

**THE IMPACT OF TRANSPORT INFRASTRUCTURE
INVESTMENT ON REGIONAL EMPLOYMENT:
AN EMPIRICAL INVESTIGATION**

by

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Abstract

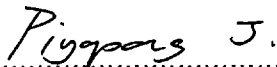
Over the past decades, substantial attempts have been made to empirically investigate whether investments in transport infrastructure can generate job opportunities throughout an economy. Previous research has provided mixed and inconclusive evidence. One possible reason is that previous work has generally suffered from several methodological drawbacks. In theory, improvements in transport infrastructure could have long-term economic impacts by influencing both firm and household decisions that can affect employment. The employment effect may take place at several points in time and space, and could vary considerably across different sectors of the economy. Provision of transport infrastructure is also endogenous; therefore, the causal relationship between transport investment and employment may be ambiguous. These issues, while acknowledged in the literature, have not been adequately addressed in empirical studies.

This dissertation explores the empirical relationship between highway infrastructure investment and regional employment. Using panel data for the 48 contiguous US states and the county level panel data for the State of North Carolina, recent advances in dynamic panel and spatial econometric methods are applied to sort out this relationship in time and space. To provide a better understanding of the causal linkages between highway infrastructure and regional employment, this dissertation presents a first attempt to examine the causal and spatial spillover effects of highways on employment in various sectors of the economy. The scope of the thesis' contribution also extends to the study of transport infrastructure and economic productivity by examining the effect of highway capacity additions on private sector output. The findings of this dissertation have several important implications on policy and methodologies used to estimate economic development impacts from highway infrastructure investments, and overall assessment of capacity additions.

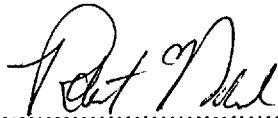
Declaration of Contribution

At various stages during this PhD I have been involved in collaborative efforts with my supervisors, working on several research papers that were presented at various conferences and submitted for journal publication. These are listed at the back of this dissertation and are all my own work. The contribution from the supervisors was supervisory and editorial.

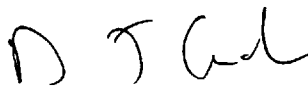
I hereby declare that besides the collaboration referred to above I have personally carried out the work described in this dissertation.



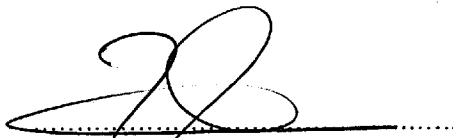
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Chapter 1

Introduction

This dissertation examines the complex interactions between transport investment and economic development with a particular focus on the macro-level relationship between highway infrastructure and regional employment. One contribution of this dissertation is to use recent advances in dynamic panel and spatial econometric methods to sort out this relationship in time and space. A significant contribution is also made to the current state of empirical knowledge on the causal linkages between highway infrastructure investment and regional employment. This dissertation presents a first attempt to examine the causal and spatial spillover effects of highways on employment in various sectors of the economy. The scope of the thesis' contribution also extends to the study of transport infrastructure and economic productivity when examining the effect of highway capacity addition on private sector production, which is another measure of economic development impacts. The findings of the present research have several important implications on policy and methodologies used to estimate economic development impacts from highway infrastructure investments.

The next section outlines the background and motivation. This begins with an overview of theoretical debates on the effectiveness of transport infrastructure as a contributor to economic development, followed by a note on how the effect on employment is of particular importance to transport infrastructure policy aimed at inducing regional development. Also, gaps in the understanding of the linkage between transport investment and employment are briefly discussed. Then, we describe the

objective and scope of the work including datasets that are used in econometric analyses. An overview of the remainder of this dissertation is then provided.

1.1 Background and motivation

*Theoretical debates on transport infrastructure and economic development*¹

The linkage between transport infrastructure and economic development has been discussed extensively in several contexts with considerable debate on the effects. In the classical theory of firm and residential location, transport is defined as a central influence on the location of economic activities (e.g. Weber, 1928; Moses, 1958; and Alonso, 1967). Emphasising the importance of transport costs, conventional wisdom has maintained that good transport facilities are important for a region's competitiveness and prosperity because they provide accessibility to resources, goods, and markets (e.g. Dodgson, 1974; Forkenbrock, 1990). Others underline the role of improving transport links between geographically separated markets in helping to remove bottlenecks in production, trade, and economic integration (e.g. Blum, 1982; Vickerman, 1987, 1995; and Rietveld, 1989). Macroeconomists have concentrated largely on endogenous growth theory, viewing that the provision of transport infrastructure could affect economic growth either through its direct contribution as a factor input in the production process or through improving technological innovation (e.g. Meade, 1952; Aschauer, 1989; Hulten and Schwab, 1991). Recent attention given to urban transport improvements contends that reductions in travel times and the costs of travel can reinforce agglomeration benefits and hence give rise to productivity growth (Eberts and McMillen, 1999; Venable, 2007; Graham, 2007a). The image or perceived status of the locations with well-provided transport infrastructure is also thought to be of particular importance to firms and regions (Rietveld, 1994; Banister and Berechman, 2000). These could translate into wider economic benefits from transport investments (e.g. increased output, productivity, and employment growth) which are not fully captured in the direct user benefits in

¹ This section does not set out to provide a comprehensive survey of this topic, but it is aimed at offering a summary of important ongoing debates on transport infrastructure and the complexity of economic development. Useful discussions and reviews of empirical research on transport and economic development are immense. For example, see Straszheim (1972), Huddleson and Pangotra (1990), Forkenbrock (1990), Rietveld (1994), Rietveld and Bruinsma (1998), SACTRA (1999), and Banister and Berechman (2000), OECD (2002), Vickerman (2002; 2007).

traditional cost-benefit assessments (e.g. travel time and cost savings, reductions in accident risk, and decreased health risk due to noise and pollution etc.).²

The effectiveness of transport infrastructure investment in stimulating growth and development may be somewhat limited or uncertain. This concern has been prompted for a variety of reasons. One supposition is that transport infrastructure may be necessary but not a sufficient condition for economic development to occur. In this regard, regional development theory (e.g. Hansen, 1965a; Nijkamp, 1986; Vickerman, 1991a; Beihl, 1991) holds that the impacts of infrastructure provision are conditional on the presence of other favourable conditions such as the availability of skilled labour and other resources, agglomeration, and sectoral composition. Also, what is perhaps not immediately clear is the direction of causality in this relationship (e.g. Straszheim, 1972; Reitveld, 1994). Unlike an initial stage of development where building infrastructure exerts considerable influence on growth and induced economic expansion, the growth inducing effects could subsequently generate demand for transport services and spur additional traffic, which in turn influences the allocation of transport infrastructure.

The contribution of transport infrastructure to growth in a mature economy is, however, likely to decline because of diminishing returns to continued infrastructure investments (e.g. Hulten and Schwab, 1991; Fox and Murrey, 1993). Additional provision of transport infrastructure supply in the presence of a well-provided and extensive transport network is thought to have little or no impact. This is because further investments may only have limited effects on transport costs (Rietveld, 1994), improve accessibility only marginally (Thompson et al, 1993; Banister and Berechman, 2000), and make firms become more footloose and hence reduce the importance of transport infrastructure as a location factor (e.g. Chapman and Walker, 1991; Banister and Lichfield, 1995; Forkenbrock and Foster, 1996; Rietveld and Nijkamp, 2000). On this basis, the main concern tends to be linked to the trend that transport costs of goods movement have not been large relative to total production costs.³ However, the claim that transport costs are

² One has to be aware of double-counting of benefits since there are some aspects in which the two concepts are overlapping. Given the current state of the art in this field, there is no formal guidance for combining one with the other in order to measure the total economic benefits.

³ An early study by Edwards (1970), for example, suggests that transport costs amounted to about 3.5 percent of the value of sale and 6.6 percent of the net value of output in British production industries. According to SACTRA (1999), Parkinson (1981) reports that transport costs constituted around 5-10 percent of total production costs, and a survey of European logistic costs (McKinnon, 1996; pp.2) reveals that transport expenditures by manufacturers, on average, account for only 1.5-2.0 percent of sale revenue.

less significant to businesses and industries might be premature since moving people could still be costly (Glaeser and Kohlhase, 2004). Transport costs as a barrier to spatial trade and interactions could remain high, and little is also known about the significance of generalised costs involving reliability, scheduling costs, and individual comfort (Rietveld and Vickerman, 2004).

In addition, provision of transport infrastructure can have spatial implications and competition effects that entail the uncertainty of predicting its economic effects. At micro scales, location theory predicts that a reduction in transport costs may encourage economic activities to change their locations. One classical example would be a central business area where improved transportation services may increase household out-migration because there are some incentives for people to reside at greater distance (e.g. better living conditions and lower values of land and property) and commute to work with perhaps the same amount of generalised costs. Based on the Hotelling (1929) model, SACTRA (1999) and Goodwin (2002) draw attention to the "two-way road" argument, in that improving a transport link could lead some firms to move away from one location to another where the prices of their products remain competitive in both markets. Recent developments in the new economic geography literature (e.g. Fujita et al, 1999; Fujita and Thisse, 2002) also hypothesise that transport improvements could encourage centralisation as well as the dispersion of economic activity, depending primarily on the level of initial transport costs, the amount of reduced transport costs, and the extent of agglomeration economies (e.g. Venables and Gasiorek, 1999; Vickerman, 2002). In the case that lower transport costs help to remove trade barriers, there could be export-based sectors gaining at the expense of local production in other sectors that encounter increased market competition from cheap imported products (e.g. Rietveld, 1986; Button 1998). Others are also concerned with the existence of spatial competition for economic activity as provision of transport infrastructure in one region might draw mobile factors of production away from elsewhere (e.g. Boarnet, 1998; Chalermpong, 2004). A lack of attention to these issues may lead to an overestimate of the total economic benefits stemming from transport infrastructure investments.

When the emphasis is on the generation of employment resulting from transport infrastructure investment, possible adverse impacts of transport improvements on

demand for employment should not be overlooked. The background is that cheaper transport inputs could also result in a substitution effect away from making use of labour in the production process. It is also likely that the removal of trade barriers could create employment losses in some sectors that are exposed to market competition (Button, 1998; Rietveld and Bruinsma, 1998; Lakshmanan et al, 2001; Vickerman, 2007). Given that the relative extent of these opposing effects is uncertain, there is no guarantee that the net employment effect would be positive. In addition, one may overstate the role of transport infrastructure in generating job opportunities if the spatial level in question is too narrowly defined. This is because the creation of jobs in one area could be at the expense of employment growth in others where some jobs were previously located. When measuring employment changes due to transport investments, it is also essential that a distinction be made between growth and relocation, and that spatial spillovers in employment be taken into account.

Transport infrastructure, employment, and regional development policy

While many of these arguments and debates seem to be purely an academic matter, transport infrastructure has continued to play an important role in the formulation of policies aimed at facilitating or stimulating regional development. Improving transport systems and links within the transport network has commonly been seen as one of several policy instruments for generating output and productivity growth, attracting new businesses, creating job opportunities, and spurring income growth. The primary incentive for economic development is the long-term employment gain that is promoted as a rationale for investment in transport. In a survey of all 50 state departments of transportation in the United States, for example, Forkenbrock and Plazak (1986) reported that a key feature of economic development-related highway programmes in several states was to increase the competitive advantage for attracting and retaining employment-generating activities. This was similar to the United Kingdom and continental Europe where there were transport investment strategies for stimulating job opportunities particularly in disadvantaged regions (Hart, 1993). In the policy community, there is also a common interest for the generation of jobs related to construction of infrastructure, though they are generally thought to be marginal and of a

short-term nature. In addition, promoting local development on the basis of long-term job creation is also popular with the general public because it is most easily understood. It is therefore unsurprising that employment growth associated with public investments in transport infrastructure is often asserted as a justification for the allocation of transport funding by policy makers.

Empirical research on the employment impact of transport infrastructure

Exploring evidence on the employment impact of transport investment has been the focus of substantial research interest by economists, regional scientists, and transport policy analysts over the past decades. Given that employment gains associated with expenditures on infrastructure construction might diminish rapidly after completion of construction work, much attention has been concerned with the issue of whether and to what extent transport investments help to generate long-term job opportunities throughout an economy. While the political interest in the importance of transport infrastructure as a prerequisite for employment growth has remained high, direct use of empirical evidence in shaping transport policy and supporting particular investment decisions has been rather limited.

To date, a number of macro-level studies have sought to establish the statistical link between highway infrastructure investments and overall employment. However, they provided mixed and inconclusive evidence. Many studies, for example, find that overall employment is positively and significantly related to the stock of highway infrastructure (Lombard et al, 1992; Dalenberg et al, 1998; Carlino and Mills, 1987; Clark and Murphy, 1996), government expenditure on highways (Crane et al, 1991; Jones, 1990; Carroll and Wasylenko, 1994; Islam, 2003), and the availability of major highway access (Luce, 1994; and Boarnet, 1994). Whilst these findings seem very promising, other studies reveal no significant effect of highway infrastructure stock (Thompson et al, 1993; and Duffy-Deno, 1998) and highway expenditures (Eagle and Stephanedes, 1987; Clark and Murphy, 1996). Furthermore, some researchers find that an increase in highway capital (Pereira, 2000) or public spending on highways (Lombard et al, 1992; and Dalenberg and Partridge, 1995) could reduce the demand for overall employment.

Less attention has been paid to understanding the contradictory evidence emerging from this line of research. Apart from the common differences among studies in scope and methodology, another possible reason is that much of the previous work has generally suffered from several methodological drawbacks. In many studies, for instance, several important determinants of employment are omitted, and the regression models estimated are not formulated on any coherent theoretical basis. Those studies based solely on cross-sectional data also typically do not account for unobserved regional heterogeneity that may explain spatial differences in employment changes.

Another limitation of much of the empirical research is the hypothesis that employment is a function of transport infrastructure. This is a strong assumption since it is likely that the relationship between transport infrastructure investment and employment is bi-directional. As already mentioned, both regions with a growing economy or, alternatively, lagging economic performance, could be targets for public investment in transport infrastructure. The failure to account for these reverse causal links may give rise to the presence of estimation biases from the endogeneity of transport infrastructure.

There is another problem of endogeneity in most studies that estimate dynamic panel models in attempting to capture time lags in the employment impact of transport infrastructure. It is well known that the presence of a lagged dependent variable induces simultaneity bias when conventional panel regression techniques (e.g. pooled OLS, within-group estimator and random effects estimator) are utilised. However, efforts to deal with this issue are minimal.

Misspecification due to spatial autocorrelation is also a major shortcoming of previous research relying on purely cross-sectional or panel data. This is a central issue in the field of spatial econometrics which emphasises the need to account for the potential existence of spatial interdependencies between observations, particularly when using data for geographically contiguous areas. In this strand of empirical work, the majority of previous studies have used aggregate data for contiguous regions. However, this spatial issue has received little attention; therefore, it is likely that the empirical evidence would be potentially misleading.

While the failure to account for these econometric issues has led our current understanding of the employment impact from transport infrastructure investments to remain unclear, there are also crucial gaps in empirical knowledge on this research topic. First, little work has been done to empirically identify the existence of reverse causality from employment to transport infrastructure. There is no doubt that policies designed to stimulate employment by improving transport infrastructure have existed, and that growing employment and hence demand for transport have often driven policy decisions to allocate funding for transport projects at almost all levels. The literature gives us little insight into whether and how these phenomena could be important and captured in statistical analysis at high levels of geographic aggregation. Empirical evidence that could emerge from modelling the causal relationship explicitly could have a significant implication for further research in this area.

Secondly, more emphasis should be placed on examining the employment impact of transport investments that take place in other regions. The empirical literature on the spatial spillover effects of transport infrastructure is growing, but much of the previous work is concerned with productivity and output spillovers from infrastructure development. Indeed, they reveal clearly that transport infrastructure could produce both positive and negative spillovers across regions. Only recently have some studies attempted to examine the existence of the spillover effects of transport provision on the job market. Given this current state of the literature, it is unclear what the spatial dimension of the employment impact resulting from transport investments is.

Finally, a sectoral analysis of the influence of transport infrastructure provision on employment merits further attention. What does matter to the research and policy communities is not just whether and how transport investments affect overall employment, but whether and to what extent improving transport infrastructure has implications in the structure of employment. The focus in the literature has been largely on manufacturing. While its significant dependence on transport has been traditionally acknowledged in urban and regional economics, empirical work has been inconclusive in terms of statistical evidence. The service sector constitutes the largest share of gross domestic product and employment in many nations, whereas several others are evolving

from a manufacturing-oriented economy into a service-oriented economy. Empirical work with emphasis on services could have immediate policy relevance.

A clearer understanding of the relationship between highway investment and employment is essential for improving policy and allocation decisions with respect to highway infrastructure investment. Also, it could provide guidance on key empirical issues that need to be addressed for future work in this area. This dissertation sets out to address these gaps that remain in both methodological framework and empirical knowledge. The objective and scope of the present research is described in the next section.

