The “C” in ICT: communications capital, spillovers and UK growth

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Abstract
Part of the ICT revolution has been the advances in communications technology, the “C” in ICT. Using data on telecommunications equipment prices based on Corrado (2011) we estimate two effects of “C” on UK productivity growth: the direct effect from growth accounting and the indirect effect via network effects. We find (a) “C” price data as used in ONS capital services estimates substantially understate quality-adjusted telecoms equipment prices (b) using new price data substantially increases the growth accounting contribution of “C” to productivity growth, (c) using new price data also yields spillover effects from investment in C capital. Overall, for 1990-2008, communications capital is 2.6% of total capital payments but accounts for 7.8% of growth in capital services and 21.9% of growth in value-added, of which 3.7% are private gains and 18.2% are spillovers.

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1. Introduction

The consequences of the ICT revolution for productivity have been extensively studied by growth accountants see e.g. Van Ark and Inklaar (2005) for EUKLEMS, Oulton (2002) in early work for the UK and Jorgenson (2001) for the USA. The vital lesson from computer hardware was that in periods of very fast technical change standard price deflators potentially (vastly) understate the impact of nominal asset investment. The development of suitable deflators for hardware and software has rightly been a major priority.\(^1\)

Interestingly, however the “C” part of ICT remains somewhat neglected. As pointed out by Doms (2005), Corrado (2011), Byrne and Corrado (2009) and OECD (2008)\(^2\) this is potentially important. For example, one way of thinking about the internet is that it is a (very large) piece of communications capital equipment, building on older telecoms capital and being augmented by broadband and mobile technologies. So its contribution to growth is potentially measureable as part of the ICT contribution. In addition, if communication networks have network/spillover effects, the expansion of the communications network might show up not only in the standard contribution of ICT capital to growth, but also in MFP.\(^3\)

By the computer hardware logic above, to measure growth contributions and to test for spillovers, the capital services derived from communications equipment investment needs a suitable deflator. This simple observation is the starting point for this paper. First, we document that ONS UK capital services data deflates nominal telecommunications equipment investment using a non-computer plant and machinery deflator.\(^4\) This deflator grows at 0.6%pa, 1983-2008.

\(^{1}\) Research databases such as EUKLEMS (O’Mahony et al 2007) use harmonised hardware data, but not software data. A consistent software series, based on the US quality-adjusted software series but using country-specific software spending compositions in set out in Corrado, Haskel et al (2012).

\(^{2}\) Indeed section 3c is called “The Impact of the “C” in “ICT””.

\(^{3}\) Other methods of measuring the economic contribution of the internet include for example the Boston Consulting Group (2010) who tried to count “Internet GDP” by e.g. consumption mediated on the internet by e-commerce; parts of business investment and consumer computer spend (e.g. subscriptions to ISPs); and government spending on the internet. Greenstein and McDevitt (2011) measure consumer surplus from free goods on the internet.

\(^{4}\) We note that there is a difference in ONS methods for the estimation of capital services, and that for GFCF and capital stocks in the national accounts. Traditionally, ONS data on capital services, GFCF and capital stocks have grouped communications equipment with general plant & machinery. As this paper was being written, in
This is in contrast to the official computer hardware deflator, which falls at 11.9%pa over the period. This sits oddly with for example, the observation from engineering data that investment in fibre optic cable and equipment in the late 1990s increased capacity in telecoms networks by a factor of 40.\(^5\) Thus our research question is whether the contribution of communications equipment might be understated in a similar fashion to that of hardware before adopting quality-adjusted deflators.

Our second step is then to note that US researchers have been assembling quality-adjusted communications equipment deflators (Doms (2005), Byrne and Corrado (2009), and Corrado (2011)). These show prices falling swiftly, reflecting the use of semi-conductors in equipment at either end of the network and massive investment and technical progress in the network itself (e.g. fibre optic equipment). For example, Byrne and Corrado (2009) find an average price decline of -5.9%pa (1983-2008). We note further that ONS capital services data uses US deflators for hardware and (purchased) software\(^6\) and so we broadly follow this by applying the US telecom deflator produced in Byrne and Corrado (2009) and Corrado (2011) to the UK data on telecommunications transmitters, for this is where the bulk of technical progress has occurred. For the other aspects of UK telecommunications investment (insulated wire and cable; receivers) we use Producer Price Indices (PPIs) from ONS. We weight together these three deflators using their investment shares in total telecoms investment. We find the following. First, the deflator falls at -4.1%pa, as opposed to the non-quality adjusted which rises at 0.6%pa. Second, we derive therefore growth in the real UK telecoms capital stock of around 9.3%pa, 1983-2009, in contrast with 4.4%pa using the official deflator. Third, this turns out to approximately double the standard growth

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\(^5\) For instance, data in OECD (2008) show that DSL broadband price fell 19% in September 2005 to October 2006, whilst speeds rose by 29% in the same time period.

\(^6\) As with telecoms equipment, there is a difference in method here between the data for ONS capital services and data in the national accounts (GFCF and capital stocks). ONS capital services deflate software using specific deflators for purchased and own-account software. The own-account software deflator is a wage index for software writers with a small adjustment for assumed growth in productivity. The purchased deflator is an average of the (exchange rated adjusted) pre-packaged US deflator and the own-account deflator, where the latter is used to account for purchases of custom software. In the national accounts, both purchased and own-account software are deflated using the Services Producer Price Index (SPPI) for “computer services”, which it turns out looks remarkably similar to the own-account price index used in the estimation of capital services.
accounting contribution of telecoms over the late 1990s, and increase it around four-fold in the 2000s. (0.15%pa as opposed to 0.08%pa in the late 1990s, 0.11%pa as opposed to 0.03%pa in the early 2000s, and 0.05%pa as opposed to 0.01%pa in the late 2000s).

Our third step is to ask if there is any evidence of spillovers from telecoms equipment. Such a question is very natural if one thinks of such equipment as building networks. We investigate this in a standard manner, by regressing lagged growth of telecoms equipment capital stock on TFP growth and find evidence of spillovers. With the plant and machinery deflator we find no evidence of spillovers. However the quality-adjusted deflator gives a statistically significant correlation between telecoms equipment growth rates and TFP growth four years later. It is economically significant too, accounting for 37.4% of TFP growth, 1990-2008.

