

\[
SV_{\beta_i} = \frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial \beta_{\psi}} = \frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial c_{\psi}}
\]

\[
= \frac{1}{b} \left[ \int_{t_i}^{t_i+i} \frac{dA}{d\beta_{\psi}} \left( \frac{dA}{dz_A} + bw_A \right) dt + \int_{t_i}^{t_i+i} \frac{dA}{d\beta_{\psi}} \left( \frac{dA}{dz_T1} + bw_T1 \right) dt + \int_{t_i}^{t_i+i} \frac{dA}{d\beta_{\psi}} \left( \frac{dA}{dz_T2} + bw_T2 \right) dt + \int_{t_i}^{t_i+i} \frac{dA}{d\beta_{\psi}} \left( \frac{dA}{dz_B} + bw_B \right) dt - \frac{dc_{\psi}}{d\beta_{\psi}} \right]
\]

The meaning of expression (5.19) is that the value of any changes in the quality of ICT will result from changes in the impact on the intensity (productivity), and thus utilities and consumption impacts, associated with particular activities, integrated over the periods of activities’ duration, net of cost of that quality change. In other words, the value attached to higher processing power of a laptop will come from the latter’s impact on the intensity (and thus productivity if the activity is salaried) and hence satisfaction and consumption increase, net of change in direct cost of higher processing power. This theoretical result supports the empirical findings of Maliranta and Rouvinen (2006) who noted that certain qualities of ICT such as storage, processing capabilities or wireless connectivity had different impacts on productivity. Using expression (5.19), values attached by individuals to such productivity changes can be estimated.

Furthermore, expression (5.19) enables the derivation of an expression for the value of in-travel ICT services such as availability or reliability of on-board Wi-Fi. Assuming that on-board Wi-Fi affects only in-travel activities \(T1\) and \(T2\), its value \(SV_{\beta_i}^{\psi\text{WiFi}}\) can be defined as (see Appendix 8 for the detailed derivation):

\[
SV_{\beta_i}^{\psi\text{WiFi}} = -\frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial \beta_{\psi}^{\psi\text{WiFi}}} = \frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial c_{\psi}^{\psi\text{WiFi}}} = (5.20)
\]
In other words, the value one attaches to a quality of on-board Wi-Fi is based on its impact on the satisfaction and productivity experienced in all in-travel activities throughout their duration, less reduction in consumption due to expenditure made on such service. Another important case would be that of a tele-worker. Assuming that the initial activity is non-salaried leisure, i.e. $w_A = 0$, and also by definition travel duration $r_{ij} = 0$ without any in-travel activities, the value $SV_{\beta_{\psi_{telW}}}$ of an ICT quality, such as higher broadband speed, to a tele-worker would be:

\[
SV_{\beta_{\psi_{telW}}} = \frac{\partial V_{AB,T1T2,i,j,\psi}}{\partial \beta_{\psi_{telW}}} - \frac{\partial V_{AB,T1T2,i,j,\psi}}{\partial c_{\psi_{telW}}}
\]

\[
= \frac{1}{b} \left[ \int_{t_0}^{t_E} \frac{\partial z_A}{\partial \beta_{\psi_{telW}}} \frac{du_A}{dz_A} \, dt + \int_{t_E}^{t_1 + r_{ij}(t_1)} \frac{\partial z_B}{\partial \beta_{\psi_{telW}}} \left( \frac{du_B}{dz_B} + bw_B \right) \, dt \right] - \frac{dc_{\psi_{telW}}}{d\beta_{\psi_{telW}}}
\]

In other words, the value would reflect higher utility of the initial activity, e.g. ability to listen to the music online while eating breakfast, and in any changes to satisfaction and productivity of tele-work, again net of any changes to ICT costs. The importance of equations (5.20) and (5.21) is such that they conceptualise the valuation of ICT bundles in various contexts. While the former can provide a useful guidance for pricing of in-travel ICT services, such as in-train, in-plane or in-coach Wi-Fi using stated preference exercises (as shall be discussed in section 5.4.4), the latter could prove useful when conducting cost-benefit analyses of ICT provision to employees working under flexible regimes (Butler et al., 2007).

**5.4 Application of the framework to conceptualisation of hypothetical activity-travel choice scenarios**

In order to demonstrate the applicability of the approach as a means of conceptualising various patterns of ICT and activity-travel behaviour interactions,
three hypothetical activity-travel choice scenarios reflecting possible real-life situations are presented. Each scenario is subsequently encapsulated using the microeconomic framework which can effectively be perceived as thought experiments, similar to those in theoretical physics or philosophy.

In doing so, specific values of different components of the indirect utility function, i.e. $M_A, M_{T_1}, M_{T_2}, M_T, M_B, bc_{ij}, bc_{\psi}$, are assumed for particular choices of mode of activity participation, i.e. tele-activity versus physical requiring travelling by a particular mode $i$ on route $j$. For simplicity and comparability (though without much loss of generality), two in-travel activities are assumed: work and leisure. Furthermore, it is also assumed that any requirement for additional travel time results in reduction of the pre-journey activity duration, i.e. activity $B$ always starts at the same time.

The magnitudes of the components, while arbitrary in their absolute values, are qualitatively justified by the assumptions made in each of the scenarios. These values, when summed up according to the equation (5.16) lead to choices that are consistent with certain empirical results reported elsewhere in the literature. Thus the approach resembles a reversed estimation procedure where the values of specific components would be established given the observed choices – a case discussed in more detail in section 5.4.4). By following the thought experiment approach, it is possible to demonstrate how to move from the basic principles of microeconomics and certain real-world conditions to specific patterns of ICT use and travel behaviour, including the possibility of complementarity, substitution, modification, and neutrality relationships.

**5.4.1 Scenario 1: Severe weather**

In the first scenario, an individual needs to perform certain office tasks for which physical presence is not critical, e.g. produce a report, or respond to e-mails. The prevailing conditions on the transport network are expected to be poor as a result of severe weather conditions, while the individual’s employer displays positive attitude towards occasional tele-work practices. Consequently, the individual is facing the following choices (summarised in Table 5.5):
• **Tele-activity (tele-commuting):** individual incurs no reduction in the benefit from participating in the initial activity as no travel takes place (hence also null travel cost, and null travel-specific utility). While there is no benefit from in-travel activities, there is extra productivity due to avoided travel fatigue due to difficult conditions. There are, however, extra costs incurred due to the requirement for ICT ensuring efficient tele-work participation (Butler et al., 2007).

• **Public transport:** individual needs to depart early due to the longest travel duration, though the cost is lower than for the car. Since public transport does not require individual’s effort to operate, he or she can easily engage in work and leisure while travelling though the experience of travel itself is the lowest due to unpleasant waiting time and high travel time uncertainty possibly leading to an increased fatigue in the final activity. The cost of ICT is lower than for tele-work, though still present due to the potential use of on-board ICT facilities.

• **Car (as driver):** individual can depart slightly later than in case of the public transport, but will not be able to engage in any work-related activities during travel as driving requires full attention though leisure, e.g. listening to music, is still possible. Travel experience is slightly better than for the public transport, though still negative due to severity of the weather conditions. While travel cost is the highest, there is no associated ICT cost.

### Table 5.5 Scenario 1 choices breakdown

<table>
<thead>
<tr>
<th>Mode</th>
<th>Component value</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele-activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_A$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{T_1}$ (work)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{T_2}$ (leisure)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_T$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_B$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$b_{c_{ij}}$</td>
<td></td>
</tr>
<tr>
<td>Public Transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assuming certain values for the components which are consistent with the qualitative description above, Table 5.5 presents the values for utilities $V$ associated with each of the alternatives, calculated using expression (5.16). Clearly, engaging in tele-activity emerges as the most attractive choice due to effectiveness of work for tele-work substitution while also avoiding potential travel disruptions and fatigue. Such circumstances were quoted by Mokhtarian (2009, p. 11) as an example of situation where the availability of tele-activity can easily lead to substitution of travel. In addition, due to severity of the weather, when comparing public transport and car, the
individual would prefer to use the former to avoid driving in poorer road conditions and, in addition, make use of travel time by means of ICT despite longer journey duration. In this context, the use of ICT could be seen as possibly leading to more travel if journey and face-to-face interaction were required, e.g. meeting involving sensitive negotiations (Lu and Peeta, 2009). Such a case would reflect complementarity between ICT use and the amount of travel as suggested by Mokhtarian (2009).

In the real world context, conditions similar to those summarised in Table 5.5 were observed following the 2010 Eyjafjallajökull volcano eruption in Iceland and the consequent disruptions to air travel when videoconferencing tools emerged as the most efficient backup plan (Reuters, 2010). Furthermore, similar circumstances may emerge as a result of transport infrastructure overloading or its reduced capacity. The former situation was observed during London 2012 Olympics when employers were encouraged to allow employees to make use of tele-commuting options as a means of reducing pressure on the public transport system. Similarly, occasional strikes by transport operators may motivate promotion of tele-commuting as an alternative mode of working.

What is more, under such disrupted travel conditions, the actual journey duration \( r_{ij} \) could become less predictable, making the individual operate in conditions of uncertainty. As previously discussed, such a situation could be captured by assuming \( r_{ij} \) to be a randomly distributed variable, whilst particular utility components from Table 5.5 represent expected values. By doing so, not only relevant behavioural aspects of decision-making under such circumstances can be understood and conceptualised, but additionally the indirect utility and subjective value formulations provide a means of attaching monetary values to travel time reliability, itself a vital aspect of travel behaviour modelling for both researchers and policy-makers (Bates et al., 2001; Brownstone and Small, 2005).

**5.4.2 Scenario 2: Autonomous vehicles introduction**

In this scenario, an additional mode of transport is introduced: autonomous vehicle (AV), which is assumed to be capable of completely automatic driving without any human intervention. By this virtue, it effectively combines the benefits of public
transport (possibility to undertake in-travel activities) and private car (speed and flexibility of travel, control of the surrounding environment). However, while autonomous vehicles are argued to be capable of navigating on their own, studies suggested that their use may (at least in the earlier phases) be limited to certain, AV-capable routes characterised by stable conditions of driving, e.g. motorways, as compared to areas with multiple users of frequently unpredictable behaviour (Fagnant and Kockelman, 2014).

As a result, in the current scenario, there are two routes available. The shorter route 1 leads through the city centre but due to its congested, multi-modal use (including pedestrians and cyclists) it has been declared AV-incompatible and AV users are required to drive the vehicles by themselves. Route 2, on the other hand, is a longer motorway bypass which is AV-compatible. In this scenario, there is no particular definition of the pre- and post-journey activities and no preference regarding the need for face-to-face versus virtual interaction, and thus $M_B$ elements are equal across the choices. Under such circumstances, the individual faces the following choice situation (summarised in Table 5.6):

- **Tele-activity**: similarly to the previous scenario, the main benefit comes from the longer duration of initial activity though there is also additional cost associated with the higher ICT expenditure.
- **Public transport**: individual needs to depart earlier but is yet again capable to make use of some travel time for work and leisure purposes. There is additional loss associated with travelling itself due to the fatigue, as well as the costs of travel and on-board ICT use.
- **Car (as driver)**: individual can depart slightly later than in the case of public transport, but is not able to engage in any work-related activities as his or her

<table>
<thead>
<tr>
<th>Mode</th>
<th>$M_A$</th>
<th>$M_{T1}$ (work)</th>
<th>$M_{T2}$ (leisure)</th>
<th>$M_T$</th>
<th>$M_B$</th>
<th>$bc_{ij}$</th>
<th>$bc_{ij}$</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele-activity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Public Transport</td>
<td>-2</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-0.5</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>Car: route 1</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Car: route 2</td>
<td>-1.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-1.5</td>
<td>0</td>
</tr>
<tr>
<td>AV: route 1</td>
<td>-1.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-2</td>
<td>1</td>
</tr>
<tr>
<td>AV: route 2</td>
<td>-1.5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>-0.5</td>
<td>-2.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Note: route 1 is shorter but AV operation incapable (through city centre), route 2 is AV capable but longer (motorway bypass)
attention to driving is required. The travel experience is better than for public transport, though at a higher cost of travel.

- **Autonomous vehicle:**
  
  - Route 1: conditions are the same as faced by conventional car since autonomous driving capabilities cannot be used. Additionally, the cost of AV use is assumed to be higher as compared to the conventional car.
  
  - Route 2: Individual can capitalise on the benefit of being able to depart at a time identical to that of a conventional car and can still use the travel time in a way similar to the public transport case. Moreover, the utility of leisure is potentially higher as the benefits of not being required to drive (assuming complete trust in the self-driving capabilities) and being in control of the surroundings add up. However, the cost of using that mode is slightly higher due to the autonomous capabilities, longer route as well as some additional expenditure associated with in-travel ICT use.

Under such conditions, AV use on route 2 emerges as the most attractive alternative where the benefits of quicker and flexible departure as well as in-travel time use outweigh additional direct costs as well as the opportunity cost of travel time (as compared to tele-activity). Under such conditions, the use of autonomous vehicle on the longer, AV-compatible route emerges as the most desired alternative. This result is of particular interest as it demonstrates (within the frames of the proposed framework) that developments in ICT facilitating travel time use and AV-capabilities may in fact lead to modification (different route) and consequent travel generation (complementarity). While such effects have been hypothesised by some researchers (for discussion see Fagnant and Kockelman, 2014), the actual evidence for the likelihood of such outcome is still to emerge, possibly with the commercial availability of AV.

### 5.4.3 Scenario 3: Lazy friends

Certain activities, such as meetings, by their very nature require co-participation of other individuals. This requirement leads inevitably to the need for co-ordination of activity choice, timing, and location. In this final scenario, such possibility is framed
by means of a simple two-agent strategic game. Let there be two persons, identical in terms of preferences and conditions faced as described by equation (5.16), who seek to meet. Such a meeting is possible either in physical or virtual (tele-conference) reality. The former, face-to-face meeting can take place at either person’s current location (in which case the other one needs to travel), or in a neutral destination assumed to be half-way between people’s locations. Tele-conferencing, on the other hand, does not require any travel but is less preferred to face-to-face meeting. For simplicity, modal split is ignored and an assumption is made that people can travel by public transport only. Consequently, each person faces the following, symmetrical choice set (summarised in Table 5.7):

- **Travel to neutral destination**: in this case the meeting takes place in the face-to-face environment, but the utility is reduced (for both individuals) by the need to travel (partially offset by in-travel activities) and its associated cost.
- **Travel to other person’s location**: in this case the meeting takes place in the face-to-face environment, but the utility is reduced by even more for the individual as bear the whole opportunity and monetary cost of travel.
- **Stay, with the other person travelling**: the meeting still takes place but the person does not need to incur any travel-related cost. From that individual’s point of view, this outcome is the most desirable.
- **Stay, and engage in tele-conferencing**: in this case both individuals choose not to travel and engage in tele-conferencing which, though avoiding travel costs does not yield utility as high as that of face-to-face meeting.

In this situation, the outcome of the decision does not depend solely on the individual’s action, but also on the decision of the other individual. Various outcomes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Component value</th>
<th>( M_A )</th>
<th>( M_{T_1} ) (work)</th>
<th>( M_{T_2} ) (leisure)</th>
<th>( M_T )</th>
<th>( M_B )</th>
<th>( b_{c \theta} )</th>
<th>( b_{c_{ij}} )</th>
<th>( V )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel: neutral destination</td>
<td></td>
<td>-1</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Travel: other’s destination</td>
<td></td>
<td>-2</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>Stay: other person travels</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Stay: no one travels, tele-conferencing</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: neutral destination is closer than destination of the other person.
of this game are represented in a form of payoff matrix (Figure 5.4) which includes the values of \( V \) for the individuals given their own and other person’s decision.

It can be seen that travelling to the neutral location would be the most equitable and efficient (from the aggregate point of view) outcome. However, given that person 2 chooses to travel, there is an incentive for person 1 not to do so with a symmetric logic applying to person 2’s perspective. However, in this case person 2 would need to travel the whole distance which, given that person 1 now does not want to travel, is less desirable than staying at their own place and engage in tele-conferencing. The latter case is therefore a Nash equilibrium situation, as no person is willing to change their decision, given the behaviour of the other one. The situation mirrors the famous Prisoner’s Dilemma situation in that lack of co-operation (both people travelling) leads to less efficient outcome (tele-conferencing).

While simple in nature, the example provides a clear example of how the relationships between ICT and travel behaviour in the context of social interactions can be framed. Such approach has previously been applied, for instance, to conceptualise interaction between employers and employees in the context of telecommuting adoption and frequency (Brewer and Hensher, 2000). The current development can be seen as providing an additional theoretical contribution towards understanding what payoffs in such games may depend on, and hence guide design of state choice experiments similar to those used by Brewer and Hensher (2000).

In addition, games similar to those presented in Figure 2 could be extended to allow heterogeneous agents (e.g. by employment status), asymmetric conditions and information (e.g. ICT skills, availability of modes of transport) or multiple games.
(e.g. to reflect multiple occurrences of interactions) thus opening avenues for better microeconomic understanding of digitisation of social contacts (Castells, 2000), proliferation of Internet based communication tools (Skype, Viber), or social network platforms uptake (Facebook, LinkedIn).

5.4.4 Further means of the framework operationalisation

The theoretical contribution presented in the sections above could be operationalised by a number of econometric tools which this section seeks to briefly present. In such an instance, however, the important issue is that of data needs and data collection protocols. Stated preference exercises would appear effective solution for situations similar to those in scenarios 1-3 (Rose and Bliemer, 2009) while laboratory experiments such as those used by experimental economists could be utilised for obtaining well-controlled and efficient designs for interactive situations similar to scenario 3 (Greiner et al., 2014; Smith, 1989). On the other hand, Brewer and Hensher (2000) employed interactive stated choice experiments which included interviewing employers and employees in rounds, asking for their preferred choice given the other party’s earlier decision. Such a procedure provides a means of not only establishing which combination of choices resulted in Nash equilibrium situation, but also tracing path of arriving to this equilibrium. Moreover, the enables investigation of significance of characteristics associated with particular choices and in the current context could help in determining the importance of face-to-face as opposed to digital interaction, travel costs, or ICT use for in-travel time activities and their associated productivity and satisfaction.

What follows naturally from discrete nature of the choice problem as well as stated choice experiment protocol, is application of the discrete choice modelling techniques. The first step in employing such methods involves identifying possible factors that may influence individual’s choices. For this purpose, equation (5.16) could serve as guidance in terms of deconstructing the overall choice problem into a number of more elementary components, similarly to those presented in Table 5.5-Table 5.7, or even more disaggregate. Using this knowledge, a number of choice scenarios can be developed exploring individuals’ decisions between alternatives depending on the differences in journey duration, transport modes’ characteristics, ICT availability and capabilities as well as intensities and productivities associated
with participation in initial, final, and in-travel activities among others. While this is hardly different from the vast body of choice modelling studies, it demonstrates how a theoretical development can help linking various behavioural aspects and hence facilitate design of appropriate data collection protocols. Hence it is possible to imagine that the severe weather scenario from section 5.4.1 could be converted into a set of choice tasks characterised by different journey durations and costs, urgency for physical presence, intensity of tele-participation, or productivity of in-travel time use among others.

Once such data is available, an appropriate modelling structure needs to be selected to reflect possible correlation structure between the alternatives. This is especially important in light of the alternatives possibly consisting of combination of choices, some of them overlapping. As a result, the selection between simple multinomial logit structure, and more flexible network (Bierlaire, 2002) or mixed Generalised Extreme Value (GEV) models would ultimately depend on what behavioural components individuals are allowed to choose simultaneously. Hence if only choice of travel mode (including tele-participation) i, is investigated, with all other elements (i.e. A, B, T1, T2, j, and ψ) exogenous, simpler structures should suffice. Note also, that in such case the expression for indirect utility function could by further truncated by removing elements invariant to modal choice, e.g. \(bc\). However, if the full, joint choice problem described in equations (4.10) and (4.11) is explored, employment of the latter, more complex formulations would be necessary. As for the interactive games, operationalisation of the discrete choice models along the lines presented by Bresnahan and Reiss (1991) can be utilised.

Regarding specification of the indirect utility function (5.16), the most prevalent linear-in-parameters formulation could serve as a first-order approximation. However, its use would mean introduction of a number of implicit assumptions, such as additive separability of intensity and utility components, time-of-day invariance of such factors, or perfect substitutability between attributes. While such formulation could certainly form a starting point for investigation, especially given its convenience and ease of implementation, the implicit assumptions would need to be reflected in interpretation of the empirical results.
An alternative way specifying the utility function could make use of contributions from the models of activity scheduling (Ettema et al., 2007, 2004; Polak and Jones, 1994). In such models, themselves based on Winston’s concept of instantaneous utility, the intensity and utility functions are defined explicitly. Given that Spencer (1987) provided evidence that people’s circadian rhythm approximately follows sinusoidal shape, it would appear convincing to model the instantaneous time-dependent intensity (productivity) as a symmetrical Cauchy distribution due to its single peak time and existence of analytical solution to integration exists as suggested by Ettema et al. (2007). On the other hand, duration dependence could follow the formula proposed by Bhat and Misra (1999), thus yielding time-dependent expression for $z$:

$$z(t, \psi, \theta) = \frac{1}{\pi f(\psi, \theta)} \left[ \frac{(t - t^*)^2}{(f(\psi, \theta))^2 + 1} \right] * z_{MAX} + \frac{\eta f(\psi, \theta)}{t}$$ \hspace{1cm} (5.22)

In this formulation, $f(\psi, \theta)$ reflects the possible dependence of intensity $z$ on ICT bundle $\psi$ and other factors $\theta$ other than time, $t^*$ is the optimal activity timing while $z_{MAX}$ is an arbitrary maximum value of the intensity. Additionally, $\eta$ reflects the impact of duration of the activity on the intensity, potentially reflecting fatigue or boredom. In such a case, and following the assumption of non-negative intensity $z$, natural logarithm could be used to reflect diminishing marginal utility of intensity:

$$u(z(t, \psi)) = \gamma_1 \ln(\gamma_2 z(t, \psi) + 1)$$ \hspace{1cm} (5.23)

where $\gamma_1$ is a scaling parameters and $\gamma_2$ indicates the direction and sensitivity of the utility to activity intensity. The latter coefficient would thus capture the effect of productivity on satisfaction derived from work. An additional advantage of the expression (5.23) lies in the possibility to use the Taylor series (Mercator series and Euler transform in this particular case) to approximate the otherwise cumbersome expression and integrals. However, while working with the explicit utility expressions would appear conceptually straightforward, its implementation in terms of estimating highly non-linear expressions with entangled parameters could prove challenging.

Yet another way of operationalising the theoretical framework can involve using the first order conditions associated with in-travel time use, i.e. equation (4.18), and departure time (4.19). Whilst it was demonstrated in the previous chapter how the
former can be linked to the hazard-based formulation, the latter equation forms a possible theoretical underpinning for departure time models which were in the past operationalised using discrete choice models which captured the willingness to trade-off between schedule delay and participation penalty, i.e. deviations from the optimal departure and arrival timings (Polak and Jones, 1994).

Whereas stated choice exercises and subsequent estimation of discrete choice models constitutes a well-established path, and hence arguably a convenient one to follow for researchers, it is by no means the only one to linking the current theoretical results and empirical application. An additional way collecting the necessary data could be by means of so-called ‘social diaries’ (communication diaries) in which individuals record their social interactions (both physical and virtual) as well as information on location, relationship to other people or travel conditions (Mokhtarian and Meenakshisundaram, 1999; Van den Berg et al., 2014). Such data collection protocols should, however, reflect possible factors which would enter different components of the framework, i.e. $M_A, M_{T1}, M_{T2}, M_T, M_B$, as well as set of other, unchosen alternatives means of communication which could be added through follow-up questionnaires.

A number of further possible ways of improving the formulation exist that have not been explicitly addressed in this chapter. For example period-specific utilities could include explicit terms reflecting dependence between them which is essential in modelling situations where occasional tele-activity is desirable while permanent is not. For instance, permanent tele-workers could experience sense of isolation and reduced opportunity for promotion as discussed previously in section 2.4.1. This could be possibly framed as an appropriate set of backward- and forward-looking variables entering the intensity $z$. Additionally, more explicit treatment of the heterogeneous and stochastic processes such as intra-individual variations in timing preferences or travel time variability could be included in the framework. As mentioned earlier, such effects could be captured by allowing some variables ($z, r_{ij}$) to be randomly distributed. Finally, additional layer of simultaneous activities concurrent to in-travel ones could be incorporated together with terms capturing compatibility (or its lack) between them, e.g. listening to relaxing as compared to loud and disturbing music while attempting to have a nap.
5.5 Summary

This chapter demonstrated two ways in which the theoretical and econometric framework developed in chapter 4 could contribute to better understanding as well as decision-making in conditions of increased interaction between ICT and travel behaviour. One application of the contributions was shown in the area of business travel time valuation as presented in sections 5.1 and 5.2, while the other one was more theoretical and discussed in sections 5.3 and 5.4.