1.2 Objective and scope of the work

The objective of this dissertation is to explore the empirical relationship between highway infrastructure investment and regional employment. With a primary aim to gain a better understanding of this relationship, this research sets out to address a number of relevant issues that can be grouped into four broad themes:

- 1) the impact of highway infrastructure on private sector employment,
- 2) the sectoral differences in the employment impact of highway investments,
- 3) the existence of employment spillovers from highway infrastructure across regions, and
- 4) the existence of reverse causality from the evolution of employment to the addition of highway capacity

This dissertation is also aimed at providing empirical evidence and hence some implications for highway infrastructure policy towards promoting economic development. Thus, in addition to exploring the above employment-related issues, another objective is to examine the direct and spatial effects of highway infrastructure on private sector production, which is an alternative measure of economic development. While there is a large body of empirical research addressing this different, but related, issue, econometric analysis conducted in this dissertation differs significantly from previous studies in terms of the measurement of highway capital and analytical frameworks.

Within the context of this dissertation, the empirical strategy involves developing and estimating econometric models that can statistically isolate the influences of highway infrastructure from those due to other factors as suggested by relevant theoretical principles. Rigorous econometric methods are considered in empirical implementation with particular attention given to making use of recent advances in dynamic panel and spatial econometric methods to model the effects of highway investments in time and space. To further ensure the robustness of estimation results, we have attempted to explicitly address the common shortcomings inherent to previous research, including the omission of relevant variables, the potential endogeneity of highway infrastructure, the endogeneity problem in dynamic panel estimations, and the problem of spatial dependence.

In this research, empirical analyses are performed using different panel datasets from the United States. Basically, the data are from (1) annual observations on all 100 counties of the State of North Carolina from 1985 to 1997, and (2) annual observations on the 48 contiguous US states from 1984 to 1997. The major reason for choosing these study areas is the availability of data on highway lane mileage that can capture roadway capacity. This is superior to the use of total lengths of highways as in many studies in the literature. For the North Carolina dataset, we obtain data on aggregate lane miles of interstate highways, all state highways, and other primary roads from Fulton et al (2000). State-level data on lane miles are collected from the Highway Statistics series published by the Federal Highway Administration (FHWA)⁴. They are available in aggregate and disaggregated by functional classification, including interstate highways, arterial highways, collector roads, and local roads. To account for differences in region size, the standardisation by area is performed. This yields a measure for the density of lane miles that represents the coverage and capacity of the highway infrastructure network.

1.3 Outline of the dissertation

This dissertation comprises nine chapters, including the present one. An overview of the individual chapters in the remainder of this dissertation is as follows.

⁴ See the website of the Office of Highway Policy Information, FHWA - <http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm>.

Chapter 2 sets out to provide a background discussion on the literature on public infrastructure and economic development. It begins with a brief review of empirical studies looking at the effects of public infrastructure on economic development, measured by output, productivity, and employment. This is followed by a discussion on the issue of causality and how the economic impacts of infrastructure could vary across industrial sectors as well as regions. A comprehensive review of recent work examining the hypothesis of economic spatial spillovers from infrastructure is then presented with emphasis on theoretical arguments about the spatial effects of public infrastructure, modelling strategies, and research evidence. In the final part of this chapter, key broad issues that need to be taken into account for the empirical work are identified.

Chapter 3 identifies the current state of knowledge on how transport infrastructure affects employment. Based on a survey of relevant theoretical principles through which transport infrastructure can affect employment, a theoretical foundation to establish the linkages between transport infrastructure investments and employment is developed as a guide to further research. Other theoretical considerations in modelling this relationship are also discussed.

Chapter 4 presents a critical review of empirical research on the relationship between transport infrastructure investment and employment at the macro-level. The main focus in this literature review is on econometric methodologies used in previous studies and a synthesis of their research findings. Common methodological pitfalls and gaps in empirical knowledge on this topic are identified and discussed in detail.

Chapter 5 is the first empirical chapter in this dissertation. It presents an application of recent advances in dynamic panel econometrics to investigate the impact of highway infrastructure on county employment in the State of North Carolina. The dynamic panel estimation is also extended to examine the possibility of employment spillovers from highway infrastructure in neighbouring counties.

Chapter 6 analyses the data for the 48 contiguous states to sort out the direction of causality between highway infrastructure and aggregate employment for the entire private sector. In doing so, a Granger causality test is performed in a panel vector autoregressive (VAR) framework. The test for the spatial spillover effect of highways is also included in this analysis. Apart from these, a highlight of this chapter is an

application of a spatial filtering technique to deal with the issue of spatial autocorrelation in dynamic panel models.

Chapter 7 extends the work of Chapter 6 to sort out the causal relationship between highway infrastructure and sectoral employment. State-level data on employment in three major sectors: manufacturing, construction, and services are analysed using an empirical strategy similar to that of Chapter 6. This chapter underlines the importance of disaggregate analysis in revealing significant information that the aggregation is unable to show.

Chapter 8 also extends the work of Chapter 6 but addresses a different research question. In this chapter, we examine whether highway investments can make a significant contribution to private sector output. The results are obtained from estimating Cobb-Douglas production functions in the static and dynamic modelling frameworks while the dynamic specification is extended to test the hypothesis that improving highway infrastructure could produce output spillovers across states. In addition, this chapter seeks to estimate the economic return from the addition of highway capacity in present dollars.

Chapter 9 provides a summary of the main findings from all the empirical chapters, and discusses some implications for policy and research in this topic, followed by the acknowledgement of limitations of the present research and discussions on some fruitful areas for future work.

Chapter 2

On the Linkages between Public Infrastructure and Economic Development: An Overview of the Literature

2.1 Introduction

Public investment in infrastructure has been typically viewed as a policy instrument for development in almost all levels of policy decisions. Despite the fact that its links to national or regional economic development have continued to justify government funding for providing and improving infrastructure services, there has been much debate and controversy in the empirical literature concerning the contribution of publicly provided infrastructure. There is a large body of macroeconomic studies that has sought to empirically link public infrastructure to private sector productivity, or to employment. Previous work in this crowded literature has often revealed widely varying evidence. A basic intuition behind the lack of clear-cut results is differences in empirical strategies and implementations, some of which have been criticised on several grounds. Complications also arise when emphasising the role of public infrastructure in a regional economy. Recent research efforts have examined and suggested the importance of local-specific characteristics of a region and of spatial spillovers in infrastructure's impacts, which have some implications for further empirical work.

The purpose of this section is to provide a background discussion on the literature pertaining to the linkages between public infrastructure investment and economic development. We begin in Section 2.2 with a brief review of empirical studies that have

attempted to identify the contributions of public infrastructure to output and productivity growth. In this section, our main focus is on the U.S. literature where the Aschauer debate originated. Section 2.3 is concerned with previous studies attempting to examine whether infrastructure provision induces growth in terms of employment, while Section 2.4 highlights the issue of causality, one of the main criticisms of previous empirical work in this area. In Sections 2.5 and 2.6, we review empirical studies that estimate the economic impacts of public infrastructure across industrial sectors and across regions with different characteristics respectively. Section 2.7 focuses on recent empirical work that has examined the hypothesis of economic spillovers from public infrastructure. Some lessons from this literature review are drawn in the final section.

2.2 Public infrastructure and the productivity puzzle

In the literature on public infrastructure and economic development, the majority of empirical studies have been concerned with the question of whether infrastructure contributes towards output and productivity growth. The basic premise is that public investments in infrastructure can raise private output and productivity in both direct and indirect ways. Directly, public infrastructure services are thought of as intermediate inputs that enter into a firm's production process in the same way as private inputs (e.g. labour and private capital). For the indirect effect on private sector production, it arises from the role of public infrastructure in augmenting the productivity of other private inputs. For example, improvements in transport infrastructure could reduce workers' commuting time and costs of freight inputs. In the literature, this argument has often been referred to as the "public capital hypothesis".

Although the theoretical foundation and some historical evidence has emerged from earlier research by development economists (e.g. Meade, 1952; Mera, 1973; Blum, 1982; Ratner, 1983; Eberts, 1986; Dalenberg, 1987; Costa et al., 1987; Keeler and Ying, 1988; Deno, 1988), it was the seminal work by Aschauer (1989) and Munnell (1990) that sparked the current surge of empirical research on this subject. Based on annual data for the United States, their time-series production function estimates indicate a very strong contribution from aggregate public infrastructure to private sector output. These studies

have been widely criticised as yielding implausible results due to several methodological drawbacks including omitting the influence of energy prices and the pace of technological changes, spurious regressions due to the non-stationary nature of the data, and the possible endogeneity of public capital (e.g. Tatom, 1991, Tatom, 1993; Munnell, 1993; Hulten and Schwab, 1993; World Bank, 1994; Gramlich, 1994). At the state level, many production function studies (e.g. Costa et al., 1987; Munnell, 1990b; and Garcia-Mila and McGuire, 1992, Williams and Mullen, 1992), albeit yielding the output elasticities that are lower than national estimates by both Aschauer and Munnell, have also been questioned on econometric grounds. Apart from simultaneity bias, another major criticism of these state-level studies has centred on the absence of controlling for state-specific characteristics (e.g. climate, topography, geographical location, and resource endowment) that may influence the overall productivity of firms within a state (e.g. Holtz-Eakin, 1994; Evans and Karras, 1994; Baltagi and Pinnoi, 1995; Garcia-Mila et al, 1996).

When taking these econometric problems into account, subsequent studies find weak evidence on the link between public capital and private sector production. At the national level, Tatom (1991) and Sturm and Hann (1995) find no significant evidence that public infrastructure is productive when including energy prices and time trends in regressions or using first-difference specifications. Based on usual specifications of error components for panel data analysis, state production function estimates indicate that the productivity effect of public infrastructure is much smaller than those obtained by previous studies (Andrews and Swanson, 1995) or even statistically insignificant (e.g. Evans and Karras, 1994; Holtz-Eakin, 1994; Baltagi and Pinnoi, 1995; and Garcia-Mila et al, 1996).

In another stream of research, many studies have employed the duality between production and cost functions to investigate the productivity effect of public infrastructure. In contrast to studies based on an estimation of a production function, previous work estimating a cost function in various forms reveals consistent evidence of production cost savings and productivity growth associated with public capital provision in manufacturing industries using data for the United States (Nadiri and Manuneas, 1994; Morrison and Schwartz, 1996; Cohen and Paul, 2004), the United Kingdom (Lynde and

Richmond, 1993a), and West Germany (Seitz, 1993; Seitz and Licht, 1995). Broadening the cost function analysis to explore the cost saving and productivity effects in other industrial sectors, some studies have confirmed the link between infrastructure and reduced production costs for 35 two-digit industries of the U.S. economy (Nadiri and Mamuneas, 1998), and for three sectors of the West German economy: manufacturing, construction, trade and transport (Conrad and Seitz, 1994).

In recent years, many researchers have investigated the productivity effect of public infrastructure using a vector autoregressive (VAR) approach. Despite being recognised as “atheoretical” in the sense that less *a priori* information or theoretical underpinning is required to explicitly specify structural relationships between various sets of economic variables, the VAR approach has one major advantage. It allows the dynamic interactions among the variables of interest, treating all variables as jointly determined in its model specification and estimation. Therefore, the major criticism about the endogeneity of public capital can be explicitly addressed with the VAR framework.

Interestingly, many VAR studies provide weak evidence that there has been a strong linkage between infrastructure investment and private production as suggested in the previous empirical literature. McMillin and Smyth (1994), for example, use U.S. national time series data to estimate VAR models and find no clear evidence of a significant effect of publicly provided capital on private output. The VAR estimation by Pereira and Flores de Frutos (1999) reveals that public capital is productive but its contribution to private sector output in the U.S. is substantially smaller than that found in the prominent work of Aschauer (1989). In the Australian context, Otto and Voss (1996) find that the estimated elasticity of output with respect to public infrastructure within the VAR framework is approximately one-half of their earlier estimates using a production function approach (Otto and Voss, 1994). However, exceptions are a VAR analysis by Sturm et al (1999), showing that public investments in aggregate infrastructure and transport infrastructure have a positively significant impact on GDP in the Netherlands, and the estimated VAR models of Pereira and Roca-Sagalés (2003), which identify a strong contribution of public capital to private sector output in the economy of Spain.

In conclusion, the literature on the effect of public infrastructure on private sector productivity is already crowded and extensive, but the magnitude and significance of the

productivity effect has been a subject of continuing controversy. The empirical findings from the recent literature vary dramatically, ranging from no role to a very strong role of public capital investment, according to the geographical scale of analysis, data set employed, and econometric modelling framework. Given the different empirical strategies employed, one would expect the lack of clear-cut results, but must be careful when interpreting the empirical evidence.⁵ Using solid and well-ground econometric methodology to address several econometric issues (e.g. endogeneity, spurious correlation, omitted variables, and heterogeneity of cross-sectional units), much of the previous work tends to suggest that the contribution of public infrastructure to private productivity and output is modest or even insignificant. While this highlights the complexity and substantial challenges in examining the link between infrastructure and productivity, there remain some relevant issues and gaps in empirical knowledge that limit our understanding of the role of public infrastructure in the economy. We will discuss them later in this chapter.

2.3 Public infrastructure and its effects on employment

Another strand in the literature has sought to investigate the linkage between public infrastructure investment and employment. Given that employment gains associated with government expenditures on infrastructure construction might diminish rapidly after completion of construction work, research attention has been focused on the long-term impact of public infrastructure investment on employment. Fundamentally, one way in which provision of infrastructure supply could lead to long-term employment changes is through its effect on productivity. As public infrastructure investments could enhance firm productivity, a smaller amount of labour inputs is required to produce a given level of output demanded. Thus, the demand for workers used in firm production may decline if the demand for a firm's output remains unchanged. In this case, public capital is a substitute for labour. On the other hand, public capital and labour may be

⁵ Some attempts have been made to determine possible causes of contradictory evidence of the literature. For instance, Vijverberg et al (1997) compare the estimated results among three approaches, a production function, a cost function, and a profit function, based on the same dataset for the United States. They find that the results differ significantly from one modelling approach to another. Kelejian and Robinson (1997) find that coefficient estimates are very sensitive to model specifications. A sensitivity analysis by Batina (1999) suggests that the productivity and output gains from public capital depend critically on the proxies used to measure labour and private capital in the production function.

complements. This is because improved productivity due to infrastructure investments could induce more private investment and hence employment. Accordingly, the net effect of improved productivity due to infrastructure improvements on the demand for labour is uncertain.

Some empirical studies examining the productivity effect of public infrastructure, reviewed in the previous section, have shed some light on these relevant issues. However, the results obtained from these studies are mixed. By estimating cost and input demand functions simultaneously, most studies find that public capital and labour are substitutes (e.g. Shah, 1992; Lynde and Richmond, 1992; Lynde and Richmond, 1993a; Seitz, 1993; Seitz, 1994; Conrad and Seitz, 1994; Nadiri and Mamuneas, 1994; Seitz, 1995a; Seitz and Licht, 1995; Nadiri and Mamuneas, 1998). In contrast, the complementary relationship between public capital and labour demand has emerged from studies estimating profit functions (i.e. Deno, 1988; and Cribfield and Panggabean, 1996) and translog production functions (e.g. Costa et al, 1987; Munnell, 1990b; Moomaw et al, 1995).

In addition to the productivity effects that could lead to changes in labour demand, other researchers suggest that public infrastructure investments also affect the supply side of the labour market (e.g. Eberts and Stone, 1992; Dalenberg and Partridge, 1995; and Dalenberg et al, 1998). As public infrastructure is one type of household consumption good, improvements in the availability and quality of infrastructure services could enhance residential amenities, thereby stimulating in-migration, which in turn increases the supply of labour. More specifically, Dalenberg et al (1998) argue strongly that studies using the production or cost function approach to examine the role of infrastructure in employment changes may yield underestimated results because such an approach, which considers the importance of public infrastructure from a firm perspective, ignores the fact that considerable benefits of improved infrastructure also accrue to the household sector.

When taking into account the influences of infrastructure provision on both labour demand and labour supply, several studies find a positive and significant association between public infrastructure investments and employment. Eberts and Stone (1992) who estimate a structural model of labour demand and labour supply find that public infrastructure stocks are positively associated with employment. Subsequent work by Dalenberg and Partridge (1995) and Dalenberg et al (1998) obtain similar results when

estimating a reduced form equation of employment growth in which public capital and other factors influencing the demand for and the supply of labour are included. However, Dalenberg and Partridge (1995) also find a negatively significant relationship between employment and highway expenditures.

The employment effects of public infrastructure have also been empirically investigated by several different approaches. Various researchers (e.g. Munnell, 1990b; Mofidi and Stone, 1990; Crane et al, 1991; Lombard et al, 1992; Thompson et al, 1993; Singletary et al, 1995; Haughwout, 1999; Islam, 2003) estimate a single equation regression that incorporates several measures of infrastructure investment and other exogenous factors that are hypothesised to affect employment. Another group of econometric studies estimate simultaneous equation models of population and employment in which the variables representing the availability of public infrastructure services are included (e.g. Carlino and Mills, 1987; Boarnet, 1994; Luce, 1994; and Clark and Murphy, 1996). Other studies estimate vector autoregression models and perform Granger causality tests to examine whether employment is temporally influenced by infrastructure investments (e.g. Eagle and Stephanedes, 1987; Stephanedes, 1990; and Zografos and Stephanedes, 1992; Seitz, 1995b; Pereira and Flores de Frutos, 1999, and Pereira, 2000). Generally, estimated results from most of these studies indicate a positive impact of public infrastructure. However, exceptions are some studies showing that the relationship between infrastructure and employment is not significant (Eagle and Stephanedes (1987) and Thompson et al (1993) or negative (Lombard et al, 1992; Pereira and Flores de Frutos, 1999, and Pereira, 2000).