How is this paper related to others? The pioneering ICT work for the UK was by Oulton (Oulton (2002) for example) but this concentrated on software and hardware and used the official UK asset price index for telecoms. The EUKLEMS dataset reports a separate series for telecoms assets, but while the implied deflator used there does fall (at 1.5% p.a. over 1970 to 2007, and 2.9% over the more comparable period of 1983 to 2007), the changes are not as fast as those implied by the US work. Jalava and Pohjola (2007) undertake growth accounting for Finland, estimating the contribution of ICT to Finnish growth using BEA IT and CT price data. Doms (2005) makes some informed guesses as to how US growth accounting would change with a different deflator, but does not formally do growth accounting (his paper is primarily concerned with price measurement). Much cross-country work follows Roeller and Waerman’s (2001) method see e.g. Koutroumpis (2009) and Gruber and Koutroumpis (2011), which is to study country data on productivity growth and telecoms penetration (they were careful to subtract out telecom capital from the official cross-country capital data); subsequent work has used mobile and broadband penetration see e.g. the survey in OECD (2008). Such work typically finds a sizable correlation, although measurement issues especially in developing country data are a challenge.
Our paper is most directly related to Corrado (2011). She presents new deflators. She then studies the telecoms industry itself, documenting capital productivity and utilisation, and presents market sector-wide contributions as well. She also finds evidence of spillovers, but using a different method. She finds a faster acceleration in post-2000 industry MFP in industries scoring highly on an index, for year 2000, of “internet-readiness” due to Forman, Goldfarb et al. (2003). Interestingly, she finds that communications capital accounts for 32% of MFP growth, 2000-07, our comparable figure is 37.4%, 1990-2008.

The plan of the rest of this paper is as follows. In the next section, we set out our data and different deflators used. Section 3 shows the impact on measurement. Section 4 considers other aspects of telecoms investment. Section 5 shows growth accounting and section 6 spillover results. Section 7 concludes.

2. Data

2.1 Investment data

Historically, conventional measures of investment and capital stocks, as recorded in the UK National Accounts, have aggregated data for hardware and telecoms into the broader asset category of “Plant and Machinery” (P&M). Since 2007, in the ONS Volume Index of Capital Services (VICS), computer hardware has been separated out of P&M and treated as a distinct asset. The well-documented falls in the price of hardware, and its faster rate of depreciation compared to other P&M, meant that estimates of growth in capital services were greater than previously measured, increasing the contribution of computers in growth accounting decompositions for the UK. See Appleton and Wallis (2011) for detail on ONS VICS data.

Communications investment however has not been separated out and hence is implicitly deflated by the aggregate non-computer plant and machinery deflator. Studies by Doms (2005), Byrne and Corrado (2009) and Corrado (2011) show that the prices of communications equipment have been in steady decline. Although the pace has not been as fast as hardware, the fall is larger than that implied by official datasets from National Statistical Institutes (NSIs) including the ONS, and this decline has not slowed in recent years.
as has been the case for computers. Therefore, by similarly separating out telecommunications investment and applying an improved estimate of price changes, we attempt to provide better estimates of growth in telecommunications capital, and its contribution to UK growth.

In order to do this we first must identify investment in telecommunications capital. Figure 1 sets out data for nominal investment in the product groups identified as telecommunications assets using Gross Fixed Capital Formation (GFCF) data in previous vintages of the Supply Use Input-Output (IO) tables. There are three IO product groups that fall into the telecommunications asset category: i) ‘Insulated wire and cable’; ii) ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’; and iii) ‘Television and radio receivers, sound or video recording or reproducing apparatus and associated goods’. The second product group is by far the largest in terms of investment, and largely pertains to investment in capital by the communications industry that is used to provide telecommunications services.

As Figure 1 shows, in 1992 and 2000, approximately 85% of telecommunications investment was in the second group. By 2008 this had fallen to 70.2%, with the third group having risen to 13.7%, from 5.2%. An interpretation of this change in the composition of investment is that the 1990s was a time of ‘network build out’ creating much of the telecoms network infrastructure with investment in fibre-optic equipment, largely by the telecommunications services industry itself. Increased investment in receivers since then appears to be reflective of increased ‘network utilisation’ by the rest of the market sector. Looking directly at the data for the ‘Post and Telecommunications’ industry (SIC03 64 or section I), investment by the telecommunications industry in 2008 accounted for 63% of total investment in telecommunications capital, compared to 47% in 1984.

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7 The latest versions of the IO tables are not sufficiently detailed to separately identify elements of telecommunications investment.
2.2 Telecommunications asset prices

To re-estimate growth in telecommunications capital services separately we must first deflate the nominal investment data to obtain real measures of investment. A suitable UK deflator does not exist. Instead we construct one from three sources. For insulated wire and cable we use the ONS PPI for this product, likewise for Receivers for TV & Radio. For Transmitters, which includes the fibre-optic and switching centre equipment where technical progress has been rapid, we use the price index presented in Byrne and Corrado (2009) and Corrado (2011), adjusted using Purchasing Power Parity (PPP) indices. We are very grateful to Carol Corrado for providing us with these data.

Doms (2005) provides an excellent, comprehensive description of the technical progress that has occurred in the production of telecommunications equipment, which underlies the price falls in the Byrne and Corrado price index. Broadly speaking, telecommunications equipment can be viewed as being made up of two main components. First, (local area) network

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8 This was the case at the time of writing. As this paper was being written, the ONS released a new GFCF deflator for telecommunications equipment. Over the period 1997 to 2009, the new ONS deflator falls at an average rate of -8.9%pa, compared to -7.8%pa for our new deflator over the same period.
equipment or LAN, largely being made up of the fibre-optic equipment connecting different locations to a central hub, through which information is transmitted. Second is the switching equipment, which, loosely speaking, transmits the information through the network. It includes the switching centre which acts as a central hub, receiving information and re-transmitting it to the relevant part of the network. At the ends of the network are the equipment that transmit, receive and translate that information, including semi-conductors, modems, satellite and fixed line equipment. These items fall under the heading of ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’ in the UK investment data.

The prices for equipment in this category have fallen significantly due to the rapid technical progress that has occurred. The production of telecommunications equipment is a large user of semiconductors, and the transmission speed of modems has grown massively over the last twenty or so years, on a comparable scale to Moore’s Law. However even larger technical progress has occurred in the growth in capacity of fibre-optic cable and equipment which has gradually replaced traditional copper wire, resulting in huge increases in the volume of transmissions at lower cost. Doms (2005) notes that the pace of progress in fibre-optic capacity is well above that of Moore’s Law: between 1996 and 2001 the potential capacity of a glass fibre stand doubled every year.

The methodology used to construct the BC deflator is set out in Byrne and Corrado (2009) and Corrado (2011), as well as Doms (2005) which describes the construction of an earlier version. In constructing their aggregate index, Byrne and Corrado (2009) use prices for over fifty different communications products. Underlying each product are further disaggregations meaning that underlying some products are observations on dozens of varieties. The end result is an updated series for most telecommunications products for 1963 to 2009, including for wired local area network (LAN) equipment, and the high-speed routers and switches employed in wireless wide-area networks (WAN) (Corrado 2011).