5.5.1 Results of the microsimulation-based valuation of employer’s business travel time savings

Sections 5.1 and 5.2 presented an application of the developed framework for in-travel time use and productivity in the context of valuation of business travel time savings. In doing so, the debate surrounding the appropriateness of the two prevailing approaches, cost-saving and Hensher’s, was highlighted. As the latter approach has been criticised on the grounds of cumbersome operationalisation, contribution towards its application by means of the framework developed in chapter 4 was presented. While the results proved promising, it was also noted that the application was of a limited extent as only the employer’s value net of fatigue was considered. Moreover, the application was based on the assumptions that the observed in-travel time use patterns and productivity would approximate those taking place during travel time changes. Finally, the estimated models demonstrated only limited capabilities in making inferences about the values which nevertheless was sufficient to prove the case of potential applicability of the current contribution in this context.

Addressing the need for a valuation approach reconciling cost-saving and Hensher’s approaches, a novel method for investment valuation was proposed basing on the two approaches. The proposed method was shown to reduce to the cost-saving approach under specific circumstances when the sole purpose and effect of investment is travel time reduction. At the same time, however, the approach enabled incorporation of possible implications of investments in the improvement of in-travel time quality and its productive output. Hence the framework was shown to link the developments in ICT and their use in the course of travel to the investment appraisal methodologies in
hope that by doing so more efficient decision-making and resource allocation, but also more pleasurable travelling can be achieved.

5.5.2 Application to modelling the joint choice of ICT and travel behaviour

The second contribution of this chapter, demonstrated that despite the additional complexity coming from the specificity of ICT and tele-activities, the well-established time allocation frameworks and goods-leisure paradigms can still prove useful in understanding interaction between digital and physical worlds with the consequent implications for travel behaviour. Within the framework the choice of pre-, in-, and post-travel activities (including their mode of conduct, i.e. physical or ICT-based/tele-activity), their timings and durations, travel mode and route, as well as ICT use is made endogenously, given individual time-specific intensities (or productivities) and the associated utilities as well as monetary reward (wage). In doing so, an expression for the indirect truncated utility function conditional on activity timing was derived which could form the basis of systematic component of utility in activity-travel choices, perhaps operationalised by means of discrete choice models. Such models would then obtain justification for use not only on the basis of econometric convenience, but also on sound underlying behavioural mechanism and microeconomic theory.

Drawing upon the concept of indirect utility function, the expressions for valuing travel time reductions, or changes in the ICT qualities such as increase in broadband speed or availability of on-board Wi-Fi were derived. While no additional empirical implementation of the framework was provided (the area representing a clear direction for further research efforts), the model was employed as a means of conceptualising three activity-travel and ICT choice scenarios potentially faced by individuals in real lives, including use of autonomous vehicles or dealing with interaction between people. In doing so, exemplar situations were presented that could be tested by means of appropriate data, including stated preference exercises, laboratory experiments, or diaries of social interactions. Progressing along such a research path could help in improving the framework and in the process of doing so, improve understanding of the mechanisms behind ICT and travel behaviour relationships. Therefore, as the final contribution additional ways of operationalising the framework such as discrete choice models, or direct specification of the intensity
and utility functions were discussed (recall that Chapter 4 included operationalisation based on hazard-based duration model).

While the formulation is based on a number of simplifying assumptions on the grounds of parsimony and analytical clarity, it nevertheless retains a high degree of comprehensiveness in formalising notoriously complex phenomena and demonstrating various possible outcomes of interactions between ICT and travel behaviour noted in other empirical studies. This theoretical contribution provides not only better explanation of the existing phenomena, but offers a path for reconciliation of some seemingly contradictory empirical results discussed in Chapter 2.
Chapter 6
RO3: TEMPORAL PERSPECTIVE

The previous chapters approached analysis of the interactions between ICT and travel behaviour from rather static, cross-sectional perspectives. However, as previously shown in Chapter 2, one of the major shortcomings in the existing body of knowledge exploring this research topic has been that of studies looking at temporal changes in the relationships between digital behaviour and physical mobility. This apparently low number of studies taking a longitudinal point of view can be attributed largely to lack of large-scale datasets containing either repeated information on the same individuals (panel data) or repeated samples from the same population (repeated cross-sectional). Partially due to this data deficiency and partially as a result of rapid evolution in the ICT functionalities and uses, understanding of the dynamics of the relationships between digital behaviour and physical mobility has remained fairly limited to date.

However, an interesting opportunity is offered by the United Kingdom’s ONS Opinions and Lifestyle Survey which has been collecting monthly surveys on various aspects of lifestyles (for more details see ONS, 2014). As part of that effort, five cross-sectional waves were collected between years 2005 and 2010, which simultaneously recorded the respondents’ use of ICT and engagement in tele-activities as well as some limited information regarding travel behaviour (a more detailed description of the data will follow in 6.1). The coincidence of availability of such data for that period is indeed very convenient given that the first decade of 2000s was a period of intense uptake in the use of various ICT (recall, for instance, Figure 1.1).

Though limited in scope by the type of variables and their level of detail, the datasets offer a valuable opportunity for gaining empirical insights into the topic that has
remained relatively underexplored and speculative to date. Consequently, the aim of this chapter is, to the extent permitted by the data, to analyse evolution in the relationships between the participation in ICT-enabled tele-activities and travel behaviour given various sociodemographic and situational characteristics of the individuals. Subsequently, the results will be interpreted in relation to the theory of diffusion of innovations (Rogers, 2003) in order to provide deeper understanding of the observed patterns.

In conceptual terms, such an approach requires a working definition of innovation. In the current context it is the emergence and changes in the patterns of relationships between ICT use and travel behaviour that constitutes innovation rather than sheer adoption of the technologies *per se*. Clearly, this requires moving away from the technology-centred, and towards behavioural interpretation of innovation. As discussed in section 2.2.6, the definition of innovation offered by Line et al. (2011: 1491) appears the most accurate given the present research focus:

‘Innovation is taken […] to mean novel or creative uses of material artefacts (e.g. mobile phones, computers, etc.) and/or services (e.g. web services, iPhone apps) that impact upon social practice.’

In the current context, the social practice would be the acquisition and use of ICT to participate in tele-activities which impacts the travel behaviour, and possibly vice-versa. For example, the mere act of purchasing and using a tablet computer would constitute an act of technology adoption. However, its use while travelling as a means of facilitating productivity of travel time would be considered an innovation in the behavioural sense, explored in the current chapter.

The actual ICT variables that are considered in the current analysis include:

- Number of communication-related tele-activities the respondent has participated in, including use of e-mail, voice-over-Internet protocol (VoIP), and chat groups;
- Number of shopping-related tele-activities the respondent has participated in, including the actual online shopping, obtaining information about goods and services online, and downloading media;
- Number of tele-services the respondent has used, including tele-banking, seeking health-related information online (tele-medicine), participation in online courses and training (tele-education), online news retrieval, and booking travel and accommodation online.

While unfortunately no detailed information was available for the five waves in terms of the frequency, or level of engagement, Hjorthol (2002) previously demonstrated the usefulness of using the number of ICT-enabled activities as descriptors for digital behaviour when describing the interactions with travel behaviour. At the same time, the following information on travel behaviour is available and incorporated in the analysis:

- Modal choice:
  - Travelling by car (as driver or passenger) at least once a week;
  - Travelling as bus passenger at least once a week;
- Most frequent journey purpose being work (as compared to most frequent purpose being shopping, escorting children, leisure, or personal business);
- Travel timing in terms of whether the respondent would usually undertake the journeys for the most frequent purpose during the morning and/or afternoon peak hours.

Additionally, information on the use and availability of Internet and broadband connection at the home location, use of Internet at the workplace, as well as whether the respondent used Internet in the last 3 months is treated as exogenous, contextual variables. It should be noted that even individuals who do not possess home or workplace Internet access could still participate in ICT-based activities using Internet cafes or public libraries. This statement is important as emphasising the availability, in theory, of tele-activity participation to all the respondents. Additionally, the number of cars available to the household is included as potentially important of travel behaviour of the individuals.

Despite its limited extent, the availability of the repeated cross-sectional information covering period of almost six years offers a promising opportunity for exploring the temporal dynamics in the relationships between digital and physical behaviour. In doing so, the following section 6.1 includes more detailed description of the datasets.
used in the current analysis, especially in terms of their representativeness as compared to the UK census population. Presentation of the empirical data and its specificity at that stage is to clarify on the rationale for the subsequent analytical approach. A more detailed discussion on various analytical methods applicable under to such repeated cross-sectional (RCS) data is provided in section 6.2, demonstrating their relative strengths and weaknesses, and justifying the use of pooling independent cross-sections across time (PICSaT) approach. Subsequent section 6.3 describes research design of the current analysis including the rationale for using a multi-group structural equation model in the current analytical context. Following that, section 6.4 presents the results of estimating the assumed multi-group SEM using PICSaT data with each cross-sectional wave treated as a separate group of observations. Additionally, in interpretation of the estimated indirect (mediation) effects is attempted in section 6.5 to identify segments of population displaying particular patterns of adoption of the relationships between ICT use and travel behaviour. In doing so, the conceptual reference is made to the theory of diffusion of innovations (Rogers, 2003). This is to provide a means of interpreting the results in the wider context of technological impacts on society as well as to stimulate the discussion on possible future trajectories for the evolution of relationships between digital and physical lifestyles. Furthermore, another conceptual link is shown which combines the current findings with the theoretical results of the microeconomic analysis developed in Chapter 4 and Chapter 5. Finally, section 6.6 summarises and concludes the chapter.

6.1 Data

The available data consist of five cross-sectional waves collected by the UK Office for National Statistics as part of the Opinions and Lifestyle Survey. Each monthly wave of the survey consists of about a thousand UK respondents aged 16 or providing information on various aspects of their lifestyles, with the exact content differing between the waves, together with some general sociodemographic and situational questions common to all the waves. As such, the waves of July 2005, January 2007, January and February 2009, and February 2010 included simultaneously information on ICT use and travel behaviour of a representative and, perhaps more importantly, comparable samples of around 1000 individuals. This is demonstrated in Table 6.1 on
the next page where the sample compositions in terms of a selection of basic sociodemographic features are compared with the census data for England and Wales.

Table 6.1 Sample and ONS census population compositions

<table>
<thead>
<tr>
<th>Wave</th>
<th>Census 2001</th>
<th>Census 2011</th>
<th>Census* (interpol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Jul 2005</td>
<td>52%</td>
<td>51%</td>
<td>52%</td>
</tr>
<tr>
<td>2 Jan 2007</td>
<td>55%</td>
<td>57%</td>
<td>56%</td>
</tr>
<tr>
<td>3 Jan 2009</td>
<td>45%</td>
<td>43%</td>
<td>44%</td>
</tr>
<tr>
<td>4 Feb 2009</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
</tr>
<tr>
<td>5 Feb 2010</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
</tr>
</tbody>
</table>

Gender (16+)  
Female  
Male  
Age (16+)  
25 %title  
Median  
75 %title  
Mean household size  
Higher education  
Below degree  
Degree  
Income* (£000s)  
Household car ownership  
Sample size

*Mid-points between 2001 and 2011 values  
*Median personal gross annual for full-time employed in 2012 prices  

Table 6.2 Variables used in the current study

<table>
<thead>
<tr>
<th>Exogenous (sociodemographic)</th>
<th>ICT use</th>
<th>Travel behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender: male</td>
<td>Tele-conferencing index (sum of activities, 0-3)</td>
<td>Commuting: travelling to/from work is the most frequent journey purpose</td>
</tr>
<tr>
<td>Age</td>
<td>Use of e-mail</td>
<td>Regular car user: travelling by car as driver or passenger at least once a week</td>
</tr>
<tr>
<td>Marital status: single (never married)</td>
<td>Use of VoIP</td>
<td>Regular bus user: travelling by bus at least once a week</td>
</tr>
<tr>
<td>Marital status: married</td>
<td>Use of chat groups</td>
<td>Peak time traveller: travelling for the most frequent journey purpose during morning and/or afternoon peak hours</td>
</tr>
<tr>
<td>Household size</td>
<td>Tele-shopping index (sum of activities, 0-3)</td>
<td></td>
</tr>
<tr>
<td>Residential property owner</td>
<td>Use of online shopping</td>
<td></td>
</tr>
<tr>
<td>Long-standing illness or disability</td>
<td>Downloading media online</td>
<td></td>
</tr>
<tr>
<td>Personal income</td>
<td>Tele-services index (sum of activities, 0-5)</td>
<td></td>
</tr>
<tr>
<td>(in £000s per year)</td>
<td>Use of tele-banking</td>
<td></td>
</tr>
<tr>
<td>Academic degree</td>
<td>Seeking health-related information online (tele-medicine)</td>
<td></td>
</tr>
<tr>
<td>Employed full-time</td>
<td>Seeking job online</td>
<td></td>
</tr>
<tr>
<td>Managerial occupation</td>
<td>Participation in online courses (tele-education)</td>
<td></td>
</tr>
<tr>
<td>Supervisory duties</td>
<td>Retrieving news online</td>
<td></td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Booking travel and accommodation online</td>
<td></td>
</tr>
<tr>
<td>Uses Internet at home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadband Internet at home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used computer within last 3 months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cars available to household</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
As a result of the data in the samples including also respondents from Scotland and Northern Ireland), comparison to the census data can only serve as a proxy benchmark for the representativeness of the samples. Moreover, as the census data was available only for 2001 and 2011, interpolated, mid-point values were additionally included to serve as indicators of the composition of the waves collected in-between these years. A brief analysis of Table 6.1 reveals that the waves are similar in terms of sociodemographic composition, perhaps with the only exception of slight shift upwards in the median age following the 3rd wave (January 2009). The sample compositions are fairly consistent when compared to the census data, again perhaps with the exception of age which appears to be biased towards more significant presence of older adults in the sample datasets.

The variables considered in the current study (see Table 6.2) include exogenous sociodemographic and contextual characteristics, ICT use (termed tele-activities) and travel behaviour. As previously discussed, measures of sophistication of tele-activity participation are based on composite indices derived from number of related activities a respondent participated in which follows from Hjorthol (2002). Four aspects of travel behaviour available in the datasets are considered: commuting behaviour, modal choice, i.e. car and bus use, and timing of the most frequent purpose trip.

6.2 Methods for analysing RCS data

When dealing with data of RCS character, the following three main analytical approaches can be used to investigate the dynamics of change:

- pseudo-panel analysis,
- pooling independent cross-sections across time (PICSaT),
- hazard-based models.

While the first two methods treat time as essentially exogenous, discrete input variable (either explicitly in the pseudo-panel analysis, or implicitly in the PICSaT approach), the hazard-based model looks at time as continuous output, i.e. expected time of certain event such as adoption or cease of activity. More details on the underlying logic of these methods are presented in the following sections 6.2.1-6.2.3.
6.2.1 Pseudo-panel methods

The pseudo panel techniques introduced by Deaton (1985) attempt to make use of RCS data to reconstruct a panel-like dataset by defining a set of cohorts consisting of homogenous units (individuals, companies). The cohorts are subsequently used as the pseudo-units of analysis with the cohort means serving as proxies for the values of the variables under investigation for which the conventional time series methods can be used. Thus the most efficient application of the method is in contexts where the impact of time on variation in another variable, usually of continuous or at least ordinal character, is of the primary interest, e.g. evolution in car ownership patterns (Biao, 2007), rather than where multiple interactions between the variables are investigated simultaneously. The pseudo panel method is well-suited for very large datasets as the properly constructed cohorts should normally consist of around 100 of individuals or more, to ensure that the cohort means provide stable approximation to the true values of the variables unaffected by presence of outlying values (Propper et al., 2001). Moreover, the cohort-defining variables must be time-invariant which severely limits the set of possible measures to be used for cohort definition to age, place of birth, perhaps gender, with the implicit assumption that such discriminants could accurately define a group of homogenous behaviour which may not always be a sustainable assumption. Finally, for pseudo-panels RCS waves should ideally have been collected at equal intervals of time as additional corrections for such inequalities could add to uncertainty in the subsequent analysis.

The requirements stated above do not place the method as favourable for analysing the current datasets amounting to around 1000 observations per wave which would translate into roughly 10 cohorts per wave. Such pseudo-sample would be unlikely to provide sufficient statistical power for a robust analysis of relationships between multiple variables as is the need in the current context.

6.2.2 Pooling independent cross-sections across time (PICSaT)

An alternative method for analysing RCS involves implicit treatment of time through acknowledging the possible presence of wave-specific effects on the relationships between variables. In doing so, the wave-specificity is captured by means of
additional parameters associated with suitable indicator (dummy) variables (Wooldridge, 2013). Such indicator variables could be included either as standalone and thus reflecting changes in the constant term, or as interacting with other covariates. Consider a simple linear model of the relationship between variables $y$ and $x$ with the parameters $\beta_0$ and $\beta_1$ describing the constant term and slope respectively:

$$y = \beta_0 + \beta_1 x$$

(6.1)

Assume further that there are two waves of cross-sectional data $W_1$ and $W_2$, with a dummy variable $\delta_{W2}$ indicating that a particular respondent belonged to wave $W_2$. In such a case it would be possible to define the following model capturing the wave-specific effects through parameters $\beta_{0W2}$ and $\beta_{1W2}$:

$$y = \beta_0 + \beta_{0W2} \delta_{W2} + \beta_1 x + \beta_{1W2} \delta_{W2} x$$

(6.2)

The additional coefficients $\beta_{0W2}$ and $\beta_{1W2}$ reflect changes in the constant and slope coefficients observed in wave $W_2$ as compared to $W_1$ assuming common error structure for the pooled datasets. Such formulation can accommodate various wave-specific effects, e.g. cross-sections collected at different points in time, among different socioeconomic groups, or treatment effects. It is worth noting that extension of equation (6.1) to multiple groups (waves) is straightforward, requiring defining additional indicator variable(s) for each distinctive group(s), or wave(s). Despite the requirement for a potentially large number of additional parameters, the approach possesses a number of distinctive advantages:

- It is readily applicable to wide range of models ranging from simple linear regressions to structural equation models, to non-linear formulations also including categorical explanators and outcome variables. This feature is especially desirable given the prevalence and cost-efficiency of cross-sectional data, including RCS, as compared to, e.g. panel data.
- It enables readily approach for inspection for structural differences between the datasets using well-established tests, e.g. Wald, likelihood ratio, Chow or F-test.
- It provides a systematic way of finding the most parsimonious description of a phenomenon occurring across different groups of data, including subsequent cross-sectional waves.
• While it assumes a common error structure across the pooled datasets, it enables incorporation of heterogeneity by inclusion of factor-specific error components though in such a case the approach may effectively reduce to estimation of independent models for each group (wave) of data.

• If both samples can be assumed to arise from similar surveying protocols (which is usually the case for RCS data), it is reasonable to assume that the differences in the estimated relationships can be attributed to the group (wave) specificity.

Given the flexibility of the PICSaT approach, there appears to be no obstruction of its employment in the current analysis where the need is to implicitly capturing the temporal variations between the simultaneous, multiple interrelationships between the variables framed as a structural equations model.

6.2.3 Hazard-based modelling

The final method of analysing RCS data was discussed by Sarkar (2003) in the context of Internet adoption. The method involves estimating hazard-based duration models in which the time variable is derived based on the date of collection of particular wave of data. In the current case, assuming a reference point of January 2005 would mean that the respondents from the July 2005 wave would be assigned with values of 7 (months), January 2007 - 24 months etc. Subsequently, a variable which describes adoption (use) of Internet is used for right-censoring i.e. accounting for whether the innovation was adopted at the time of data collection or not. At the same time, left censoring should be incorporated to capture pre-data-collection adoption accurately which, despite references in the paper, was surprisingly, not incorporated in the actual analysis.

Sarkar (2003) demonstrated by means of a simple Monte Carlo experiment that such approach would be viable if adoption was assumed to be an absorptive state (i.e. innovation once adopted is not given up), or there was a variable that described when the innovation was adopted and given up which would allow appropriate accounting for by means of interval censoring. Moreover, the actual adoption would have to take place in the temporal vicinity of the data (wave) collection. Interestingly, while the first two assumptions are defensible on both conceptual and methodological grounds, the third is perhaps the most controversial and yet surprisingly unexplored. Its
meaning is such that the actual (unobserved) adoption time can be approximated by data collection time. Whereas for short and equal intervals this could form a reasonable approximation, it can lead to significant biases otherwise as all respondents who reported adopting a particular innovation during a perhaps lengthy period would be treated as if they did so in the month of data collection. The extent to which such biases could emerge under different scenarios of unequally-spaced data collection requires further investigation before becoming a robust methodology. Otherwise the method appears advantageous in situations where the adoption time is the primary quantity of interest as well as where an innovation can be described as a discrete, binary outcome. In the current context however, innovation would be reflected in changes in the direction and strength of the relationships which are of continuously evolving nature, and possibly of non-absorptive character. Consequently, use of the Sarkar's approach in the current research context and data does not appear justifiable

6.3 Research design

When taking a dynamic temporal (dynamic) perspective on societal phenomena such as adoption of innovative behaviour, it is customary to make use of longitudinal data which can be either of panel or repeated cross-sectional character depending on whether the sample units differed or stayed the same between the consecutive waves of data collection. The enormous advantage of the former type lies in the possibility of tracing individual behaviour over time and thus distinguishing between intra- and inter-individual variability, and isolating factors associated with decisions on innovation adoption. In addition, as discussed in section 2.3 such data can also be helpful in exploring for evidence supporting (or not) hypotheses of causal relationships, e.g. using Granger test (Greene, 2012).

However, panel data can be costly, subject to attrition and thus possibly lack of representativeness (Yee and Niemeier, 1996) though these effects can be in principle corrected through appropriate weighting. Additionally, revising set of question asked to the panel respondents may be difficult to implement and hence lead to difficulties in comparability between the waves, or risk missing information on the impacts of novel technological developments. This challenge leads to a paradoxical question of whether traditional panel data may ever accurately meet the data needs arising in the
domain of ICT and travel behaviour interactions. Perhaps a more open-ended nature of certain question could aid in the cases where such rapid changes are most likely.

These issues are arguably more easily addressable with the RCS data, already relatively widespread both in the context of ICT (e.g. Internet use surveys) and travel behaviour (e.g. travel surveys). What is more, the RCS data can also be employed in the context of data pooling, such as that presented in Chapter 3. Nonetheless, the advantages of RCS in terms of modifying the survey design between the consecutive waves as well as flexibility in ensuring representativeness of the population come at a cost. Most importantly, RCS data may not readily enable distinguishing between inter- and intra-individual variations in behaviour, that is, the statistical power of the models based on such data will be inherently reduced with the two sources of variability confounded (Yee and Niemeier, 1996). Moreover, the third source of variability coming from sampling variance and possibly change in composition needs to be taken into consideration, e.g. by appropriate weighting to avoid biased conclusions, especially when dealing with aggregate effects. Finally, the treatment of time as an explanatory variable may be less straightforward, especially if the waves were collected in unequal intervals of time.

Finally, it is worth noting that it has not been uncommon to estimate innovation diffusion models using single cross-sectional datasets, e.g. by means of logistic regression or cluster analysis (Abu-Shanab and Abu-Baker, 2014; Aguila-Obra and Padilla-MeLéndez, 2006; Noce and McKeown, 2008). Such approaches distinguish factors that are associated with higher probability or advancement of the stage of adoption and thus speculate about the characteristics of various segments and stages of adoption process. However, such approaches may mask dynamic character of the process (Sarkar, 2003), prevent conclusions about the evolution in the relationships over time which in the current context is the essential feature.

6.3.1 Multi-group SEM for PICSaT approach

Based on discussion in the previous section, the PICSaT approach emerges as the most suitable for the current context of simultaneous modelling of interactions between multiple dimensions of ICT use and travel behaviour. In fact, application of the PICSaT approach to structural equation modelling can be implemented by means of so-called multi-group SEM, with each wave treated as a separate group of
observations, and also set of estimated parameters. As composition of the samples was found stable over time (recall Table 6.1), a reasonable confidence can be placed in the observed changes in the relationships being due to external factors, rather than pure sampling variability. Unfortunately, formal comparison of the estimated parameters’ values, and hence magnitudes of the relationships, is possible only for unstandardised parameters since standardisation is based on wave-specific variances and covariances. At the same time, the use of polychoric correlation coefficients as a means of capturing latent nature of the endogenous (behavioural) variables (Holgado–Tello et al., 2008) restricts the analysis to standardised coefficients and thus only qualitative inspection of the evolution in the relationships is possible.

Whilst SEM provides a means of simultaneous modelling of a number of relationships, there are no means of establishing whether the postulated a priori structure, itself implicitly implying causality between the variables, is true or not. Goodness-of-fit and modification indices can serve as indication of the fit quality in statistical sense, but not as definite evidence for truthfulness of the assumed structure of interactions. Thus it is important to stress that the role of SEM is that of testing and describing the degree of interactions between the variables within the postulated structural environment, and not in absolute sense (see section 3.3 for more detailed discussion on the SEM methodology). Additionally, within the current context it is possible to observe how such interactions evolve over time which is ensured by maintaining a common postulated structure for all the waves.