In summary, the question of whether public infrastructure investments affect employment has been studied widely, but it is not well understood. A number of different approaches have been used, and conflicting results have been reported. Indeed, much of the empirical work indicates the evidence of insignificant and negative effects of public infrastructure. While this would inevitably be a matter of controversy over economic and infrastructure policies aimed to boost employment by allocating more funding to increase infrastructure endowments, the ambiguity in the evidence has proven to be an interesting and important area of inquiry. Surprisingly, very little attention to date has been given to the details of aggregate studies in this line of research.

More importantly, many have yielded estimation results that are very likely to suffer from econometric problems. In Chapter 4, we provide a critical review of econometric studies on the macro-level relationship between transport infrastructure investment and employment.

2.4 The endogeneity of public infrastructure

As we have already mentioned, the issue of causality is among several econometric problems which critics have articulated. The basic idea is that the direction of causality between public infrastructure and private sector economic performance may run either or both ways. For instance, improved public infrastructure could lead to output growth as suggested by theory, but an increase in private sector output may also raise the demand for infrastructure services and hence cause more resources being allocated to public infrastructure provision. For these reasons, public infrastructure is possibly endogenous to an economy.

Providing that the causal relationship also works in the reverse direction, estimated results could be subject to simultaneity bias if one simply ignores or does not address this problem properly. Studies estimating VAR models have explicitly accounted for this possible feedback, and their empirical results tend to indicate the existence of reverse causality. However, little attention has been given to the issue of causality in many studies relying on a single-equation regression framework or estimating cost/profit functions in a system of equations. Only some studies have attempted to address this crucial issue. For example, the work by Bollinger and Ihlanfeldt (2003) applies Granger and Sim causality tests to panel data, but does not indicate if a common problem of endogeneity due to the presence of a lagged dependent variable is taken into account. Boarnet (1998) performs a Granger causality test to check whether there is a reverse causal link, using the VAR techniques proposed in Holtz-Eakin et al (1988) which involve differencing equations and using instrumental variables. Other studies perform a Hausman test of exogeneity of infrastructure, and, if the null is rejected, they reestimate models using a two-stage least squares (2SLS) or instrumental variable (IV) estimator (e.g. Holtz-Eakins, 1994, Dalenberg and Partridge, 1995; Dalenberg et al, 1998).

A question that could arise is whether valid instruments have been used. The performance of the Hausman test of exogeneity and estimation techniques based on the usage of instrumental variables depends on the quality of instruments. There are two criteria that have to be taken into account when making a choice of instruments. In particular, one has to choose instrumental variables that are uncorrelated with the error term in the regression and not weakly correlated with the endogenous variable. However, none of these studies report any tests for instrument exogeneity and instrument relevance so that it is impossible to judge the validity of their results.

2.5 Differential effects by sector

The discussions in this literature survey thus far are primarily concerned with the impacts of public infrastructure on an aggregate economy. Another important issue that should be taken into account when examining whether and the extent to which infrastructure investment contributes to general economic or regional development is the distribution of the impacts of public infrastructure on various sectors of an economy.

Public investments in infrastructure can have both direct and indirect impacts at the sector level. The direct effects of public infrastructure are likely to be sector specific. This is mainly because some types of infrastructure might be particularly relevant to some sectors and/or certain types of activities. Indeed, relatively large effects could be expected among the most intensive users of public infrastructure since the extent to which publicly provided infrastructure is involved in the production and distribution process may differ from one sector to another. However, this is not to deny that sectors or industries that are not making use of infrastructure directly could also be affected by increases in public infrastructure endowments through some other channels. Regardless of whether there exists any direct link between infrastructure and private sector production, improvements in infrastructure services could augment the productivity of factor inputs of production (e.g. private capital and labour). Apart from the production side, the amenity role of public infrastructure could positively influence the demand side which may in turn lead to increases in production and sales. In addition, the economic effects of public infrastructure can be universal throughout the economy because of input

and output linkages, the strength and weakness of which usually differ between sectors. For these reasons, it is natural to expect that the economic impacts of public infrastructure could be unevenly distributed across industrial sectors.

In the empirical literature, the majority of papers in this research arena have focused on the impact of infrastructure on either the aggregate economy or the manufacturing sector. Given that disaggregated data by sector could reveal some detailed and important information that aggregation is unable to disentangle, some studies have investigated the differential effects of public infrastructure across industrial sectors of the economy. Previous sectoral analyses reveal that the differences in the economic impact of infrastructure investment exist in several patterns.

First, the effect of infrastructure investments may be confined to certain sectors in an economy (e.g. Munnell, 1993; Conrad and Seitz, 1994; Carroll and Wasylenko, 1994; Seitz, 2000; Fernandez and Montuenga-Gomez, 2003). While it is found that provision of public infrastructure contributes to productivity growth in some particular sectors, the significant dependence of manufacturing activities on public infrastructure is consistently acknowledged.

Second, some studies find that the extent to which public infrastructure improvements affect economic performance of certain industrial sectors varies considerably (e.g. Kuehn and West, 1971; Munnell, 1993; Conrad and Seitz, 1994; Nadiri and Mamuneas, 1998). However, synthesising empirical findings from these studies suggests no clear-cut pattern for sectoral variations in terms of the relative magnitude of the impacts.

Finally, the timing and duration of infrastructure impacts may not be uniform across different economic sectors. Crane et al (1991) and Zografos and Stephanedes (1992), for example, find that an increase in highway expenditures generates long-term employment in the manufacturing and service sectors, but provides only a temporary benefit in terms of construction employment. Similar results are shown in Rephann and Isserman (1994) and Chandra and Thompson (2000) which find that the effect of interstate highway systems on industry earnings in several sectors is positive and significant many years after the opening of interstate highways, but construction earnings increase for only a few years during the construction period. These findings

provide support to the view that investments in public infrastructure could increase wages and employment opportunities of the construction sector in the short-term only, but could have considerable long-term impacts in other industrial sectors.

2.6 Differential effects by region

The regional differential in the effects of infrastructure investment is another piece of evidence from the literature pertaining to the role of infrastructure in regional development. For example, many studies find that the effects of public capital on private sector output (e.g. Munnell, 1990b; Munnell, 1993; and Moomaw et al, 1995), production costs (e.g. Morrison and Schwartz, 1996; and Cohen and Paul, 2004), and the demand for private capital and labour inputs (e.g. Cohen and Paul, 2004) vary significantly across geographical regions of the United States. Unfortunately, most of these studies do not provide any clear explanation for the findings they obtain. This is probably because the geographical location of a region acts as a crude proxy that does not reflect local characteristics (e.g. the stage of development, urbanization status, proximity to metropolitan areas, etc.) that may contribute to differences in infrastructure impacts between regions.

2.6.1 Hansen's (1965a) hypothesis

A theoretical discussion on the potential effectiveness of public infrastructure provision and the characteristics of regions is found in a prominent paper of Hansen (1965a). Hansen hypothesised that the economic development potential of public capital investment depends on the type of public capital and the development level of a region in which investment takes place. He argued that economic overhead capital (EOC) such as road, bridge, water supply, electricity supply could have a greater effect on economic growth in intermediate regions than in either congested or lagging regions whereas provision of social overhead capital (SOC) such as schools, hospitals, and parks would benefit lagging regions.⁶

⁶ Hansen disaggregated public capital into two categories: economic overhead capital (EOC) and social overhead capital (SOC). Economic overhead capital, defined as infrastructure that facilitates the productive activities and the movement of economic goods, consists of transport infrastructure, electricity supply, water supply, drainage and sewer systems, irrigation systems, and other types

For congested regions that have reached optimal capacity due to very high concentrations of population, industrial and commercial activities, and public infrastructure, Hansen contended that investments in both types of public capital will not be economically justified.⁷ Although such investments could probably lead to expansion of economic activity, marginal social benefits that accrue from increased agglomeration economies may be outweighed by marginal social costs (e.g. congestion due to an increase in the utilization of public infrastructure). Instead, Hansen suggests that appropriate policy measures be implemented to control expansion of congested regions and induce economic growth in other alternative regions.

In the case of intermediate regions where there is a wide range of favourable conditions (e.g. cheap power, proximity to raw materials and qualified labour, and existing transportation access, etc.) to the location of private investments, Hansen conjectures that EOC investments can induce more private investment and stimulate regions' economic growth because expansion of economic activity could increase external scale economies that substantially exceed concomitant social costs. Moreover, the marginal social benefit to cost ratio would be greater in these regions than in congested regions.

In lagging regions characterised by small-scale agriculture or stagnant/declining industries, the economic conditions are relatively less attractive to new private investment, compared with those available in intermediate regions. Hansen (1965a; pp. 12) argues that *"it is not economically rational to attempt to induce economic growth in lagging regions via excess EOC capacity, so long as better alternatives exist in intermediate regions"* and that social overhead capital should be provided in order to improve local human resources for potential development opportunities in lagging regions.

There is a body of empirical work that has sought to test Hansen's hypothesis using two different approaches. The first approach generally involves classifying regions into three broad categories (i.e. congested regions, intermediate regions, and lagging regions) and comparing results from the three separate regressions. Looney and Frederikson (1981), in a study examining the impact of infrastructure regional

of public works. Social overhead capital, for example education, public health facilities, fire and police protection, and parks and athletic fields, enhances human capital and provides social services (Hansen, 1965b).

⁷ Hansen (1965a) suggests that some examples of congested regions may include London, Paris, and very large cities along the northeastern coast of the United States.

development in Mexico, reveal evidence supporting Hansen's theoretical arguments. They find that the impact of economic overhead capital investments on GDP is statistically significant in the intermediate group of regions but not in the lagging regions whereas regression results for the impact of social overhead capital are the opposite. Bergman and Sun (1996) estimate the impact of various types of infrastructure on manufacturing productivity across counties in the state of North Carolina with three different levels of urbanization. They find that their production function estimates lend general support to Hansen's hypothesis as interstate highway access appears to enhance labour productivity in counties that are neither the most urbanized counties nor rural counties. More recently, Berechman et al (2006) extend their empirical analysis on the productivity effect of highway capital in the United States to test the Hansen hypothesis at the state level. Using data on highway capital, employment, and population to categorise states into the three types of regions, they find that the contribution of highway capital to state output is greater in the group of intermediate states (Florida, Kentucky, Louisiana, Michigan, New Jersey, and Virginia) than in congested states (California, Illinois, New York, Ohio, Pennsylvania, and Texas).⁸

While these empirical studies broadly confirm the Hansen hypothesis of public infrastructure benefits for intermediate regions, some of them also reveal disadvantages of infrastructure provision in lagging regions. In the empirical work by Berechman et al (2006), the result based on data for all other states, which are classified as lagging states, indicate the negative output elasticity of highway capital. Bergman and Sun (1996) argue that their finding of the negative relationship between the availability of interstate highway and rail services and labour productivity in rural counties may reflect the possibility of out-migration or out-commuting of highly skilled labour from poorly developed counties that are served by network infrastructure, to more productive counties.

Other studies argue that according to Hansen's hypothesis one could expect the magnitude of the productivity effect of public infrastructure to be related to the size of infrastructure already accumulated. To test this conjecture, some empirical work in this area has examined the relationship between the output elasticity of public capital and the

⁸ It is a bit unclear how these definitions are derived as those states defined as uncongested have areas of regional congestion.

stock of existing public capital; the latter is normalised by the existing stock of private capital or population. However, the empirical literature that tests the Hansen hypothesis by this approach has been somewhat inconclusive because of contradicting results and, more importantly, a disagreement over the interpretation of the Hansen hypothesis.

Given the relative ineffectiveness of public infrastructure investments in lagging regions, Costa et al (1987), William and Mullen (1992), and Moreno and López-Bazo (2007) assert that the *negative* association between the output effect of public capital and the size of existing infrastructure endowments lends support to Hansen's arguments. The work by Costa et al (1987), which is a first attempt to test the Hansen hypothesis in this way, finds evidence consistent with their expectation for the role of public capital in regional development across the 48 contiguous US states. Moreno and López-Bazo (2007) report similar findings of a negative relationship between returns to public infrastructure and the ratio of public infrastructure to private capital for Spanish provinces.

In contrast, the study of the 48 contiguous US states by William and Mullen (1992) finds that the output elasticity of highway capital is positively related to the ratio of highway capital to private capital. They conclude that this finding does not support Hansen's hypothesis, and that public investments in highways could play a significant role in stimulating growth in lagging states. Subsequent work by Moomaw et al (1995) using data for U.S. states obtains very similar results. However, they argue that the findings of the *positive* relationship between the output elasticity of public capital and the intensity of public capital should have been interpreted as evidence supporting the Hansen hypothesis. This is because Hansen's prediction of a greater effect of public capital in intermediate regions than in either congested or lagging regions could mean that "excess" public capital can induce economic growth. Based on this opposite view, Moomaw et al (1995) conclude that additional spending on highways and other public infrastructure would be a wise development strategy for state policymakers.

2.6.2 The role of agglomerations

The extent to which public infrastructure investments contribute to economic growth could also depend on the degree to which economic activities are spatially concentrated in an area where such investments take place.

The theoretical links between agglomeration, productivity, and infrastructure investments are well established (e.g. Eberts and McMillen, 1999; Graham, 2007a; Venables, 2007). Firms located in agglomeration areas tend to operate more efficiently because such firms can take advantage of external economies stemming from the close spatial proximity to other firms and to a large population by sharing nonexcludable inputs such as a common labour pool, technical expertise, general knowledge, and personal contacts. As public infrastructure is one type of shared, but unpaid, input for production, improvements in public infrastructure can promote agglomeration benefits by reducing external scale diseconomies such as congestion and pollution from the concentration of people and business activities in space. A good example is the case of reductions in travel time and transport costs associated with transport improvements that could raise accessibility for some economic activities. These potential increases in the positive spatial externalities achieved from the combined effects of infrastructure and agglomeration could therefore lead to the expansion of private investment, thereby stimulating economic development and growth in regions under the influence of agglomeration.

There have been a number of empirical studies that have attempted to identify the economic benefits of public infrastructure in urbanised areas. Wheat (1969), for example, finds no evidence that accessibility to freeways generates manufacturing employment growth when comparing all freeway cities with all non-freeway cities in the United States. On the contrary, manufacturing employment gains associated with freeway access are confined to the freeway cities above 16,000 in population or served by airline services. In subsequent studies, the provision of public infrastructure supply are found to have positive effects on productivity (e.g. Moomaw, 1983, Eberts, 1986; Dalenberg, 1987; Seitz, 1993; and Lobo and Rantisi, 1999), and personal income (Duffy-Deno and Eberts, 1991) in metropolitan areas.

Other studies find that economic gains from positive externalities in core (or agglomeration) areas could be at the expense of peripheral and lagging areas. This could leave the net effect on a given economy being unclear. In a study of the relationship between highway infrastructure and regional development in the state of Minnesota, Eagle and Stephanedes (1987) and Stephanedes (1990) examine whether the employment impact of highway improvements across counties depends on the urbanization status and socioeconomic characteristics of the county.⁹ While there is no significant evidence for a state-wide effect, they find that highway expenditures generate long-term employment in urban counties that are the economic centres of the state but lead to a decline in employment in other counties. Stephanedes argues that the regional economic centres gain employment benefits because of the existence of economic activities necessary for absorbing benefits of highway investments. Improvements in highway infrastructure in other counties, on the other hand, may redistribute economic activity from such counties into the regional centres.

2.6.3 Discussion

The theoretical and empirical literature we have reviewed suggests that the extent to which public investments in infrastructure affect a region's economic development may differ across regions because the economic effect of infrastructure investment are subject to dependence upon specific characteristics of recipient regions. One fundamental reason behind this is that infrastructure, as one of several determinants of regional development, may be unable to induce economic activities by itself. Improvements in public infrastructure can create a necessary, but not sufficient, condition for growth and development (Nijkamp, 1986; Huddleson and Pangotra, 1990; Vickerman, 1991a; Fox and Murray, 1993; Worldbank, 1994). In other words, infrastructure provision alone does not guarantee that growth will occur but acts as a prerequisite for local economic development. Therefore, the effect of infrastructure provision on economic growth and development depends on the extent to which there are other necessary conditions

⁹ Eagle and Stephanedes (1987) classify Minnesota counties into certain groups based on the criteria of whether a county contains a city with a certain level of population. Stephanedes (1990) uses differences in accessibility by roads, population density, average income, and median age of people for county classification.

present and a region's capacity for responding to the development opportunities offered by improved infrastructure.