Indices for each product are then constructed as an unweighted average of the data by variety, and an index for telecommunications assets is formed as a weighted average of the products.
The main differences between the official US series and the BC deflator occur in the 1948 to 1973 and 1995 to 2007 periods. Since the latter is just after the widespread introduction of the internet and in a period of significant investment in telecommunications, the implications for measurement of output and productivity growth are significant.

In the analysis that follows in this paper, we reconstruct estimates of real UK investment in telecommunications using our new deflator for the UK, largely based on the BC deflator, as described above. To do this, we took the nominal investment data, which is under the three headings above, and matched these headings to the nearest ones for the available price deflators. In the case of ‘Insulated wire and cable’ and ‘Television and radio receivers, sound or video recording or reproducing apparatus and associated goods’ these were the ONS producer price indices. For ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’ we used the BC deflator. We converted the BC deflator to UK currency using the UK:US PPP. This adjustment only affects data for years prior to 1991, due to a very stable relationship between the purchasing power of the dollar and sterling from 1992. Our overall communications deflator is then an investment-share weighted average of the deflator for the three different categories. The price index for each category and its share in total telecoms investment are presented in Appendix 2.

It could be argued that it is not appropriate to use the US deflator as a component in our UK price index. However we note that importantly the pattern of price change is strikingly similar across a diverse range of communications products and technologies (Corrado 2011). Second, such products are internationally traded and should therefore be priced competitively across countries. Third, in the case of both hardware and purchased software, official UK indices are PPP (or exchange rate) adjusted versions of those produced by the US Bureau of Economic Analysis (BEA).

3. Preliminary impacts and measurement

Figure 2 sets out the annual changes in the non-computer plant and machinery deflator and our new deflator, and compares them to those for hardware and purchased software. As can
be seen, on average over the whole period (1983-2008), the general plant and machinery deflator rises at +0.6% p.a. whereas our new series falls at -4.1% p.a.. Comparable figures for UK hardware and purchased software are -11.9% p.a. and -3.5% p.a. respectively. In particular, in the late 1990s, the new deflator falls very rapidly, at a rate of -8.61% p.a. over 1995 to 2000, compared to -3.11% p.a. for the plant and machinery deflator. As we see below, this has significant implications for measurement as the late 1990s were a period of very sharply rising communications investment.

*Figure 2: UK deflators for ICT assets*

![Figure 2: UK deflators for ICT assets](image)

Note to figure: Data are annual natural log changes for each price index. The thick solid line are changes in the telecoms equipment deflator constructed for this paper. Thick dashed line are those for the general plant and machinery deflator as used by the ONS. Thin solid line are those in the official price index for computer hardware. Thin dashed line are changes in the UK price index for purchased software. Source: Official data from ONS VICS. New data based on Byrne and Corrado (2009) and ONS PPIs.

Armed with these deflators, we create a telecoms equipment capital stock using a perpetual inventory model and depreciation rate of 0.115, the same rate as used in EUKLEMS. For more details on the construction of the telecoms capital stock, please see Appendix 1.
Figure 3 presents estimates of growth in telecommunications capital under the old and new treatment respectively. Applying the new deflator suggests that over the period 1983 to 2008 the stock of telecommunications capital has on average grown at a rate almost 5 percentage points higher than the current treatment suggests (9.3%pa compared to 4.4%pa). In the year 2001 this differential was 8.6 percentage points.

Figure 3: Growth in telecommunications equipment capital stock using alternative deflators

![Graph showing growth in telecommunications capital stock using alternative deflators](image)

Notes: Data are changes in natural logs of the telecommunications equipment stock, so e.g. 0.1 refers to a change of 10%. The dashed line is an estimate of growth in the telecommunications capital stock, where real investment has been calculated using the general plant and machinery deflator. The solid line is a comparable series generated using the new telecommunications asset deflator described in this paper.

Underestimation of the price falls for telecommunications assets also results in mismeasurement of the asset income share in value-added. Figure 4 presents estimates of telecommunications (Tornqvist) income shares using the new deflator, compared to the current treatment using a P&M deflator. Note that the rental prices of capital assets are adjusted using data on corporation tax and specific subsidies and allowances for each asset type including telecommunications capital. The income share is a product of the rental price and the level of the asset stock, where the rental price is also partly determined by the asset price.
Figure 4: Effect telecoms equipment income shares of value-added

Notes: Income shares are presented as Tornqvist averages of the annual shares in the current and previous period. For comparison, income shares for hardware and software assets are around 0.015 and 0.028 respectively in 2008. See Appendix for details on calculation of rentals and income shares. Income shares in this chart are based on the National Accounts baseline, where the only intangibles treated as assets are software, mineral exploration, artistic originals and R&D (due to be officially capitalised in the National Accounts in 2014).

We now turn to the impact of treating telecommunications as a distinct asset and applying our new deflator on aggregate estimates of UK market sector capital services. Within Figure 5, the solid line is the published series for VICS (Appleton and Wallis 2011) and the dashed line is a new measure of total capital services where telecommunications has been separated out and treated as a distinct asset using the deflator described above. As the graph shows, the major effects are between 1995 and 2005, with the new growth rate being as much as 0.7 percentage points per annum higher in 2000.
Figure 5: Growth in market sector capital services across all assets

Notes: The solid line represents growth in aggregate market sector VICS (across all assets) as calculated in Appleton and Wallis (2011). The dashed line represents growth in VICS after treating telecommunications capital as a distinct asset and applying our new deflator with a depreciation rate specific to telecoms capital, of 11.5%. Source: Appleton and Wallis (2011) and own calculations.

4. Private investment in spectrum rights

4.1 Summary

So far we have taken data on nominal telecommunications equipment investment as published. However, there is one significant aspect of investment in telecommunications not recorded in the official figures: private investment in spectrum licences. In April 2000 the UK Government conducted an auction of rights to third-generation (3G) mobile phone licences, raising £22.5bn from the sale of five licences, around 2.5% of UK GNP (Binmore and Klemperer 2002). Prior to that, payments by UK firms for 2G licences were in the thousands rather than millions. Current estimates of private investment do not include these payments. In this and the next section, we document that so incorporating them adds 0.01% to 0.04% pa to growth post 2000. The details are as follows.

4.2 Details of spectrum calculations

Why aren’t such investments treated as such in the National Accounts? The reason is that the spectrum is a non-produced asset with rights to its use held by the state. Therefore there was no production of additional “spectrum output”, in 2001 or at any point prior to that date, and
neither did the sale of spectrum rights result in any new output that generated factor incomes for labour and capital. Therefore in the context of the whole economy, the treatment is perfectly sensible, as the sale of licences simply represented an asset transfer between the government and private firms. That is, positive GFCF for the buyers (telecommunications firms), and negative GFCF for the seller (the UK Government). But we are estimating investment and growth in the market sector (given the worries on public sector output data quality). So, as outlined above, even though the auction resulted in a reduction of assets on the government balance sheet, it also meant a corresponding increase to assets on the aggregate balance sheet for private firms. Therefore we ought to treat those payments as investment when conducting a decomposition of market sector growth (if we did not, then the additional output due to the use of spectrum rights would be allocated to TFP).