In terms of the assumed structure in the current context (see Figure 6.1 on the next page), it was based on the combination of understanding prevailing in the literature on ICT and travel behaviour discussed in Chapter 2, and the available data. Naturally, as with any SEM and indeed most models used in this research domain, the risk of endogeneity due to bi-directional causality (simultaneity) is non-negligible which increases the risk of a number of consequences described earlier in section 2.3. One of the possible alternatives for directly addressing this issue could be achieved by estimating a joint choice model in which alternatives would be defined as combinations of ICT and travel behaviour choices described by the variables in Table 6.1. However, this approach would result in a prohibitively high number of alternatives, i.e. 1536 (4x4x6x2x2x2x2). At the same time, no variables in the data
Figure 6.1 Evolution of ICT and travel behaviour relationships between 2005 and 2010 (5 RCS waves)

*significant at 90% level  **significant at 95% level
provide information that could either serve as instrumental variable, or direct inference about the causal direction in the relationships. As a result, informed and as complete as possible SEM specification remains the only feasible alternative. More detailed discussion of potential consequences of simultaneity issue in the present analysis is included along with the findings in the next section.

In terms of the dependent variables, tele-conferencing participation is assumed to be determined solely by the sociodemographic characteristics of the respondents, reflecting the basic need communication most strongly influenced by exogenous characteristics. Tele-conferencing is assumed to influence other ICT uses (tele-services, tele-shopping) reflecting higher propensity to engage in online activities by those already making use of Internet-based communication. Furthermore, tele-conferencing is also included as explanatory variable for work-related travel (termed ‘commuting’ for simplicity) which reflects individual's use of such tools for work-related duties possibly influencing travel (contact with team members, customers) as well as remote work practices. Additionally, commuting variable is assumed to determine the mode of travel. Tele-shopping and tele-services variables, on the other hand, would influence the regular use of car and/or bus as well as the likelihood of travelling during the peak hours which is to investigate for potential impacts of ICT use on these aspects of travel behaviour. Inclusion of additional relationships was restricted by reaching almost saturated specification (see Table 6.3 on the next page).

The actual estimation was performed using the lavaan 0.5.16 package implemented in R environment (Rosseel, 2012) and using asymptotically distribution-free diagonally-weighted least squares method. A common specification was used for all waves of data to control for possible changes in the relationships arising from modifications in the implied correlation structure. This ensures that higher confidence can be placed in claiming that the observed changes result from evolution in the behavioural patterns, and are not simply a feature of modified specification which confounded the results.

6.4 Findings

A number of goodness of fit indices associated with the models are presented in Table 6.3 which reveals that the models do not fully reproduce the covariance matrices observed in the samples. This is reflected in the high value of the chi-square and
RMSE, though the former measure may be inflated by the large sample size (see section 3.3 for a more detailed discussion of the goodness-of-fit indices). At the same time, the relative fit indices suggest significant improvement in the overall fit resulting from inclusion of the variables of interest. Both results appear intuitive and reasonable, given that the outcome variables being possibly co-determined by further factors of which descriptors are not available in the available data. It is also worth noting that the specification had only two degrees of freedom indicating almost complete saturation. As a result, inclusion of additional parameters (relationships) could lead to problems with identifiability of the model.

### 6.4.1 ICT and travel relationships over the investigated period

Before commenting on the results presented in Figure 6.1 which describe evolution in the relationships between ICT and travel behaviour variables between July 2005 (wave 1) and February 2010 (wave 5), it is useful to investigate the aggregate changes to patterns of ICT use and travel behaviour over the period. Table 6.4 on the next page presents results of such analysis which suggest existence of a trend towards a more widespread and richer use of ICT by increased proportion of the population. In the case of travel behaviour characteristics, the modal split has remained relatively stable between 2005 and 2010 while there was a slight increase in the non-work related travel then. In addition, an increase in the proportion of travel outside the peak hours for the most frequent trip purpose can be observed.

<table>
<thead>
<tr>
<th>Fit measure</th>
<th>Wave</th>
<th>1 Jul 2005</th>
<th>2 Jan 2007</th>
<th>3 Jan 2009</th>
<th>4 Feb 2009</th>
<th>5 Feb 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square</td>
<td></td>
<td>133.585</td>
<td>110.489</td>
<td>65.549</td>
<td>99.525</td>
<td>80.603</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>p-value (H0: RMSE=0)</td>
<td></td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
</tr>
<tr>
<td>RMSE</td>
<td></td>
<td>0.234</td>
<td>0.213</td>
<td>0.168</td>
<td>0.214</td>
<td>0.198</td>
</tr>
<tr>
<td>Goodness-of-fit index (GFI)</td>
<td>Benchmark: &gt;0.90</td>
<td>0.952</td>
<td>0.959</td>
<td>0.971</td>
<td>0.950</td>
<td>0.952</td>
</tr>
<tr>
<td>Comparative fit index (CFI)</td>
<td>Benchmark: &gt;0.93</td>
<td>0.945</td>
<td>0.968</td>
<td>0.966</td>
<td>0.962</td>
<td>0.963</td>
</tr>
<tr>
<td>Normed fit index (NFI)</td>
<td>Benchmark: &gt;0.90</td>
<td>0.948</td>
<td>0.960</td>
<td>0.972</td>
<td>0.953</td>
<td>0.955</td>
</tr>
<tr>
<td>Sample size</td>
<td></td>
<td>1207</td>
<td>1197</td>
<td>1130</td>
<td>1069</td>
<td>1004</td>
</tr>
</tbody>
</table>

Estimation method: Diagonally-weighted Least Squares (DWLS)  
*Benchmark values based on (Byrne, 1994)
Another interesting observation that can be made based on inspecting Table 6.4 involves the diffusion pace of ICT uses. In this case, a significant step-like change between the waves 2 and 3 can be seen in terms of reduced number of people who do not participate in tele-activities at all (from 50% in case of tele-conferencing, 45.4% for tele-services, and 43.8% for tele-shopping, to 41.2%, 37.5%, and 39.6% respectively). Another such a change appears between waves 4 and 5. During these changes the main increase in case of tele-conferencing and tele-shopping can be seen in the highest, 2- and 3-activity categories which may indicate a gradual shift towards saturated adoption of all different possible online activities. As for the tele-services, in the first step change the highest (4-, 5-, and 6-activities) categories have increased mostly, while in the second the medium ones. This pattern might indicate that tele-services’ diffusion may have been less monotonic than tele-conferencing and tele-

<table>
<thead>
<tr>
<th>Activities</th>
<th>Wave</th>
<th>Jan 2007</th>
<th>Jan 2009</th>
<th>Feb 2009</th>
<th>Feb 2010</th>
<th>Change (1 to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele-conferencing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 activities</td>
<td>50.5%</td>
<td>50.0%</td>
<td>41.2%</td>
<td>42.4%</td>
<td>34.8%</td>
<td>-15.7%</td>
</tr>
<tr>
<td>1 activity</td>
<td>37.3%</td>
<td>34.8%</td>
<td>31.9%</td>
<td>30.4%</td>
<td>31.4%</td>
<td>-5.9%</td>
</tr>
<tr>
<td>2 activities</td>
<td>11.0%</td>
<td>10.9%</td>
<td>19.6%</td>
<td>20.4%</td>
<td>23.1%</td>
<td>+12.1%</td>
</tr>
<tr>
<td>3 activities</td>
<td>1.2%</td>
<td>4.3%</td>
<td>7.3%</td>
<td>6.8%</td>
<td>10.8%</td>
<td>+9.6%</td>
</tr>
<tr>
<td>Tele-services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 activities</td>
<td>49.0%</td>
<td>45.4%</td>
<td>37.5%</td>
<td>37.9%</td>
<td>32.8%</td>
<td>-16.2%</td>
</tr>
<tr>
<td>1 activity</td>
<td>10.1%</td>
<td>14.0%</td>
<td>9.3%</td>
<td>9.6%</td>
<td>7.0%</td>
<td>-3.1%</td>
</tr>
<tr>
<td>2 activities</td>
<td>12.0%</td>
<td>14.4%</td>
<td>12.4%</td>
<td>11.9%</td>
<td>13.4%</td>
<td>+1.4%</td>
</tr>
<tr>
<td>3 activities</td>
<td>11.4%</td>
<td>12.8%</td>
<td>14.8%</td>
<td>13.1%</td>
<td>17.8%</td>
<td>+6.4%</td>
</tr>
<tr>
<td>4 activities</td>
<td>9.9%</td>
<td>7.7%</td>
<td>12.4%</td>
<td>13.4%</td>
<td>14.8%</td>
<td>+4.9%</td>
</tr>
<tr>
<td>5 activities</td>
<td>5.8%</td>
<td>4.2%</td>
<td>9.0%</td>
<td>10.0%</td>
<td>10.4%</td>
<td>+4.6%</td>
</tr>
<tr>
<td>6 activities</td>
<td>1.7%</td>
<td>1.7%</td>
<td>4.6%</td>
<td>4.1%</td>
<td>3.8%</td>
<td>+2.1%</td>
</tr>
<tr>
<td>Tele-shopping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 activities</td>
<td>47.2%</td>
<td>43.8%</td>
<td>39.6%</td>
<td>38.9%</td>
<td>34.2%</td>
<td>-13.0%</td>
</tr>
<tr>
<td>1 activity</td>
<td>9.8%</td>
<td>12.4%</td>
<td>10.9%</td>
<td>12.3%</td>
<td>12.4%</td>
<td>+2.6%</td>
</tr>
<tr>
<td>2 activities</td>
<td>24.0%</td>
<td>29.9%</td>
<td>29.3%</td>
<td>28.0%</td>
<td>30.8%</td>
<td>+6.8%</td>
</tr>
<tr>
<td>3 activities</td>
<td>19.0%</td>
<td>13.9%</td>
<td>20.2%</td>
<td>20.8%</td>
<td>22.7%</td>
<td>+3.7%</td>
</tr>
<tr>
<td>Most frequent journey purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-work</td>
<td>47.6%</td>
<td>53.3%</td>
<td>57.3%</td>
<td>56.9%</td>
<td>59.2%</td>
<td>+11.6%</td>
</tr>
<tr>
<td>Work-related</td>
<td>52.4%</td>
<td>46.7%</td>
<td>42.7%</td>
<td>43.1%</td>
<td>40.8%</td>
<td>-11.6%</td>
</tr>
<tr>
<td>Regular travel by car</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than once a week</td>
<td>14.4%</td>
<td>12.9%</td>
<td>19.2%</td>
<td>18.1%</td>
<td>15.1%</td>
<td>+0.7%</td>
</tr>
<tr>
<td>Once a week or more</td>
<td>85.6%</td>
<td>87.1%</td>
<td>80.8%</td>
<td>81.9%</td>
<td>84.9%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Regular travel by bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than once a week</td>
<td>76.7%</td>
<td>71.3%</td>
<td>67.0%</td>
<td>66.3%</td>
<td>73.9%</td>
<td>-2.8%</td>
</tr>
<tr>
<td>Once a week or more</td>
<td>23.3%</td>
<td>28.7%</td>
<td>33.0%</td>
<td>33.7%</td>
<td>26.1%</td>
<td>+2.8%</td>
</tr>
<tr>
<td>Travel time for the most frequent purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside the peak hours</td>
<td>52.7%</td>
<td>65.8%</td>
<td>67.0%</td>
<td>69.2%</td>
<td>64.8%</td>
<td>+12.1%</td>
</tr>
<tr>
<td>During the peak hours</td>
<td>47.3%</td>
<td>34.2%</td>
<td>33.0%</td>
<td>30.8%</td>
<td>35.2%</td>
<td>-12.1%</td>
</tr>
<tr>
<td>Sample size</td>
<td>1207</td>
<td>1197</td>
<td>1130</td>
<td>1069</td>
<td>1004</td>
<td></td>
</tr>
</tbody>
</table>
shopping, possibly because the category encompasses a greater variety of activities some of which may be less likely to be adopted by individuals (e.g. tele-medicine, tele-education) or adopted only occasionally, e.g. job seeking.

When it comes to the actual relationships between ICT use and travel behaviour in Figure 6.1, there appears to be a stable and positive correlation between the levels of participation in ICT-enabled tele-activities. This suggests that engagement in digital activities is not limited to a single functional dimension but rather simultaneously encompass various aspects of lifestyle. In terms of the relationships between travel variables themselves, individuals for whom work is the most frequent travel purpose are also more likely to be regular car users which remained stable over the investigated period, possibly reflecting propensity of using flexible private cars for commuting and other work-related travel.

Regarding the relationship between tele-conferencing and commuting variables, there appears to be some evidence for emergence of a negative relationship between the two starting in the 3rd wave. This could be taken as indication for higher work-related flexibility among more advanced users of tele-conferencing tools.

When it comes to the impacts on regular use of car, tele-conferencing is positively associated in the 3rd while tele-shopping in the 4th wave respectively, though without a clear temporal trend. In addition to that, regular bus use indicates a positive correlation with tele-conferencing (2nd wave) whereas a negative one with tele-shopping (3rd wave) though without a noticeable temporal trend. Additionally, a weak trend in the relationship between peak time travel for the most frequent purpose and engagement in tele-services can be seen, possibly suggesting that over time rather than encouraging the outside-peak travel, the use of tele-services started to enhance the propensity to travel during morning and afternoon time. A possible interpretation of this effect could be that tele-services enabled reduction of the amount of additional time required before- or after- their main trip purpose to fulfil other needs, now conducted by means of tele-services. This effect could push people’s trips back towards the peak times, as well as disrupt trip chains serving multiple purposes (Mokhtarian et al., 1995).
<table>
<thead>
<tr>
<th>Wave</th>
<th>Tele-conferencing index</th>
<th>Tele-services index</th>
<th>Tele-shopping index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gender: male</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.059**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.025</td>
<td>-0.001</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>0.010</td>
<td>0.035</td>
<td>-0.028</td>
</tr>
<tr>
<td></td>
<td>-0.064</td>
<td>-0.108*</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>-0.223**</td>
<td>-0.123**</td>
<td>-0.233**</td>
</tr>
<tr>
<td></td>
<td>-0.228**</td>
<td>-0.194**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.063*</td>
<td>0.032</td>
<td>-0.160**</td>
</tr>
<tr>
<td></td>
<td>-0.018</td>
<td>-0.088**</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>0.149</td>
<td></td>
<td>0.098**</td>
</tr>
<tr>
<td></td>
<td>0.049</td>
<td>0.079</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>0.050*</td>
<td>0.023</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.001</td>
<td>0.005</td>
<td>-0.028</td>
</tr>
<tr>
<td></td>
<td>0.007</td>
<td>0.029</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.035</td>
<td>-0.094**</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>-0.034</td>
<td>0.061**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.018</td>
<td>-0.088**</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marital: single</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.008</td>
<td>-0.050**</td>
<td>-0.054*</td>
</tr>
<tr>
<td></td>
<td>-0.033</td>
<td>-0.012</td>
<td></td>
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Table 6.6 Standardised direct effects of exogenous covariates on travel behaviour variables

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Note: bold indicates significance at 90% level,
*significant at 90% level  **significant at 95% level
Table 6.6 Standardised direct effects of exogenous covariates on travel behaviour variables

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<td>Managerial occupation</td>
<td>-0.023</td>
<td>0.026</td>
<td>-0.039</td>
</tr>
<tr>
<td>Supervisory duties</td>
<td>-0.030</td>
<td>-0.008</td>
<td>-0.045</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>0.074</td>
<td>0.120**</td>
<td>0.039</td>
</tr>
<tr>
<td>Uses Internet at home</td>
<td>0.039</td>
<td>-0.085</td>
<td>-0.040</td>
</tr>
<tr>
<td>Broadband Internet at home</td>
<td>0.052</td>
<td>0.063</td>
<td>0.004</td>
</tr>
<tr>
<td>Used computer within last 3 months</td>
<td>-0.087</td>
<td>-0.045</td>
<td>-0.122</td>
</tr>
<tr>
<td>Number of cars available to household</td>
<td>-0.443**</td>
<td>-0.491**</td>
<td>-0.458**</td>
</tr>
</tbody>
</table>

Note: bold indicates significance at 90% level, *significant at 90% level   **significant at 95% level
6.4.2 Impacts of the exogenous variables

In addition to the relationships between ICT and travel behaviour variables, Table 6.5 and Table 6.6 include standardised (correlation) coefficients describing impacts of exogenous variables on their ICT-based activity participation, and travel behaviour. Inspecting the tables reveals lack of significant association between gender and ICT which is consistent with a previously reported inconclusiveness regarding the role of gender in tele-shopping (Farag, 2006; Hjorthol and Gripsrud, 2009; McKeown and Brocca, 2009). At the same time, the results point towards males more likely travelling for work as their most frequent purpose, though (surprisingly) lower chances of regular car use.

In case of the age effects, younger people have been more likely to adopt multiple tele-conferencing, tele-services, and tele-shopping activities which is also in line with some of the results reported elsewhere in the literature (Hjorthol and Gripsrud, 2009; Van den Berg et al., 2008, 2014). In addition, younger people are also less likely to travel for work as their most frequent purpose, especially towards the end of the study period, be regular bus users, or travel during the peak time for primary journey purpose.

As for the marital status, married individuals seem to be less likely to engage in tele-conferencing and tele-shopping in the initial waves though keener users of tele-services in the later waves. At the same time, single have initially been less keen on using various tele-services.

In terms of the household size, larger households are less likely to adopt tele-conferencing tools and, initially, also tele-shopping. This could indicate such individuals’ need to devote more time to household duties on one hand, and availability of social contact on everyday basis on the other, possibly reducing need for an online-based contact. In case of travel behaviour, members of larger households are less likely to have work as the primary travel purpose which results from inherently higher probability of being not a worker (students, house workers, elderlies).

No strong trends appear in terms of the relationship between residential property ownership, long-standing disability, or income, and ICT-based activity participation.
The latter effect seems somewhat surprising as more affluent individuals would usually be quoted as the first to adopt innovations due to their easier ability to acquire novelties. Additionally, more affluent people tend to travel more for work purpose which could reflect their higher position and thus more demanding duties. Finally, a long-standing disability or illness is in a stable manner associated with lower propensity to use buses regularly, possibly due to inherently lower accessibility of such mode for people with reduced mobility capabilities.

When it comes to higher education, individuals possessing an academic degree are more likely to make use of more ICT-based activities in general but less probable to travel for work as the most frequent purpose, or be less regular car users. Individuals employed on full-time unsurprisingly have higher chances to have work as the primary travel purpose though their regular use of bus or car would not differ from those part-time or unemployed. Full-time employees would also be less likely to make use of multiple tele-conferencing activities which is possibly linked to the aforementioned age and stage-of-life effects, though this association seems to have been weakened towards the end of the study period. Those with managerial occupations are associated with multiple tele-conferencing tools, but fewer tele-shopping uses whilst the opposite was true for those with supervisory duties. This leads to a conclusion that for the respondents with both managerial occupations and supervisory duties the effects may cancel out as one hand they could be keener adopters of novelties, but on the other could also experience time pressure and be unwilling to adopt, sometimes more social- and leisure-oriented tele-activities. In either case, however, the associations have weakened during the study period, possibly indicating more widespread ICT adoption.

Unsurprisingly, the use of Internet at home or work has strong and positive association with the number of various tele-activities individual would engage in. Also, availability of broadband connection at home location appears to be an important determinant of ICT use, especially in terms of tele-conferencing. These findings demonstrate clearly that the level of accessibility to the Internet plays key role in adoption of multiple online based activities as previously reported in a number of studies (Farag, 2006; Ferrell, 2004; Mokhtarian and Tang, 2013). Naturally, the use
of Internet at work is also positively associated with the work-related and peak-time travel.

Finally, the number of cars available to respondents’ household is only weakly related with the propensity to engage in tele-conferencing activities, yet without a stable trend in the relationship. On the other hand, greater availability of car in the households has been consistently associated with a more regular use of that mode and less regular use of bus which is a reasonably intuitive finding supporting the well-established result from various modal-split studies.

6.5 SEM mediation analysis with reference to the theory of diffusion of innovations and segments of adoption

Apart from estimating the direct impacts of particular variables, SEM enable analysing indirect (mediation) effects of the variables. Such effects take place when a particular variable is influenced by an exogenous characteristic, but also influences another variable. In such a situation, the impact of exogenous factor is effectively mediated to the final outcome variable. In the current case, such analysis provides insights into the evolution of impacts of sociodemographic variables on travel behaviour (ICT use) as mediated by ICT variables (travel behaviour). Such interpretation provides basis for deducing the characteristics of respondents who adopted particular ICT use or travel behaviours, and as a result modified other aspects of their ICT use or travel behaviour. This in turn enables delimitation of population segments that can be characterised as early or late adopters, and hence link the empirical results conceptually to the innovation diffusion theory.

A number of significant indirect (mediation) effects are presented below together with a brief interpretation regarding the observed diffusion patterns in adoption of ICT, travel behaviour (Table 6.7), as well as the relationships between the two (Table 6.8). The latter is probably the more important outcome of the analysis demonstrating the dynamics of change and adoption in ICT and travel behaviour relationships (note that only statistically significant relationships have been reported). Statistical significance of the results was inferred by means of robust bootstrapped standard errors whilst the interpretations were derived on the basis of inspecting changes over time in the direction and significance of the observed correlation coefficients.
Table 6.7 Standardised mediation (indirect) effects of covariates on outcome variables for ICT use and travel behaviour

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Mediator</th>
<th>Outcome</th>
<th>Wave</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Jul 2005</td>
<td></td>
</tr>
<tr>
<td>ICT use</td>
<td></td>
<td></td>
<td>2 Jan 2007</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>-0.141**</td>
<td>Younger people were more likely to be early adopters of tele-services and tele-shopping due to faster adoption of tele-conferencing tools.</td>
</tr>
<tr>
<td>Age</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>-0.144**</td>
<td></td>
</tr>
<tr>
<td>Marital: married</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>-0.005</td>
<td>Married people, those in larger households, employed full-time were less likely to initially adopt tele-conferencing tools which led them to later adoption of tele-services and tele-shopping activities. The effect diminished over time.</td>
</tr>
<tr>
<td>Marital: married</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>-0.005</td>
<td></td>
</tr>
<tr>
<td>Household size</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>-0.039*</td>
<td></td>
</tr>
<tr>
<td>Household size</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>-0.040*</td>
<td></td>
</tr>
<tr>
<td>Employed full-time</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>-0.035*</td>
<td></td>
</tr>
<tr>
<td>Employed full-time</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>-0.035*</td>
<td></td>
</tr>
<tr>
<td>Academic degree</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.012</td>
<td>People with academic degree and managerial occupation were more likely to make use of tele-conferencing services which encouraged their use of multiple tele-services and tele-shopping activities. Whereas the effect for academic degree seems to sustain throughout the whole period, the effect of managerial occupation seems to have weakened over time. Moreover, if the managerial occupations had additional duties of supervising other people, the aforementioned effects were cancelled.</td>
</tr>
<tr>
<td>Academic degree</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>Managerial</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.058**</td>
<td></td>
</tr>
<tr>
<td>Managerial</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.059**</td>
<td></td>
</tr>
<tr>
<td>Supervisory duties</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>-0.031*</td>
<td></td>
</tr>
<tr>
<td>Supervisory duties</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>-0.031*</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.7 Standardised mediation (indirect) effects of covariates on outcome variables for ICT use and travel behaviour

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Mediator</th>
<th>Outcome</th>
<th>Wave</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Jul 2005</td>
<td>2 Jan 2007</td>
</tr>
<tr>
<td>Used computer within last 3 months</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.225**</td>
<td>0.305</td>
</tr>
<tr>
<td>Used computer within last 3 months</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.229**</td>
<td>0.342</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.095**</td>
<td>0.091**</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.096**</td>
<td>0.101**</td>
</tr>
<tr>
<td>Uses Internet at home</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.198**</td>
<td>0.248**</td>
</tr>
<tr>
<td>Uses Internet at home</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.202**</td>
<td>0.278*</td>
</tr>
<tr>
<td>Broadband Internet at home</td>
<td>Tele-conferencing</td>
<td>Tele-services</td>
<td>0.067**</td>
<td>0.028**</td>
</tr>
<tr>
<td>Broadband Internet at home</td>
<td>Tele-conferencing</td>
<td>Tele-shopping</td>
<td>0.068**</td>
<td>0.032**</td>
</tr>
</tbody>
</table>

Travel behaviour

| Gender: male                | Commuting               | Regular car user | 0.063*              | 0.003                           | 0.035*                          | 0.019                           | 0.036                           | 标记为 | *significant at 90% level |
| Employed full-time          | Commuting               | Regular car user | 0.366**              | 0.026                           | 0.294**                         | 0.229*                          | 0.219                           | 标记为 | **significant at 95% level |

Note: bold indicates significance at 90% level, *significant at 90% level **significant at 95% level
**Table 6.8 Standardised mediation (indirect) effects of covariates on outcome variables for ICT and travel behaviour interaction**

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Mediator</th>
<th>Outcome</th>
<th>Wave</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Jul 2005</td>
<td>2 Jan 2007</td>
</tr>
<tr>
<td>Age</td>
<td>Tele-conferencing</td>
<td>Commuting</td>
<td>-0.075</td>
<td>-0.023</td>
</tr>
<tr>
<td>Academic degree</td>
<td>Tele-conferencing</td>
<td>Commuting</td>
<td>0.012</td>
<td>0.009</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Tele-conferencing</td>
<td>Commuting</td>
<td>0.050</td>
<td>0.026</td>
</tr>
<tr>
<td>Uses Internet at home</td>
<td>Tele-conferencing</td>
<td>Commuting</td>
<td>0.106</td>
<td>0.070</td>
</tr>
<tr>
<td>Gender: male</td>
<td>Tele-shopping</td>
<td>Peak-time traveller</td>
<td>-0.018*</td>
<td>-0.021*</td>
</tr>
<tr>
<td>Employed full-time</td>
<td>Tele-shopping</td>
<td>Peak-time traveller</td>
<td><strong>-0.128</strong>*</td>
<td><strong>-0.104</strong>*</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Tele-shopping</td>
<td>Peak-time traveller</td>
<td>-0.037*</td>
<td>-0.029*</td>
</tr>
<tr>
<td>Employed full-time</td>
<td>Tele-services</td>
<td>Peak-time traveller</td>
<td>-0.078**</td>
<td><strong>-0.124</strong>*</td>
</tr>
<tr>
<td>Uses Internet at work</td>
<td>Tele-services</td>
<td>Peak-time traveller</td>
<td>-0.026</td>
<td>-0.042**</td>
</tr>
<tr>
<td>Used computer within last 3 months</td>
<td>Commuting</td>
<td>Tele-shopping</td>
<td><strong>0.062</strong>*</td>
<td>0.101</td>
</tr>
</tbody>
</table>

Note: bold indicates significance at 90% level, *significant at 90% level **significant at 95% level
6.5.1 Patterns of diffusion in ICT use and travel behaviour

Inspecting Table 6.7 provides grounds for a number of interesting observations regarding the ways that sociodemographic characteristics are associated with particular ICT uses and travel behaviour characteristics. Younger people are in general more enthusiastic about adopting online communication tools (teleconferencing) which included e-mail use, VoIP, and chat groups. Consequently, being exposed to the benefits of such form of communication, they appear also to be more likely user of additional tele-services and tele-activities.