Investments in highways and other types of public infrastructure could allow regions to maintain or enhance their competitive advantage. Empirical evidence emerging in the literature has confirmed that provision of public infrastructure can reinforce positive benefits of agglomeration economies. In other areas unable to take advantage of improved infrastructure to expand or retain economic activities within their own jurisdictions, public infrastructure investment may be less effective or even lead to unintended consequences. Some studies have revealed evidence regarding this latter concern. This suggests that regional differences in infrastructure impacts may result from the spatial redistribution of economic activity in response to public infrastructure investments that trigger comparative advantages between regions. There are some recent studies that have sought to explicitly address this spatial issue. We review their econometric methodology and empirical findings in the next section.

2.7 Spatial spillover effects of infrastructure

While the role of public infrastructure investment in stimulating economic growth and development within a recipient region has been the subject of considerable research efforts for many decades, another important issue that has recently received attention is whether infrastructure geographically affects other regions. The general idea is that the effect of public infrastructure investments may not be confined to certain regions where publicly provided facilities are located. Rather, such effects could spatially extend to immediately contiguous regions or even other distant regions (Vickerman, 1991b; Munnell, 1992; Button 1998; and Rietveld and Bruinsma, 1998).¹⁰ Transport infrastructure is usually considered as a primary source for spatial spillovers because of its network character. Other types of public infrastructure without network effects could also have spatial implications across jurisdictions. For instance, economic benefits of public

¹⁰ For an extensive discussion on various types of spatial impacts of public infrastructure, see Mikelbank and Jackson (2000, pp. 246-248).

facilities such as schools, hospitals, and recreation facilities may accrue to both local residents and people living in neighbouring regions.

Another reason for economic spillovers from public infrastructure is the role of regional differences in infrastructure endowments in triggering spatial competition in factors of production. Given the importance of access to public infrastructure, it is likely that a region with more or better infrastructure services could draw economic activities away from elsewhere. A theoretical model derived in Boarnet (1998) shows that private capital and labour inputs migrate from regions with relatively poor levels of public infrastructure to those with well-developed infrastructure. In particular, the model predicts that output will increase in regions where infrastructure investments are made whereas other regions in which out-migration of labour and capital inputs takes place will experience a decline in the level of production. As such, public investments in infrastructure may not only have a positive output effect locally but create negative output spillovers across regions.

Given the disagreement on the productivity effect of public infrastructure at different levels of aggregation, Munnell (1992) contends that small or insignificant output elasticities of public capital obtained from data for US states is due to the failure to capture cross-state spillovers in productivity benefits. Following the work by Holtz-Eakin and Schwartz (1995) which seeks to address this hypothesis, several researchers have attempted to gain insights into the existence of economic spillovers from public infrastructure. Table 2.1 summarises information on previous studies examining spatial spillover effects of public infrastructure.

Table 2.1 Macro-level studies examining the existence of spatial spillover effects of public infrastructure

Author(s)	Data	Type of public infrastructure	Spillover variable			Economic development measure	Spatial spillovers from infrastructure
			Specification	Scope of spillovers	Spatial weight definition		
<u>United States</u>							
Holtz-Eakin and Schwartz (1995)	48 US states, 1969-1986	State highways	Spatial lag	Adjacent states	Straight sum, average sum, state area	Output	Not significant
Kelejian and Robinson (1997)	48 US states, 1969-1986	Aggregate and disaggregated by type of infrastructure *	Spatial lag	Adjacent states	Population density weighted average	Output	Not significant
Dalenberg et al. (1998)	48 US states, 1972-1991	Highways	Spatial lag	Adjacent states	Population weighted average	Employment	Positive
Pereira and Andraz (2004)	48 US states, 1977-1999	Highways	Spatial lag	All other states	Straight sum	Output	Positive
Cohen and Paul (2004)	48 US states, 1982-1996	Highways	Spatial lag	Adjacent states	The value of goods shipped between states combined with the relative size of economic activity	Production costs in manufacturing Employment and private capital investment in manufacturing	Positive Negative
Berechman et al. (2006)	48 US states, 1990-2000	Highways	Spatial lag	Adjacent states	Straight sum	Output	Not significant
	18 counties in NY/NJ metropolitan areas, 1990-2000		Spatial lag	Adjacent counties	Straight sum	Output	Not significant
	389 municipalities in NY/NJ metropolitan areas, 1990-2000		Spatial lag	Adjacent municipalities	Straight sum	Output	Negative
Boarnet (1998)	CA Counties, 1969-1988	Highways and streets	Spatial lag	Adjacent counties	Connectivity of the highway network	Output	Positive
			Spatial lag	All other counties	Similarity in socio-economic characteristics	Output	Negative
			Spatial lag	Adjacent counties	Straight sum	Output	Not significant
Gillen and Haynes (2001)	CA Counties, 1969-1997	Highways	Spatial lag	Adjacent counties	Straight sum	Output	Negative
Ozbay et al. (2007)	18 counties in NY/NJ metropolitan areas, 1990-2000	Highways	Spatial lag	Adjacent counties	Straight sum	Output	Negative
			Spatial lag	All other counties	Straight sum	Output	Negative

Note: * including highways, water and sewage facilities, and others. CA, NY, NJ denote California, New York, and New Jersey, respectively.

Table 2.1 Macro-level studies examining the existence of spatial spillover effects of public infrastructure (cont'd)

Author(s)	Data	Type of public infrastructure	Spillover variable			Economic development measure	Spatial spillovers from infrastructure
			Specification	Scope of spillovers	Spatial weight definition		
<i>Spain</i>							
Mas et al (1996)	17 regions, 1964-1991	Aggregate public capital stocks	Combined infrastructure stocks	Adjacent regions	Straight sum	Productivity	Positive
Pereira and Roca-Sagalés (2003)	17 Regions, 1970-1995	Transport infrastructure and communications ^b	Spatial lag	All other regions	Straight sum	Output	Positive
Cantos et al. (2005)	17 regions, 1965-1995	Transport infrastructure ^b	Combined infrastructure stocks	All other regions	Volume of trade flows	Output and TFP	Positive
Ezcurra et al. (2005)	16 regions, 1965-1995	Transport infrastructure	Spatial lag	All other regions	Volume of trade flows	Output and production costs in industrial and service sectors	Positive
Delgado and Álvarez (2007)	50 provinces, 1970-1998	Highways	Spatial lag	Adjacent provinces	Straight sum	Output (Total, Agriculture, Energy, Industry, Construction, Business services)	Positive (Total and some sectors) and negative (industry) ^c
			Spatial lag	All other provinces	Similarities in socio-demographic characteristics and government size		Negative (Total and some sectors) and positive (industry) ^c
Moreno and López-Bazo (2007)	50 provinces, 1965-1997	Transport infrastructure ^b	Spatial lag	Adjacent provinces	Average sum	Manufacturing output	Negative
			Spatial lag	All other provinces	Geographical distance, similarity in population density, value added and geographical distance	Manufacturing output	Negative
			Combined infrastructure stocks	All other provinces	Straight sum	Manufacturing output	Not significant

Note: ^b Transport infrastructure includes roads, rail roads, ports, and airports. ^c Different results across sectors were obtained. See details in the paper.

Two alternative approaches first introduced by Holtz-Eakin and Schwartz (1995) and followed by others have been employed to specify models that explicitly account for the effect of public capital stock accumulated in other regions. The first approach is to incorporate a measure of infrastructure installed in other regions as a separate variable in regression models. This is conceptually analogous to the idea of a spatial lag in the spatial econometric literature. Consider the following log-linear Cobb-Douglas production function as an example:

$$\log Y_{it} = \beta_0 + \beta_1 \log L_{it} + \beta_2 \log K_{it} + \beta_3 \log G_{it} + \beta_4 \log \mathbf{W}G_{jt} + \varepsilon_{it} \quad (2.1)$$

where Y , L , K , and G denote measures of output, labour, private capital, and public infrastructure respectively, t indexes time, and i and j index regions. $\mathbf{W}$ is a spatial weight matrix that is defined to account for the relative importance of infrastructure located outside region i . The existence of output spillovers from public infrastructure is examined by interpreting the sign and significance of the coefficient β_4 .

In the second approach, a variable that combines the stock of public infrastructure of each individual region with that of other regions is defined to replace one that measures only infrastructure of each individual region in a basic specification (2.2):

$$\log Y_{it} = \beta_0 + \beta_1 \log L_{it} + \beta_2 \log K_{it} + \beta_3 \log G_{it} + \varepsilon_{it} \quad (2.2)$$

$$\log Y_{it} = \beta_0 + \beta_1 \log L_{it} + \beta_2 \log K_{it} + \beta_6 \log (G_{it} + \mathbf{W}G_{jt}) + \varepsilon_{it} \quad (2.3)$$

where all variables and subscripts are as described. To test for output spillover effects of infrastructure involves comparing output elasticities with respect to infrastructure (β_3 and β_6) estimated from these two specifications. A higher value of β_6 , for example, is interpreted as evidence of positive output spillovers, providing that both are positive and statistically significant.

Of particular importance when using either of these approaches is the issue of defining a spatial weight matrix ($\mathbf{W}$) that can capture spatial interaction from the spillover effects of public infrastructure. This has two important aspects. The first involves the distance over which the effect is felt. Many previous studies restrict attention to the effects of public capital of *geographically adjacent* regions. Since the effect of public capital in one region could extend far beyond its bordering regions, public capital stock installed in *all other* regions in a dataset is also frequently examined.

The second aspect is concerned with the relative importance of public infrastructure located among a group of regions being modelled. The simplest way used in the literature is to take the straight sum of other regions' public infrastructure, assuming that the total stock of public infrastructure located in other regions matters. When the main focus is on the spillover effects of public infrastructure located in directly adjacent regions, this is analogous to the use of a binary contiguity matrix, the elements of which are set equal to one if regions share a common boundary, and zero otherwise. Following a standard practice in the spatial econometric literature, some studies specify this spatial matrix in a row-standardised form such that the sum of all elements in each row equals one; therefore, a spatial infrastructure variable represents the average endowment of infrastructure in surrounding regions.

Such simple procedures, however, ignore some frictional issues (e.g. transportation costs, geographical barriers) and the nature and degree of the spatial interactions of economic activities that actually happen. On these grounds, the assumption that the total or equal share of public infrastructure located in any region is effectively or fully utilized by its neighbours is not tenable. Several adjustment procedures for measuring the extent of other regions' infrastructure that could be important have been proposed. In addition to the straight sum, for example, Holtz-Eakin and Schwartz (1995) consider a weighted average of state highways in neighbouring states, where the weight for each region is inversely proportional to the share of that state in the geographical area of all neighbours. In other studies, the stock of public infrastructure installed in other regions is weighted by geographical distance between any pair of regions, the relative sizes of economic activity (e.g. population, population density, value added, and output), the value of goods shipped between regions, the intensity of commodity flows between regions, and the number of major highways crossing the border. Moreover, some researchers use a spatial weight matrix that captures similarity in local characteristics that proxy for how mobile factors of production competed between regions.

Despite the fact that several different approaches to modelling spatial spillovers have been used and their relative merits are uncertain, econometric evidence emerging in the literature tends to support the hypothesis that public infrastructure can produce both positive and negative spillover effects across regions. In the U.S. literature, there is

disagreement over the evidence of geographical spillovers from infrastructure's impacts among studies using data from U.S. states. Some earlier studies that are concerned with testing for positive output spillovers find that spatial public capital variables appear to be insignificant in their preferred specifications (Holtz-Eakin and Schwartz, 1995; Kelejian and Robinson, 1997). However, the significant evidence of the spatial spillover effect of public infrastructure is found in other state-level studies such as those of Dalenberg et al. (1998), Cohen and Paul (2004), and Pereira and Andr  z (2004), though it is worth noting that only the work by Cohen and Paul has revealed the negative spillover effects of highways at the state level. When exploring evidence of spillovers at smaller scales, many studies including a work by Boarnet (1998) tend to show a consistent result in that highway infrastructure not only generates more output within the same region but creates negative output spillovers for neighbours. In addition, there are some other studies, albeit using different approaches not discussed above, that reveal evidence of negative spillover effects of highways at the county level (e.g. Rephann and Isserman, 1994; Haughwout, 1999; Chandra and Thompson, 2000) and at the census tract level (Chalermpong, 2004).

Empirical findings of studies using Spanish data are more consistent in the sense that all of them have revealed the existence of economic spillover effects from public infrastructure. In particular, they find significant evidence of positive spillover effects of infrastructure stocks installed outside the jurisdiction at both regional and provincial levels for Spain. However, recent research by Delgado and   lvarez (2007) and Moreno and L  pez-Bazo (2007) find the presence of negative output spillovers from transport infrastructure across Spanish provinces.

These findings are in line with those obtained from U.S. data which tend to report the evidence of negative spillover effects at finer levels of aggregation. This seems to imply that negative spillovers from infrastructure are more likely to exist within limited spatial ranges. It is important to note that the spatial implications of infrastructure at such relatively smaller scales may also involve positive spillovers as can be seen in Table 2.1. To the extent that both positive and negative spillovers could take place simultaneously, there can be difficulty in estimating the net effects of public infrastructure (Boarnet, 1998).

Overall, available empirical evidence has clearly confirmed the possibility of gains and losses from public infrastructure installed elsewhere. Recent research also shows that the economic effects of infrastructure provision could spill over into not only geographically contiguous but spatially separated regions. For the literature based on U.S. data, the evidence reviewed generally agrees with the idea that the inconclusive evidence on the productivity effect of public infrastructure might be partly due to the fact that geographical spillovers in infrastructure impacts have not been taken into account (e.g. Gramlich, 1994; Boarnet, 1998; Mikelbank and Jackson, 2000; Perara and Roca-Sagalés, 2003). These studies highlight the importance of addressing the spatial spillover effect of infrastructure in empirical studies that attempt to understand the role of public infrastructure investment in the economy, particularly at a highly disaggregated level at which previous work consistently find the existence of positive as well as negative spillovers.

2.8 Lessons learnt from the literature

This literature review has illustrated the current stage of knowledge and the ongoing debate regarding the impact of public infrastructure investment on economic development. There are several lessons learnt from the literature as follows.

Inconclusive evidence in the literature has reflected the complexity and difficulty in estimating the magnitude and nature of the effect of public infrastructure investment on an economy. Linkages between public infrastructure investment and economic growth could be established but the direction of causation may not be unambiguous: whether infrastructure investment causes growth or growth induces infrastructure investment. In addition, there are several other factors that determine the level and growth in output, productivity and employment. Without taking into account these crucial issues systematically and effectively, estimated effects of infrastructure provision may be subject to estimation biases. Therefore, in order to empirically investigate the influence of public infrastructure investment and its impact on economic development, it is crucially important to employ estimation techniques that can disentangle the causal

nature of infrastructure impact and that can isolate economic changes attributable to improved infrastructure from changes due to other factors.

An important research theme relates to differentials in the impact of public infrastructure investment among various industrial sectors. Most previous research has been devoted to examining the role of public infrastructure investment in an aggregate economy. However, the results found may mask significant information on sectoral differences in the economic development impact of infrastructure improvement. Some previous studies have shown that the significance, magnitude, and timing of the impact of infrastructure investment can vary dramatically for different sectors of the economy.

Recent research evidence has suggested that regional differences in the effects of infrastructure improvement on economic development or growth are attributable to differences in the economic characteristics and the urbanization status of recipient regions. This has an important research implication, in that the effect of public capital on state output and productivity becomes very small or insignificant after controlling for state-specific characteristics. Therefore, it is crucially important to take into account local characteristics of a region in which infrastructure provision takes place when examining the relationship between public infrastructure investment and regional development.

Finally, the possibility that provision of infrastructure in one region affects economic performance of other regions must be explicitly taken into account. Previous studies have revealed clearly that improvements in transport and other public infrastructure could produce both positive and negative spillovers across regions. As such, ignoring this spatial dimension in infrastructure impacts may underestimate or overestimate the importance of infrastructure provision in the location of economic activity and a region's economic performance.

The exclusion of these considerations could be a source of uncertainty in the understanding of these issues. More rigorous methodologies are called for to clarify these relationships. Thus, the issues highlighted in this chapter will be taken into account as a basis for the empirical work in this dissertation. Before proceeding to critically review previous research on the employment impact of transport investments, we present in Chapter 3 a brief review of the theoretical literature on the underlying mechanisms

through which transport infrastructure provision can affect employment and other theoretical considerations in modelling this relationship.

Chapter 3

Transport Infrastructure and Employment: Theoretical Considerations

3.1 Introduction

As a measure of the economic development impact from infrastructure, the employment impact from transport infrastructure investment has been a subject of considerable interest for decades. While the direct economic impact on jobs generated from construction works of transportation projects is of a short-term nature, reduced travel times and costs of travel associated with improved transport facilities could have long-term economic impacts by influencing both firm and household decisions that can affect employment in several ways.

The purpose of this chapter is to identify the current state of knowledge on how transport infrastructure affects employment, particularly at the regional level as a guide to further research. While we have briefly noted in Section 2.3 of Chapter 2 the ways in which provision of public infrastructure can have impacts on employment, the present chapter offers more detailed discussions with a particular focus on transport infrastructure. We begin in Section 3.2 with a literature survey of theoretical principles through which transport infrastructure is hypothesised to affect employment. Based on relevant theoretical arguments reviewed, we develop a theoretical foundation to establish the linkages between transport infrastructure investments and employment by distinguishing their effects on labour demand and supply in Section 3.3. A short

discussion on other theoretical considerations in modelling this relationship is also provided. The final section presents concluding comments.