In estimating the stock of spectrum rights, as well as using the observation of investment at the 2001 UK 3G auction, we also make use of data from OFCOM on payments for analogue licences from 1986 to 2001 (the analogue networks were closed in 2001). Further improvements that could be made to our data include the adding in of spectrum payments for the broadcasting and transport industries, although such spend is small in comparison to the 3G licence payments. For a deflator we apply a price index for the gross output of the (downstream) telecommunications industry, sourced from EUKLEMS (see Corrado, Goodridge and Haskel (2011) for further information on the reasoning behind this). To estimate depreciation we apply a geometric rate of as close to zero as possible, due to the fact that there is no depreciation of the spectrum until the licence expires, making the appropriate schedule a one hoss shay model.

Incorporating investment in spectrum rights into our dataset does however present some problems. The investments required to acquire spectrum rights prior to the 3G auction in 2000 were very small, meaning the stock is almost entirely made up of the 3G licence payments. The arrangements for 2G and 3G payments were also different. Prior to 2001 2G payments were in the form of annual charges. In contrast, 3G licences, which last for twenty years, were sold for an up-front payment, after which annual charges will be incurred (in 2021). Therefore the decomposition is affected by the decision of state authorities on the nature and length of the licences to be sold. For instance, the series for the stock and the
contribution of capital deepening would look very different if auctions took place every five years or every twenty years.

The result of introducing an asset with only one significant investment observation is that the series’ for growth in the ‘spectrum capital stock’ and the associated factor income share exhibit a sharp rise in 2001 and a steady decline thereafter. However, when the 3G licences were first purchased almost no 3G phones/smartphones existed in the UK and so the licences were not immediately put into productive use, that is the full extent of the rights were not part of the productive capital stock immediately after their sale/purchase. For that reason we incorporate a utilisation factor for this specific piece of telecommunications capital.

Ideally we would wish to use data which reflects actual spectrum utilisation by firms. However, aside from anecdotal suggestions that use of the 3G spectrum allocation may be nearing capacity, we have not been able to find any such data. However, we do have data on UK 3G subscriptions from the OFCOM Communications Market Report (OFCOM 2010; OFCOM 2011). Therefore to estimate a proxy for the utilisation factor we assume that spectrum utilisation was close to zero in 2000 when the licences were first purchased (mid-year), and at almost full capacity in 2011. For years in between we estimate the utilisation factor (µ) using the growth rate in 3G mobile subscriptions. Since the OFCOM CMR data begin in 2004, we impute subscription levels for the years 2001-3. All in all, incorporating spectrum in this fashion adds 0.01% to 0.04% pa to growth post 2000.

This discussion raises the question of why we do not use a utilisation factor for the communications capital stock. The obvious analogy to under-utilised spectrum is fibre-optic cable. However, as Figure 1 shows, cable is in fact a very small part of telecommunications investment. Rather, the bulk of investment is in the transmitters that pass the signal down the cable and process messages at either end.9

9 So for example, fiber-optic communication systems require (a) an optical transmitter to convert an electrical signal into an optical signal (b) a cable (c) amplifiers to maintain signal strength and (d) an optical receiver to recover the signal as an electrical signal. Multiplexing, i.e. sending multiple signals down the existing fibre, a major increase in fibre capacity, requires enhanced transmitters and receivers.
5. Growth accounting results

We apply the standard growth-accounting model to estimate the contributions of capital by asset type. Output growth is for market-sector value added, 1990-2008. TFP growth is this growth less share-weighted input growth of J=9 capital assets and L=3 labour types as follows:

\[
\Delta \ln TFP_t \equiv \Delta \ln Y_t - \sum_{j=1}^{J} \tilde{s}_{kj} \Delta \ln K_{jt} - \sum_{l=1}^{L} \tilde{s}_{lt} \Delta \ln L_{lt}
\]

\(j= \)telecoms, computer hardware, software, buildings, vehicles, non-computer plant and machinery, mineral exploration, artistic originals, R&D

\(l= \) skill, age, gender

(1)

\[
s_{kj} = \left( \frac{P_{kj} K_j}{P_j Y} \right)_t, \quad s_{lj} = \left( \frac{P_{lj} L_l}{P_l Y} \right)_t, \quad \tilde{s}_t = (s_t + s_{t,1}) / 2, \quad \sum_j s_{kj} + \sum_l s_{lj} = 1
\]

\[
P_{kj} = \tau_j P_{kj} (r + \delta_j - \pi_j)
\]

Where capital shares are calculated using tax-adjusted rental prices (see final line of (1) and the Appendix), with the total capital share adding up to one minus the labour share. \(P_{kj}\) is the asset rental price, \(P_{lj}\) is the investment price, \(r\) is the net rate of return estimated ex-post such that it is equalised across all assets and rental costs exhaust operating surplus, \(\delta_j\) is the geometric rate of depreciation, \(\pi_j\) is a capital gains term estimated using changes in the asset price deflator and \(\tau_j\) is an asset-specific tax adjustment factor. Labour inputs are quality-adjusted labour services. Capital inputs are capital services for telecoms equipment, computer hardware, computer software, other tangible inputs (commercial buildings, vehicles, non-computer plant & machinery) and other intangibles already or soon to be capitalised in the national accounts (mineral exploration, artistic originals and R&D).

For all assets other than telecoms, data on GFCF, investment prices and the capital stocks are as used in the ONS VICS. Data on output/income are taken from the National Accounts.
Tangible tax-adjustment factors are from Wallis (2012b) and for intangibles from Wallis (2012a). All investment categories are those already treated as capital assets in the National Accounts with the exception of R&D, capitalised in the UK in 2014. The asset price deflator used for R&D is the implied value-added deflator and depreciation is set at 20%pa.