At the same time married respondents and those belonging to larger households are found to be less enthusiastic about using multiple tele-conferencing tools with the consequent reduction in the number of tele-services and tele-shopping activities. A possible explanation for this pattern may be greater abundance of physical-reality based contact on everyday basis. As a consequence of this lower exposure to online communication tools, such individuals would also be less likely to adopt additional tele-services or tele-shopping activities.

Full-time employment has initially been associated with lower chances of using multiple tele-conferencing tools, and thence lower exposure to other tele-activities. Whilst academic degree and thus possibly greater literacy in terms of technological use as well as managerial position have been positively associated with teleconferencing adoption, the latter effect is weaker for individuals who supervise other people. This may be linked to greater inertia in adoption due to time needed to learn such tools, as well as potential aversion to malfunctioning or disadvantages of such tools. This interpretation appears to be in line with the fact that, the effect of supervisory duties became insignificant following the 1st wave of data (January 2005) which could indicate increased trust and perceived usefulness of the communication tools and other tele-services among those of managerial occupations. Clearly, accessibility, availability, as well as frequency of use of computer and Internet facilities, be it at work or home location, have remained key determinants of richer digital lifestyles. This result is hardly surprising, possibly reflecting numerous previous findings regarding the role of provision of facilities and incentives in exposing individuals to innovations which they can subsequently try and ‘customize more closely to [their] own conditions’ (Rogers, 2003, p. 258). In fact, it is likely that
the level of accessibility to computer and Internet facilities would also be associated
with other members of individual’s social networks, be those household members or
colleagues, adopting tele-activities. This fact can also serve as further explanation of
the observed importance of the covariates describing general availability and exposure
to digital technologies and their uses.

In terms of the travel behaviour characteristics, the findings largely conform to the
prevailing understanding of the relationships between gender, employment, need to
travel for work purposes, and regular car use. It is worth recalling that it was reported
previously in Table 6.5 that males were less likely to be regular car users though more
likely to have work as the primary travel purposes. This finding when seen in
conjunction with the current observations points out that the total (summed) effect of
gender on regular car use would be at most uncertain case. At the same time, it is
possible to observe a natural and stable relationship between employment and travel
for work purpose emphasising that propensity of regular car use tends to be linked in
a stable manner to the professional situation of an individual.

6.5.2 Patterns of diffusion in ICT and travel behaviour relationships

The primary objective of the current analysis has been that of investigating how what
variables can be used to delimit segments of population in which particular
interactions between ICT use and travel behaviour would emerge early or late. In such
a case, such groups could be identified as early adopters and early majority, or late
adopters and laggards in accordance with Rogers’ taxonomy (Rogers, 2003) and thus
provide consistent theoretical interpretation for how digital lifestyle and physical
mobility are co-evolving.

As a result Figure 6.2 (see next page) visualises the conceptual representation and
interpretation of the results previously summarised in Table 6.8. It should be noted
that that the logistic-shape of the curve is only a typical approximation to the process
of innovation diffusion usually encountered in the studies on adoption of new
products and services. In addition, the categorisation into groups of early/late
adoption etc., while emphasised as discrete for convenience is in fact an artificial
construct. In reality, the boundaries between the groups will typically be more blurred
reflecting smooth transition of the process between the categories. Finally, the dates
on the horizontal axes conform to the times when the effects became either significant
Figure 6.2 Characteristics of adoption segments and dynamics for three ICT and travel behaviour interactions in relation to the Rogers’ theory of diffusion of innovations
or ceased to be such, as observed in Table 6.8. In the current analysis, this fact is interpreted as an approximate commencement of the diffusion process (in the former case) widespread adoption of behaviour in the latter when the available characteristics of respondents cannot be used as indicators for higher or lower likelihood or adoption.

Investigating Table 6.8 and the uppermost panel in Figure 6.2 suggests that young to mid-age, well-educated, and Internet-using individuals would be in general keener to adopt tele-conferencing tools, and as a result of the connection with work-related travel, may also be associated with higher probability of reduction in work related travel. These findings are also consistent with the studies discussed in Chapter 2 where mid-aged and highly educated individuals were found more likely to adopt tele-work schemes (de Graaff and Rietveld, 2007; de Graaff, 2004; Hjorthol and Gripsrud, 2009; Hjorthol, 2002; Lila and Anjaneyulu, 2013; Nossum and Hjorthol, 2007; Sener and Bhat, 2010; Sener and Reeder, 2012; Singh et al., 2012). Similar conclusions can be reached in case of the impacts of home- and work-based Internet use which was also found as playing key role in tele-work and tele-commuting, though with more underlying heterogeneities discussed by (Hjorthol, 2002). At the same time, it is noticeable that a number of factors which would be conventionally seen as significant predictors of such behaviour, e.g. managerial position or personal income, appear have not been found significant in this current context. Possibly more detailed disaggregation in terms of actual duties, and necessity to be present physically at the office could shed more light on this finding.

These effects became noticeable following January 2007 which may suggest that a significant proportion of individuals, conforming to the segments of early adopters and early majority must have started to adopt such behaviour between January 2007 and January 2009. As the relationship started to weaken towards the later waves, without any further data it is only possible to speculate about future trajectories of this process. Such behaviour could either spread amongst the general population, or alternatively be limited to only certain groups which could be interpreted as what Moore called a ‘chasm’ somewhere in the region of early adoption/early majority (Moore, 1991). In fact, the latter case seems to be more likely given various rigidities involving remote work practices placing limitations on the possibility of reducing travel for work-related purposes as previously discussed in section 2.4. Moreover, the
continuing existence of significant work-related peak commute and other business trips suggests that this particular behaviour is not likely to reach complete penetration in the very near future. Nevertheless, more occasional use of tele-conferencing channels especially as a back-up solution, e.g. in case of illness or transport problems, should appears as a more and more popular feature interaction with physical mobility.

The middle panel indicates that those employed full-time, males, and Internet users are those who use more advanced tele-services and tele-shopping features, associated with less travel during peak times, usually for work-related purposes. When this result is confronted with the findings reported in Table 6.4, it is possible to notice that such characteristics coincide with higher likelihood of travelling for work-related purposes, and during the peak hours. Thus participation in tele-shopping and tele-services appeared to, at least partially, reduce such behaviour by providing degree of flexibility in terms of handling services that could perhaps require travel during the peak hours. The impact of sociodemographic characteristics has disappeared in the later waves which can be interpreted in conjunction with the more widespread tele-shopping and tele-services use at this time. A possible interpretation of this phenomenon could be in the context of relaxation of the fixity of schedules, activity participation constraints, and increasing spatio-temporal fragmentaiton (Alexander et al., 2010; Hamer et al., 1991; Zhu, 2012) which provided invididuals making use of ICT with more flexibility in terms of organising their activity-travel behaviour.

Regarding the bottom panel of Figure 6.2, the analysis indicates in the first wave of July 2005, existence of a positive relationship between the use of computer within the previous three months, and the level of engagement in tele-shopping activities as mediated due to negative relationships between the two and the likelihood of travelling for work as the most frequent purpose. Though (weakly) significant only in the first wave, this result could suggest that those using computer would be more likely to travel for non-work purposes, and also as a result be more willing to use ICT for shopping-related activities. This behaviour could be interpreted as initial use of tele-shopping channels by people who would travel more for tele-shopping, possibly having more interested in shopping activities in general. At the same time, it is worth noting that adoption of particular pattern of tele-shopping behaviour in relation to travel does not seem to be strongly associated with any sociodemographic features,
such as occupational characteristics, or affluence. This fact can be interpreted either as confirmation of the lack of consensus also reported in the literature (Cao, 2009) as well as with possible heterogeneity in tele-shopping behaviour (Bhat et al., 2003), or alternatively as indication of adoption of tele-shopping behaviour without regardless of travel behaviour characteristics, or for purposes which do not interact with it.

A final note on the patterns observed in Figure 6.2 concerns the time horizon over which the changes appear to have been taking place. Whereas some of the changes in relationships may have not been observed in the current analysis due to them taking place over longer time span, the three changes discussed appear to have taken place within a relatively short period of less than 5 years. This fact not only provides evidence for dynamism of the field, but also leads to implications for data collection efforts. More precisely, certain relationships between ICT and travel behaviour may emerge over a number of years while others may take only months. In both cases, (longitudinal) data collection protocols would need to be suitably adjusted to provide information of suitable granularity to enable accurate inference about the factors and pace of adoption of particular uses of ICT in relation to travel behaviour needs. In addition, it would be possible to argue that one of the possible outcomes of such evolution is change in the structure of the model implying different SEM specifications for different waves. However, tracing such changes in the current data context is not possible as modifying the specification could confound the estimates, and hence possibly lead to biased conclusions. Nonetheless, this point also emphasizes the need for more in-depth behavioural understanding of the ICT and travel behaviour relationships to be able to account for such structural changes for which simple econometric tools may not provide enough robust guidance.

6.5.3 Interpretation of the results in relation to the microeconomic framework

While the current findings reflect an aggregate, quasi-longitudinal perspective, to a significant extent driven by the characteristics of the available data, their emergence can be explained by referring to the microeconomic modelling framework developed in Chapter 4 and Chapter 5. Recall equation (5.16) which defined indirect utility associated with a particular choice of origin, in-travel and destination activities, $A, T1, T2, B$ respectively, mode $i$, route $j$, and ICT use $\psi$ conditional on trip and in-travel activity timing $(t_1^*, t_2^*)$: 
\[
V_{A,B,T_1,T_2,i,j,\psi}|_{t_1^*,t_1^*} = \int_{t_0}^{t_1^*} (u_A(z_A) + bw_A z_A) \, dt + \int_{t_1^*}^{t_1^*+r_{ij}(t_1^*)} (u_{T_1}(z_{T_1ij}) + bw_{T_1} z_{T_1ij}) \, dt \\
+ \int_{t_1^*}^{t_2^*} (u_{T_2}(z_{T_2ij}) + bw_{T_2} z_{T_2ij}) \, dt + \int_{t_1^*}^{t_1^*+r_{ij}(t_1^*)} u_T(z_Tij) \, dt \\
+ \int_{t_1^*}^{t_E} (u_B(z_B) dt + bw_B z_B) \, dt - bc_{ij} - bc_{ij} (r_{ij}(t_1^*)) 
\]

As it was discussed in section 5.3, such a formulation is capable of handling multiple aspects of travel behaviour and ICT use, including the case of remote participation in (tele-) activities as opposed to physical and travel-requiring participation. Assume for now that the current travel behaviour of an individual is characterised by a certain value of utility \(V_0\). This value would represent the status-quo situation such as travelling for work as the most frequent purpose, use of car or travelling during peak time as it is.

Now assuming in addition that due to a certain external condition, a new, ICT-based alternative characterised by utility \(V_1\) becomes available. This stage is in fact what Rogers identified as the first stage in innovation-decision process, (termed ‘Knowledge’) when ‘an individual is exposed to an innovation’s existence and gains understanding of how it functions’ (Rogers, 2003, p. 169). An additional requirement is that such innovation is also available to an individual in terms of conforming to various physiological, mental, and social needs and constraints. These would normally be different for innovators and early adopters, themselves more likely to be up-to-date with emerging technological novelties, and late majority and laggards who might only learn about an innovation from their social networks when it is comparatively widespread, or when they see that the level of advancement reduces risk of malfunction to an acceptable level.

As a result, a particular interaction of ICT and travel behaviour will emerge (i.e. be adopted) and possibly diffuse, only if alternative one characterised by indirect
utility $V_1$ is expected to be more beneficial than the status quo situation characterised by $V_0$ over the life-time of such a decision process, i.e. such a decision situation exists, e.g. remote work option is available or tele-service can be conducted. The latter qualification can be represented as a summation of the utilities over the expected number of such decision situations $E(S)$. That is to say that the probability of observing emergence of a particular interaction between ICT and travel behaviour, as represented by transition from alternative zero to alternative one can be described by the following condition:

$$P(0 \rightarrow 1) = P \left( E \left( \sum_{s=1}^{E(S)} V_0^s \right) > E \left( \sum_{s=1}^{E(S)} V_1^s \right) \right)$$

(6.3)

One can recall from the previous chapters that the indirect utilities are flexible in terms of incorporating functional forms and variables describing various impacts both alternative and individual specific. Thus the probability of adoption would normally be higher for innovators and early adopters, ceteris paribus, because of their attitudes, preferences, sociodemographic as well as situational characteristics. When aggregated over the whole population and over time, equation 6.3 describes the conditions which would lead to initial take up of innovation as well as subsequent adoption by the later groups leading to the multiple patterns observed earlier. Consequently, such interpretation provides a novel and consistent theoretical link between decisions undertaken by an individual in terms of their use of ICT and travel behaviour, the trends and patterns observed when modelling more aggregate and simultaneous relationships between digital and physical lifestyles.

6.6 Summary

The analysis presented in this chapter embarked upon an uneasy task of attempting to investigate and conceptualise the interactions between ICT and travel behaviour from a temporal perspective. Given the dynamic nature of the ICT sector and shortcomings in the availability of relevant data, the results obtained in the course of this investigation provide novel and original contribution to the research field despite their limited scope.
The current analysis revealed that young to mid-age, well-educated, and employed males as well as those with good access to ICT facilities are the most likely early adopters of particular behavioural interactions between ICT use and travel behaviour characteristics. While largely consistent with the cross-sectional results reported elsewhere exploring the field from a more time-oriented perspective demonstrated that such relationships would undergo a dynamic evolution over time which may also contribute to explaining some of the contradictory results reported in the studies on ICT and travel behaviour interaction. Moreover, a link to the theory of innovation diffusion was made which could be used as a means of further understanding of past evolutions and possible future trajectories of the relationships between physical and virtual realities. In addition, the SEM character of the study provided more detailed insight into the composition of aggregated travel and ICT demand, as well as their co-evolution over time. Such insights, especially when enhanced with information on particular segments of population to which they apply to, can prove beneficial when attempting to understand and react to ongoing changes in the lifestyles by designing appropriate policies as well as developing business cases focused on the interface between digital behaviour and physical mobility.

From the methodological point of view, the PICSaT approach was applied in the novel context of ICT and travel behaviour interaction. When combined with the multi-group SEM capabilities, the approach followed in the current analysis provided an interesting and easy to implement method for dealing with dynamics of complex phenomena when only RCS data is available. The added value of using SEM structure lies in its capability to provide insights into how different components of ICT and travel behaviour may be co-evolving at different paces for different individuals, introducing additional challenge for researchers attempting to model and understand such aspects of behaviour.

Clearly, the analysis possesses a number of limitations, of which perhaps the most fundamental is that of assuming a particular structure of the relationships between the variables. Being subject to a number of potential consequences and biases resulting from the possibility of bi-directional, simultaneous causality discussed in section 2.3 (itself to a large extent inherent feature of models dealing with multiple simultaneous relationships) the actual estimates may not be fully capable of translating the actual
complexity of the world into a simple abstraction. Nonetheless, demonstration of how such relationships emerge in terms of different segment of adoptions, their possibly different characteristics as well as times is in principle immune to the quality of the data characteristics which largely pre-determined the extent of the analytical methods available in the present context. Yet recommendation for the future data collection efforts is to incorporate (even in RCS) travel-related questions similar to those reported in a more traditional travel behaviour surveys (frequency of travel by various mode, purpose of travel, monetary cost of the trip, in-travel time use) simultaneously with information on ICT use. Moreover, continuous nature of such information (rather than simple categorical binary) could facilitate use of more advanced statistical tests to infer about causal effects, as well as quantify the impact of time on such evolutions. Additionally, more studies on what information could serve as instrumental variables for ICT uses (e.g. awareness of various web-based services and tools) or travel behaviour (e.g. cost of car insurance, type of bus ticket used) could possibly aid in obtaining results more robust to the aforementioned issues. Finally, investigation of possible ways of exploring structural changes in the relationships between variables and hence requirements for appropriate adjustments in model specifications should be explored, especially in terms of how such changes could be captured empirically.

Despite these limitations, the current contribution demonstrates the feasibility of gaining insights and interpretations of how the ICT use and travel behaviour relationships have evolved over time. Given the growing omnipresence of the former, and the continuing vitality of the latter, the importance of capability to investigate, model, and understand their joint interaction is essential for better provision of smart services, more efficient policies, and development of future business cases around the interface between digital lifestyles and physical mobility.
Chapter 7
CONCLUSIONS

In a recent ranking of the 20 largest companies in the world by market capitalisation, four (Apple, Google, and Microsoft, Samsung) had their core businesses focused on or closely related to mass ownership and use of ICT (PwC, 2014). Four years earlier in 2010, Mark Zuckerberg, the 26-year-old founder of Facebook was named Person of the Year by the Time Magazine. Both facts may be taken as simple indicators of the key role that ICT have been playing in today’s world. In addition, people’s increased participation in ICT-reliant activities has fuelled the beliefs that the importance of physical reality activities and thus travel, may diminish. So far, these effects have only been seen in certain and limited contexts which indicates much more significant sophistication of the interface between virtual and physical realities. What then are the implications for travel and transport systems resulting from the continuing evolution in ICT? What degree of confidence can be placed in the studies that have to date yielded either ambiguous or sometimes even contradictory answers? Can any universal conclusions be established given the dynamism and unprecedented pace of changes in this domain? These questions are what have motivated this thesis in trying to extend the existing modelling techniques to gain a more comprehensive understanding of the interactions between ICT and travel behaviour. Thus the three principal research objectives were pursued leading to a number of behavioural and methodological contributions discussed in the following sections.

7.1 RO1 contributions: Macro (Cross-national) Perspective

As part of the RO1 explored in Chapter 3, data from 4 countries: Canada, the United States, the United Kingdom, and Norway, were investigated for differences in the relationships between ICT use and travel behaviour using either complete (Canada),
or pooled datasets (the remaining countries) to estimate SEM. To the extent permitted by the data, the analysis suggested the existence of significant cross-national differences in the relationships between ICT use and travel behaviour. This was in spite of consistency across the countries in terms of the propensity to engage in multiple dimensions of ICT use simultaneously, as well as negative relationships between the amount of work-related travel and amounts of travel for any other purposes. Thus the results indicated that further developments and penetration of ICT in the society may not necessarily display homogenous patterns of interaction with travel behaviour. Last but not least, it was discussed that the aggregate patterns observed in the data would result from the decisions of individuals to adopt particular ICT use in relation to their travel behaviour which emphasised the presence of conceptual link to the microeconomic framework developed as part of RO2.

From the methodological point of view, the data pooling technique using the \( k \)-NN algorithm was shown to perform well in the current context. Comparative analysis of the differences in how parameter uncertainty could be quantified showed that by combining resampling and imputation procedures in the proper bootstrap method could provide robust means for inferences about the parameters’ significance.

### 7.2 RO2 contribution: Micro (Individual-level) Perspective

Addressing the RO2 in Chapter 4 and Chapter 5 was achieved through development of the microeconomic framework for decision-making involving joint choices on travel behaviour and ICT use. Application of the theoretical results in the context of modelling in-travel time use and productivity using data collected in the context of rail business travel in the United Kingdom revealed that multiple factors such as ICT use (in particular laptop, mobile phone, PDA/Smartphone, or Wi-Fi) together with journey characteristics, sociodemographics, as well as attitudes and prior in-travel activities were responsible for how the travellers chose to allocate their time between work and non-work purposes, and how productive they felt. In addition, the hypothesis of productive potential of in-travel time was incorporated in the context of business travel time valuation by means of the Hensher’s approach, demonstrating how increased capabilities of ICT may influence the perception of travel time, and thus possibly the investment appraisal methodologies. Another way in which the framework demonstrated its usefulness was by explaining a number of hypothetical,
yet reported elsewhere real-life scenarios such as the choice of remote activity participation during disrupted travel conditions, introduction of autonomous vehicles, or interaction of decision-making of two individuals.

The main methodological contribution was that of developing a suitable microeconomic representation grounded in the time allocation and goods-leisure trade-off paradigms, which enabled conceptualisation of a wide range of possible interactions between physical and ICT-enabled virtual reality, and the consequences for travel behaviour. The consequent theoretical results provided microeconomics-grounded decision rules for in-travel activity choice, interpretation of in-travel productivity, choice origin and destination activities (including the possibility of remote, or tele-activity participation), ICT use as well as travel mode, route, and trip timing. The econometric translation of these theoretical results was shown to lead to an empirically estimable specification as well as to provide capabilities of forecasting in-travel time use and productivity. The latter functionality could, on the other hand, be used in the context of valuation of business travel time from the employers’ point of view. In addition, the framework was shown to be linked with a number of econometric formulations, including hazard-based and discrete choice models. The latter link was also shown to provide theoretical justification and interpretation of subjective valuation of various qualities characterising travel alternatives (e.g. travel duration) or ICT bundles (e.g. Wi-Fi bandwidth).

7.3 RO3 contributions: Temporal (Pseudo-longitudinal) Perspective

In the analysis associated with the RO3 and described in Chapter 6, five repeated cross-sectional datasets from the 2000s UK were pooled across time to provide insights into how the ICT and travel behaviour interactions evolve over time. Subsequently, multi-group SEM relating ICT use and travel behaviour characteristics was estimated with the results related conceptually to the theory of innovation diffusion as well as the microeconomic framework of RO2.

In providing insight into how certain relationships between ICT use and travel behaviour evolved over the period, the analysis provided a novel contribution in a research area previously explored in only a handful of studies. The main behavioural conclusion that can be drawn from the analysis included the delineation of population
segments characterised by early and later adoption of particular relationships between particular ICT uses and travel behaviour. Thus younger, well-educated Internet users (both at home and work) were found to have their work-related travel reduced possibly as a result of more use of tele-conferencing tools with the pattern emerging as significant between late 2007 and early 2009. At a roughly similar time, another pattern was found to diminish. In particular, full-time employed males using Internet at work were found to exhibit reduction in propensity to travel during peak times (morning and afternoon), mostly for work-related purposes which could be attributed to their increased use of tele-services and tele-shopping. The final finding was that of an increased tele-shopping use among computer users as a result of more non-work-related travel which was observed in 2005. When interpreted in conjunction with the general patterns of ICT use and travel behaviour in the population, the first result applied only to a limited segment of population, i.e. early adopters, and necessarily being feasible to diffuse among all people due to restrictions placed by employers or occupations. At the same time the latter disappearance of two results could be perhaps interpreted on the grounds of diffusion of similar practices to beyond the segments of early adoption, i.e. into the general population, following more widespread ICT use.