3.2 A literature survey of relevant theories

Provision of transport infrastructure is hypothesised to affect employment throughout an economy from many channels. The most obvious and direct impact on jobs arises from infrastructure construction. Although the construction of infrastructure could create employment in the construction sector and may stimulate additional demand for labour in other sectors through the multiplier process, these employment benefits are generally thought to be marginal and of a short-term nature. In addition, if the infrastructure is built by government funds, this is merely a shift from employment that could be generated by other government expenditures. Therefore, the key issue is long-term employment impacts from transport improvements.

One strand in the literature primarily emphasises the role that public infrastructure can play in affecting the production and location decisions of firms (e.g. Lichter and Fuguitt, 1980; and Eagle and Stephanedes, 1987; and Munnell and Cook, 1990). Improvement in highways and streets, for example, is simply seen as a means of stimulating employment growth by encouraging the expansion of existing firms and attracting new industry. The fundamental rationale for this idea is expressed in Button (1998) and Rietveld and Bruinsma (1998) who classify two major ways in which transport infrastructure investment can potentially affect employment. First, they argue that employment impacts may occur via substitution and complementary relationships between labour and other production inputs, since additional infrastructure inputs enter the production process. Their second concern is provision of transport infrastructure that stimulates interregional trade and competition, leading to differential impacts on employment across industrial sectors. Nevertheless, these theoretical perspectives regarding the impact of infrastructure investment are limited to the production side of the economy.

The other approach, which explains the employment effects more extensively, considers the influences of transport infrastructure on the labour market. In particular,

investments in transport infrastructure are viewed to have effects on both the labour demanded by firms and the quantity of labour force supplied to the labour market by households (e.g. Eberts and Stone, 1992; Dalenberg and Partridge, 1995, 1997; and Dalenberg et al, 1998). Transport infrastructure provision can represent a firm amenity, thereby enhancing a firm's productivity and attracting businesses into an area, which in turn leads to changes in the local demand for labour. On the supply side of the job market, improvements in transport infrastructure could lead to adjustments in labour supply by attracting households that consider access to good transport services as a residential amenity. Therefore, to the extent that transport infrastructure investment causes these shifts in labour demand and labour supply, this can be translated into changes in employment.

The remainder of this section presents a review of theoretical perspectives regarding the linkages through which transport infrastructure investment could lead to long-term employment changes in several respects. Section 3.2.1 employs the standard theory of the firm to discuss the influence of transportation investment on firm production and its consequences on the labour inputs demanded for production. The importance of transport improvements in the location decisions of households and firms are discussed in Sections 3.2.2 and 3.2.3 respectively. We discuss the role of transport in facilitating people's accessibility to jobs and its implications on the labour market in the final section.

3.2.1 Transport infrastructure and firm production

The production process can be defined as the manner in which a firm combines various inputs (such as labour, equipment, raw materials, etc) to obtain outputs (e.g. goods, services) given the level of production technology. The basic theory of the firm defines a production function to represent the technological relationship by which production inputs are efficiently transformed into the output of goods and services. Any changes in technology will result in new production possibilities for the firm, leading to adjustments in inputs employed to produce outputs at the level that meets market demand.

There are two possible ways in which transport infrastructure could affect firm production (Meade, 1952). The basic premise in the theoretical literature is that the stock

of transport infrastructure available enters the production process as an unpaid input, directly contributing to firm production. An obvious example is public roads that are available free of charge to industrial and commercial activities. On the other hand, transport infrastructure is considered to enter the production process as a factor that augments the productivity of other inputs employed by firms. Therefore, improvements in transport infrastructure can generally be regarded as an increase in the technology of production that could enhance the overall productivity of affected businesses. Better transportation systems, for instance, enable the movement of goods and workers to be more efficient. It can also increase firm productivity by lowering the transportation costs of inputs and outputs. Moreover, productivity gains may come from a reduction in other business costs. For example, good quality roads could lead to savings on vehicle maintenance costs. An increase in the reliability of transport allows firms to reduce stock inventory costs. In some circumstances, transport improvements may also help improve access to customers or remove trade barriers, encouraging firms to exploit economies of scale by serving larger markets. This will result in a reduction in long-run average costs of such firms that can be translated into an increase in productivity. Therefore, one way in which transport infrastructure investment influences firm productivity is by its effect on production costs.¹¹

Furthermore, overall productivity growth may also arise because transport infrastructure investment can be directly responsible for augmenting the productivity of labour. For example, exhausted workers may be less productive if they have to spend more time commuting. Thus, improvements in transportation services can have a direct impact on labour productivity by lowering commuting time spent getting to and from work (Prud'homme and Lee, 1999; SACTRA, 1999; OECD, 2002).¹² In another particular case, an increase in labour productivity can result from a better match between the supply of jobs and skilled workers. The underlying reason for this is that transport investments can lead to an increase in labour supply by attracting in-migration of

¹¹ A number of aggregate studies estimating cost functions confirm that highway capital stock can lead to a reduction in production costs (e.g. Keeler and Ying, 1988; Seitz, 1993; Seitz, 1995, and Nadiri and Mamuneas, 1998;). Other empirical studies (e.g. Lynde and Richmond, 1992, 1993a, 1993b; Nadiri and Mamuneas, 1994) that estimate aggregate public capital data, in which highway capital is a major component, report similar results. Some of these studies reach similar conclusions in that the provision of public infrastructure contributes positively to private sector productivity by generating production cost savings.

¹² An empirical study by Prud'homme and Lee (1999) found that average speed for journey-to-work trips in 23 cities in France is positively related to the productivity of labour.

households and improve job accessibility (See discussions on these effects in Section 3.2.2). With more choices of prospective employees, firms will have more opportunities to recruit those who have working experience and appropriate skills they need.

To the extent that investments in transport infrastructure enhance the overall productivity of firms, this could lead to changes in the quantities of inputs of production. Of particular importance here is the linkage between the productivity effects of transport investment and changes in the demand for labour required in firm production. Consider a simple form of a production function

$$Q = g(TRAN)f(K, L) \quad (3.1)$$

where Q denotes output, K is private capital input, L is labour input. $TRAN$ is a stock of transport infrastructure available that is considered as a production shift factor. Thus, additional investment in transport infrastructure ($TRAN^*$) can represent an increase in production technology and hence in total factor productivity, leading to an upward shift of the production function. As shown in Figure 3.1, a rise in firm productivity permits more output (Q_B) to be produced from a given quantity of private inputs (X_0). Alternatively, the production of a given level (Q_A) using lower quantities of inputs is also feasible (X_1). With respect to the demand for labour, an increase in labour productivity may have a negative impact on employment because fewer labour inputs are demanded to produce output at a predetermined level. In other words, if market demand and hence output requirements do not expand in line with increased productivity, the demand for employment may decline. In this literature, this is known as the substitution effect.

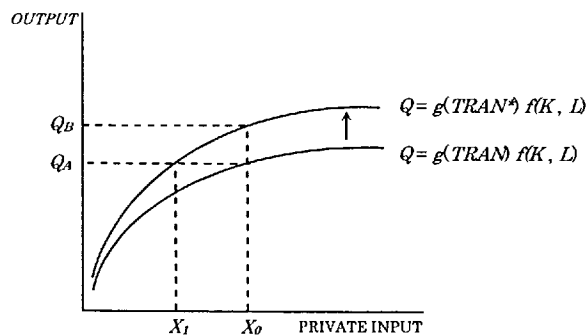


Figure 3.1 Effect of transport investment on production technology

In addition to the substitution effect away from labour, there could exist a complementary effect in that productivity growth due to transport improvements leads to a rise in labour demand, which suggests that the net employment effect is ambiguous. The primary reason for this is twofold. First, the overall cost reduction associated with increased productivity enables firms to expand their markets. One specific example would be the case of competition in goods markets. That is, firms experiencing productivity gains could lower the prices of their products in order to increase market share. Falling relative prices would stimulate the demand for outputs produced by these firms, thus increasing the demand for workers. This impact on the demand for labour depends in part on the price elasticity of product demanded (Button, 1998; Lakshmanan, et al. 2001). If it is high, then one may anticipate a large increase in output and thus potentially in employment. Second, a higher productivity environment could be attractive to investment. Transport investment that enhances a region's productivity and competitive position may thus encourage expansion of existing businesses and attract private inward investment to enter a region. This could generate an increase in overall production and a higher demand for employment.

To the extent that reduced transport costs associated with transport investment removes trade barriers and allows export of products to other regions, there could be the employment effects from this interregional trade competition (Button, 1998; Rietveld and Bruinsma, 1998; Rietveld and Nijkamp, 2000). Whereas an increase in the demand for employment could be anticipated from those expanding their markets geographically, some firms in other sectors that were formerly protected by high transport costs may encounter competition from cheaper imported products and probably experience a decline in sales and employment. However, cheap imports from firms based elsewhere could lead to a substitution effect that gives rise to demand for other products which are produced by some other sectors in the same region. Since there could be potentially both gainers and losers in each region from the trade competition, the net effect on employment in a region is dependent upon its sectoral structure.

3.2.2 Transport infrastructure and firm location behaviour

The location behaviour of firms has long been documented in the context of urban and regional economics. The classical models of industrial location theory state that transport costs play a significant role in determining industrial locations (e.g. Weber, 1928; Moses, 1958). The chosen location of profit-maximising firms is the location at which the total costs for transporting inputs and outputs are minimised. Hotelling (1929) emphasises the importance of spatial monopoly power in firm location decisions. He suggests that under conditions of spatial competition firms will locate where they can gain a greater market share. Another observation is that industrial locations exhibit certain patterns over space. Some firms may cluster within particular regions to take advantage of external scale economies or agglomeration economies such as labour market pooling, production input sharing, and knowledge or information spillovers whereas others tend to be spatially dispersed (McCann, 2001). Taking these theoretical considerations together, it is plausible to form a conclusion that the location decisions of firms have been driven primarily by several factors that could help optimise their different needs and satisfaction; and transport cost is one of the influencing factors of firm location choice.¹³

Fundamentally, transport infrastructure investment can enhance the attractiveness of a region as a location for new establishments or the expansion of businesses in several different ways. For example, improvements in the quality and density of a transportation network can reduce a firm's production costs by offering lower transport costs of obtaining inputs from suppliers and shipping finished goods to the market. Firms locating in a region with major transportation access would be able to reach a larger market and hence achieve better economies of scale. A reduction in travel time variability associated with transport network improvements could be an important factor attracting businesses that operate on a just-in-time strategy.¹⁴ Transport improvements can also promote the realisation of agglomeration economies by facilitating the efficient operation of a dense city. In general, transport infrastructure investment can attract businesses by

¹³ Empirical studies on firms' location choice are voluminous. See Bartik (1985), Bartik (1989), and Coughlin et al (1991) for examples of state level studies; and Fox and Murray (1990), and Coughlin and Segev (2000) for county level studies. The assumption of these studies is that firms examine the relative profitability of different locations. Among several location characteristics that are considered to determine the location of firms is transportation access.

¹⁴ See Allen et al (1994) for useful discussions on the importance of highway investment to logistic operations.

increasing the productivity of the region. These underlying reasons are broadly similar to those previously described in Section 3.2.1.

This is a prominent argument in a substantial body of empirical research on the location determinants of employment and population (e.g. Steinnes and Fisher, 1974; Carlino and Mills, 1987; Boarnet, 1994; Clark and Murphy, 1996). The basic premise of this literature is that the location decisions of firms and households are simultaneous. Providing that jobs follow people, some firms may prefer to locate near a large pool of customers and skilled labour. Given that the link between transportation services and residential amenities, improvements in transport systems can thus attract those firms indirectly by encouraging people living elsewhere to move to a region (See Section 3.2.3 for theoretical discussions on transport and household locations). This migration response could lead to an increase in population, which represents not only increased potential customers in the local market for firms in non-basic sectors but also a potential labour force for any industries in the region. Accordingly, these potential effects of transport infrastructure investment on labour and product markets can also be an important determinant of firm location.

3.2.3 Transport infrastructure and household locations

Residential location theory explains why individuals or households choose and prefer some places in which to reside, rather than other places. It is assumed that households maximise their utility or satisfaction in choosing a residential location. Their location choice is primarily driven by the costs of land, local amenities, public services, and commuting, given budget constraints. The theoretical foundation is traditionally based on the mono-centric model assuming that land prices tend to fall with distance from a central business district, where employment activities locate. Households decide how far to reside from the city centre, by trading off between the amount of housing they can buy and their commuting costs (i.e. vehicle operating costs and opportunity costs). If they live further from the centre, the costs of commuting are more expensive but land is cheaper, or vice versa. The mono-centric model predicts that households may locate their residence further away from the employment centre in response to a decline in

commuting costs. Obviously, transport costs play a crucial role in influencing household location choices in this model of residential location.

The major role that investment in transport infrastructure supply plays in attracting households to a region is twofold. On the one hand, investment in transport affects households' location decision through the provision of a residential amenity. Transportation facilities can serve as public goods to be consumed by people residing in an area where they provide transport services. The extent to which transportation investment reduces travel times and costs for access to jobs, goods markets, public services, and other activities (i.e. social, leisure, etc.) can be thought of as a proxy for the quality of living and working environment. On the other hand, transport infrastructure investment could stimulate inward investment and expansion of local business, which represent job and income opportunities, thereby attracting households to enter the region. In sum, transport improvements such as the provision of high quality roads could increase household in-migration and/or halt out-migration directly by improving an amenity, and indirectly by inducing more business activities and employment.¹⁵

3.2.4 Transport infrastructure and job accessibility

The role of transport in improving accessibility to jobs has been acknowledged in the economic theory of labour markets (Borjas, 1996) and, more recently, in the literature on transport and economic growth (e.g. SACTRA, 1999; Vickerman, 2002). To the extent that provision of transport infrastructure reduces commuting costs, this can have important implications on labour markets.

Labour market areas will tend to increase in geographic size because of a commuting response (Rietveld, 1994; SACTRA, 1999; Vickerman, 2002). A reduction in commuting costs would enable workers to increase the area of job search and make longer journeys for a given amount of generalized costs. In certain cases, if improved transport services allow workers to commute across jurisdictional boundaries, the supply of the labour force available to firms will not be limited to the area in which commuting

¹⁵ Previous empirical studies reveal that the availability of transportation facilities is positively related to population growth (e.g. Carlino and Mills, 1987; Luce, 1994; Boarnet, 1994; Clark and Murphy, 1996). However, Henry et al (1997) find that the density of highways does not explain rural population growth.

costs and times decline. Rather, the additional source of labour supply may come from adjacent areas.

Moreover, improved accessibility to employment opportunities could encourage people to participate in the labour force. Borjas (1996) suggests that commuting costs could affect individuals' decisions to enter the labour force on the grounds that commuting costs raise the reservation wage (i.e. the lowest wage that people are willing to supply their labour), which in turn lowers the probability of entering the labour force. Reduced travel time and costs associated with transport improvements could thus remove this significant barrier to labour-market participation by facilitating people in seeking a job that offers wages higher than or equal to their reservation wage. Some empirical work providing evidence of an inverse relationship between commuting times and employment probabilities include Macek et al. (2001) and Berechmann and Passwell (2001).

3.3 Underlying mechanisms through which transport infrastructure investment affects long-term employment

Based on an extensive review of relevant theoretical literature, we draw a simple diagram (Figure 3.2) to illustrate how provision of transport infrastructure could potentially affect long-term employment within the framework of labour market theory. The basic principle of the theory maintains that the interaction between the demand for labour and the supply of labour determines the equilibrium level of wages and employment in a local labour market. The equilibrium state of the labour market would remain unchanged unless it is disturbed by an economic disturbance or shock to the market. As explicitly pointed out by Eberts and Stone (1992), public infrastructure investment can be thought of as a shock to the labour market. It could lead to the enhancement of a region's attractiveness, thereby affecting the decisions of firms and households in several ways. Therefore, if transport infrastructure investment leads to adjustments in labour demand and/or labour supply, the current equilibrium of the labor market will move toward a new position that subsequently results in changes in the levels of local wages and/or employment.