As set out in Appendix 1, our data on telecommunications investment begin in 1984. To construct reasonable estimates of the initial stock which reflect the fast falls in the price of communications equipment that took place prior to 1984, we backcast nominal investment data using that reported in EUKLEMS. We then convert the EUKLEMS capital stock to a nominal/wealth measure using the EUKLEMS deflator, and back into a real measure using our own. We then re-construct the stock using our extended estimates of investment and the EUKLEMS initial value, using a perpetual inventory model in the usual way. Spectrum rights are included as a separate asset, and calculated as described above. Our final decomposition is presented below in Table 1.
Table 1: Decomposition of growth in UK market sector value-added, 1990-2008

<table>
<thead>
<tr>
<th>Year</th>
<th>DlnV</th>
<th>sDln(L)</th>
<th>sDln(K) cmp</th>
<th>sDln(K) software</th>
<th>sDln(K) telecom</th>
<th>sDln(K) spec</th>
<th>sDln(K) oth tan (min, cop, R&amp;D)</th>
<th>DlnTFP</th>
<th>Memo: sLAB</th>
<th>Memo: sDln(K) ICT</th>
<th>Memo: sDln(K) CT</th>
</tr>
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<tr>
<td>1) Baseline Results: Telecoms treated as if part of P&amp;M</td>
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<tr>
<td>1990-95</td>
<td>1.69%</td>
<td>-0.78%</td>
<td>0.29%</td>
<td>0.18%</td>
<td>0.00%</td>
<td>0.40%</td>
<td>0.04%</td>
<td>1.56%</td>
<td>0.64</td>
<td>0.47%</td>
<td>0.00%</td>
</tr>
<tr>
<td>1995-00</td>
<td>4.20%</td>
<td>0.83%</td>
<td>0.72%</td>
<td>0.27%</td>
<td>0.08%</td>
<td>0.64%</td>
<td>0.07%</td>
<td>1.60%</td>
<td>0.62</td>
<td>1.07%</td>
<td>0.08%</td>
</tr>
<tr>
<td>2000-05</td>
<td>2.50%</td>
<td>0.25%</td>
<td>0.38%</td>
<td>0.09%</td>
<td>0.03%</td>
<td>0.57%</td>
<td>0.04%</td>
<td>1.13%</td>
<td>0.65</td>
<td>0.50%</td>
<td>0.03%</td>
</tr>
<tr>
<td>2005-08</td>
<td>2.01%</td>
<td>-0.77%</td>
<td>0.09%</td>
<td>0.14%</td>
<td>0.01%</td>
<td>0.70%</td>
<td>0.03%</td>
<td>0.26%</td>
<td>0.64</td>
<td>0.24%</td>
<td>0.01%</td>
</tr>
<tr>
<td>2) New Results: treating telecoms as a distinct asset with new deflator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-95</td>
<td>1.72%</td>
<td>-0.78%</td>
<td>0.29%</td>
<td>0.18%</td>
<td>0.02%</td>
<td>0.35%</td>
<td>0.05%</td>
<td>1.61%</td>
<td>0.64</td>
<td>0.49%</td>
<td>0.02%</td>
</tr>
<tr>
<td>1995-00</td>
<td>4.19%</td>
<td>0.83%</td>
<td>0.70%</td>
<td>0.28%</td>
<td>0.15%</td>
<td>0.53%</td>
<td>0.06%</td>
<td>1.64%</td>
<td>0.62</td>
<td>1.13%</td>
<td>0.15%</td>
</tr>
<tr>
<td>2000-05</td>
<td>2.55%</td>
<td>0.25%</td>
<td>0.36%</td>
<td>0.09%</td>
<td>0.11%</td>
<td>0.44%</td>
<td>0.05%</td>
<td>1.26%</td>
<td>0.65</td>
<td>0.56%</td>
<td>0.11%</td>
</tr>
<tr>
<td>2005-08</td>
<td>2.02%</td>
<td>0.77%</td>
<td>0.08%</td>
<td>0.14%</td>
<td>0.05%</td>
<td>0.60%</td>
<td>0.04%</td>
<td>0.34%</td>
<td>0.64</td>
<td>0.27%</td>
<td>0.05%</td>
</tr>
<tr>
<td>3) New Results: treating telecoms as a distinct asset with new deflator and also including spectrum payments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-95</td>
<td>1.72%</td>
<td>-0.78%</td>
<td>0.29%</td>
<td>0.18%</td>
<td>0.02%</td>
<td>0.35%</td>
<td>0.05%</td>
<td>1.61%</td>
<td>0.64</td>
<td>0.49%</td>
<td>0.02%</td>
</tr>
<tr>
<td>1995-00</td>
<td>4.19%</td>
<td>0.83%</td>
<td>0.70%</td>
<td>0.28%</td>
<td>0.15%</td>
<td>0.53%</td>
<td>0.06%</td>
<td>1.64%</td>
<td>0.62</td>
<td>1.13%</td>
<td>0.15%</td>
</tr>
<tr>
<td>2000-05</td>
<td>2.55%</td>
<td>0.25%</td>
<td>0.36%</td>
<td>0.09%</td>
<td>0.11%</td>
<td>0.44%</td>
<td>0.05%</td>
<td>1.26%</td>
<td>0.65</td>
<td>0.57%</td>
<td>0.12%</td>
</tr>
<tr>
<td>2005-08</td>
<td>2.02%</td>
<td>0.77%</td>
<td>0.08%</td>
<td>0.14%</td>
<td>0.05%</td>
<td>0.59%</td>
<td>0.04%</td>
<td>0.35%</td>
<td>0.64</td>
<td>0.31%</td>
<td>0.09%</td>
</tr>
</tbody>
</table>

Notes: The above decomposition is based on growth in market sector value-added. Since our later estimates of externalities are based on growth in capital rather than growth in capital deepening (per hour), we also estimate the private contribution on the same basis. All results produced using conventional National Accounts capitalised assets plus R&D. That is, the only capitalised intangibles are software, mineral exploration, artistic originals and R&D. The first panel deflates and depreciates telecommunications capital in the conventional way as if part of Plant and Machinery. The second panel uses data where telecommunications are treated as a distinct asset, deflated using the price index described in this paper and using the depreciation rate from EUKLEMS. The third panel is the same as the second panel except spectrum rights are also introduced as a capital asset. Estimated rental prices for all assets are corrected using tax-adjustment factors. First column is growth in value-added. Column 2 is the contribution of labour services, namely growth in labour services times share of labour in MGVA. Column 3 is growth in computer capital services times share in MGVA. Column 4 is growth in software capital services times share in MGVA. Column 5 is growth in telecoms capital services times share in MGVA. Column 6 is growth in spectrum capital services times share in MGVA. Column 7 is growth in other tangible capital services (buildings, plant, vehicles) times share in MGVA. Column 8 is growth in other intangible capital services (mineral exploration, artistic originals, R&D) times share in MGVA. Column 9 is TFP, namely column 1 minus the sum of columns 2 to 8. Column 10 is the share of labour payments in MGVA. Column 11 is the total contribution of ICT capital, namely the sum of columns 3 to 6. Column 12 is the total contribution of communications capital, namely column 5 plus column 6.
One way to read Table 1 is to ask the following question: what is the impact of the new deflator on the estimated contributions of CT and ICT to growth in value-added? This is answered in columns 5, 6 and 12. Looking at our baseline results in the first panel, conventional measurement of real investment in telecommunications (using the non-computer plant & machinery deflator) suggests a contribution of CT capital of (column 5) 0.03% in 2000-05 and 0.01% in 2005-08, approximately 1.2% of ΔlnV in the first period (e.g. 0.05/2.59 in 2000-05), and 0.5% in the second. The overall contribution of ICT capital deepening (hardware, software and telecommunications, column 11) in each of these periods is estimated at 0.5% and 0.24% p.a..