Given that one of the biggest methodological challenges in this research field has remained the relative lack of suitable longitudinal data for modelling dynamics of change in the interactions between ICT and travel behaviour, the use of pooling independent cross-sections across time, or PICSaT, was found a promising alternative. Though limited in its capabilities by dealing only with comparative statics, it still demonstrated how a well-established econometric tool, i.e. multi-group SEM could be employed in such contexts, and how its mediation analysis could be used in conjunction with the innovation diffusion theory to provide valuable interpretations of the trends observed in data. Finally, a conceptual link was demonstrated in terms of how the microeconomic framework developed as part of RO2 could be linked with the decisions by individuals regarding their adoption of ICT in relation to travel behaviour.

7.4 Synthesis

The overall picture that emerges from drawing together the results obtained in the previous chapters is that of an individual who, in the more and more digitised world,
faces multiple ways to satisfy various needs. This is because activities which would traditionally fulfil such needs can be increasingly undertaken either in physical, or virtual, or indeed in a mixture of the two realities. The developments presented in the thesis provide novel ways of abstracting and understanding how such an individual would make decisions facing different trade-offs resulting from attributes characterising particular choices defining activity-travel behaviour, including its ICT-enabled aspects.

When approaching the issue from a micro perspective by means of modelling the interactions at the level of an individual, the actual choices will ultimately depend on the interplay of multiple factors, including preferences, attitudes, and socioeconomic characteristics, as well as external factors such as capabilities of ICT, travel conditions, or even higher aspects of natural conditions, regulations, policies, and social norms. What the microeconomic framework developed in the thesis enables is joint treatment of such factors in a single model of individual behaviour flexible enough to accommodate various patterns of their interaction. Such framework provides a means of decomposing notoriously complex patterns of interaction between ICT use and travel behaviour into more basic, and easier to handle in terms of understanding, modelling or possibly influencing, behavioural components. These capabilities, on the other hand, open avenues for devising more efficient solutions such as services, products, and policies aimed at better utilisation of the growing interface between physical and virtual realities.

At the same time, the temporal perspective on the phenomenon reveals that despite the growing popularity and use of various applications of ICT, i.e. their diffusion among general public, the exact implications and impacts for travel behaviour will differ between the segments of population. Whereas these results, pointing towards complexity of the interactions between ICT and travel behaviour, have been noted in the existing studies, the current contribution demonstrated in a systematic manner how this complexity and possibly contradictory empirical results may be arising from individual decisions, even when the decision-makers are assumed to follow simple, economically rational rules.

In addition, the results obtained in the thesis lead to a number of recommendations for potential future actions by various stakeholders operating in the area, including
academia, industry, and policy makers. One of such fields would most likely be that of facilitation of richer, more resource-efficient, and better informed decision-making in situations such as those conceptualised in the microeconomic framework. Thus more accurate, up-to-date and reliable information provision, smart solutions more closely integrating ICT and transport infrastructures, or decision support tools appear as areas where efforts ought to be concentrated and novel solutions generated. Moreover, such solutions could benefit both individuals and society in more general through, for instance, leading to greater satisfaction from the choices made and ultimately more efficient and equitable allocation of resources as well access to knowledge and services.

In addition, further sophistication in terms of virtualisation and automatisation of certain activities may be seen as the future means of freeing up time and resources from actions that individuals would normally seek to avoid. This freeing from tiring and repetitive maintenance tasks may enable reallocation of more assets to pleasurable activities. At the same time, wider range of virtual activities may lead to benefits of greater and longer-lasting independence for groups previously socially excluded and disadvantaged on the grounds of various mobility difficulties and limitations. Obviously, such solutions may require adequate adjustment to local cultural, legal and natural conditions, as well as establishment of appropriate regulations and best practices which is especially evident in light of the evidence for cross-national differences in ICT and travel behaviour interactions. At the same time, however, cross-national exchange of experience would almost certainly yield beneficial outcomes and synergies, for instance in terms of inspecting cross-nationally the role of changing economic circumstances, such as those of the late 2000s financial crisis, on mobility and ICT use patterns. Furthermore, closer focus on younger generations bred in the conditions of omnipresent ICT and widespread connectivity may provide insights into what future uses of technologies in relation to travel needs may look like, thus also stimulating innovative solutions for the more digitally-immersed generations.

Nevertheless, there are also challenges which must be confronted in parallel to such potential novelties. Just as travel relies on transport infrastructure, so do tele-activities on ICT infrastructure. This fact justifies continuing efforts towards increasing
resilience against disruptions and threats posed by detrimental actions such as cyber terrorism, identity thefts, frauds, or harassments. The perplexing nature of this area will be that of ensuring that more effective policing does not compromise individuals’ privacy and liberty given the growing set of pervasive sensing and monitoring tools. This is also an important area for researchers as pervasive sensing and monitoring technologies could be seen data and research paradise, but at the same time can be ethical and privacy hell if appropriate regulatory mechanisms, best practices, and levels of awareness are not ensured. The developments presented in this thesis may not completely solve these incoming dilemmas, but can perhaps contribute to increased understanding of how the interactions between the ICT and travel behaviour take place and hence help guiding societies not only to more digitised future, but also to more prosperous and efficient one.

7.5 Limitations and potential directions for future research

Yet as in case of any research effort undertaken in a field that is dynamically changing and challenging, the results obtained in the thesis while providing novel insights are not free from limitations that could, nevertheless, be seen as potential avenues for future studies.

Perhaps the most pressing issue remains that of the available data which, for various reasons, provided a means of investigating only limited aspects of the field only. The specific topics that would deserve exploration in the future include gaining insights into the robustness of the data pooling approach, the extent to which productivity can be assessed by individuals themselves, as well as harmonisation in data aimed at consistent, and hence also comparative measurements of digital behaviour. Perhaps such efforts could also facilitate testing of the proposed theoretical (microeconomic) framework in other empirical contexts, such as those discussed as the hypothetical scenarios, or using different econometric formulations. Such approaches could lead to refinements in the proposed theory and hence lead to more comprehensive and universal understanding of the interactions between digital behaviour and physical mobility.

Another direction which could be pursued in the future is that of investigating the degree of existence of causal relationships in the interactions between ICT and travel
behaviour. The challenging nature of this question resulting from the possibility of impacts occurring along multiple, and complex dimensions, have to date limited the extent to which such areas were explored. Nevertheless, the area certainly requires deeper inquiry, especially in terms of investigating suitability of potential remedies for the issues of endogeneity, including tests of possible instrumental variables, and or questions that should be included in the future data collection efforts.

Finally, the study was from the very beginning strongly focused on the behavioural (demand) side of the interactions between ICT and travel. However, there exists also another, also dynamically evolving supply side of such interactions in the field of ITS, including autonomous driving, more accurate positioning, or travel time prediction. Whereas the current study attempted to incorporate some of these developments at least at a theoretical level, further efforts should be directed at empirical studies into interaction between these two sides of technological impacts on travel behaviour. Such approaches will definitely become increasingly desirable, especially in light of the continuing integration of functionalities of modern ICT leading to impacts originating in behavioural and infrastructural changes alike.
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Appendix 1
Travel time studies reviewed in section 2.8

Table A.1 Reviewed travel time studies

<table>
<thead>
<tr>
<th>No.</th>
<th>Authors</th>
<th>Date</th>
<th>Approach</th>
<th>Context</th>
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<td>1</td>
<td>Verschuren and Ettema</td>
<td>2007</td>
<td>Mixed multinomial logit, multitasking scale, stated preference exercise</td>
<td>Car and public transport commuters in Eindhoven, the Netherlands, public transport and car</td>
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<td>3</td>
<td>Lyons et al.</td>
<td>2007</td>
<td>Cross-tabulations</td>
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<td>2012</td>
<td>Cross-tabulations, multinomial regression</td>
<td>National Rail Passenger Survey in the United Kingdom</td>
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<td>Lyons and Urry</td>
<td>2005</td>
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<td>Review of the prevailing discourses in the light of ICT development</td>
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<td>2005</td>
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<td>Gamberini et al.</td>
<td>2013</td>
<td>Descriptive statistics, multinomial regression</td>
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<td>Jain and Lyons</td>
<td>2008</td>
<td>Focus groups, conceptual discussion</td>
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<td>Report for the US Department of Energy</td>
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<td>O'Hara et al.</td>
<td>2002</td>
<td>Activity diaries, interviews</td>
<td>Mobile professionals, various modes of transport, United Kingdom</td>
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<td>Ettema et al.</td>
<td>2010</td>
<td>2-day activity-travel-communication diaries, CHAID to explore interaction between the factors</td>
<td>Car/train/bus/tram/metro travellers, Utrecht-Amersfoort-Hilversum region, the Netherlands</td>
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<td>Van der Waerden et al.</td>
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<td>Context</td>
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<td>Survey, cross-tabulations and descriptive statistics, Chi-square tests</td>
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<td>Bellinger et al.</td>
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<td>Laboratory experiment, correlations, ANOVA, hierarchical regression</td>
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<td>Holley et al.</td>
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<td>Townsend</td>
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<td>White et al.</td>
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<td>Alexander et al.</td>
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<td>Activity-travel-communication diaries, bivariate correlations, cluster analysis</td>
<td>The Netherlands</td>
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50 Redmond and Mokhtarian 2001 Survey, focus groups, Tobit regression, ordered probit Commuters in the San Francisco Bay Area, United States

51 Batley et al. 2012 Policy analysis Discussion on economic appraisal methods in the United Kingdom in the context of High Speed 2 investment

52 DfT 2012 Policy analysis Discussion on economic appraisal methods in the United Kingdom in the context of High Speed 2 investment

53 Sipress 1999 Interviews Washington DC, United States

54 Kwan et al. 2007 Guest editorial Complexity of interactions between ICT and travel behaviour

55 Price and Matthews 2013 Interviews Rail/car trips, Leeds, United Kingdom

56 Line et al. 2011 Interviews and diaries Bristol, United Kingdom

57 Ophir, et al. 2009 Laboratory experiment, graphical analysis, descriptive statistics Laboratory experiment, Stanford University students, United States

58 Haynes 2010 Interviews Ireland

59 Cheng et al. 2014 Review and discussion of Wi-Fi offloading studies Analysis of the feasibility of Wi-Fi offloading

60 De Oña et al. 2014 Survey, decision tree Rail trips, Italy

61 Hultkrantz 2013 VTTS expressions; 3 scenario analyses Rail, Norway/Sweden/China

62 Richardson 2003 Meta-analysis of a stated preference study Public/private transport modes, Singapore

63 Welki and Zlatoper 2014 Cross-national time series regression Car users, panel of 38 countries over 3 years

64 Bruyas et al. 2009 Driving simulator experiment France

65 Gerdes 2013 Discussion of the prevailing trends Important trends for the use of rail stations

66 Hislop 2012 Survey, interviews, descriptive statistics Car-driving business travellers on work-related journeys, United Kingdom

67 Hagen 2009 Survey, interviews, market segmentation Rail users, the Netherlands

68 Perry et al. 2001 Interviews Mobile professionals in the United Kingdom

69 Oulasvirta and Sumari 2007 Case study, interviews, participant observation Various transport modes, Finland

70 Rhee et al. 2013 Survey, probit regression Public/private transport mode users, South Korea

71 Fraszczczyk and Mulley 2012 Survey, cross-tabulations Public transport/car/bicycle/walking modes, United Kingdom

72 Middleton and Cukier 2006 Interviews Canada

73 Song et al. 2009 Fieldwork measurement of pollution particle sizes School buses, Connecticut, United States
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<th>Year</th>
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Appendix 2
Literature database conversion into network representation

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Figure A.1 Screenshot of a sample of the literature database structure

Structure of the input file for network-drawing software PAJEK:

*Vertices 41
1 "Ettema D"
2 "Verschuren L"
3 "Aguilera A"
4 "Guillot C"
5 "Rallet A"
6 "Lyons G"
7 "Jain J"
8 "Atkins S"
9 "Susilo Y"
10 "Urry J"
11 "Holley D"
12 "Mokhtarian P"
13 "Gamberini L"
14 "Spagnoli A"
15 "Miotto A"
16 "Ferrari E"
17 "Corradi N"
18 "Furlan S"
19 "Salomon I"
20 "Niles J"
21 "O'Hara K"
22 "Perry M"
23 "Sellen A"
24 "Brown B"
25 "Alexander B"
26 "Hagen M"
27 "van der Waerden P"
28 "Timmermans H"
29 "van Neerven R"
30 "Gripsrud M"
31 "Hjorthol R"
32 "Kenyon S"
33 "Ory D"
34 "Bull M"
35 "Du Gay P"
36 "Hall S"
37 "Janes L"
38 "Mackay H"
39 "Negus K"
40 "Murtagh G"
41 "Ross K"

*Edges
1 2
3 4
3 5
4 5
6 7
6 8
7 8
9 6
9 7
6 7
6 10
6 11
10 11
13 14
13 15
13 16
13 17
13 18
14 15
14 16
14 17
14 18
15 16
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15 18
16 17

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Python code for transforming database from figure into the input file structure:

```python
def name():
    'Asks for a name of a file from which authors will be taken'
    print('"
    Please provide a name of the file (case sensitive), e.g. "file_name.txt".
    Please do not include text file extension .txt
    If default name "data.txt" is to be used, press Enter"
    file_name_user = input('Name of the file: 
    file_name = str(file_name_user[:-1]) + ".txt"
    print (file_name)
    if file_name_user[:-1] == '':
        file_name = 'data.txt'
    print (file_name)
    return file_name

def progress_bar(tot_no_lines, current_no):
    'Shows progress of going through each line'
    accomplished = float(current_no) / float(tot_no_lines)
    if accomplished < 0.1:
        bar = ' _ _ _ _ _ _ _ _ _ _ '
    elif (accomplished >= 0.1) and (accomplished < 0.2):
        bar = '| _ _ _ _ _ _ _ _ _ _ '
    elif (accomplished >= 0.2) and (accomplished < 0.3):
        bar = '| | _ _ _ _ _ _ _ _ _ _ '
    elif (accomplished >= 0.3) and (accomplished < 0.4):
        bar = '| | | _ _ _ _ _ _ _ _ _ _ '
    elif (accomplished >= 0.4) and (accomplished < 0.5):
        bar = ' | | | | _ _ _ _ _ _ _ _ _ _ '
```
elif (accomplished >= 0.5) and (accomplished < 0.6):
    bar = '| | | | | _ _ _ _ _ |
elif (accomplished >= 0.6) and (accomplished < 0.7):
    bar = '| | | | | | _ _ _ _ |
elif (accomplished >= 0.7) and (accomplished < 0.8):
    bar = '| | | | | | | _ _ _ |
elif (accomplished >= 0.8) and (accomplished < 0.9):
    bar = '| | | | | | | | _ _ |
elif (accomplished >= 0.9) and (accomplished < 1):
    bar = '| | | | | | | | | _ |
else:
    bar = '| | | | | | | | | | |
print (bar, '\n', int(100*accomplished), '% done.\n')
print ('\n')
return

def list_creation(file):
    'Takes file as defined by name and extracts authors, creating a list with tuples'
    print ('\nCreating list of authors now.\n')
text_file = open(file, 'r')
no_lines = 0
no_lines_total = 0

for line in text_file: #Counts number of lines for progress
    no_lines_total +=1

    text_file.close()
    text_file = open(file, 'r')
    list_authors_raw = text_file.readlines()  #Imports authors
    list_final = [] #Creates empty list to store final tuples
    with the authors
        entry = '' # Defines entry
        for entry in list_authors_raw: #For each entry in the list of
            authors imported from a file
                switch_letter = 1 #If author's name has begun - variable
                set to zero
                common_paper_authors = ()
                letter_entry = ''
                author = ''

                for letter_entry in entry: #For letter in the entry list
                    if letter_entry == '"' and switch_letter == 0: #If first
                        quotation mark - indicate that it is author's name and move to next
                        letter
                            switch_letter = 1
                            continue
                    elif letter_entry == '"' and switch_letter == 1: #If
                        second quotation mark - indicate it's not author's name anymore,
                        append the current to the tuple and move to next
        if author =='':
            continue
        #switch letter = 0
        common_paper_authors += (author,)
        if common_paper_authors[0]=='':
            common_paper_authors = common_paper_authors[1:]
        print(common_paper_authors)
        author = ''
        continue
elif letter_entry != '"' and switch_letter == 1: #If
    author += letter_entry
    continue
else:
    continue
list_final.append(common_paper_authors)
print(list_final)
return list_final

def dictionary(list1):
    'Creates dictionary from a list of authors, by allocating numbers
to each author'
    print ('
Creating dictionary now
')
dict1 = {} #Creates empty dictionary
key = 1 #Sets key to one
total = len(list1) #For progress bar
current = 0 #For progress bar
for element in list1: #For each article
    current += 1
    progress_bar(total, current)
    for member in element: #For each author in an article
        if member in dict1: #Skip if already in the dictionary
            print(member, 'already in dictionary with key:',
            dict1[member])
            continue
        else: #If not yet, add to dictionary with
            print(member, key)
            dict1[member]=key #Adds to dictionary member= author,
            key is individually allocated number
            key+=1 #Update key value
print (dict1) #Displays whole dictionary
print (str(key-1), ' entries.')
dict1_file = file[4:]+'_auth_dict.txt' #Creates name for
dictionary file
dict1_file = open(name_dict1_file, 'a+') #Creates empty
dictionary file
print (name_dict1_file)
number = 1 #Variable for sorting dictionary from 1 to n
while number < key: #While number is smaller than total number of
    keys allocated (no. of keys allocated is key-1)
    for element in dict1: #For each element in dictionary
        if dict1[element]== number: #If element has key equal to
            to_write = str(dict1[element])+"'"+str(element)+"'" #Append in the Pajek-friendly form
            print(to_write)
            dict1_file.write(to_write)
            number += 1 #Update number
            to_write = None #Clean to_write variable
        else: #Skip otherwise
            continue
dict1_file.close()
return dict1 #Returns dictionary where you can search through
authors for their individual numbers

def dictionary_invert(dictionary):
    'Inverts dictionary, by making values keys, and keys values'
dict_inv = {} #Creates new empty dictionary
for element in dictionary:
new_key = dictionary[element]
dict_inv[new_key] = new_value
return dict_inv

def pajek_pairs(list1, dictionary):

    'Creates pairs of authors co-writing articles'
    current = 0  # For progress bar use
    total = len(list1)  # For progress bar use
    node1 = None  # Creates empty node 1
    node2 = None  # Creates empty node 2 which with node 1 will form a
    # pair to be exported to pajek file.
    pajek_list = []  # Creates empty pajek list

    for element in list1:  # For each element in the list of authors
        grouped by common articles
            current += 1  # For progress bar
            progress_bar(total, current)
            length = len(element)  # Deduces if the article was written by
            # single or multiple authors
            if length > 1:  # If by more than one author
                final = length - 1  # Set final position of the element in a
                # group (one smaller than the length)
                pair1 = 0  # Position of the first author in the list
                pair2 = 1  # Position of the second author in the list
                if length < 2:  # Skip if only one author (no pair to be
                    # matched)
                    continue
                else:
                    while pair1<final:  # The loop created to include all
                        possible combinations of authors ( A,B,C => AB, AC, BC)
                            while pair2<length:
                                node1 = dictionary[element[pair1]]  # Read keys for
                                # the authors from the dictionary
                                node2 = dictionary[element[pair2]]  # Read keys for
                                # the authors from the dictionary
                                entry = str(node1) + ' ' + str(node2) + '\n'  # Create
                                # pajek-friendly entry in the file
                                pajek_list.append(entry)  # Appends the list with
                                # pajek-friendly entry
                                pair2 += 1  # Updated number of pair2 variable
                                node1 = None  # Clears node
                                node2 = None  # Clears node
                                pair1 += 1  # Updates number of pair1 variable
                                pair2 = pair1+1  # Sets pair2 as bigger than pair1

    print(pajek_list)  # Prints all pairs
        name_pajek_list_file = file[4] + '_auth_pajek_list.txt'
    # Creates a name for a file with list of authors
    pajek_list_file = open(name_pajek_list_file, 'a+')  # Creates empty
    # file for list of authors
    pajek_list_file.writelines(pajek_list)  # Writes a list to a
    # separate file
    pajek_list_file.close()  # Closes the file
    return pajek_list  # Returns list with pajek pairs

def pajek_file(pajek_list, dictionary):

    'Create a complete PAJEK file, ready for drawing network'
    name_pajek_file = file[4] + '_auth_pajek.net'  # Creates name for
    # PAJEK file
    pajek_file = open(name_pajek_file, 'a+')  # Creates empty PAJEK
    # file

vertices = '*Vertices ' + str(len(dictionary)) + '
'  # Creates a line with number of vertices
pajek_file.write(vertices)  # Appends that line
number = 1  # Number set to make sure authors are written in orderly manner
while number <= len(dictionary):  # For all allocated numbers
    for element in dictionary:  # For each element
        if dictionary[element] == number:  # If value of the key is equal to current number
            to_write = str(dictionary[element]) + '"' + str(element) + '" '  # Append in pajek-compatible way
            pajek_file.write(to_write)
            number += 1  # Update ordering number
            to_write = None  # Clear to-write variable
        else:  # Skip otherwise
            continue
    edges = '*Edges
'  # Create a line with Edges
pajek_file.write(edges)  # Append that line
pajek_file.writelines(pajek_list)  # Append pajek_file with list of pairs
pajek_file.close()  # Close the file

# Actual script
print('''Welcome to ItuP 1.0 (ISI to Pajek). Copyrights: Jacek Pawlak 2011
It converts ISI-derived file to a network files suitable for analysis with PAJEK software. The input is text file, converted from HTML file exported from ISI Marked List. The output (for a file named 'data.txt') are the following files:
data_auth_pajek.net - for direct use with PAJEK, draws a non-directional network of co-authorship
data_auth_list.txt - list of authors grouped by common articles
data_auth_dict.txt - dictionary with authors and their individually allocated numbers
data_auth_pajek_list.txt - list of PAJEK pairs (using numbers from a dictionary)
...''')
raw_input('Press Enter to continue ItuP')  # Launches the programme

file = 'Authors.csv'  # name() # Takes the name of a file to be analysed
list1 = list_creation(file)  # Extracts authors from the file grouped by coauthorship
dict1 = dictionary(list1)  # Allocates individual numbers to each author, thus creating a dictionary
dict_inv = dictionary_invert(dict1)  # Creates inverted version of the dictionary
pj_pairs = pajek_pairs(list1, dict1)  # Creates PAJEK-friendly list pairs of authors (number with number)
pajek_file(pj_pairs, dict1)  # Concatenates dictionary with PAJEK-list and creates file for PAJEK usage.
input('Press enter to exit!')
## Appendix 3
### Construction of the aggregate ICT and travel behaviour variables

<table>
<thead>
<tr>
<th>Table A.2 Composition of the aggregate ICT and travel behaviour variables</th>
</tr>
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<td><strong>Country/Variable</strong></td>
</tr>
<tr>
<td><strong>Canada</strong></td>
</tr>
<tr>
<td><strong>ICT use</strong></td>
</tr>
</tbody>
</table>
| Communication | Total daily duration (in minutes) of:  
- using E-mail (writing and reading);  
- talking on the phone;  
- text messaging using a cell-phone;  
- writing/typing letters;  
- other media or communication. |
| Social | Total daily duration (in minutes) of participating in:  
- chat groups;  
- social networking websites. |
| Shopping | Total daily duration (in minutes) of:  
- online selling goods and services;  
- purchasing everyday goods, durable household goods;  
- downloading and/or ripping media. |
| Leisure | Total daily duration (in minutes) of:  
- playing video games/computer/exercise-based games;  
- surfing the Internet;  
- listening to radio and watching television online;  
- other computer and Internet-based leisure activities. |
| Services | Total daily duration (in minutes) of:  
- searching Internet for recipes;  
- using the Internet for research; |
- reading online magazines, newspapers;
- other education-related and any other Internet-based activities.

<table>
<thead>
<tr>
<th>Travel Work</th>
<th>Total daily duration (in minutes) of travel to/from/during paid work.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Total daily duration (in minutes) of travel to/from socializing meetings.</td>
</tr>
<tr>
<td>Shopping</td>
<td>Total daily duration (in minutes) of travel to/from shopping.</td>
</tr>
</tbody>
</table>

**Leisure**

Total duration (in minutes) of travel to/from attending/participating in:
- sport events;
- coaching activities;
- entertainment events;
- hobbies;
- pleasure drives.

**Other**

Total duration (in minutes) of travel to/from:
- unpaid domestic activities;
- care for household members;
- personal care activities;
- civic or voluntary services;
- religious services;
- school education;
- media and communication;
- restaurants and cafes;
- other personal reasons and purposes.