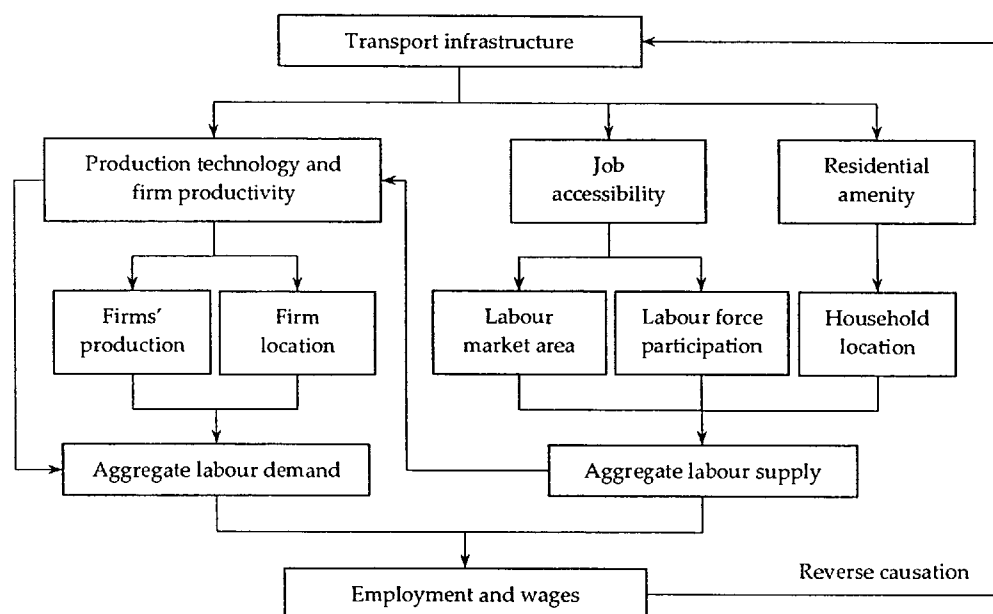


Figure 3.2 Linkages between transport infrastructure and labour market

The supply side of the labour market can be influenced by transport infrastructure in two major ways. With a given population, improved access to jobs caused by investments in transportation can lead to adjustments in local labour supply in the short run through changes in the geographical size of the labour market and amount of labour force participation. A reduction in commuting time and costs associated with transport improvements enables people to increase the geographical scale of their job search and could also encourage potential workers to participate in the labour force. In the long run, improved transport infrastructure could cause the overall population base of a region to increase beyond what it would otherwise be by attracting in-migrations or halting out-migration. As good transportation services can directly serve as a household amenity, improvements in transport infrastructure in the region can also stimulate employment opportunities, which are bound to attract households. Therefore, it is possible that investments in transportation infrastructure could result in an increase in population size, all else being equal, which in turn increases the number of persons who will be available to supply labour to the market.

The effects of transport infrastructure investment on the demand side of the labour market are relatively more complicated. Additional provision of transport infrastructure can improve production technology. Better transportation systems increase the productivity of firms primarily by facilitating the efficient movement of people and goods, providing lower costs of transporting inputs and outputs, and making the expansion of market areas more profitable. Furthermore, improvements in transportation services can have a direct impact on labour productivity by lowering commuting time spent getting to and from work. As a result of the influences of transport improvements on the availability of the labour supply, an increase in labour productivity in the production process is also probably attributable to a better match between the supply of jobs and skilled workers.

As additional investments in transport infrastructure can be considered as an increase in production technology, the theory of production suggests that this could lead to an upward shift of the production function. However, the direction of changes in labour demand, as productivity enhancements associated with improved transportation services, can have both substitution and complementary effects, making the net impact on employment unclear. If market demand and hence output requirements remain unchanged, growth in firm productivity simply implies that the quantity of labour demanded may decline. However, firms may take advantage of a reduction in generalised transport costs and production costs to expand their markets, either through lowering price or through serving a larger market from which it was not previously profitable due to high shipping costs. As a result, the demand by such firms for employment will increase to meet the rise in output. Moreover, the provision of transport infrastructure that enhances a region's productivity could induce more businesses to enter a region. Therefore, to the extent that transport investments attract a number of businesses, this could simply lead to increases in the region's demand for labour.

Although the structural mechanisms by which transport infrastructure developments can have impacts on employment are theoretically identifiable, one major criticism against these is the issue of causality. The above theoretical arguments suggest that transport investments could affect regional and local employment; however, an area where employment growth is occurring may attract transport infrastructure

expenditures. Likewise, a region that suffers high unemployment may also attract investment with the hope that this spurs employment growth. This reverse causation may potentially arise in several ways. High-employment-growth economies could have a large tax base and can therefore afford further development of their transport network. Government policy might also be oriented towards additional investments in transport infrastructure for regions with concentrations of jobs and people in order to tackle congestion externalities. In other cases, public policy with the objective of stimulating certain declining regions may involve increases in spending on transport infrastructure supply. To further complicate any causal analysis, provision of transport infrastructure may also be a response to forecast demand for transport services. That is, in the case of effective transport planning, transport investment may be considered as the effect of employment growth. In addition, transport infrastructure expenditures are sometimes directed politically to satisfy local constituencies, and thus may not always be allocated where the existing travel demand or anticipation of future economic growth would dictate. For these reasons, it might be employment that affects provision of transport infrastructure, not the other way around.¹⁶

However, one must be aware that the effects of transport infrastructure on firm and household decisions which could be translated into employment changes are unlikely to be large in certain circumstances. There are some possibilities that provision of transport infrastructure would tend to reduce the locational advantage of a region. Improvements in transport facilities may induce more vehicle traffic, leading to congestion and environmental effects. For example, building more highways or expanding highway capacity could induce more travel, which increases vehicle emissions, noise, and traffic.¹⁷ Apart from these negative externalities, transport infrastructure investment may result in higher values of land and property in particular

¹⁶ There has been some recent evidence suggesting that transport infrastructure investment is endogenous to the economy. Rietveld and Boonstra (1995) and Rietveld and Wintershoven (1998), for example, estimate a model of transport infrastructure supply in European regions and find that population density and the level of gross domestic product per capita have a significant impact on the supply of the transport infrastructure network. Other authors have provided evidence on the reverse causation from broadly defined public infrastructure to economic growth. For example, see Duffy-Deno and Eberts (1991) and Pereira and Flores de Frutos (1999).

¹⁷ Empirical evidence on the induced travel demand from transport investment has been provided in many econometric studies using data for the United States. See Noland (2001) for examples of recent estimates of induced travel effects at the state level; Noland and Cowart (2000), Fulton et al (2000), Cervero and Hansen (2002) for county-level estimates. Noland and Lem (2002) provide a comprehensive review of literature on this aspect.

areas.¹⁸ Higher prices of land and property may represent a significant cost barrier that not only limits households' ability to move into a region but discourages inward investment and expansion for existing firms.¹⁹ To the extent that road investments induce more traffic and hence congestion in the road network, this also implies that travel time and cost savings due to such investments may potentially have less significant effects.

The diagram depicted in Figure 3.2 is simplified to provide a theoretical foundation for the analysis of the linkages between transport infrastructure and employment. Another theoretical aspect that needs to be considered is that the employment effect of transport investment has both temporal and spatial dimensions. It is plausible that employment does not instantaneously or fully respond to improved transport systems during a single period of time but there might be considerable time lags. The primary reasons behind this include adjustment costs incurred by firms and households in response to improved transport facilities, and imperfect information gained by those actors on changed circumstances. However, there might also be a lead effect in the sense that some economic activities are likely to react in anticipation of accessibility changes due to major transport infrastructure improvements.

The theoretical arguments thus far have concentrated largely on several implications of transport infrastructure investment in an individual area or region directly served. This does not deny that transport improvements in one region could affect local employment of other regions. With network characteristics, transport infrastructure can have spatial implications across jurisdictional boundaries, affecting employment of neighbouring or more distant regions. The role of transport improvements in altering geographical advantages across locations which in turn leads to the spatial redistribution of economic activity also implies that the employment impact is not necessarily distributed evenly over space.

¹⁸ Many studies have found a positive relationship between transport infrastructure investment and the prices of land or housing (e.g. McDonald and Osuji, 1995; Haughwout, 1997; Boarnet and Chalermpong, 2001; Siethoff and Kockelman, 2002).

¹⁹ A recent study by Cameron and Muellbauer (1998) reveal the importance of housing prices on migration decisions. Their empirical results suggest that high relative house prices discourage in-migration.

3.4 Concluding remarks

This review has elaborated on the theory behind the link between transport infrastructure investment and employment. While there is a widely held belief among the general public and policymakers that investments in transport infrastructure can help to create long-term employment gains throughout an economy, the reviewed theoretical literature suggests that the direction of employment changes in response to transport improvements could be ambiguous. Productivity growth stemming from improved transport infrastructure could give rise to increased firm output and hence increased demand for employment. However, cheaper transport inputs could also result in a substitution effect away from making use of labour in the production process. Apart from this labour saving effect, transport infrastructure improvements that stimulate the volume of trade and competition regionally are likely to create employment losses in some sectors that are exposed to such competition. Since the relative extent of these opposing effects is uncertain, there is no guarantee that in any region the net employment impact would be positive. Given the possibility that transport infrastructure is endogenous to an economy, moreover, it is crucially important to understand that the causal relationship between transport infrastructure investment and employment may not be immediately clear and this clearly complicates any empirical analysis. Another source of complication concerns time and space dimensions of the employment effects that need to be taken into account. In the next chapter, we review macro-level studies and specifically their application of econometric methods to examine the relationship between transport infrastructure investment and employment, and synthesise empirical findings emerging in this literature in order to identify the current stage of empirical knowledge on this topic.

Chapter 4

A Critical Review of Econometric Analyses of Transport Infrastructure Investment and Its Employment Effects

4.1 Introduction

A number of research studies have been conducted to empirically ascertain the relationship between transport infrastructure and employment. Considering the fact that transport infrastructure is only one of several factors contributing to changes in the demand for labour or the location of employment, researchers have applied econometric techniques to statistically isolate the effect of transport infrastructure while controlling for the effects associated with other determinant factors. These studies have used different levels of aggregation, and have used a variety of modeling approaches based on theoretical motivations, assumptions, and focused on specific questions of interest that may vary. The empirical evidence emerging from previous research is generally rich, but contradictory and elusive. To some extent, such inconclusive evidence reflects the complexity and difficulty in estimating the magnitude and nature of the effect of transport investment on employment in an economy.

This chapter reviews econometric studies on the relationship between transport infrastructure investment and employment. The substantive scope of this review focuses primarily on macro level analyses that estimate the total system effect of transport

investments on employment in an economy.²⁰ Table 4.1 summarises the important features of empirical studies reviewed in this chapter.

The remainder of this chapter is organised as follows. In Section 4.2 we discuss various methods that have been applied to measure transport infrastructure in macro-level econometric studies. This is followed by Section 4.3 that contains a review of several modeling techniques used in the empirical literature together with discussions on methodological issues in previous work. In Section 4.4 we identify and organise the current state of empirical knowledge obtained to date concerning the effect of transport infrastructure investment on employment. The final section presents concluding comments, highlights some gaps in the understanding of the topic, and links this to the empirical analyses of this dissertation.

4.2 Measurements of transport infrastructure

Econometric estimation of employment impacts from transport infrastructure investment requires appropriate measures to capture the role of transport infrastructure. Four typical approaches have been used in the literature. The most common approach, which is employed in cross-sectional analysis, is to use a dummy variable to capture the presence of transport facilities in study areas. In the work by Lichter and Fuguitt (1980) and Briggs (1981), for example, the value of one is assigned for counties containing an interstate highway, and zero otherwise. This dummy variable approach has the obvious disadvantage that it contains no information on the physical size and quality of transport infrastructure available that will differ from one area to another. This qualitative nature of dummy variables presents a serious limitation.

²⁰ Another line of research on the employment impact of transport infrastructure investment, which is not in the scope of this paper, involves case studies that have sought the existence of employment changes associated with particular transport projects in a defined study area. See, for example, Dodgson (1974), Clay et al (1992), Linneker and Spence (1996), Bruinsma et al (1997), Bollinger and Ihlanfeldt (1997), and Chalermpong (2004).

Table 4.1 A summary of econometric studies on the impact of transport infrastructure investment on employment

Author	Modelling approach	Type of model	Data and unit of analysis	Transport infrastructure measure	Scope of analysis			
					Aggregate employment	Sectoral employment	Spatial spillover effect	Differential effect by region
Seitz (1993)	Cost function	A system of equations	Panel data, 31 German manufacturing industries, 1970-1989	Length of the total motorway network and the real net capital stock of roads and bridges		x		
Nadiri and Mamuneas (1998)	Cost function	A system of equations	Panel data, 35 US industrial sectors, 1950-1991	Highway capital stock in monetary term		x		
Cohen and Paul (2004)	Cost function	A system of equations with first-order serial correlation and spatial autoregressive error specification	Panel data, US manufacturing in 48 US states, 1982-1996	Highway capital stock in monetary term		x	x	
Seitz and Licht (1995)	Cost function	A system of equations	Panel data, manufacturing in the 11 federal states of West Germany, 1970-1988	A stock of public road capital in monetary term		x		
Deno (1988)	Profit function	A system of equations	Panel data, US manufacturing in 36 SMSA, 1970-1978	Highway capital stock in monetary term		x		x
Jones (1990)	Cross-sectional analysis	Disequilibrium adjustment, OLS model	Cross-section, US States, 1964-1984	Per capita highway expenditure	x			
Haughwout (1999)	Cross-sectional analysis	OLS models with long differences specifications	Cross-section, 2,583 US counties, 1943-1992	Highway capital stock in monetary term	x		x	
Lombard et al (1992)	Cross-sectional analysis	OLS model	Cross-section, all 92 Indiana counties, 1980-1988	Highway density and total highway expenditure per square mile	x	x		
Thompson et al (1993)	Cross-sectional analysis	Disequilibrium adjustment, OLS model	Cross-section, all 67 Florida counties, 1980-1990	Highway density	x			
Islam (2003)	Cross-sectional analysis	Disequilibrium adjustment, OLS and spatial lag models	Cross-section, 410 US counties in the 13 Appalachian states, 1990-2000	Highway capital outlay	x			
Lichter and Fuguitt (1980)	Cross-sectional analysis	OLS model	Cross-section, all nonmetropolitan counties in the 48 contiguous US states, 1950-1975	Presence of an interstate highway		x		x

Table 4.1 A summary of econometric studies on the impact of transport infrastructure investment on employment (cont'd)

Author	Modelling approach	Type of model	Data and unit of observation	Transport infrastructure measure	Scope of analysis			
					Aggregate employment	Sectoral employment	Spatial spillover effect	Differential effect by region
Briggs (1981)	Cross-sectional analysis	OLS model	Cross-section, all nonmetropolitan counties in the 48 contiguous US states, 1950-1975	Presence of an interstate highway		x		
Singletary et al (1995)	Cross-sectional analysis	OLS and spatial lag models	Cross-section, 477 small regions in South Carolina, 1960-1989	Two-lane highway density, access to an interstate ramp, access to interstate highways 85, and presence of 4-lane highway projects		x		
Crane and Leatham (1993)	Time-series analysis	Distributed lag model	Annual observations for urban and rural counties in Texas, 1969-1986	Highway construction and maintenance expenditures		x		x
Mofidi and Stone (1990)	Static panel regression analysis	Five-year first difference model with fixed effects	Panel data, 50 US states for the years 1962, 1967, 1972, 1977, and 1982	Highway expenditure per personal income		x		
Carroll and Wasylenko (1994)	Dynamic panel regression analysis	First difference model with fixed effects and a partial adjustment scheme	Panel data, US states, 1967-1988	Highway expenditure per capita	x	x		
Dalenberg et al (1998)	Static panel regression analysis	OLS model, OLS model with fixed effects, first-order autoregressive model (AR1) with fixed effects, and two-stage least squares (2SLS) model	Panel data, 48 US states, 1972-1991	Highway capital stock in monetary term	x		x	
Dalenberg and Partridge (1995)	Dynamic panel regression analysis	Three-year first difference model with fixed effects and a partial adjustment scheme, and two-stage least squares (2SLS) model	Panel data, 28 US metropolitan areas, 1966-1981	Highway expenditure per personal income	x	x		
Crane et al (1991)	Dynamic panel regression analysis	Distributed lag model	Panel data, 24 highway districts in Texas, 1969-1986	Highway expenditure	x	x		
Eagle and Stephanedes (1987)	Dynamic panel regression analysis	Autoregressive distributed lag model	Panel data, all 87 Minnesota counties, 1964-1982	Highway expenditure	x			x
Bollinger and Ihlanfeldt (2003)	Static panel regression analysis	Fixed effects model	Panel data, 299 census tracts in the Atlanta region from 1985 through 1997	Highway expenditure and percentage of a rail station impact area	x	x		

Table 4.1 A summary of econometric studies on the impact of transport infrastructure investment on employment (cont'd)

Author	Modelling approach	Type of model	Data and unit of observation	Transport infrastructure measure	Scope of analysis			
					Aggregate employment	Sectoral employment	Spatial spillover effect	Differential effect by region
Carlino and Mills (1987)	Simultaneous equations of employment and population	Simultaneous model with a partial adjustment scheme	Cross-section, nearly 3,000 US counties for the 1970s	Interstate highway density	x	x		
Clark and Murphy (1996)	Simultaneous equations of employment and population	Simultaneous model with a partial adjustment scheme	Cross-section, 3,017 US counties during the period 1981-1989	Highway density and percent of public expenditures on highways	x	x		
Duffy-Deno (1998)	Simultaneous equations of employment and population	Simultaneous model with a partial adjustment scheme	Cross-section, 250 non-urban counties in the eight intermountain states of the U.S., 1980-1990	Highway density	x	x		
Luce (1994)	Simultaneous equations of employment and population	Simultaneous model with a partial adjustment scheme	Cross-section, 340 municipalities in the Philadelphia metropolitan area for the years 1970 and 1980	Presence of major highway access and of railroad access	x	x		
Boarnet (1994)	Simultaneous equations of employment and population	Simultaneous model with a partial adjustment scheme and spatial lags	Cross-section, 365 municipalities in northern New Jersey, 1980-1988	Presence of major highway access and of railroad access	x			
Pereira (2000)	Vector autoregression (VAR)	VAR models with four variables - output, private capital, labour, and highway capital	Time-series, the entire US economy, 1956-1997	Highway capital stock in monetary term	x			
Stephanedes (1990)	Vector autoregression (VAR)	VAR models with two variables - employment and highway expenditure	Panel data, all 87 Minnesota counties, 1957-1982	Highway expenditure	x			x
Zografos and Stephanedes (1992)	Vector autoregression (VAR)	VAR models with two variables - employment and highway expenditure	Panel data, all 87 Minnesota counties, 1957-1982	Highway expenditure		x		x

The majority of empirical studies included in Table 4.1 have attempted to ascertain a statistical link between government expenditures on transport infrastructure and growth in terms of employment. Given that creation of jobs is widely used as a justification for funding decisions, analysing data on transport expenditures directly examines whether there is empirical evidence supporting this funding justification criteria. However, careful consideration of various issues is required when modelling the effects of transport expenditures. A main issue is concerned with the fact that taxation is a primary source of government revenues that finance public infrastructure investments. Ignoring the countervailing effect of taxes on economic performance could lead an estimated coefficient for expenditures for transport infrastructure not to be meaningful. In addition, more spending on transport infrastructure may reduce funding available for provision of other public services (e.g. health and education) and other competing programs that could also affect economic activity. Accordingly, one needs to disentangle the effect of transport expenditures from the confounding effects of taxes and other types of expenditures in order to avoid misleading interpretations. The work by Helms (1985) explicitly models the government budget constraint and demonstrates that incorporating both tax and expenditure variables in regressions can help to identify the effect of these fiscal policies. In estimating the employment impact of transport expenditures, only a few studies have followed this approach, which include Modifi and Stone (1990) and Dalenberg and Partridge (1995).