Results in the second panel are based on our new treatment of telecommunications capital as a separate asset with a more appropriate price index, but without spectrum. Looking again at the periods 2000-05 and 2005-08, columns 5 and 11, we see higher estimated contributions for CT and ICT capital, at 0.11% and 0.56% p.a. in 2000-05 and 0.05% and 0.27% p.a. in 2005-08. Results in the third panel incorporate the contribution of spectrum rights into that of CT, giving higher contributions still, of 0.12% in 2000-05 and 0.09% in 2005-08, representing 4.7% p.a. of average annual ΔlnV in 2000-05 and 4.5% in 2005-08. Taken together, data for 2005-08 suggests that the proposed treatments of CT as set out in this paper result in an extra 0.08 percentage points of annual average ΔlnV that can be explained by the additional contribution of CT capital compared to previous estimates.

6. Estimation of spillovers

Numerous studies have investigated the possibility that new communications technologies and the internet have generated network externalities or spillovers. The following section sets out a model to study this, and includes some preliminary analysis of whether the build-up of new communications equipment has had positive effects on aggregate market sector growth in TFP, above and beyond the contribution of telecommunications capital deepening to growth in labour productivity.
There are many ways in which communications capital deepening may have contributed to improved growth in TFP, for example, improved opportunity and ability for collaboration and communication that might, for example, improve supply chains; and improved access to freely available knowledge via the internet; For example, recent studies (Adams, Black et al. 2005; Ding, Levin et al. 2009) have shown a positive impact from the internet on academic collaboration and productivity.

6.1 Model & preliminary results

Since our main focus is on the effect of possible spillovers from growth in telecoms capital, we shall estimate:

$$\Delta \ln TFP_t^{\text{smoothed}} = \alpha + \beta \Delta \ln K_{\text{Telecoms}, t} + v_t$$

Where we lag $\Delta \ln X$ since spillovers likely take time and TFP is smoothed as an equally weighted three-year moving average based on the current period (t) and two leading periods, (t+1) and (t+2); smoothing removes uninformative annual noise from the data and we use leads as we are seeking to estimate network externalities derived from utilisation of capital after that capital has been built. Our data are up to 2008, but the smoothing function used means that the final data points for TFP remain unsmoothed, further, TFP is strongly negative from 2007, and so the regressions are for 1983 to 2006.

Table 2 sets out a first look at this model. Columns 1 and 2 use as regressors in (6) $\Delta \ln K(\text{ICT})$ and $\Delta \ln K(\text{Comms})$ using the implicit UK deflator for Comms i.e. non-computer plant and machinery. The coefficient on ICT is negative and statistically insignificant. The point estimate of $\Delta \ln K(\text{telecomms})$ suggests an spillover coefficient of 0.0457, but is insignificant.

Data in remaining columns are estimated using the new deflator described in this paper. Column 3 shows the coefficient for growth in ICT capital which remains negative and statistically insignificant when we use the new deflator. Column 4 breaks out ICT into IT
and CT, where IT includes software capital. The coefficient on IT is negative and statistically insignificant. That on CT is positive and statistically significant at the 5% level, with a large coefficient of 0.0814. Column 5 shows that, when we enter it on its own, the coefficient for growth in CT capital is positive and significant when we use the new deflator, with elasticity 0.0498. Column 6 shows we get the same result when we use a version of CT capital that excludes spectrum. The results in columns 5 and 6 are also statistically significant when we use four lags (for parsimony we only present here the third lag).

Table 2: Spillover results for lagged linear model equation (6)(dependent variable: smoothed ΔlnTFP dated t, t+1, t+2) (1983-2006)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>Non-computer plant &amp; machinery deflator</th>
<th>Non-computer plant &amp; machinery deflator</th>
<th>New deflator</th>
<th>New deflator</th>
<th>New deflator</th>
<th>New deflator</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔlnK(All ICT)(t-3)</td>
<td>-0.0140</td>
<td>-0.00375</td>
<td>(0.0340)</td>
<td>(0.0308)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔlnK(IT incl. soft.)(t-3)</td>
<td>-0.0461</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔlnK(tele&amp;spec)(t-3)</td>
<td>0.0457</td>
<td>0.0814**</td>
<td>0.0498**</td>
<td>(0.0278)</td>
<td>(0.0330)</td>
<td>(0.0226)</td>
</tr>
<tr>
<td>ΔlnK(tele)(t-3)</td>
<td>0.0522**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.0230)</td>
</tr>
</tbody>
</table>

Observations 24 24 24 24 24 24
R-squared 0.008 0.055 0.001 0.241 0.123 0.133

Notes: All columns have a constant. “All ICT” capital is defined as computer hardware, software, telecoms equipment and spectrum. Robust standard errors in parenthesis, ** indicated p<0.05, * p<0.1.

Before moving to the statistical robustness of these results, let us look at the economic significance. Table 3 shows, in column 1 unsmoothed ΔlnTFP. Column 2 shows mean growth in the CT capital stock, lagged 4 periods. We use 4 lags as the coefficient in Table 2 was estimated using 3 lags, plus ΔlnTFP was smoothed using lead terms.
Column 3 shows the estimated spillover, or excess contribution, from telecommunications capital, estimated as the coefficient in Table 2 column 5 (0.0498) times column 2. Column 4 shows the percentage of TFP that can be explained by the excess contribution in column 3. Over the full period, 1990-2009, 37.5% of TFP can be explained by such spillovers.

To complete the picture, column 5 sets out the private contribution of telecoms and spectrum for the periods, using Table 2, columns (5+6), and column 6 ΔlnV. Finally column 7 shows the fraction of ΔlnV accounted for by the private and spillover contributions, i.e. column 3+5 as a proportion of column 6. As the last row shows, over the whole period, the private and social contributions of ΔlnK(comms) account for 21.9% of ΔlnV (of which 3.7% are private gains and 18.2% are spillovers). These are quite considerable contributions for capital equipment which is, as Table 4, memo columns 8 and 9 show is 2.6 % of total capital rental payments and 7.8% of VICS. Note that the contribution in the 2000s is particularly high reflecting the roll out of equipment in the late 1990s. Overall, we conclude that, on the basis of this first pass at the data, the results are economically significant.