### United States

#### ICT use

<table>
<thead>
<tr>
<th>Communication</th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• made a phone call online;</td>
</tr>
<tr>
<td></td>
<td>• sent or read e-mail.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social</th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• created or worked on their own online journal or blog;</td>
</tr>
<tr>
<td></td>
<td>• read someone else's online journal or blog.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shopping</th>
<th>Binary variable describing whether an individual has ever ordered a product or service that was offered in an unsolicited email.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Leisure</th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• looked for information about a hobby or interest online;</td>
</tr>
<tr>
<td></td>
<td>• took material from online-like songs, texts or images-and remix it into your own artistic creation;</td>
</tr>
<tr>
<td></td>
<td>• watched videos online;</td>
</tr>
<tr>
<td></td>
<td>• created an avatar or online graphic representation of themselves.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Services</th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• got news online;</td>
</tr>
</tbody>
</table>
- not including email, did any type of work or research online for your job;
- looked for information on Wikipedia;
- looked for religious or spiritual information online.

### Travel

Total daily duration (in minutes) of travel related to:

**Work**
- working;
- work-related activities;
- income-generating activities.

**Social**
- socializing and communicating;
- attending or hosting social events;
- phone calls.

**Shopping**
- grocery shopping;
- purchasing gas;
- purchasing food (not groceries);
- shopping, excluding groceries, food, and gas.

**Leisure**
- related to relaxing and leisure;
- related to arts and entertainment;
- related to participating in sports/exercise/recreation;
- related to attending sporting/recreational events;
- as a form of entertainment.

**Other**
- personal care;
- housework;
- eating and drinking
- food and drink preparation, clean-up, and presentation;
- interior and exterior maintenance, repair, and decoration;
- lawn, garden, and houseplant care and services;
- care for animals and pets, including pet services;
- vehicle care and maintenance;
- appliance, tool, and toy set-up, repair, & maintenance;
- household management and services, including real estate;
- caring for and helping household and non-household children and adults, including education, health, and childcare;
- job search and interviewing;
- extracurricular activities (excluding sports);
- taking class
- research/homework;
- registration/administrative activities and government services, including civic obligations and participation;
- financial services and banking;
- using legal services;
- using medical services;
- religious/spiritual practices
- volunteering;
- other personal reasons and purposes.

<table>
<thead>
<tr>
<th>United Kingdom</th>
<th>ICT use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of activities individual participated:</td>
</tr>
<tr>
<td></td>
<td>• sent/received e-mails;</td>
</tr>
<tr>
<td></td>
<td>• telephoned over the Internet/video calls.</td>
</tr>
<tr>
<td>Communication</td>
<td>Social</td>
</tr>
<tr>
<td></td>
<td>Binary variable describing whether an individual has ever posted a message to chat sites, blogs, or other social networking sites.</td>
</tr>
<tr>
<td></td>
<td>Number of activities individual participated:</td>
</tr>
<tr>
<td></td>
<td>• looked for information about goods and services online;</td>
</tr>
<tr>
<td></td>
<td>• ordered food;</td>
</tr>
<tr>
<td></td>
<td>• ordered clothes</td>
</tr>
<tr>
<td></td>
<td>• ordered furniture.</td>
</tr>
<tr>
<td>Social</td>
<td>Shopping</td>
</tr>
<tr>
<td></td>
<td>Number of activities individual participated:</td>
</tr>
<tr>
<td></td>
<td>• listened to web radio or watched web television;</td>
</tr>
<tr>
<td></td>
<td>• uploaded self-created content to any website to be shared;</td>
</tr>
<tr>
<td></td>
<td>• played or downloaded games, images, films or music.</td>
</tr>
<tr>
<td>Shopping</td>
<td>Leisure</td>
</tr>
<tr>
<td></td>
<td>Number of activities individual participated:</td>
</tr>
<tr>
<td></td>
<td>• used services related to travel and accommodation;</td>
</tr>
<tr>
<td></td>
<td>• arranged travel online;</td>
</tr>
<tr>
<td></td>
<td>• ordered tickets online;</td>
</tr>
<tr>
<td></td>
<td>• read or downloaded online news/newspapers/news magazines;</td>
</tr>
<tr>
<td></td>
<td>• looked for a job or sent a job application;</td>
</tr>
<tr>
<td></td>
<td>• sought health-related information</td>
</tr>
<tr>
<td></td>
<td>• ordered health-related product;</td>
</tr>
<tr>
<td></td>
<td>• sought information about education, training or course offers;</td>
</tr>
<tr>
<td></td>
<td>• did an online course (in any subject);</td>
</tr>
<tr>
<td></td>
<td>• consulted the Internet with the purpose of learning;</td>
</tr>
<tr>
<td></td>
<td>• did Internet banking;</td>
</tr>
<tr>
<td></td>
<td>• donated to charities online;</td>
</tr>
<tr>
<td></td>
<td>• obtained information from public authorities web sites;</td>
</tr>
<tr>
<td></td>
<td>• downloaded official forms;</td>
</tr>
<tr>
<td></td>
<td>• sent filled in forms;</td>
</tr>
<tr>
<td>Leisure</td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Total daily duration (in minutes) of travel related to:</td>
</tr>
<tr>
<td></td>
<td>• commuting;</td>
</tr>
<tr>
<td></td>
<td>• business duties.</td>
</tr>
<tr>
<td>Travel</td>
<td>Work</td>
</tr>
<tr>
<td></td>
<td>Social</td>
</tr>
<tr>
<td></td>
<td>Total daily duration (in minutes) of travel related to:</td>
</tr>
<tr>
<td></td>
<td>• visiting friends at their houses;</td>
</tr>
<tr>
<td></td>
<td>• visiting friends elsewhere.</td>
</tr>
<tr>
<td><strong>Shopping</strong></td>
<td>Total daily duration (in minutes) of travel related to shopping.</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Total daily duration (in minutes) of travel related to:</td>
</tr>
<tr>
<td></td>
<td>- entertainment;</td>
</tr>
<tr>
<td></td>
<td>- sport;</td>
</tr>
<tr>
<td></td>
<td>- travel for holidays.</td>
</tr>
<tr>
<td><strong>Leisure</strong></td>
<td>Total daily duration (in minutes) of travel related to:</td>
</tr>
<tr>
<td></td>
<td>- education;</td>
</tr>
<tr>
<td></td>
<td>- escorting children and other household members;</td>
</tr>
<tr>
<td></td>
<td>- other personal reasons and purposes.</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Total daily duration (in minutes) of travel related to:</td>
</tr>
<tr>
<td></td>
<td>- education;</td>
</tr>
<tr>
<td></td>
<td>- escorting children and other household members;</td>
</tr>
<tr>
<td></td>
<td>- other personal reasons and purposes.</td>
</tr>
</tbody>
</table>

**Norway**

**ICT use**

<table>
<thead>
<tr>
<th><strong>Communication</strong></th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- used e-mail in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- participated in videoconferencing in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- used the Internet to make phone calls.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Social</strong></th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- used chats in the last 3 months?</td>
</tr>
<tr>
<td></td>
<td>- sent messages in the chat, newsgroups, and other forums.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Shopping</strong></th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- requested information about products/services in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order goods/services in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to sell goods/services in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order food/groceries in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order household products in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order a movie/music in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order books/newspapers/magazines/learning materials in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order clothing/sporting goods in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order a computer program product in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order PC hardware in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order electronic equipment in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- used Internet to buy/order another product/service in the last 12 months;</td>
</tr>
<tr>
<td></td>
<td>- purchased movies/music over the Internet.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Leisure</strong></th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- used Online Radio/TV in last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- used played/downloaded games/music in the last 3 months.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Services</strong></th>
<th>Number of activities individual participated:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- used services related to travel/accommodation in the last 3 months;</td>
</tr>
<tr>
<td></td>
<td>- downloaded software in the last 3 months;</td>
</tr>
</tbody>
</table>
- used/read/downloaded newspapers/magazines in the last 3 months;
- looked for work/made job application via the Internet in the last 3 months;
- used Internet for banking services in the last 3 months;
- used Internet to purchase shares/do other financial services in the last 3 months;
- used Internet to obtain information from the authorities in the last 3 months;
- used Internet to download a form in the last 3 months;
- used Internet to send a completed form to the authorities in the last 3 months;
- used Internet to take formal education in the last 3 months;
- used Internet to continue formal education for the past 3 months;
- used Internet to take second course of formal education in the past 3 months;
- used Internet to obtain health-related information;
- made an online appointment with a doctor in the last 3 months;
- used Internet to ask the doctor about a prescription;
- used Internet to ask the doctor for a medical advice;
- used Internet to buy/order shares/bonds/insure in the last 12 months;
- used Internet to buy/order travel/accommodation in the last 12 months;
- used Internet to buy/order lottery/betting in the last 12 months;
- received books/newspapers over the Internet;
- received/updated software over the Internet.

<table>
<thead>
<tr>
<th>Travel</th>
<th>Frequency of trips during the survey week related to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>work (travel to / from);</td>
</tr>
<tr>
<td></td>
<td>school (travel to / from);</td>
</tr>
<tr>
<td></td>
<td>business duties.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Work</th>
<th>Frequency of trips during the survey week related to visits (private visits with family, friends, home visits).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency of trips during the survey week related to purchase of groceries; other purchases (all purchases).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leisure</th>
<th>Frequency of trips during the survey week related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>visit at cinema, theatre, concert, exhibition;</td>
</tr>
<tr>
<td></td>
<td>visit at a cafe, restaurant, pub;</td>
</tr>
<tr>
<td></td>
<td>sport participation;</td>
</tr>
<tr>
<td></td>
<td>football match, sporting event as a spectator;</td>
</tr>
<tr>
<td></td>
<td>pleasure walk/cycling/jog/skiing;</td>
</tr>
<tr>
<td></td>
<td>boat trip.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
<th>Frequency of trips during the survey week related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pickup/take/follow children to/from kindergarten/park/childcare/school;</td>
</tr>
</tbody>
</table>
• pickup/take/follow children to/from sports and leisure activities;
  other pick up/take/ follow-travel;
• any other journey purposes.
Appendix 4
Analysis of differences between the covariance matrices

The Enas and Choi (1986) heuristics described in 3.2.2 provide a means of choosing the appropriate value of \( k \) based on the difference in sample sizes and their underlying covariance structures. Whereas the differences in sample sizes are evident, difference in covariance structures need to be investigated explicitly.

By definition two matrices \( \Sigma_1 \) and \( \Sigma_2 \) are identical if and only if all their elements \( \sigma_{\tau r \tau c}^1 \) and \( \sigma_{\tau r \tau c}^2 \) are equal for any combination of row and column indices \( \tau_r \) and \( \tau_c \):

\[
\Sigma_1 = \Sigma_2 \iff (\sigma_{\tau r \tau c}^1 = \sigma_{\tau r \tau c}^2, \forall \tau_r \forall \tau_c, \sigma_{\tau r \tau c}^1 \in \Sigma_1, \sigma_{\tau r \tau c}^2 \in \Sigma_2) \quad (A.1)
\]

or equivalently:

\[
\Sigma_1 - \Sigma_2 = 0 \iff (\sigma_{\tau r \tau c}^1 - \sigma_{\tau r \tau c}^2 = 0, \forall \tau_r \forall \tau_c, \sigma_{\tau r \tau c}^1 \in \Sigma_1, \sigma_{\tau r \tau c}^2 \in \Sigma_2) \quad (A.2)
\]

Thus equation (A.2) indicates that if any element of a matrix obtained from taking the difference between the covariance matrices differs from zero, the covariance matrices can be deemed different. At the same time, percentile-based confidence intervals can be constructed by means of bootstrapping to preserve the non-parametric character of the approach. Should the estimated confidence interval for a particular parameter not contain zero, the element itself can be deemed significantly different from zero. The resulting confidence interval matrices for each of the countries, i.e. the US 323, the UK 324 and Norway 325 are presented below. Upper values and lower values in the submatrices represent 2.5 and 97.5 percentile values respectively. Thus by observing the matrices it is possible to see that majority of the elements are non-zero, and hence covariance structures can be deemed different.

322
\[
\begin{pmatrix}
0.001 & -0.002 & -0.010 & -0.008 & -0.010 & -0.003 & 0.007 & 0.003 & -0.003 & 0.008 & 0.001 & 0.000 & 0.006 \\
0.001 & -0.002 & -0.010 & -0.008 & -0.010 & -0.003 & 0.007 & 0.003 & -0.003 & 0.008 & 0.001 & 0.000 & 0.007 \\
-0.002 & 0.003 & -0.006 & -0.011 & 0.002 & -0.007 & 0.000 & 0.006 & -0.003 & 0.000 & -0.017 & -0.032 & 0.007 \\
-0.002 & 0.003 & -0.005 & -0.010 & 0.002 & -0.003 & 0.007 & 0.007 & -0.003 & 0.001 & -0.017 & -0.032 & 0.007 \\
-0.010 & -0.006 & -0.028 & -0.022 & 0.003 & 0.005 & -0.013 & -0.003 & -0.002 & -0.007 & -0.011 & -0.031 & -0.023 \\
-0.010 & -0.005 & -0.028 & -0.021 & 0.004 & 0.005 & -0.012 & -0.003 & -0.002 & -0.006 & -0.011 & -0.031 & -0.022 \\
0.008 & -0.011 & -0.022 & -0.006 & -0.006 & -0.002 & -0.004 & 0.020 & -0.002 & 0.007 & 0.005 & 0.003 & 0.039 \\
0.008 & -0.010 & -0.021 & -0.006 & -0.006 & -0.002 & -0.004 & 0.021 & -0.002 & 0.007 & 0.005 & 0.003 & 0.040 \\
-0.010 & 0.002 & 0.003 & -0.006 & 0.000 & 0.005 & -0.011 & 0.006 & -0.001 & -0.009 & -0.014 & 0.000 & 0.001 \\
-0.010 & 0.002 & 0.004 & -0.006 & 0.000 & 0.006 & -0.011 & 0.006 & -0.001 & -0.009 & -0.014 & 0.000 & 0.002 \\
-0.003 & 0.002 & 0.005 & -0.002 & 0.005 & 0.023 & -0.011 & 0.006 & 0.001 & -0.005 & -0.004 & -0.004 & 0.013 \\
-0.003 & 0.003 & 0.005 & -0.002 & 0.006 & 0.023 & -0.011 & 0.006 & 0.002 & -0.005 & -0.004 & -0.004 & 0.013 \\
0.007 & -0.007 & -0.013 & -0.004 & -0.011 & -0.011 & -0.017 & 0.032 & 0.005 & -0.003 & 0.003 & 0.015 & 0.000 \\
0.008 & -0.007 & -0.012 & -0.004 & -0.011 & -0.011 & -0.016 & 0.033 & 0.005 & -0.002 & 0.002 & 0.015 & 0.000 \\
0.003 & 0.000 & -0.003 & 0.020 & 0.006 & 0.006 & 0.032 & -0.064 & 0.000 & 0.014 & 0.001 & 0.006 & 0.014 \\
0.003 & 0.000 & -0.003 & 0.021 & 0.006 & 0.006 & 0.033 & -0.064 & 0.000 & 0.014 & 0.002 & 0.006 & 0.015 \\
-0.003 & 0.006 & -0.002 & -0.002 & -0.001 & 0.001 & 0.005 & 0.000 & -0.003 & -0.003 & 0.002 & 0.000 & 0.002 \\
-0.003 & 0.007 & -0.002 & -0.002 & -0.001 & 0.002 & 0.005 & 0.000 & -0.003 & -0.003 & 0.002 & 0.000 & 0.002 \\
0.008 & -0.003 & -0.007 & 0.007 & -0.009 & -0.005 & -0.003 & 0.014 & -0.003 & 0.008 & -0.015 & -0.002 & 0.047 \\
0.009 & -0.003 & -0.006 & 0.007 & -0.009 & -0.005 & -0.002 & 0.014 & -0.003 & 0.008 & -0.015 & -0.002 & 0.048 \\
0.001 & 0.000 & -0.011 & 0.005 & -0.014 & -0.004 & 0.003 & 0.001 & 0.002 & -0.015 & -0.012 & 0.021 & -0.018 \\
0.002 & 0.001 & -0.011 & 0.005 & -0.014 & -0.004 & 0.003 & 0.002 & 0.002 & -0.015 & -0.011 & 0.022 & -0.017 \\
0.000 & 0.017 & -0.031 & 0.003 & 0.000 & -0.004 & 0.015 & 0.006 & 0.000 & -0.002 & 0.021 & 0.083 & 0.017 \\
0.000 & -0.017 & -0.031 & 0.003 & 0.000 & -0.004 & 0.015 & 0.006 & 0.000 & -0.002 & 0.022 & 0.084 & 0.017 \\
0.006 & -0.032 & -0.023 & 0.039 & 0.001 & -0.013 & 0.000 & 0.014 & 0.002 & 0.047 & -0.018 & 0.017 & 0.029 \\
0.007 & -0.032 & -0.022 & 0.040 & 0.002 & -0.013 & 0.000 & 0.015 & 0.002 & 0.048 & -0.017 & 0.017 & 0.029 \\
\end{pmatrix}
\]

Notes: 1) Bold indicates percentile-based 95% confidence intervals which do not contain zero. 2) Presented values are rounded to 3 decimal places, though bold indication is based on results up to 10 decimal places.
<table>
<thead>
<tr>
<th></th>
<th>-0.003</th>
<th>-0.001</th>
<th>0.000</th>
<th>0.000</th>
<th>0.000</th>
<th>0.000</th>
<th>0.000</th>
<th>0.005</th>
<th>0.002</th>
<th>-0.013</th>
<th>0.007</th>
<th>-0.009</th>
<th>-0.004</th>
<th>0.021</th>
<th>-0.006</th>
<th>0.033</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.003</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.006</td>
<td>-0.012</td>
<td>0.008</td>
<td>-0.008</td>
<td>-0.003</td>
<td>0.021</td>
<td>-0.005</td>
<td>0.034</td>
</tr>
<tr>
<td>-0.001</td>
<td>0.000</td>
<td>0.001</td>
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Notes: 1) Bold indicates percentile-based 95% confidence intervals which do not contain zero. 2) Presented values are rounded to 3 decimal places, though bold indication is based on results up to 10 decimal places.
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Appendix 5
SPURT questionnaire (re-printed)

Research into Business Travel on Trains

This questionnaire concerns how you spend your time on the train. Therefore, please don't complete it until the end of your rail journey.

Thank you for agreeing to take part in this short survey on rail travel. It is being conducted by Accent on behalf of Department of Transport and should take no more than 10 minutes to complete. Any answer you give will be treated in confidence in accordance with the Code of Conduct of the Market Research Society.

Please complete this questionnaire towards the end of the train journey you are making when this was handed to you, and send back to us in the provided envelope. Returned questionnaires will be entered into a prize draw for £500. Thank you for your help.

Please complete this questionnaire even if you did not work on this train.

UNLESS OTHERWISE SHOWN PLEASE ENTER 'X' IN ONE BOX ONLY

Details of train trip

Q1. Are you on the outward or return leg of your business trip?
   □ Outward  □ Return

Q2. What is or was the main purpose of your business trip?
   □ Visiting a branch office for management purposes
   □ Visiting a client
   □ Attending a business meeting
   □ Attending a seminar, course, etc
   □ Delivering or picking up supplies
   □ Other (please write in)

Q3. Thinking about this leg of your business trip, what type of location did you start from?
   □ Home
   □ Usual workplace
   □ Another workplace of employer
   □ Education/Training/Conference centre
   □ Client/customer workplace
   □ Hotel/guest house/restaurant
   □ Other type of location (please write in)

Q4. At what time did you start this leg of your business trip? (ie TIME LEFT LOCATION IN Q3). PLEASE USE 24 HOUR CLOCK

Q5. At what station did you board this train?

Q6. How did you get from your starting point to this station? ENTER 'X' FOR ALL THAT APPLY
   □ Another train
   □ Bus / coach
   □ Underground/metro
   □ Car/motorbike/van
   □ On foot / walked all the way
   □ Taxi
   □ Bicycle
   □ Other (please write in)

Q7. What was the scheduled departure time of this train? PLEASE USE 24 HOUR CLOCK
Q8. When is this train scheduled to reach the station you get off at? PLEASE USE 24 HOUR CLOCK

Q9. At which station will you get off this train?

Q10. How will you get from that station to your destination? ENTER X FOR ALL APPROPRIATE

- Another train
- Car/motorbike/vans
- On foot / walk all the way
- Bicycle
- Other (please write in)
- Underground/metro
- Taxi

Q11. Thinking about this leg of your business trip, what type of location are you going to?

- Home
- Client/customer workplace
- Hotel/guest house/restaurant
- Education/Training/Conference centre

Q12. At what time did you or will you finish this leg of your business trip? (i.e. TIME ARRIVED AT LOCATION IN Q11). PLEASE USE 24 HOUR CLOCK

Q13. Are you travelling alone or with other adults in a group?

- Alone
- With two others
- With one other
- With 3+ others

Q14. Do you have a single, return or season ticket for this rail journey?

- Single
- Return
- Season ticket

Q15. How much did your ticket cost?

- £

FOR OFFICE USE ONLY

Q16. How will the costs of this rail journey be paid for?

- Paid by employer/business
- Paid out of own pocket
- Claimed from employer/business
- A combination

Q17. For what proportion of this rail journey were you able to sit?

- All of it
- About half
- About a quarter
- None of it

Q18. Were you in Standard or First Class?

- Standard Class
- First Class

Q19. Which if any of the following were available to you during this rail journey? PLEASE ENTER 'X' FOR ALL APPROPRIATE

- Pull down/lift up table
- Fixed table
- Power socket
- WiFi
- None of the above

Q20. How crowded would you say the carriage was when this train departed your boarding station?

- 25% of seats occupied
- 50% of seats occupied
- 75% of seats occupied
- 90% of seats occupied, a few people standing
- 90% of seats occupied, nobody standing
- 100% of seats occupied

Q21. Did the level of crowding change significantly during your journey on this train?

- Yes
- No

Accent

327
Q22. What was the most crowded that the carriage became?
- 25% of seats occupied
- 50% of seats occupied
- 75% of seats occupied
- 90% of seats occupied, nobody standing
- 90% of seats occupied, a few people standing
- 100% of seats occupied, nobody standing

Q23. What was the least crowded that the carriage became?
- 25% of seats occupied
- 50% of seats occupied
- 75% of seats occupied
- 90% of seats occupied, nobody standing
- 90% of seats occupied, a few people standing
- 100% of seats occupied, nobody standing

Q24. Did the level of crowding have any impact on the work you undertook or wished to undertake on the train?
- No, level of crowding had no impact
- Yes, level of crowding meant that I found it difficult to undertake some work
- Yes, level of crowding meant that I actually could not undertake any work

Q25. Given that you could not undertake any or as much work on this train as intended, did you have to undertake this work later on today after this train journey?
- Yes, had to complete the tasks after leaving the train
- No, did not have to complete the work today

Activities on the train

Q26. How long did you spend on this train itself? ENTER HOURS AND MINUTES. IF DON’T KNOW PLEASE GIVE BEST ESTIMATE.

Q27. Have you or do you intend to do any of the following on this train? PLEASE ENTER ‘X’ FOR ALL THAT APPLY IN COLUMN A

<table>
<thead>
<tr>
<th></th>
<th>A (Q27)</th>
<th>B (Q28)</th>
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<tbody>
<tr>
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<tr>
<td>2. Studying related to employment (reading/writing/typing/thinking)</td>
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<td>4. Talking to other passengers - work related</td>
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<td>6. Text messages/phone calls - work related</td>
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<td>7. Text messages/phone calls - personal/social</td>
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<td>8. Eating/drinking</td>
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<td>9. Leisure activity (playing games/reading/listening to music/radio etc)</td>
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<td>10. Relaxing (sleeping/napping/window gazing/people watching etc)</td>
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<td>11. Being bored</td>
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<td>12. Being anxious about journey (eg delays or where to get off)</td>
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<td>13. Planning onward or return journey</td>
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<td>14. None of the above</td>
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Q28. And which one of the above activities did you spend most time on? ENTER A SINGLE ‘X’ IN COLUMN B ABOVE

Q29. Could you please estimate the amount of time you spent on this train doing each of the following activities. IF YOU PREFER, YOU CAN ENTER THE PERCENTAGE OF TIME. IF YOU DON’T KNOW PLEASE GIVE BEST ESTIMATE

<table>
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<tr>
<th>Activity</th>
<th>Minutes</th>
<th>Percentage</th>
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<td>☐</td>
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<tr>
<td>Work activities related to employment (eg reading, writing/typing, discussion, thinking, business meals etc)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Personal activities (eg reading, listening to music, chatting, thinking, eating, drinking etc)</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>Preparing to disembark</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td><strong>TOTAL TIME ON TRAIN</strong></td>
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<td>100%</td>
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</table>
Q30. Which, if any, of the following work activities related to your employment did you do on this train?

**PLEASE ENTER 'X' FOR ALL THAT APPLY**

- [ ] None - I didn't work on this train GO TO Q35
- [ ] Prepare for a meeting
- [ ] Make/receive business calls/text messages
- [ ] Talk to colleagues/others travelling with me
- [ ] Use laptop
- [ ] Use PDA/Blackberry
- [ ] Other work related to employment

Q31. Can you please indicate when during this rail journey you undertook work-related activities.