There are some merits of using data on transport expenditures. It can capture to some extent the quality and condition of infrastructure. This is because expenditures usually relate to not only construction activities for physical infrastructure but maintenance of existing transport facilities. An increase in highway spending, for example, may partly reflect better pavement conditions, improvements in traffic signals and safety devices, and even implementation of intelligent transportation systems; all of which could enhance traffic flows and the reliability and performance of the highway network. Moreover, the use of monetary data could allow one to capture the full spectrum of employment effects from expenditures on transport infrastructure (i.e. direct and indirect employment generated by expenditures on transport improvement projects during construction phases and changes in long-term employment after completion of

the projects), providing that temporal dynamics of employment changes would be correctly specified to take into account all sorts of these employment effects. However, data on expenditures are not informative about the timing of changes in capacity and accessibility provided by new or improved transport infrastructure; therefore, specifying a correct lag specification to capture long-term employment changes appears to be a very difficult task. There are also other limitations inherent to the use of expenditure data. As pointed out by Prichett (1996), the lack of efficiency with which public infrastructure projects are undertaken may characterise the mismatch between the total amount of money invested in transport infrastructure and the actual services provided by such investment. In addition, costs of construction and maintenance of transport infrastructure may differ across regions. In the absence of regional price indexes, estimated effects of transport expenditures could be potentially misleading. More importantly, the importance of existing infrastructure is not taken into account as data on transport expenditures capture only monetary flows.

Some studies have relied on a more promising approach to measure transport infrastructure, using the stock of transport infrastructure in monetary terms (e.g. Seitz and Licht, 1995; Nadiri and Mamuneas, 1998; Dalenberg et al, 1998; Haughwout, 1999; Cohen and Paul, 2004). Data on this monetary stock are usually unavailable and have to be constructed. In most studies, the methodology used to estimate the value of transport infrastructure capital is based on the perpetual inventory technique. Basically, the stock of transport infrastructure at a particular year is obtained as the sum of real expenditures on transport infrastructure in the past, adjusted for depreciation. However, the quality of capital stock estimates are questionable, and some difficulties with this approach are widely documented (e.g. Eberts, 1990; Pritchett, 1996; Fraumini, 1999; and Vickerman, 2007). The main issues include the validity of assumptions regarding prices used to value each unit of capital, depreciation rates, the difference between actual government spending on infrastructure and its economic costs (e.g. whether prices paid are cost-minimising), estimating or benchmarking the level of capital stock for an initial year, and the need for quality adjustments over time.

By using physical measures of transport infrastructure stock (e.g. length of roads, number of kilometres of railways), one can avoid the problems inherent in the estimation

of monetary capital stocks. Many studies use data on the total length of highways, standardised by area to take account of differences in region size (e.g. Carlino and Mills, 1987; Clark and Murphy, 1996; Duffy-Deno, 1998). Although this measure of highway density incorporates information about the coverage of the highway network, it does not reflect differences in capacity which are more useful in measuring the level of services provided by highway infrastructure. Thompson et al (1993) is the only empirical work that uses data on lane-mileage to calculate the density of highway lane-miles which could capture the effects of both new routes and capacity expansion. It should be pointed out that these physical quantity measures do not account for the quality of infrastructure (Rietveld and Bruinsma, 1998; Bougheas et al, 2000) which might be captured when using monetary data.

4.3 Modelling framework

The choice of econometric model that is used to empirically address the question of whether transport investment affects employment is based on theoretical motivations, assumptions, and specific questions of interest that are different among studies. This section reviews the modelling frameworks applied in the literature organised into five categories. We start Section 4.3.1 with the use of cost or profit function models in determining the extent to which changes in the stock of transport infrastructure affect firms' demand for labour and other production inputs. In Section 4.3.2, we discuss several types of employment models estimated in a single-equation framework, which is the most common approach used in the literature. Section 4.3.3 focuses attention on simultaneous equation models of population and employment used in cross-sectional studies that view transport infrastructure as one of several location determinants of firms and households. Section 4.3.4 is devoted to the application of vector autoregression that allow transport infrastructure, employment and other variables of interest to be jointly determined. In Section 4.3.5 we review attempts to estimate the employment effect of transport infrastructure investment using spatial econometric techniques that account for the potential dependence between spatial observations that is generally ignored in the first four approaches. Finally, we summarise common problems inherent in the existing

literature in Section 4.3.6. Empirical strategies for dealing with these problems are also briefly discussed.

4.3.1 Cost or profit function models

The effect of transport infrastructure on the demand for employment is one piece of evidence emerging from recent studies that have applied duality theory to analyse the productivity effect of highway infrastructure using a cost function (e.g. Seitz 1993, Seitz and Licht 1995, Nadiri and Mamuneas 1998, Cohen and Paul, 2004) or a profit function (Deno 1988).

In the cost function studies, it is explicitly assumed that firms are price takers, and the cost function represents the cost-minimising behaviour of such firms with respect to their combination of inputs (i.e. labour, private capital, and materials) in producing a given level of output for a given level of technology. The stock of highways is considered a fixed and free input that influences production technology. More highway infrastructure could enhance production possibilities resulting in cost-minimising firms adjusting their demand and use of inputs, given input prices and the existing output level. The general structure of the aggregate cost function model used in Seitz (1993), Seitz and Licht (1995), and Nadiri and Mamuneas (1998) takes the following form:

$$C = C(w, r, z, t, Q, G) \quad (4.1)$$

in which w , r and z are the price of labour, private capital, and other private inputs respectively, t represents a proxy for technical change, Q is output, and G denotes the stock of highway infrastructure capital available within a jurisdiction. This cost function is derived by minimising the private production cost: $C = wL + rK + zM$, subject to the production function: $Q = f(L, K, M, t, G)$, where L , K , M denotes labour, private capital, and other inputs respectively. To explore the relationship between highway infrastructure capital and firms' input demand decisions, the authors apply Shephard's lemma, which states that the optimal (cost-minimising) input demand equation can be obtained by partially differentiating the cost function with respect to the price of the production input in question, to derive the *conditional* input demand functions:

$$L^* = \partial C(w, r, z, t, Q, G) / \partial w = L(w, r, z, t, Q, G) \quad (4.2a)$$

$$K^* = \partial C(w, r, z, t, Q, G) / \partial r = K(w, r, z, t, Q, G) \quad (4.2b)$$

$$M^* = \partial C(w, r, z, t, Q, G) / \partial z = M(w, r, z, t, Q, G) \quad (4.2c)$$

from which the input demand adjustment effects of highway investments can be estimated by differentiating the demand function with respect to G . Consider the demand for labour, $\partial L^* / \partial G > 0$ (< 0) which indicates that highway infrastructure and private labour are complements (substitutes), whereas infrastructure is neutral with respect to labour if $\partial L^* / \partial G$ is equal to zero.

While the cost function given in equation (4.1) is the long-run or full equilibrium cost function, in which all private inputs are considered as variable inputs, more recent work by Cohen and Paul (2004) focuses on the short-run effect of highway investments on manufacturing production by treating private capital and highway infrastructure as quasi-fixed factors. In addition, Cohen and Paul present an extension of earlier studies by measuring the extent and significance of spatial spillover effects of highway infrastructure investment. The short-run variable cost function applied to manufacturing industry data for the 48 contiguous US states is given by:

$$C = C(w, z, t, Q, K, G, \bar{G}) \quad (4.3)$$

where $\bar{G}$ is the measure of highway capital stock in neighbouring states.

For empirical implementation, the cost functions are specified in generalised Leontief form (Seitz, 1993; and Cohen and Paul, 2004) or in translog form (Seitz and Licht, 1995; Nadiri and Mamuneau, 1998). A set of input demand (share) equations is obtained straightforward by applying Shephard's lemma to the generalized Leontief (translog) cost function. A system of cost and input demand (share) equations are then jointly estimated. All of the cost function studies except Cohen and Paul (2004), who use the number of production workers and all employees in the manufacturing sector to represent labour quantities, use the total number of working hours to measure the quantity of labour input. In most studies, estimated coefficients for input demand responses of highway infrastructure investments tend to demonstrate the complementary relationship between highway infrastructure and the demand for private capital, whereas private labour input and highway capital are consistently found to be substitutes.

Nevertheless, there is a shortcoming to estimating the employment effect of infrastructure provision within the traditional cost function framework. As pointed out by Deno (1988) and others (e.g. Duffy-Deno, 1991; Seitz and Licht, 1995; Seitz, 1995, 2001), cost function estimates of input demand adjustments due to changes in the supply of transport infrastructure are *conditional*; this is in the sense that the input demand functions, derived from the cost function, are the conditional demand for private inputs, holding output and input prices constant. Since a cost reduction associated with improved transport infrastructure (e.g. the use of fewer inputs or an increase in productivity) could lead to an expansion of output, the cost function approach is not capable of capturing the mechanism by which transport infrastructure investments can have an indirect effect on the demand for private inputs (e.g. labour and private capital) through its output expansion effect. In other words, studies using the cost function approach to examine the role of transport infrastructure provision in employment changes may underestimate the effect.

An alternative approach is to relax the restricted assumption in the cost function approach that output is exogenously given by estimating a profit function. In this approach, firms are assumed to be profit maximisers that choose the quantity of production inputs to be employed and the level of output to be produced given their price, and the stock of highway infrastructure capital. The profit function derived from the maximisation of the firm profit, $pQ - (wL + rK + zM)$, subject to the production function: $Q = f(L, K, M, t, G)$, can be expressed as

$$\Pi = \pi(p, w, r, z, t, G) \quad (4.4)$$

where p denotes the output price. First-order conditions such as the application of Hotelling's lemma result in *unconditional* demand functions for labour, private capital, and other private inputs. For example, the unconditional labour demand function is

$$L^* = L(p, w, r, z, t, G) \quad (4.5)$$

Estimation of the *unconditional* demand functions yields the unconditional effect of changes in highway infrastructure on the demand for private inputs as an adjustment in all of the firms' decision variables (i.e. output and private inputs). The unconditional effect is the sum of the conditional effect and the output expansion effect (Seitz, 1995, 2001).

An example of such an approach is found in the empirical work of Deno (1988). Using manufacturing data for US metropolitan areas, Deno adopts a translog profit function to examine the unconditional effect of highways and other types of public capital on manufacturing production decisions (i.e. outputs produced and inputs employed). In contrast to the findings of the cost function studies, Deno finds that highway capital has a complementary relationship with private capital and labour.

Drawing heavily upon the economic theory of the firm, the cost or profit function approach provides a theoretically useful framework in examining whether transport provision is a factor driving employment changes. Nevertheless, the cost and profit functions typically applied in the literature do not account for potentially lagged responses of firms to changes in the stock of transport infrastructure in adjusting the quantity of labour required (Sturm et al, 1998), in particular since there are non-recurring costs associated with expanding the labour force (e.g. hiring and training costs) that may make firms more cautious. While all the studies reviewed above have analysed time-series cross-sectional data, only Nadiri and Mamuneas (1998) and Cohen and Paul (2004) corrected for a first-order serial autocorrelation so as to deal with temporal lags. Furthermore, there is possibly a reverse causal link between input demand and highway investments. The work by Cohen and Paul (2004) explicitly accounts for this potential simultaneity bias, whereas all other studies do not provide clear information on whether and how they have dealt with the issue of causality.

Finally, with strict emphasis on transport infrastructure's influence on the production side of the economy, studies using these approaches also overlook the fact that improved transport services can serve as a household amenity and facilitate people's accessibility to jobs, thereby affecting the supply of labour (Dalenberg and Partridge, 1997; Dalenberg et al, 1998). As transport investment can affect employment through its roles in leading adjustments of both labour demand and supply, another important and inherent weakness with these studies is the failure to capture other potential effects of transport infrastructure on the labour market.

4.3.2 Single-equation models of employment

The most commonly used approach for estimating the employment impact of transport infrastructure investment is single-equation regression analysis. This section examines several different forms of single equation models used in the literature. Empirical work relying upon this approach can be categorised into three primary groups with respect to three types of data used for analysis: cross-sectional, time-series, and panel data.

Cross-sectional analysis

Most studies based on cross-sectional regressions have examined whether a percentage change or an absolute change in employment in each jurisdiction of interest is associated with transport infrastructure investment while controlling for other relevant variables. Various measures of transport infrastructure and other control variables are used in the models that have been estimated. In this stream of research, there have been several key assumptions behind the cross-sectional regression models that seek to explain the observed changes in employment and their association with transport infrastructure.

The first modelling strategy relies on the concept of *the disequilibrium-adjustment model*. This approach, which is commonly applied in cross-sectional studies of regional growth, is based upon the assumption that differences in locational characteristics across regions at the beginning of a period are sufficiently large to cause regional differentials in economic or demographic change (Plaut and Pluta, 1983). More specifically, such changes are assumed as the effect of the initial disequilibrium in the base year. These models are estimated by regressing employment *change* during a selected period on beginning-of-period *levels* of transport infrastructure and other explanatory variables.

There are several cross-sectional studies that follow this modelling approach. These include Jones (1990), who analyses the effects of state and local government expenditures (e.g. highways, education, welfare, and health) on state employment growth; and Islam (2003), who attempts to determine whether highway capital outlays measured in 1990 have a significant impact on county employment growth between 1990 and 2000 using county data in the 13 Appalachian states. Multiple regression models estimated by Lombard et al (1992) estimate the change in employment between 1980 and 1988 specified as a function of the 1980 levels of highway mileage per square mile and

other factors (e.g. education levels, wage rates, property tax rates, electricity prices) and highway expenditures per square mile from 1980 to 1988 are also defined as an independent variable. However, this specification, which is similar to the disequilibrium framework, has its shortcomings. Newman and Sullivan (1988) argue that locational changes (e.g. employment growth) may be affected by certain circumstances during the change period in question, and hence the estimated coefficients based solely on beginning-of-period variables may be subject to omitted variable problems.

The second approach involves the treatment of observed employment changes by comparing different equilibria in a *comparative static framework*. The theoretical underpinnings of this approach are based on the notion that the equilibrium level of employment will not change as long as certain influencing factors remain unchanged. During a certain period, changes in the availability or quality of transport infrastructure are viewed as an exogenous disturbance to equilibrium that may cause employment to move from its initial equilibrium to a new one. The modelling strategy is thus to test whether, *ceteris paribus*, the observed change in employment and the change in transport infrastructure during the contemporaneous period are statistically correlated. In the literature, this approach is applied in the cross-sectional analysis of Haughwout (1999) that relates state infrastructure (highway and non-highway) growth to county-level employment growth in the USA over the period 1974-92. Note that this comparative static approach is also referred to as equilibrium modelling or the 'changes' model with the assumption that growth occurs only if the equilibrium is disturbed (Bartik 1991).