Table 3: Accounting for TFP

<table>
<thead>
<tr>
<th>period</th>
<th>ΔlnTFP</th>
<th>ΔlnK(tele&amp;spec)(t-4)</th>
<th>Spillover</th>
<th>% of ΔlnTFP</th>
<th>sDln(K) telecom&amp;spec</th>
<th>ΔlnV</th>
<th>% of ΔlnV</th>
<th>Telecoms Share: P^r K(tele&amp;spec) / P^r K</th>
<th>Telecoms share of VICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-95</td>
<td>1.61%</td>
<td>7.93%</td>
<td>0.39%</td>
<td>24.60%</td>
<td>0.02%</td>
<td>1.72%</td>
<td>24.13%</td>
<td>2.10%</td>
<td>2.04%</td>
</tr>
<tr>
<td>1995-00</td>
<td>1.64%</td>
<td>5.08%</td>
<td>0.25%</td>
<td>15.41%</td>
<td>0.15%</td>
<td>4.19%</td>
<td>9.62%</td>
<td>2.48%</td>
<td>8.55%</td>
</tr>
<tr>
<td>2000-05</td>
<td>1.26%</td>
<td>16.53%</td>
<td>0.82%</td>
<td>65.42%</td>
<td>0.12%</td>
<td>2.55%</td>
<td>36.98%</td>
<td>3.11%</td>
<td>11.54%</td>
</tr>
<tr>
<td>2005-08</td>
<td>0.35%</td>
<td>9.79%</td>
<td>0.49%</td>
<td>140.45%</td>
<td>0.09%</td>
<td>2.02%</td>
<td>28.60%</td>
<td>2.77%</td>
<td>9.98%</td>
</tr>
<tr>
<td>1990-2008</td>
<td>1.31%</td>
<td>9.84%</td>
<td>0.49%</td>
<td>37.41%</td>
<td>0.10%</td>
<td>2.69%</td>
<td>21.93%</td>
<td>2.60%</td>
<td>7.81%</td>
</tr>
</tbody>
</table>

Note to table: Column 1 is ΔlnTFP, unsmoothed. Column 2 is mean growth in the telecommunications capital stock, lagged 4 periods. Column 3 is the estimated spillover, that is the coefficient in Table 3 times column 2. Column 4 is the percentage of TFP explained by telecoms spillovers, that is column 3 over column 1. Column 5 is the private contribution of telecoms capital. Column 6 is growth in market sector value-added. Column 7 is the percentage of value-added growth explained by the private and excess contributions of telecoms capital, that is columns 3 plus 5 as a share of column 6. Memo items are in columns 8 and 9. Column 8 is the share of telecoms capital payments in total operating surplus. Column 9 is telecoms capital services as a percentage of total capital services.
6.2 Robustness checks

Of course the previous tables just document preliminary investigations and clearly take no account of potential omitted variables. Table 4 sets out the results of incorporating the above specification into our estimates for telecommunications as well as some additional robustness checks on the regressions above.

First, in column 1 we show that the telecoms result is robust to incorporating an additional delta term into the dependent and independent variable, that is using an acceleration model. We consider this a powerful result, as the additional change term magnifies the measurement error which we would expect to result in a loss of precision.

Second, In previous work, Goodridge, Haskel and Wallis (2014a) and Haskel and Wallis (2013) we have found some evidence of spillovers from, respectively, private and public R&D. In the former paper we use industry data and found statistically significant effects of lagged $\Delta \ln K(R&D)$ in industry j on $\Delta \ln TFP$ in industry i in an industry/year panel. Here we have aggregate data and so are missing the cross-sectional industry variation which is large since $\Delta \ln K(R&D)$ differs between industries. However, we still estimate a large elasticity for private R&D (t-5) in column 2. However, the inclusion of private R&D renders the telecoms variable insignificant. Regarding public R&D we found a significantly declining marginal impact from public R&D as a proportion of output ($R_{PUB}^*/Y$) over time. Column 3 therefore adds ($R_{PUB}^*/Y$) and ($R_{PUB}^*/Y)^2$ and finds them significant. Private R&D also remains significant with a larger coefficient, and telecoms capital is significant at the 10% level. We note that growth in the stocks of private R&D and telecoms capital are quite highly correlated, as shown below in Figure 6.

---

10 As a matter of data, $R_{PUB}^*$ trebled in just three years from 2001 to 2004 and it would appear sensible to allow for diminishing rates of return from this increase, as evidence from Haskel and Wallis (2013) suggests. We recognise that there is a mismatch in the sense that our private stock incorporates a depreciation rate whereas our public measure assumes no depreciation. We feel this is justified in the sense that private R&D is applied commercial research, whereas our public science measure represents basic research. If we do apply a specification for private R&D the same as that used for public, we do find positive and significant results, also with high implied rates of return. Another possibility to include is foreign public R&D (our data on foreign R&D is not restricted to just science funding). Again, using a non-linear specification we find large and strongly significant coefficients. Foreign R&D as a share of GDP was also tested as an instrument for UK public science research but with no success.
Figure 6: Growth in capital services from CT and (private) R&D, and the public research / MGVA ratio (%)

Note to figure: Growth in telecoms capital services (incl. spectrum) capital services and public research as a percentage of market sector GVA (MGVA) on left-hand axis, and growth in R&D capital services on right-hand axis. Growth in IT capital (incl. software) capital services not shown. Correlation coefficient for IT and CT capital services (1983-2006) is 0.36

The economic significance implied by Table 4 is slightly less than in Table 3, that is using the coefficients in Table 4 (column 3) with the methods in Table 3, ΔlnK(comms) accounts for 29% of ΔlnTFP, 1990-2008.
Table 4: Spillovers from telecommunications capital and public R&D

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ(ΔlnK(tele&amp;spec))(t-3)</td>
<td>0.106***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔlnK(tele&amp;spec)(t-3)</td>
<td>0.0303</td>
<td>0.0383*</td>
<td></td>
</tr>
<tr>
<td>ΔlnK(priv R&amp;D)(t-5)</td>
<td>0.159***</td>
<td>0.284***</td>
<td></td>
</tr>
<tr>
<td>(R/Y)PUB SCI (t-2)</td>
<td>296.2***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[(R/Y)PUB SCI (t-2)]^2</td>
<td>-61,084***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.242</td>
<td>0.245</td>
<td>0.575</td>
</tr>
<tr>
<td>Constant not reported</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: All columns bar column 1 have a constant. Robust standard errors in parentheses. (*** indicate p<0.01, **p<0.05, * p<0.1). In Column 1 variables are in acceleration form, with a double delta term on the independent and dependent variable and with no constant. By using the public science share of GDP as an independent variable, we are implicitly assuming that the public stock of scientific capital does not depreciate. Whilst this may not be so it appears reasonable to assume that it would depreciate very slowly, with a much smaller rate of decay than say private R&D. The terms in parentheses next to variable names refer to the number of lags employed.