**PLEASE DRAW A LINE OR LINES IN THE GRID BELOW**

**THE EXAMPLE BELOW INDICATES WORK DONE IN FIRST 30% OF TRIP, AND AGAIN BETWEEN 60% AND 70% OF TRIP**

<table>
<thead>
<tr>
<th>Start</th>
<th>Middle</th>
<th>End</th>
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Please can you now complete the grid for this rail journey.

<table>
<thead>
<tr>
<th>Start</th>
<th>Middle</th>
<th>End</th>
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</table>

Q32. Approximately how long would the same work-related activity have taken you if you had done it at your normal place of work? Please refer back to your answer to Q29 for work activities.

- [ ] About the same time
- [ ] More time
- [ ] LESS time

**PLEASE WRITE IN HOW MANY MINUTES LONGER**

- [ ] minutes

**PLEASE WRITE IN HOW MANY MINUTES LESS**

- [ ] minutes

Q33. Suppose this rail journey was scheduled to last 10 minutes **longer** how long would you have spent undertaking work-related activity on train?

- [ ] About the same time
- [ ] More time
- [ ] LESS time

**PLEASE WRITE IN HOW MANY MINUTES LONGER**

- [ ] minutes

**PLEASE WRITE IN HOW MANY MINUTES LESS**

- [ ] minutes

Q34. Suppose this rail journey was scheduled to last 10 minutes **shorter** how long would you have spent undertaking work-related activity on train?

- [ ] About the same time
- [ ] More time
- [ ] LESS time

**PLEASE WRITE IN HOW MANY MINUTES LONGER**

- [ ] minutes

**PLEASE WRITE IN HOW MANY MINUTES LESS**

- [ ] minutes

Q35. If this train was scheduled to arrive at your destination station 10 minutes **earlier**, do you think you would have worked or not in the 10 minutes saved time?

- [ ] Not worked
- [ ] Worked in usual workplace
- [ ] Worked elsewhere eg. cafe, hotel etc
- [ ] Worked at home
- [ ] Worked in other workplace
- [ ] Other (please write in)

Q36. If this train was scheduled to arrive at your destination station 10 minutes **later**, would you have spent the additional time working on train?

- [ ] Yes, spent all of the additional time working on train
- [ ] Yes, spent some of the additional time working on train
- [ ] No, spent none of the additional time working on train
- [ ] Don't know
Q37. Did you undertake any work activity whilst waiting for and/or when changing trains during this leg of your business trip? PLEASE ENTER 'X' FOR ALL THAT APPLY IN BOTH COLUMNS

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<th></th>
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<th>Changing trains</th>
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<td>No work related activity</td>
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<td></td>
</tr>
<tr>
<td>Make/receive business calls/text messages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work on company business</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use laptop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use PDA/Blackberry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talk to colleagues/others travelling with me</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Applicable (did not change trains)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q38. Would the overall amount of work you do over the whole day be affected if this rail journey was 10 minutes shorter?

☐ No, it would make no difference to the amount of work I do over the whole day
☐ Yes, I would do less work over the whole day
☐ Other (please write in)

Choice between trains

We would now like to get you to consider the trade-off between your personal time and that of time saved on the rail journey. Please imagine that two different trains are available to make the current rail trip you have just described for us, and you are allowed by your company to spend a maximum of £15 for the one way journey, with any money saved from this being a personal gain, and any greater fare having the cost borne by yourself.

The two trains may differ in terms of fare and journey time, as well as the availability of seats and mobile phone reception. In all other aspects, you may assume that both of the train services are identical to the train you actually took, and are both scheduled to depart from the origin at the same time. It doesn't matter if the scenarios presented are different to those of the train you have used today.

**EXAMPLE:** You have the choice of taking the train as today using the full £15 allowed, or that of using a 10 minutes faster train but costing £4 more which YOU have to pay yourself.

<table>
<thead>
<tr>
<th>Train A</th>
<th>Train B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fare: £15</td>
<td>Fare: £19 (so YOU PAY extra £4)</td>
</tr>
<tr>
<td>Journey Time: current</td>
<td>Journey Time: 10 minutes shorter</td>
</tr>
<tr>
<td>Crowding: 75% of seats taken</td>
<td>Crowding: 100% of seats taken</td>
</tr>
<tr>
<td>Mobile Phone reception: Clear</td>
<td>Mobile Phone reception: Poor</td>
</tr>
</tbody>
</table>

Train A

| Fare: £13 (so YOU GAIN £2) | Fare: £15 |
| Journey Time: current | Journey Time: 5 minutes SHORTER |
| Crowding: 50% of seats taken | Crowding: 25% of seats taken |
| Mobile Phone reception: Poor | Mobile Phone reception: Clear |

For each of the scenarios below, please indicate which of the two trains you would have preferred if these were the only two available for your rail journey. PLEASE ENTER 'X' IN ONE BOX THAT APPLIES
<table>
<thead>
<tr>
<th></th>
<th>Train A</th>
<th>or</th>
<th>Train B</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td><strong>Fare:</strong> £17 (so YOU PAY extra £2)</td>
<td></td>
<td><strong>Fare:</strong> £15</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> current</td>
<td></td>
<td><strong>Journey Time:</strong> 10 minutes LONGER</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 75% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
</tr>
<tr>
<td>3</td>
<td><strong>Fare:</strong> £15</td>
<td></td>
<td><strong>Fare:</strong> £14 (so YOU GAIN £1)</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> current</td>
<td></td>
<td><strong>Journey Time:</strong> 15 minutes LONGER</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 75% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Poor</td>
</tr>
<tr>
<td>4</td>
<td><strong>Fare:</strong> £11 (so YOU GAIN £4)</td>
<td></td>
<td><strong>Fare:</strong> £15</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> 5 minutes LONGER</td>
<td></td>
<td><strong>Journey Time:</strong> current</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 100% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
</tr>
<tr>
<td>5</td>
<td><strong>Fare:</strong> £15</td>
<td></td>
<td><strong>Fare:</strong> £21 (so YOU PAY extra £6)</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> current</td>
<td></td>
<td><strong>Journey Time:</strong> current</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Poor</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
</tr>
<tr>
<td>6</td>
<td><strong>Fare:</strong> £15</td>
<td></td>
<td><strong>Fare:</strong> £16 (so YOU GAIN £1)</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> current</td>
<td></td>
<td><strong>Journey Time:</strong> current</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
</tr>
<tr>
<td>7</td>
<td><strong>Fare:</strong> £15</td>
<td></td>
<td><strong>Fare:</strong> £9 (so YOU GAIN £6)</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> 15 minutes SHORTER</td>
<td></td>
<td><strong>Journey Time:</strong> current</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
</tr>
<tr>
<td>8</td>
<td><strong>Fare:</strong> £19 (so YOU PAY extra £4)</td>
<td></td>
<td><strong>Fare:</strong> £15</td>
</tr>
<tr>
<td></td>
<td><strong>Journey Time:</strong> 10 minutes SHORTER</td>
<td></td>
<td><strong>Journey Time:</strong> current</td>
</tr>
<tr>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
<td></td>
<td><strong>Crowding:</strong> 25% of seats taken</td>
</tr>
<tr>
<td></td>
<td><strong>Mobile Phone reception:</strong> Clear</td>
<td></td>
<td><strong>Mobile Phone reception:</strong> Poor</td>
</tr>
</tbody>
</table>
Q39. In answering these choices did you ignore any of the values presented?

☐ fare  ☐ journey time  ☐ crowding  ☐ mobile phone  ☐ didn’t ignore any

Q40. Do you agree or disagree with the following statements?

I choose to travel by train and valued the fact that I can work on the train

If the train journey was shorter I would reduce the amount

of work I do on the train

Strongly disagree  Disagree  Neither agree nor disagree  Agree  Strongly agree  Not applicable

Respondent characteristics

Q41. Are you regularly employed, occasionally employed or self-employed?

☐ Regularly employed  ☐ Self-employed  ☐ Occasionally/part time employed

Q42. Which of the following best describes your occupation?

☐ Professional/Senior Managerial  ☐ Skilled Manual (With professional qualifications/served an apprenticeship)

☒ Middle Managerial/Technical  ☐ Unskilled Manual (No qualifications/not served an apprenticeship)

☐ Junior Managerial/Clerical/Supervisory/Technical  ☐ Other

Q43. How many cars or vans does your household own or have available for use by one or more members of a household?

☐ None  ☐ 1  ☐ 2  ☐ 3  ☐ 4 or more

Q44. Which of the following age groups are you in?

16-25  ☐ 35-44  ☐ 55-59  ☐ 65+

26-34  ☐ 45-54  ☐ 60-64

Q45. Are you ...

☐ Male  ☐ Female

Q46. What is your total income from employment, including from investment before tax and other deductions?

Less than £10,000  ☐ £35,000 - £49,999  ☐ £100,000 or more

£10,000 - £19,999  ☐ £50,000 - £74,999  ☐ Prefer not to say

£20,000 - £34,999  ☐ £75,000 - £99,999

Q47. What is your total annual household income, including from investment, before tax and other deductions?

Less than £10,000  ☐ £35,000 - £49,999  ☐ £100,000 or more

£10,000 - £19,999  ☐ £50,000 - £74,999  ☐ Prefer not to say

£20,000 - £34,999  ☐ £75,000 - £99,999

Thank you for your co-operation

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Name: 

Address: 

Email address: 

Telephone number: 

Source: DfT, 2009: Appendix A
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Appendix 6

Full cross-validation results

Table A.3 Hold-out validation results, (n = 188, 1000 simulations)

<table>
<thead>
<tr>
<th>Fold 1</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>56.754 (2.825)</td>
<td>60.858 (2.873)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.774 (0.078)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>2.761 (0.006)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.080 (0.570)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>31.908</td>
<td></td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td></td>
<td>94.7%</td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, ( H_0: ) constant equal to zero)</td>
<td>0.193 (0.063, 3.058)</td>
<td></td>
</tr>
<tr>
<td>slope (s.e., t-statistic for ( H_0: ) slope equal to unity)</td>
<td>0.818 (0.055, 3.309)</td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.548</td>
<td></td>
</tr>
<tr>
<td><strong>Productivity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>0.966 (0.020)</td>
<td>0.998 (0.008)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.448 (0.149)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.808 (0.418)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.404 (&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.302</td>
<td></td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, ( H_0: ) constant equal to zero)</td>
<td>0.916 (0.569, 1.610)</td>
<td></td>
</tr>
<tr>
<td>slope (s.e., t-statistic for ( H_0: ) slope equal to unity)</td>
<td>0.130 (0.582, 1.495)</td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>3 categories</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower (( \zeta \leq 0.950 ))</td>
<td>38</td>
<td>70</td>
</tr>
<tr>
<td>Same (0.950&lt;( \zeta &lt;1.050 ))</td>
<td>126</td>
<td>89</td>
</tr>
<tr>
<td>Higher (( \zeta \geq1.050 ))</td>
<td>24</td>
<td>29</td>
</tr>
<tr>
<td>( \chi^2 ) ( d.f ) (p-value)</td>
<td>26.200 (&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>2 categories</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (( \zeta \leq 0.950 ))</td>
<td>38</td>
<td>70</td>
</tr>
<tr>
<td>Same or Higher (( \zeta &gt;0.950 ))</td>
<td>150</td>
<td>118</td>
</tr>
<tr>
<td>Fisher exact test (p-value)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Fold 2

<table>
<thead>
<tr>
<th>Fold 2</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>59.324 (3.041)</td>
<td>58.354 (2.751)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.461 (0.646)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.893 (0.373)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.144 (0.037)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>28.809</td>
<td></td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td></td>
<td>94.7%</td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, ( H_0: ) constant equal to zero)</td>
<td>0.277 (0.065, 4.292)</td>
<td></td>
</tr>
<tr>
<td>slope (s.e., t-statistic for ( H_0: ) slope equal to unity)</td>
<td>0.659 (0.054, 6.315)</td>
<td></td>
</tr>
</tbody>
</table>
### Productivity

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>1.043 (0.005)</td>
<td>0.975 (0.074)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.572 (0.118)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>2.379 (0.017)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.442 (&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.590</td>
<td></td>
</tr>
</tbody>
</table>

#### Linear regression

- **Constant (s.e., t-statistic, \( H_0: \text{constant equal to zero} \):**
  - Lower (\( \zeta \leq 0.950 \)): 42, 54
  - Same (0.950 < \( \zeta < 1.050 \)): 126, 81
  - Higher (\( \zeta \geq 1.050 \)): 20, 53
  - \( \chi^2_{2.d.f.} \) (p-value): 26.200 (<0.001)

- **Slope (s.e., t-statistic for \( H_0: \text{slope equal to unity} \):**
  - Lower (\( \zeta \leq 0.950 \)): 0.997 (0.186, 5.354)
  - Same (0.950 < \( \zeta < 1.050 \)): -0.031 (0.185, 5.573)
  - Higher (\( \zeta \geq 1.050 \)): 0.950

#### Fold 3

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>57.466 (2.822)</td>
<td>57.165 (2.623)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.150 (0.881)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.893 (0.373)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.197 (0.230)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>27.423</td>
<td></td>
</tr>
<tr>
<td>Percentage correctly predicted</td>
<td>94.7%</td>
<td></td>
</tr>
</tbody>
</table>

#### Fold 4

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>58.126 (2.980)</td>
<td>56.824 (2.438)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.703 (0.483)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>1.318 (0.187)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.112 (0.180)</td>
<td></td>
</tr>
</tbody>
</table>
Root-mean-square Error (RMSE) [in minutes] 25.352
%age correctly predicted 94.7%
Linear regression
  constant (s.e., t-statistic, H₀: constant equal to zero) 0.061 (0.061, 0.998)
  slope (s.e., t-statistic for H₀: slope equal to unity) 0.959 (0.056, 0.732)
R² 0.615

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>0.967 (0.020)</td>
<td>0.999 (0.006)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.562 (0.120)</td>
<td>1.903 (0.057)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.404 (&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>0.508 (0.327, 2.149)</td>
<td>0.460 (0.236, 2.288)</td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td>96.3%</td>
<td></td>
</tr>
</tbody>
</table>
| Linear regression
  constant (s.e., t-statistic, H₀: constant equal to zero) | 0.003 (0.067, 0.046) | |
  slope (s.e., t-statistic for H₀: slope equal to unity) | 1.066 (0.063, 1.048) | |
| R² | 0.605 | |

### Fold 5

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>58.983 (3.090)</td>
<td>56.824 (2.438)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.774 (0.078)</td>
<td>2.268 (0.023)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.144 (0.037)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>26.870</td>
<td></td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td>96.3%</td>
<td></td>
</tr>
</tbody>
</table>
| Linear regression
  constant (s.e., t-statistic, H₀: constant equal to zero) | -0.003 (0.067, 0.046) | |
  slope (s.e., t-statistic for H₀: slope equal to unity) | 1.066 (0.063, 1.048) | |
| R² | 0.605 | |

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>0.937 (0.019)</td>
<td>1.009 (0.007)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>3.792 (&lt;0.001)</td>
<td>4.960 (&lt;0.001)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.505 (&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.269</td>
<td></td>
</tr>
</tbody>
</table>
| Linear regression
  constant (s.e., t-statistic, H₀: constant equal to zero) | 0.688 (0.197, 3.492) | |
  slope (s.e., t-statistic for H₀: slope equal to unity) | 0.246 (0.195, 3.867) | |
| R² | 0.009 | |

| 3 categories |
| Lower (\(\xi\leq0.950\)) | 42 | 54 |
| Same (0.950<\(\xi<1.050\)) | 126 | 81 |
| Higher (\(\xi\geq1.050\)) | 20 | 53 |
| \(\chi^2_{2.d.f.}\) (p-value) | 20.580 (<0.001) | |
| 2 categories |
| Lower (\(\xi\leq0.950\)) | 42 | 54 |
| Same or Higher (\(\xi>0.950\)) | 146 | 134 |
| Fisher exact test (p-value) | 0.405 | |
## Fold 6

### Work Duration

<table>
<thead>
<tr>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>58.758 (2.888)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.962 (0.337)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.069 (0.339)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.137 (0.055, 2.218)</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>26.098</td>
</tr>
<tr>
<td>Percentage correctly predicted</td>
<td>94.7%</td>
</tr>
</tbody>
</table>

### Productivity

<table>
<thead>
<tr>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>0.996 (0.019)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.489 (0.626)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.096 (0.339)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.266</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.018</td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, H₀: constant equal to zero)</td>
<td>0.594 (0.220, 2.703)</td>
</tr>
<tr>
<td>slope (s.e., t-statistic for H₀: slope equal to unity)</td>
<td>0.399 (0.218, 2.757)</td>
</tr>
<tr>
<td>R²</td>
<td>0.018</td>
</tr>
<tr>
<td>3 categories</td>
<td></td>
</tr>
<tr>
<td>Lower (≤0.950)</td>
<td>38</td>
</tr>
<tr>
<td>Same (0.950&lt;ζ≤1.050)</td>
<td>130</td>
</tr>
<tr>
<td>Higher (ζ≥1.050)</td>
<td>20</td>
</tr>
<tr>
<td>χ²,3,0.05 (p-value)</td>
<td>13.390 (&lt;0.001)</td>
</tr>
<tr>
<td>2 categories</td>
<td></td>
</tr>
<tr>
<td>Low (≤0.950)</td>
<td>42</td>
</tr>
<tr>
<td>Same or Higher (&gt;0.950)</td>
<td>146</td>
</tr>
<tr>
<td>Fisher exact test (p-value)</td>
<td></td>
</tr>
</tbody>
</table>

## Fold 7

### Work Duration

<table>
<thead>
<tr>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>60.690 (3.055)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.312 (0.755)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>1.011 (0.277)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.010 (0.001)</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>0.991 (0.050, 1.780)</td>
</tr>
<tr>
<td>Percentage correctly predicted</td>
<td>96.3%</td>
</tr>
</tbody>
</table>

### Productivity

<table>
<thead>
<tr>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>1.027 (0.040)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.461 (0.146)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.457 (&lt;0.001)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.010 (0.001)</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE)</td>
<td>0.031 (0.425, 2.280)</td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, H₀: constant equal to zero)</td>
<td>0.998 (0.417, 2.393)</td>
</tr>
<tr>
<td>slope (s.e., t-statistic for H₀: slope equal to unity)</td>
<td>0.031 (0.425, 2.280)</td>
</tr>
<tr>
<td>R²</td>
<td>0.001</td>
</tr>
<tr>
<td>3 categories</td>
<td></td>
</tr>
<tr>
<td>Lower (≤0.950)</td>
<td>38</td>
</tr>
<tr>
<td>Same (0.950&lt;ζ≤1.050)</td>
<td>128</td>
</tr>
<tr>
<td>Higher (ζ≥1.050)</td>
<td>22</td>
</tr>
</tbody>
</table>
### Fold 8

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>58.304 (2.857)</td>
<td>57.982 (2.741)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>0.161 (0.868)</td>
<td>0.893 (0.373)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.144 (0.037)</td>
<td>0.2638</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.979 (0.049, 1.163)</td>
<td>0.582</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>0.203 (0.057, 3.572)</td>
<td>0.203 (0.057, 3.572)</td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td>94.7%</td>
<td>94.7%</td>
</tr>
</tbody>
</table>

**Linear regression**
- constant (s.e., t-statistic, $H_0$: constant equal to zero)
  - 0.496 (0.241, 2.060)
- slope (s.e., t-statistic for $H_0$: slope equal to unity)
  - 0.441 (0.241, 2.320)

**R**$^2$ | 0.018 |

**Fold 9**

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>56.755(2.825)</td>
<td>60.861 (2.873)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.774 (0.078)</td>
<td>0.901 (0.368)</td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.144 (0.037)</td>
<td>0.659 (0.054, 6.315)</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>31.908</td>
<td>0.449</td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>0.277 (0.065, 4.292)</td>
<td>0.277 (0.065, 4.292)</td>
</tr>
<tr>
<td>%age correctly predicted</td>
<td>94.7%</td>
<td>94.7%</td>
</tr>
</tbody>
</table>

**Linear regression**
- constant (s.e., t-statistic, $H_0$: constant equal to zero)
  - 0.277 (0.065, 4.292)
- slope (s.e., t-statistic for $H_0$: slope equal to unity)
  - 0.659 (0.054, 6.315)
$R^2$ 0.001

3 categories
Lower (\(\xi \leq 0.950\)) 42 54
Same (0.950 < \(\xi < 1.050\)) 126 81
Higher (\(\xi \geq 1.050\)) 20 53
\(\chi^2_{2, d.f.} (p\text{-value})\) 26.200 (<0.001)

2 categories
Low (\(\xi \leq 0.950\)) 42 54
Same or Higher (\(\xi > 0.950\)) 146 134
Fisher exact test (p-value) 0.193

<table>
<thead>
<tr>
<th>Fold 10</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (s.e.) [in minutes]</td>
<td>54.938 (2.884)</td>
<td>57.115 (2.970)</td>
</tr>
<tr>
<td>Paired sample t-test (p-value)</td>
<td>1.001 (0.318)</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Z (p-value)</td>
<td>0.555 (0.576)</td>
<td></td>
</tr>
<tr>
<td>Kolmogorov-Smirnov D (p-value)</td>
<td>0.122 (0.111)</td>
<td></td>
</tr>
<tr>
<td>Root-mean-square Error (RMSE) [in minutes]</td>
<td>29.797</td>
<td></td>
</tr>
<tr>
<td>(%)age correctly predicted</td>
<td>94.1%</td>
<td></td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant (s.e., t-statistic, (H_0: \text{constant equal to zero}))</td>
<td>0.246 (0.057, 4.288)</td>
<td></td>
</tr>
<tr>
<td>slope (s.e., t-statistic for (H_0: \text{slope equal to unity}))</td>
<td>0.704 (0.049, 6.041)</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.525</td>
<td></td>
</tr>
</tbody>
</table>

| **Productivity** | | |
| Mean (s.e.) [in minutes] | 0.985 (0.022) | 0.981 (0.006) |
| Paired sample t-test (p-value) | 0.196 (0.845) | |
| Wilcoxon Signed-Rank Z (p-value) | 0.858 (0.390) | |
| Kolmogorov-Smirnov D (p-value) | 0.367 (<0.001) | |
| Root-mean-square Error (RMSE) | 0.300 | |
| Linear regression | | |
| constant (s.e., t-statistic, \(H_0: \text{constant equal to zero}\)) | 0.589 (0.264, 2.234) | |
| slope (s.e., t-statistic for \(H_0: \text{slope equal to unity}\)) | 0.404 (0.268, 2.224) | |
| $R^2$ | 0.012 | |

3 categories
Lower (\(\xi \leq 0.950\)) 38 61
Same (0.950 < \(\xi < 1.050\)) 135 88
Higher (\(\xi \geq 1.050\)) 15 39
\(\chi^2_{2, d.f.} (p\text{-value})\) 12.960 (<0.001)

2 categories
Low (\(\xi \leq 0.950\)) 38 61
Same or Higher (\(\xi > 0.950\)) 150 127
Fisher exact test (p-value) 0.010

\(a\) within 95\% confidence interval \(b\) As compared to usual office conditions, frequencies calculated using
Appendix 7
Composition of the sample for VEBTT analysis

Table A.4 Hold-out sample composition (for the VEBTT analysis)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Response</th>
<th>% of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg</td>
<td>Outward</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Return</td>
<td>50</td>
</tr>
<tr>
<td>Journey</td>
<td>Less than 45 min</td>
<td>9</td>
</tr>
<tr>
<td>time</td>
<td>45-89 min</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>90-149 min</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>150 min and over</td>
<td>13</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>28</td>
</tr>
<tr>
<td>Size</td>
<td></td>
<td>166</td>
</tr>
</tbody>
</table>
Appendix 8
Detailed derivations for section 5.3

Derivation of subjective value of travel time reduction

Subjective value of travel time reduction can be established using expression (5.16):

\[
SV_{r_{ij}} = - \frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial r_{ij}} = \frac{\partial M_{T2}}{\partial r_{ij}} + \frac{\partial M_{T}}{\partial r_{ij}} + \frac{\partial M_{B}}{\partial r_{ij}} - b \frac{dc_{ij}}{dr_{ij}} \tag{A.6}
\]

Note that by definition, the infinitesimal differentials are positive whereas reduction in travel time implies negative change and hence requires minus sign in the denominator. Using expression for the indirect utility function (5.16) and following the fundamental theorem of calculus as well as envelope theorem yields:

\[
SV_{r_{ij}} = \frac{dc_{ij}}{dr_{ij}} - \frac{u_{T2}(z_{T2ij}) - u_{T}(z_{Tij}) + u_{B}(z_{B})dt}{b} - w_{T2}z_{T2ij} + w_{B}z_{B} \tag{A.7}
\]

which is equivalent to expression (5.18).