We also checked robustness to indirectly measured banking sector output (FISIM). The new methodology for FISIM introduced in Blue Book 2008 resulted in upward revisions to GDP, particularly in the late 1990s and mid-2000s (Akritidis 2007). It might be felt that upward revisions to output in the late 1990s and 2000s resulted in overestimated growth in GDP and TFP or a cyclical effect if it was felt that measures for the 2000s reflect wider conditions of that time including loose monetary policy and the availability of credit. Therefore we include a series for growth in the volume of the component of FISIM that is a direct addition to GDP. We do not find any statistically significant effect and the coefficient is in any case negative.

7. Conclusions and discussion

The consequences of the ICT revolution for productivity have been extensively studied. As Corrado (2011) points out, a sizable business economics literature has developed around Metcalf’s Law, namely that the value of a network rises greatly with the number of
participants. But the implications for productivity, namely of spillovers with more connected networks, have been very hard to detect. There seems no very strong evidence of spillovers to ICT equipment.

This paper follows Doms (2005), Corrado (2011), Byrne and Corrado (2009) and OECD (2007) in suggesting that a resolution of this puzzle is around the neglect of the “C” part of ICT. Researchers have long known that measurement of hardware and software quality-adjusted prices is key to understanding their effects in periods of rapid quality change. Likewise, there has been massive quality change in communications equipment technology e.g. fibre optic cable, broadband versus dial-up etc. This raises the question of whether the contribution of communications equipment is mismeasured if prices are mismeasured.

To investigate this question, this paper has taken three steps. First, we document that UK capital services data deflates nominal telecommunications equipment investment using a non-computer plant and machinery deflator, which grows at 0.6%pa, 1983-2008, in sharp contrast to the official computer hardware deflator (based on US data), which falls at 11.9%pa over the period.

Second, based on US researchers quality-adjusted communications equipment deflators (Doms (2005), Byrne and Corrado (2009), and Corrado (2011)), which show an average price decline of -5.9%pa (1983-2008), we construct a UK deflators that falls at -4.1%pa. This doubles the growth in the real UK telecoms capital stock (9.3%pa, 1983-2008, in contrast with 4.4%pa using the official deflator). And this approximately doubles the standard growth accounting contribution of telecoms over the late 1990s (0.15%pa as opposed to 0.08%pa in the late 1990s), increases it almost four-fold in the early 2000s (0.11%pa as opposed to 0.03%pa), and increases it five-fold in the late 2000s, from 0.01% pa to 0.05% pa in the late 2000s. Incorporation of spectrum further increases the contributions to 0.12% pa in the early 2000s, and 0.09% pa in the late 2000s.
Third, we ask if there is any evidence of spillovers from telecoms equipment, by regressing three-year lagged growth of telecoms equipment capital stock on TFP growth. We find no evidence of spillovers using the plant and machinery deflator, but the quality-adjusted deflator shows a statistically significant correlation between telecoms equipment growth rates and TFP growth four years later. It is economically significant too, accounting for 37.4% of TFP growth 1990-2008. Therefore, for 1990-2008, we find that an asset which accounts for just 2.6% of capital payments actually accounts for 7.8% of growth in capital services, and 21.9% of growth in value-added, of which 3.7% are private gains and 18.2% are spillovers. This increasing importance and the possibility of spillovers makes future study and better data important.
References


Goodridge, P., J. Haskel, et al. (2014b). "The UK Productivity Puzzle is a TFP Puzzle: Current Data and Future Predictions."


Wallis, G. (2012a). "How Tangible is the Failure of the Q model." Forthcoming and available on request.

Appendix 1

Our data on telecoms investment from the Supply Use tables go back to 1984. Therefore we extend that back to 1970 using nominal investment data from EUKLEMS. We then inflate the EUKLEMS initial stock in 1970 using the EUKLEMS deflator, and deflate using our own. The telecoms capital stock is then constructed using the perpetual inventory method (PIM):

\[ K_t = I_t + (1-\delta)K_{t-1} \]  

(A1)

Where \( K_t \) is the capital stock, \( I_t \) is real investment and \( \delta \) is the geometric rate of depreciation (we use a rate of 0.115 as in EUKLEMS).

Regarding tax adjustments, in the late 1990s and 2000s we estimate \( \tau = 1.15 \) for telecoms equipment, compared to \( \tau = 1.03 \) and 0.95 for mineral exploration and R&D respectively.

In our growth-accounting exercise we work at the aggregate market sector level: we exclude non-market sectors due to the problem of measuring government output. Note the decomposition is based on growth in value-added, and not value-added per hour.

We end our analysis in 2008. We actually have data to 2009 but strongly negative TFP from 2008 onward make later data more difficult to interpret. For a deeper exploration of negative TFP and the UK productivity puzzle, see Goodridge, Haskel and Wallis (2014b).
Appendix 2

Table A2.1: Shares of total investment in telecommunications, by component

<table>
<thead>
<tr>
<th>Weights</th>
<th>Insulated wire and cable</th>
<th>Transmitters for TV, radio and phone</th>
<th>Receivers for TV and radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.11</td>
<td>0.84</td>
<td>0.05</td>
</tr>
<tr>
<td>1993</td>
<td>0.20</td>
<td>0.76</td>
<td>0.04</td>
</tr>
<tr>
<td>1994</td>
<td>0.15</td>
<td>0.80</td>
<td>0.05</td>
</tr>
<tr>
<td>1995</td>
<td>0.13</td>
<td>0.82</td>
<td>0.05</td>
</tr>
<tr>
<td>1996</td>
<td>0.12</td>
<td>0.83</td>
<td>0.05</td>
</tr>
<tr>
<td>1997</td>
<td>0.11</td>
<td>0.84</td>
<td>0.05</td>
</tr>
<tr>
<td>1998</td>
<td>0.11</td>
<td>0.83</td>
<td>0.06</td>
</tr>
<tr>
<td>1999</td>
<td>0.11</td>
<td>0.83</td>
<td>0.06</td>
</tr>
<tr>
<td>2000</td>
<td>0.09</td>
<td>0.85</td>
<td>0.05</td>
</tr>
<tr>
<td>2001</td>
<td>0.09</td>
<td>0.84</td>
<td>0.07</td>
</tr>
<tr>
<td>2002</td>
<td>0.09</td>
<td>0.82</td>
<td>0.09</td>
</tr>
<tr>
<td>2003</td>
<td>0.09</td>
<td>0.79</td>
<td>0.11</td>
</tr>
<tr>
<td>2004</td>
<td>0.11</td>
<td>0.78</td>
<td>0.11</td>
</tr>
<tr>
<td>2005</td>
<td>0.11</td>
<td>0.78</td>
<td>0.11</td>
</tr>
<tr>
<td>2006</td>
<td>0.12</td>
<td>0.76</td>
<td>0.12</td>
</tr>
<tr>
<td>2007</td>
<td>0.12</td>
<td>0.74</td>
<td>0.14</td>
</tr>
<tr>
<td>2008</td>
<td>0.15</td>
<td>0.72</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Figure A2.1: Price indices for each component of telecommunications investment