Derivation of subjective value of change in ICT quality

The subjective value of modification in the quality \(\beta_{\psi}\) of an ICT bundle \(\psi\) can be defined as:

\[
SV_{\beta_{\psi}} = - \frac{\partial V_{A,B,T1,T2,i,j,\psi}}{\partial \beta_{\psi}} = - \frac{\partial M_{A}}{\partial \beta_{\psi}} + \frac{\partial M_{T1}}{\partial \beta_{\psi}} + \frac{\partial M_{T2}}{\partial \beta_{\psi}} + \frac{\partial M_{B}}{\partial \beta_{\psi}} - b \frac{dc_{\psi}}{d\beta_{\psi}} \tag{A.8}
\]
which can be obtained using indirect utility function 5.16:

$$SV_{\beta\psi} = \frac{1}{b} \left[ \int_{t_0}^{t_1} \frac{dz_A}{d\beta_{\psi WiFi}} \left( \frac{du_A}{dz_A} + bw_A \right) dt + \int_{t_1}^{t_2} \frac{dz_{T1}}{d\beta_{\psi WiFi}} \left( \frac{du_{T1}}{dz_{T1}} + bw_{T1} \right) dt + \right. $$

$$+ \left. \int_{t_2}^{t_1 + r_{ij}(t_1^*)} \frac{dz_{T2}}{d\beta_{\psi WiFi}} \left( \frac{du_{T2}}{dz_{T2}} + bw_{T2} \right) dt + \int_{t_1 + r_{ij}(t_1^*)}^{t_1} \frac{dz_{B}}{d\beta_{\psi WiFi}} \left( \frac{du_B}{dz_B} + bw_B \right) dt \right] - (A.9)$$

$$- \frac{dc_{\psi WiFi}}{d\beta_{\psi WiFi}}$$

Note that in case of change in on-board Wi-Fi:

$$\frac{\partial z_A}{\partial \beta_{\psi WiFi}} = 0 \quad (A.10)$$

as well as:

$$\frac{\partial z_B}{\partial \beta_{\psi WiFi}} = 0 \quad (A.11)$$

And thus expression (5.20) can be obtained:

$$SV_{\beta_{\psi WiFi}} = - \frac{\partial V_{A,B,T1,T2,l,j,\psi}}{\partial \beta_{\psi WiFi}} \left( \frac{du_{T1}}{dz_{T1}} + bw_{T1} \right) dt + \frac{1}{b} \left[ \int_{t_1}^{t_2} \frac{dz_{T1}}{d\beta_{\psi WiFi}} \left( \frac{du_{T1}}{dz_{T1}} + bw_{T1} \right) dt + \right. $$

$$+ \left. \int_{t_2}^{t_1 + r_{ij}(t_1^*)} \frac{dz_{T2}}{d\beta_{\psi WiFi}} \left( \frac{du_{T2}}{dz_{T2}} + bw_{T2} \right) dt \right] - \frac{dc_{\psi WiFi}}{d\beta_{\psi WiFi}}$$

On the other hand, in case of tele-worker:

$$t_1^* = t_1^* + r_{ij}(t_1^*) \quad (A.13)$$
In which case in-travel activities do not exist which which results from conditions imposed on $t_1^*$ in 343, and neither is there any inherent travel-associated utility $u_T$. Consequently, equation (5.21) can be obtained:

\[
SV_{\beta_{TLW}} = -\frac{\partial V_{AB,T1,T2,i,j,\psi}}{\partial \beta_{TLW}} = \frac{1}{b} \left[ \int_{t_o}^{t_1^*} \frac{\partial z_A}{\partial \beta_{TLW}} dA_{ij} dt + \right]
\]

\[
+ \int_{t_1^* + r_{ij}(t_1^*)}^{t_E} \frac{\partial z_B}{\partial \beta_{TLW}} \left( \frac{dA_B}{dz_B} + bw_B \right) dt - \frac{dc_{TLW}}{d\beta_{TLW}}
\]

(A.14)
Appendix 9
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Legal Affairs Unit  
International Telecommunication Union  
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Place des Nations  
Phone: +41 22 730 6159  
Fax: +41 22 730 6503  
CH-1211 Geneva 20  
Switzerland  
www.itu.int

---

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Research Student

Centre for Transport Studies
Skempton Building
Imperial College London
South Kensington Campus
London SW7 2AZ
United Kingdom

E-mail: jacek.pawlak09@imperial.ac.uk
Tel: +44 (0) 20 7594 2705
Fax: +44 (0) 20 7594 6102
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v1.3

You will be invoiced within 48 hours of this transaction date. You may pay your invoice by credit card upon receipt of the invoice for this transaction. Please follow instructions provided at that time.

To pay for this transaction now, please remit a copy of this document along with your payment. Payment should be in the form of a check or money order referencing your account number and this invoice number RLK501375049.

Make payments to "COPYRIGHT CLEARANCE CENTER" and send to:

Copyright Clearance Center
Dept 001
P.O. Box 843006
Boston, MA 02284-3006

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BETWEEN:

HER MAJESTY THE QUEEN in Right of Canada, as represented by the Minister of Industry, having been designated as the Minister for the purposes of the Statistics Act (referred to herein as "Statistics Canada"),

AND:

Centre for Transport Studies,
(referred to herein as the "Licensor")

WHEREAS Her Majesty the Queen in Right of Canada is the lawful owner of the Microdata to be licensed;

AND WHEREAS the Licensee wishes to use the licensed Microdata;

NOW THEREFORE the Parties agree as follows:

DEFINITION
1. "Microdata file" means a non-identifiable data set containing characteristics pertaining to surveyed units as described in section 2.

DESCRIPTION OF PRODUCT

CONTACT AND CUSTODIAN
3. (1) The Licensee hereby nominates Jacen Pawlak as the contact person to whom all further communication shall be addressed by Statistics Canada on any matter concerning this Agreement.

(2) The Licensee hereby nominates Jacen Pawlak as the designated custodian of the Microdata file with responsibility for ensuring its proper use and custody pursuant to the terms of this Agreement.

DELIVERY OF PRODUCT
4. Upon signature of this Agreement, Statistics Canada shall provide to the Licensee one copy of the
OWNERSHIP

5. The Microdata file and related documentation shall at all times be and remain the sole and exclusive property of Statistics Canada. It being mutually agreed that this Agreement involves a licence for the use of the Microdata file and related documentation and that nothing contained herein shall be deemed to convey any title or ownership interest in the Microdata file or the related documentation to the Licensee.

USE OF MICRODATA

6. (1) Statistics Canada hereby grants to the Licensee a non-exclusive, non-assignable and non-transferable licence to use the Microdata file and related documentation for statistical and research purposes. The Microdata file shall not be used for any other purposes without the prior written consent of Statistics Canada.

(2) Use of the Microdata file is limited to the Licensee. The Microdata file cannot be reproduced and transmitted to any person or organization outside of the Licensee’s organization.

(3) The Licensee shall not merge or link the records on the Microdata file with any other databases for the purpose of attempting to identify an individual person, business or organization.

(4) The Licensee shall not present information from the Microdata file in such a manner that gives the appearance that the Licensee may have received, or had access to, information held by Statistics Canada about any identifiable person, business or organization.

(5) The Licensee shall not disassemble, decompile or in any way attempt to reverse engineer any software provided as part of the Microdata file.

REPRESENTATIONS AND WARRANTIES

7. The Microdata file is provided "as is" and Statistics Canada makes no warranty, either express or implied, including but not limited to, warranties of merchantability and fitness for a particular purpose.

PUBLICATION BY THE LICENSEE

8. In any publication of any information based on the Microdata file, the Licensee shall use the following form of accreditation:

"This analysis is based on the Statistics Canada General Social Survey, Cycle 24: Time-Use and Work-Life 2010. All computations, use and interpretation of these data are entirely that of Jakub Pisek, or Centre for Transport Studies."
LIABILITY

9. Statistics Canada shall not be liable to the Licensee for any design, performance, other fault or inadequacy or unauthorised use of the Metadata file or related documentation provided pursuant hereto or for damages of any kind arising out of or in any way related to or connected with such fault, inadequacy or unauthorised use of the Metadata file.

INDEMNIFICATION

10. The Licensee shall at all times indemnify and save harmless Statistics Canada and its officers, servants and agents from and against all claims, losses, damages, costs, expenses, actions and other proceedings made, sustained, brought, prosecuted, threatened to be brought or prosecuted, in any manner based upon, caused by, or in any way attributable to the use of the Metadata file and related documentation provided pursuant hereto.

TERM

11. This Agreement comes into force when signed by both Parties and shall continue in force until terminated in accordance herewith.

TERMINATION

12. (1) Statistics Canada may, by providing ten days written notice to the Licensee, terminate this Agreement if the Licensee fails to comply with any of the terms of this Agreement and to remedy such breach within the notice period.

(2) In the event of termination, the Licensee must immediately return the Metadata file to Statistics Canada, or destroy it and certify this destruction in writing to Statistics Canada.

13. Any notice to be given to Statistics Canada or the Licensee shall be in writing and sent by registered mail, electronic mail or facsimile to

(Contact information for Statistics Canada) (Contact information for Licensee)

Jacek Pawlak
Centre for Transport Studies
Imperial College London
Skeptoton Building
South Kensington Campus
London, United Kingdom SW7 2AZ

Jacek.Pawlak@imperial.ac.uk

Sections 9 and 10 hereof survive the termination of this Agreement pursuant to section 12.
AMENDMENT

16. No amendment to this Agreement shall be valid unless it is reduced to writing and signed by the Parties hereto.

ENTIRE AGREEMENT

16. This Agreement constitutes the entire agreement between Statistics Canada and the Licensee with respect to the Licensee’s right to use the Microdata file.

APPROPRIATE LAW

17. This Agreement shall be governed and construed in accordance with the laws of the province of Ontario and the laws of Canada applicable therein. The parties hereby consent to the exclusive jurisdiction of the Federal Court of Canada.

This Agreement has been executed on behalf of Statistics Canada and the Licensee by:

FOR STATISTICS CANADA:

[Signature]

[Title]

Statistical and Aboriginal Statistics Division

Statistics Canada

Date

FOR THE LICENSEE:

[Signature]

[Name]

Centre for Transport Studies, Imperial College London

Date

Page 4 of 4
Dear Pawlak,

This email has been sent to you because you registered to access data through the Economic and Social Data Service or Census.ac.uk website.

This is an automated reminder of the terms and conditions of the End User Licence (EUL) that you agreed to when you registered. A copy of the EUL is available at [http://www.esds.ac.uk/andsa/access/licence.asp](http://www.esds.ac.uk/andsa/access/licence.asp) and a summary is also available at [http://www.esds.ac.uk/andsa/access/summary.asp](http://www.esds.ac.uk/andsa/access/summary.asp).

By accepting the EUL you agreed:

- not to use the data for commercial purposes, except with prior permission
- that data supplied under the EUL can only be accessed by registered users
- that data supplied under Special Conditions that are additional to those of the EUL, can only be accessed by registered users who have accepted those Special Conditions
- to preserve the confidentiality of, and not attempt to identify, individuals, households or organisations in the data
- to provide the bibliographic details of any publications or reports based on the data collections you have used from the Data Catalogue ([http://www.esds.ac.uk/Lucene/Search.aspx](http://www.esds.ac.uk/Lucene/Search.aspx)); information about data and research used by policy makers is particularly welcome. Please email these details to help@esds.ac.uk including information regarding the data collections used. Where Census data were used, use Submit outputs at [http://census.ac.uk/Outputs/Outputs_Entry.aspx](http://census.ac.uk/Outputs/Outputs_Entry.aspx)
- to use the correct form of citation and acknowledgement in publications. Guidance is available in a 'Study information and citation' file, usually supplied with the data and available via the relevant online catalogue record. For Census data, see [http://census.ac.uk/guides/citing.aspx](http://census.ac.uk/guides/citing.aspx)
- to offer for deposit any new data collections which have been derived from the materials supplied. This includes the conversion of data into standard formats (such as SPSS or STATA) where data are supplied in non-standard formats only
- that your personal details are accurate and kept up to date by you. You can check and update your details by logging into your account at [http://www.esds.ac.uk/newRegistration/new_login.asp](http://www.esds.ac.uk/newRegistration/new_login.asp) and following the link to “Your details”
- to keep your login details and any data stored by you secure

If your registration period is ending and you are still using data, you should renew/extend your registration. Please note it is good practice to delete any copies of data at the end of the research process.

Please ensure that the information in any registered usages is kept up-to-date, including the number of students for teaching usages.

If you are unsure about any of the above, or about any of the clauses of the EUL, please contact the ESDS Help desk at [http://www.esds.ac.uk/support/helpdesk.aspx](http://www.esds.ac.uk/support/helpdesk.aspx) or the Census.ac.uk Help desk at [http://census.ac.uk/helpdesk/help.aspx](http://census.ac.uk/helpdesk/help.aspx)

Kind regards

ESDS HELP DESK
ECONOMIC AND SOCIAL DATA SERVICE
UK DATA ARCHIVE
UNIVERSITY OF ESSEX
WYVENHOE PARK
COLOCHESTER
ESSEX, CO4 3SQ, UK

T +44(0)1206 872143
F +44(0)1206 872003
email:help@esds.ac.uk
www.data-archive.ac.uk www.esds.ac.uk

ENSURING CONTINUOUS ACCESS TO HIGH QUALITY DATA IN THE SOCIAL SCIENCES AND HUMANITIES

Legal Disclaimer: Any views expressed by the sender of this message are not necessarily those of the UK Data Archive or the ESRC.

Note: registration to the UK Data Service provides a means of accessing the ONS Lifestyle data and UK National Travel Survey.
Pledge of secrecy

for persons with access to survey data from
Norwegian Social Science Data Services

Name: Jacek Pawlak
Institution: Imperial College London
Survey: National Travel Survey 2005, percentiles
Travel and Holiday Survey, April 2006

I hereby commit to:

1) a pledge of secrecy concerning any information I got access to, that can identify individuals, through the survey(s) that are made available through NSD. I am aware of the fact that neglect to this pledge of secrecy, deliberately or heedlessly, or participating to such neglect, will be prosecuted by fines or prison for one year or longer - or both - according to the Norwegian Act on protection of privacy no. 48, paragraph 38 no.2.

2) refer to producer and distributor of the data by including the following in a foreword or footnote in eventual publications:

"Some of the data applied in the analysis in this publication are based on "National Travel Survey 2005, percentiles". The survey was financed by the Institute of Transport Economics. The data are provided by SAMI University, and prepared and made available by the Norwegian Social Science Data Services (NSD). Neither the Institute of Transport Economics, nor NSD are responsible for the analysis/interpretation of the data presented here."

"Some of the data applied in the analysis in this publication are based on "Travel and Holiday Survey, April 2006". The data are provided by Statistics Norway, and prepared and made available by the Norwegian Social Science Data Services (NSD). Neither Statistics Norway nor NSD are responsible for the analysis/interpretation of the data presented here."

3) send NSD/Bergen a copy of resulting reports/publications that are based on the data, preferably digitally. These reports will be cited on our websites and can be made available online, should the authors agree to it.

[Signature]
4) destroy or return the data to NSD when analyses are finished, 27-02-2014 at the latest.

Place

London, United Kingdom

Date

25/02/2012

Signature

Jacobs Peacock

Access is given to the following project: 2794, and applies to the following project:

Project: Modelling the relationships between ICT, social and individual productivity.
Study on the Productive Use of Rail Travel Time: SPURT data-set, Release 5- Privileged Data Access Agreement

Data confidentiality agreement for users covered by the fair processing notice

This form must be completed by any party wanting access to data from the Study on the Productive Use of Rail Travel Time (SPURT). Once complete, please email a scanned signed version of this form to rail.stats@dft.gsi.gov.uk or post a signed version to Rail Statistics, Department for Transport, Zone 3/15, Great Minster House, 33 Horseferry Road Street, London, SW1P 4SR.

This agreement permits the party named herein (the "End User") to receive data (the "Data") from the SPURT, strictly subject to the confidentiality rules set out below. This agreement is between the Department for Transport, as holders of the data, and the End User.

End User name, organisation and any organisation working on behalf of:

<table>
<thead>
<tr>
<th>Name</th>
<th>JACEK PAULAK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation</td>
<td>CENTRE FOR TRANSPORT STUDIES, IMPERIAL COLLEGE</td>
</tr>
<tr>
<td>Organisation working for</td>
<td>N/A</td>
</tr>
<tr>
<td>Address line 1</td>
<td>SKELETON BUILDING, IMPERIAL COLLEGE, LONDON</td>
</tr>
<tr>
<td>Address line 2</td>
<td>SOUTH KENSINGTON CAMPUS</td>
</tr>
<tr>
<td>City</td>
<td>LONDON</td>
</tr>
<tr>
<td>Postcode</td>
<td>SW7 2AZ</td>
</tr>
</tbody>
</table>

Details of what the Data will be used for:

```
PHD RESEARCH OF JACEK PAULAK (RESEARCH ON THE RELATIONSHIPS BETWEEN ICT, TRAVEL BEHAVIOUR, AND PRODUCTIVITY)
```

Details of any project outputs:

```
PHD THESIS OF JACEK PAULAK, ACADEMIC JOURNAL PAPERS, CONFERENCE PAPERS & PRESENTATIONS & POSTERS
```

- The End User will ensure that the Data are kept confidential, in accordance with the Data Protection Act, and will not be passed to Third Parties in any form.
- The End User will ensure that the Data are kept secure and that all staff handling the data will be informed of their responsibilities for data protection. The End User will not use the Data to attempt to obtain or derive information relating specifically to an identifiable individual or household, nor to claim to have obtained or derived such information.
- The End User will only use the Data for the purpose specified above.
- The End User will delete the Data upon completion of the project.

09/03/12
• The End User will ensure that any published outputs contain only aggregate data that cannot identify individuals, nor can individuals identify any references to themselves.
• The End User will clear any outputs with the Department for Transport prior to dissemination.
• The End User, if a public authority, will consult the Department for Transport before disclosing the Data in response to a request made under the Freedom of Information Act 2000.
• The End User acknowledges that no warranty is given by the Department for Transport as to the accuracy and completeness of the Data.
• The End User undertakes to provide the Department for Transport with a full copy of any project outputs that use or refer to the Data.

Authorised user of released Data (must be signed by all authorised users):

End User name: 
Signature: 
Organisation: 
Date: 08/03/12

CENTRE FOR TRANSPORT STUDIES
INFORMAL COLLEGE, HANDBIN.
Subject: FW: CONFIDENTIAL: SPURT data


From: pws-156896643-margaret.shaw@dfg.gsi.gov.uk [mailto:pws-156896643-margaret.shaw@dfg.gsi.gov.uk] On Behalf Of Margaret Shaw
Sent: 01 August 2012 16:12
To: Pawlak, Jacek
Subject: CONFIDENTIAL: SPURT data

Jacek,

Here is the SPURT dataset with some descriptive notes. I hope these are sufficient to let you work out what's actually in the dataset.

The original cleaned data received from Accent (the Market Research company) was cleaned again for illogical responses which created additional variables (see Appendix C of the study final report also attached). The most complete set of data used for the final analysis is known as “1753 Client Data Release 5.sav” in SPSS format. This version includes many additional variables beyond the original ones in the questionnaire (the original data from Accent contained 140 variables, the final release 5 data contains 281 variables). So, to be clear: the dataset attached is the final version that was used by our consultants. It has been (a) amended following the identification of errors (largely scanning errors) during the analysis, (b) includes the extra fields generated during that analysis (some of which were adjudications upon or resolved inconsistencies between estimates obtained from the basic fields).

Unfortunately, there is no detailed supporting documentation other than the notes attached to this email. I hope this does not hamper your work unduly. I am advised that further notes could be prepared, but there would be a cost to you for full documentation of the variables.

Finally, regarding data protection, as you know, the survey was undertaken within the Code of Conduct of the Market Research Society (MRS). The MRS Code of Conduct (and the Data Protection Act) do not explicitly cover reuse of the data (providing personal data is not attached, which our data does not in SPSS form). Nonetheless, the spirit of the MRS code would mean that any reuse of data should be related to the initial purpose of the survey as it is that survey to which the respondent has given consent. Your work is in scope, so the data have been supplied on this basis.

Please treat the data as confidential as per the signed agreement.

Best wishes,
Margaret

Margaret Shaw
Rail Statistics | Rail Analysis | Department for Transport | Zone 3/15, Great Minster House | 33 Horseferry Road | London SW1P 4DR | 020 7944 4877

From: Pawlak, Jacek [mailto:jacekpawlak@imperial.ac.uk]
Sent: 09 August 2012 15:17
To: Margaret Shaw
Cc: Ed Palmer; jacekp@imperial.ac.uk
Subject: Re: SPURT data
Dear Margaret,

Please find attached the requested form. Also thank you and Ed very much for your help.

Regards,

Jacek

On 09/08/2012 15:19, Margaret Shaw wrote:

Jacek

I now have an SPSS dataset containing the SPURT data you have requested.

Please complete and return the attached form and I will send you the data.

Best wishes

Margaret

Margaret Shaw

Rail Statistics | Rail Analysis | Department for Transport | Zone 3/15, Great Minster House | 33 Horseferry Road | London SW1P 4DR | 020 7944 4977
Note on the data for the United States

The PEW Internet Survey (PEW Research Center, 2007) and American Time Use Survey (BLS, 2007) are datasets available online for free download and without the need for additional permissions.
Appendix 10
List of publications


## Appendix 11

### List of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>Asymptotically distribution-free</td>
</tr>
<tr>
<td>AIC</td>
<td>Akaike information criterion</td>
</tr>
<tr>
<td>AV</td>
<td>Autonomous vehicle</td>
</tr>
<tr>
<td>BIC</td>
<td>Bayesian information criterion</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer-aided design</td>
</tr>
<tr>
<td>CF1</td>
<td>Comparative fit index</td>
</tr>
<tr>
<td>CIA</td>
<td>Conditional independence assumption</td>
</tr>
<tr>
<td>DfT</td>
<td>Department for Transport</td>
</tr>
<tr>
<td>DWLS</td>
<td>Diagonally-weighted least squares</td>
</tr>
<tr>
<td>GFI</td>
<td>Goodness of fit index</td>
</tr>
<tr>
<td>HIT</td>
<td>Health-information technology</td>
</tr>
<tr>
<td>HS2</td>
<td>High Speed 2</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and communication technologies</td>
</tr>
<tr>
<td>IQR</td>
<td>Interquartile range</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent transport systems</td>
</tr>
<tr>
<td>IV</td>
<td>Instrumental variables</td>
</tr>
<tr>
<td>k-NN</td>
<td>k-nearest neighbours</td>
</tr>
<tr>
<td>LAN</td>
<td>Local area network</td>
</tr>
<tr>
<td>LL</td>
<td>log likelihood</td>
</tr>
<tr>
<td>ln</td>
<td>Natural logarithm</td>
</tr>
<tr>
<td>MC</td>
<td>Monte Carlo</td>
</tr>
<tr>
<td>MCAR</td>
<td>missing completely at random</td>
</tr>
<tr>
<td>MP</td>
<td>Marginal product</td>
</tr>
<tr>
<td>MPF</td>
<td>Marginal product due to reduced travel fatigue</td>
</tr>
<tr>
<td>NFI</td>
<td>Normed fit index</td>
</tr>
<tr>
<td>NGEV</td>
<td>Network generalised extreme value</td>
</tr>
<tr>
<td>NMDCEV</td>
<td>nested multiple discrete-continuous extreme value</td>
</tr>
<tr>
<td>ONS</td>
<td>Office for national statistics</td>
</tr>
<tr>
<td>PDA</td>
<td>Personal digital assistant</td>
</tr>
<tr>
<td>PICSaT</td>
<td>Pooling independent cross-sections across time</td>
</tr>
<tr>
<td>RCS</td>
<td>Repeated cross-sections</td>
</tr>
<tr>
<td>RMSE</td>
<td>Root-mean-square error</td>
</tr>
<tr>
<td>RO</td>
<td>Research objective</td>
</tr>
<tr>
<td>s.e.</td>
<td>Standard error</td>
</tr>
<tr>
<td>SEM</td>
<td>Structural equation model</td>
</tr>
<tr>
<td>SPURT</td>
<td>Study of the Productive Use of Rail Travel-time</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Term</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>SV</td>
<td>Subjective value</td>
</tr>
<tr>
<td>TAM</td>
<td>Technology acceptance model</td>
</tr>
<tr>
<td>TFP</td>
<td>Total factor productivity</td>
</tr>
<tr>
<td>VBTT</td>
<td>Value of savings in business travel time</td>
</tr>
<tr>
<td>VBTT_{EE}</td>
<td>Employee’s value of savings in business travel time</td>
</tr>
<tr>
<td>VBTT_{ER}</td>
<td>Employer’s value of savings in business travel time</td>
</tr>
<tr>
<td>VL</td>
<td>Value of leisure time relative to travel time</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice-over-Internet protocol</td>
</tr>
<tr>
<td>VOT</td>
<td>Value of time</td>
</tr>
<tr>
<td>VTTS</td>
<td>Value of travel time savings</td>
</tr>
<tr>
<td>VW</td>
<td>Value to employee of work time at the workplace relative to travel time</td>
</tr>
<tr>
<td>WebTAG</td>
<td>Web Transport Analysis Guidance</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Local area wireless network</td>
</tr>
</tbody>
</table>