Despite being potentially useful in that any unobservable fixed effects of local characteristics are automatically eliminated if one estimates a cross-sectional model in the differences specification (Bartik, 1991), empirical analysis by means of such a comparative static or equilibrium modelling framework contain some limitations. The ambiguity of the direction of the causal relationship between transport infrastructure and employment changes could result in simultaneity bias. Moreover, Newman and Sullivan (1988) argue that restoration of equilibrium ordinarily occurs with a lag because production factors are not mobile in the short run, and that the assumption of equilibrium may not be reasonable because observed changes may be correlated with the levels of beginning-of-period variables, as in the disequilibrium approach. Newman and

Sullivan suggest that the treatment of observed employment changes as a function of the levels of and the lagged changes in transport infrastructure and other determinants may be preferable. Haughwout (1999), in an attempt to address the endogeneity issue, specifies a second employment growth equation in which infrastructure growth during the period 1974-83 is related to subsequent county employment growth for the period 1983-92. However, Haughwout notes that the econometric problem due to the potential of reverse causation may still exist because employment growth may be anticipated.

Thompson et al (1993), in a study of the relationship between highway investment and economic growth across Florida counties during the years 1980-90, treat the influence of highway density on county employment growth with both disequilibrium and equilibrium models. In doing so, they incorporate the base-year level and growth of highway lane-mile density into the equation explaining job growth. Nonetheless, the estimated growth model in their study may not fully account for both locational disequilibrium and locational equilibrium because the choice and inclusion of control variables (e.g. personal income, population growth) appears arbitrary. More importantly, another weakness of this study is the absence of addressing the potential simultaneity.

Another group of cross-sectional studies examine the relationship between the presence of transport facilities and employment changes. Instead of examining the importance of differences in the stock of or expenditures on transport infrastructure in explaining regional variation in employment changes, these studies have tested whether changes in employment during certain periods are attributable to the presence of highways. Studies in the early 1980s by Lichter and Fuguitt (1980) and Briggs (1981), for example, conduct a simple path analysis to examine the causal relationship between date of completion of an interstate highway and changes in non-metropolitan county employment and population, according to the hypothetical model shown in Figure 4.1. In the regression equation estimating the direct effect of interstate highways on employment growth, a dummy variable denoting whether a county had an interstate highway during the period of observed employment growth is included in addition to other exogenous variables controlling for the influence of urbanization (i.e. proximity to metropolitan areas and size of city population in each county).

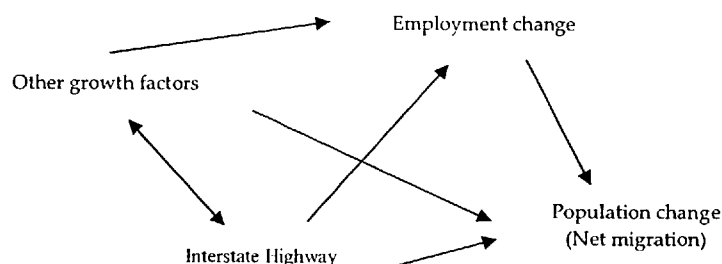


Figure 4.1 Model of the impact of interstate highways on employment and population changes (Sources: Reproduced from Lichter and Fuguitt (1980) and Briggs (1981))

More recent work by Singletary et al (1995) also applies dummy variable techniques to investigate whether the timing of four-lane highway investments is related to new job creation in the manufacturing industries of 477 disaggregated regions in South Carolina. The authors hypothesise that total employment in new establishments during the 1980s is influenced by four-lane highway projects completed not only in the 1980s but also in the 1960s and 1970s, conditional on the stock of infrastructure (e.g. two-lane roads and water and sewer facilities), the availability of interstate highway access, and agglomeration influences by 1980. In these relatively simple analyses, the possibility of reverse causality between road investments and employment change during the same period could exist.

While it is obvious that a principal problem common to this cross-sectional literature is a general failure to deal with the potential of reverse causality, they may also suffer from omitted variable bias and are unable to control for unobserved heterogeneity. Panel data techniques can overcome these limitations. There is also a lack of theoretical justification in some of these studies (Lichter and Fuguitt, 1980; Briggs, 1981; Jones 1990, Thompson et al., 1993, and Singletary et al., 1995); essentially they do not sufficiently control for classic determinants of regional employment growth, such as relative tax burdens, government spending on public services, labour quality, labour costs, unionization, and local amenities. If these variables are significant factors contributing to changes in employment, their omission may affect coefficient estimates.

Analysis of time-series data

The application of time-series analysis to modelling the empirical relationship between transport investment and employment in a single-equation framework is found in Crane and Leatham (1993). This study estimates the dynamic impacts that transport expenditures have on income and employment levels in Texas using annually aggregated observations for urban and rural counties from 1969 through 1986. Given that the effects of expenditures on highway construction and maintenance can be distributed throughout several periods of time, the authors employ polynomial distributed lag models to analyse the effects of current and lagged levels of highway expenditures, controlling for the influences of oil prices and gross national product during a contemporaneous period. The smallest standard error of regression is simply used as a criterion for determining the appropriate lag length of highway expenditures in the models. Note, however, that estimation results in this study might be subject to spurious regression bias. This is because the distributed lag models are estimated in levels, but the possibility that the data are nonstationary time series is apparently ignored.

Static panel regressions

With a number of advantages over studies based solely on cross-sectional or time-series data, panel data analysis in a single equation framework has been increasingly used for investigating the impact on employment of transport infrastructure. As shown in Table 4.1, several types of panel data models have been applied in the literature.

The empirical work of Dalenberg et al (1998) employs a static fixed effects regression to examine the relationship between highway infrastructure investment and private employment growth across 48 contiguous states in the USA. Based on the hypothesis that changes in state employment growth relative to the nation could be explained by differences in the levels of state public infrastructure and other control factors across states, the authors estimate a linear fixed effect model of state employment growth in the following form:

$$EGRW_{it} = \alpha + \beta HWY_{it} + \phi NHWY_{it} + \gamma Z_{it} + \sigma_i + \varepsilon_{it} \quad (4.6)$$

in which the state yearly employment growth *relative* to the nation ($EGRW$) is treated as a function of contemporaneous levels of the highway capital stock (HWY), non-highway

capital stock ($NHWW$), and control variables (Z) hypothesised to affect labour demand and labour supply, for example industry structure, state and local tax burdens, energy prices, unionization, educational attainment, demographic characteristics, and urbanization. The state fixed effects (σ) are included in the empirical model to control for unobservable heterogeneity of firm and household amenity across states that may be persistent during the sample period. The relative change in yearly state employment is specified as the dependent variable in order to isolate growth-induced changes due to national employment trends from growth-induced changes that occur because of factors associated with a state. In addition, the authors argue that the way in which the change in employment, instead of the level of employment, is regressed on the levels of all independent variables can help to avoid spurious regression bias.

A more recent panel data analysis by Bollinger and Ihlanfeldt (2003) estimates the effect of transport infrastructure investments and tax incentives on employment in 299 census tracts in the Atlanta region using a static panel data model with the two-way fixed effects specification:

$$\Delta E_{it} = \alpha + \beta TRAN_{it-1} + \phi TAX_{it-1} + \gamma Z_{it-1} + \sigma_i + \mu_t + \varepsilon_{it} \quad (4.7)$$

where ΔE_{it} is the one-year change in a census tract's employment share; $TRAN$ is the vector of two transport infrastructure variables, highway improvement expenditures and the percentage of rail station impact area in census tract; TAX is the vector of dummy variables denoting whether census tract was eligible for each tax incentive program; and Z is the vector of other explanatory variables such as sale and property tax rates, crime rate, median income, and per capita public expenditures on police, fire safety, parks, and sewerage; σ and μ are tract- and year- specific effects; and ε_{it} is an i.i.d error term. This research uses the annual change in employment share as the dependent variable to distinguish the effects of location-specific factors on employment changes from the overall regional growth. In contrast to Dalenberg et al (1998), the levels of all explanatory variables used are lagged one year as Bollinger and Ihlanfeldt consider that a tract's employment does not respond instantaneously to changes in transport infrastructure improvements and other circumstances. It implies that, in this study, an initial disequilibrium condition is assumed in the sense that the initial levels of the explanatory

variables are important in determining the subsequent annual changes in employment share.

The use of static panel regression in first differences is found in Modifi and Stone (1990) who study the effect of tax revenues and government expenditures on manufacturing employment and net investment in the USA. Using five time periods of data for 50 states, Modifi and Stone estimate panel data models in five-year first-difference form to eliminate the linear fixed effects for each state as well as to control for the possibility of spurious correlations. The general specification of the employment and investment equations takes the following form:

$$Y_{it} - Y_{it-5} = \alpha + \beta(RV_{it} - RV_{it-5}) + \phi(EXP_{it} - EXP_{it-5}) + \delta(Z_{it} - Z_{it-5}) + \eta R + \lambda T + \varepsilon_{it} \quad (4.8)$$

where Y is the value of the dependent variable in logarithms, which is manufacturing employment or investment; RV , EXP , and Z are the vector of government revenues, expenditures (one of which is the ratio of highway expenditure to state personal income), and other explanatory variables respectively; and ε_{it} is an i.i.d. error term. Modifi and Stone also attempt to control for any remaining region- or time-specific effects by including regional and time dummies, R and T .

One of several advantages of panel data analysis over studies based solely on cross-sectional data is that the fundamental structure of panel data allows researchers to study the dynamics of change and more complicated behavioural relationships. When analysing employment changes associated with provision of transport infrastructure, it is essential to consider the fact that, due to adjustment costs incurred by economic agents (i.e. firms and households) in the economy and imperfect information on changed circumstances, the nature of infrastructure's impact and the adjustment process of employment may exhibit considerable time lags. The application of panel data analysis in the studies reviewed above is static in nature, which overlooks the potential for dynamic responses of the labour market to changes in infrastructure and other factors. In contrast, the single-equation studies presented next test the relationship between transport infrastructure and employment within a dynamic panel model framework.

Dynamic panel regressions

Crane et al (1991) use a distributed-lag regression model to explore the time pattern of the impact of highway expenditures on employment in Texas. The level of employment is hypothesised as a function of current and lagged expenditures on highway infrastructure, current and lagged prices of crude oil, and per capita personal income. The authors use a panel data set for 24 highway districts of Texas, which is aggregated from annual observations for 254 Texas counties, over the period 1969-1986. This study applies two techniques for pooling the data: a least-squares dummy variable (LSDV) regression and a two-way random effects regression.

Another application of dynamic panel regressions in measuring the employment effect of transport investment are presented in Carroll and Wasylenko (1994) and Dalenberg and Partridge (1995). The basic assumption in these studies is that the level of employment at any given year may not completely adjust to reach its supposed equilibrium level that is determined by several exogenous factors; therefore, they estimate a dynamic panel model of employment that allows for the lagged adjustment process of employment disequilibrium in the economy. Carroll and Wasylenko (1994), who model the effect of state and local fiscal policy on employment in the USA, posit that there is likely to be a certain degree of inertia in the adjustment process of state employment levels (i.e. factor immobility and stickiness in input prices) in response to state fiscal policies and other variables. They consider a fixed effects partial adjustment model of the form:

$$E_{it} = (1 - \lambda)E_{it-1} + \lambda \left[\sum_k \beta^k X_{it}^k + \alpha_i + \mu_t + \varepsilon_{it} \right] \quad (4.9)$$

where E_{it} is the observed employment level of state i in time period t ; λ , such that $0 < \lambda < 1$, represents the speed of adjustment in which the closer λ to 1, the quicker is that adjustment. Contained in the bracket is the equilibrium or desired level of employment specified as a function of several observable factors (X) that influence employment in state i in year t (e.g. a firm's input cost and market demand characteristics, taxes and revenues, highway expenditures, and other public expenditures), unobservable time- and state- invariant components (α and μ), and the normally distributed error term (ε_{it}). In estimating the dynamic panel model, Carroll and Wasylenko apply a first-differenced

Generalized Method of Moments (GMM) technique suggested in Holtz-Eakin et al (1988) by first differencing the autoregressive model to eliminate the state fixed effects, and using lagged values of variables as instruments.

Likewise, Dalenberg and Partridge (1995) incorporate the partial adjustment mechanism into a reduced form model of metropolitan employment when examining the impact of public expenditures, infrastructure, and taxes on employment in 28 US metropolitan areas, over a 15-year period. The dynamic panel model used in this research is similar to that of Carroll and Wasylenko (1994), but it is without a time-specific component in the functional form of equilibrium employment. In addition, the model considers more thoroughly a wider variety of factors that may affect labour demand and labour supply such as wages, taxes, government expenditures (e.g. highway and education), public infrastructure, unionization, demographics, human capital, and other amenities. For empirical implementation, Dalenberg and Partridge attempt to avoid omitted variable problems by using a three-year first difference transformation to remove unobservable fixed effects. They also include regional dummies to account for any potential differences across regions (West, South, Midwest, and East) and time dummies for national cyclical effects, both of which are not measured in the first difference. The differenced employment equations are then simply estimated by ordinary least squares (OLS). However, the OLS estimates in this research are likely to be biased and inconsistent since there is endogeneity due to the constructed correlation between the transformed lagged dependent variable and the transformed error term.

Apart from the use of simple distributed lag or partial adjustment models with panel data, an autoregressive distributed lag model, which offers a more general framework for modeling dynamic responses of employment to changes in transport infrastructure, is employed in the empirical work of Eagle and Stephanedes (1987). They empirically investigate the effect of highway expenditures on employment in the state of Minnesota using annual observations of state highway construction expenditures and employment for all 87 Minnesota counties from 1964 to 1982. In addition to the use of Granger-Causality tests to determine whether highway investments statistically precede changes in employment, Eagle and Stephanedes attempt to quantify dynamic responses

of employment to changes in highway expenditures by estimating a dynamic panel model of the form:

$$E_{it} = \gamma + \alpha_0 H_{it} + \alpha_1 H_{it-1} + \dots + \alpha_q H_{it-q} + \beta_1 E_{it-1} + \beta_2 E_{it-2} + \dots + \beta_k E_{it-k} + \varepsilon_{it} \quad (4.10)$$

where E is the level of employment, H is the level of highway expenditure, i indexes counties, t indexes years, and ε is the error term. An autoregressive structure of five lags (q and k equal to 5) is specified as Eagle and Stephanedes (1987: 60) argue that '*a lag structure of three to five lags usually captures most of the dynamics of a system*'. Unlike the other forms of dynamic panel models used in the studies cited above, the inclusion of *lagged* values of the employment and *current* and *lagged* values of highway variables as regressors accounts for not only potential persistence in the process of employment adjustment but also the timing of the impact of highways. Yet, the authors note that the fact that highway spending is not the only factor that could affect employment is likely to be a source of misspecification of the model estimated. Moreover, another criticism of this work could be that it is unclear whether and how this study deals with potential estimation problems due to the correlation between unobserved time-invariant county specific effects in the error term and the lagged employment variables when estimating the dynamic model with panel data.

To summarise, a variety of panel regression techniques have been used to empirically address the notion of whether transport investments can help to stimulate regional and local employment growth. Many studies employ a fixed effects model to take explicit account of unobserved characteristics across jurisdictions; therefore, they are less likely to have omitted-variable problems, compared to the single-equation studies using cross-sectional data. Several forms of dynamic panel regressions have also been applied to take into account temporal lagged responses of employment to provision of transport infrastructure. However, a major shortcoming of many studies estimating dynamic panel models is that they tend to neglect the problem of endogeneity arising from the presence of a lagged dependent variable.

Finally, only three of seven studies using panel data are concerned with the possibility of a reverse link from transport infrastructure to employment. Bollinger and Ihlanfeldt (2003) have performed causality tests and found no evidence that changes in employment Granger cause highway improvements. Dalenberg and Partridge (1995)

conduct a Hausman test of exogeneity for highways and other variables anticipated to be endogenous and estimated the models using two-stage least squares (2SLS), whereas Dalenberg et al (1998) also use the Hausman test but do not find the need to treat the highway variable as endogenous in regressions. However, as already discussed in Chapter 2, we know very little about the validity of instruments used in the last two studies, which could affect the specification test and model results.

4.3.3 Simultaneous equations models of population and employment

Several studies that use cross-sectional models to examine the interaction of population and employment locations in a simultaneous equations framework, for example Carlino and Mills (1987), Clark and Murphy (1996), Duffy-Deno (1998), Luce (1994), and Boarnet (1994), have considered the importance of transport infrastructure in the location decisions of firms and households. Of these studies, the early work of Carlino and Mills (1987) is an important paper in this research arena. Carlino and Mills extend the basic simultaneous model of population and employment introduced by Steinnes and Fisher (1974) by specifying a lagged adjustment process for job and population changes. The refined model is applied to analyse the location determinants of population and employment growth across nearly 3000 counties in the USA. In addition, Carlino and Mills' (1987) model is followed and modified by other subsequent studies.

To derive the model, Carlino and Mills (1987) begin with the basic premise that firms and households are geographically mobile, and that their location decisions are driven largely by economic motivations (i.e. utility and profit maximisation). Considering that the locations of employment and population are simultaneously determined and conditioned by certain factors that affect the location behaviour of firms and households, Carlino and Mills assume equilibrium employment and population to be related endogenously to each other and to a variety of exogenous factors:

$$E_t^* = \alpha P_t + \beta X_t \quad (4.11a)$$

$$P_t^* = \delta E_t + \gamma Y_t \quad (4.11b)$$

where E and P are employment and population, asterisks indicate equilibrium values, X and Y are vectors of exogenous variables that can affect equilibrium levels of employment and population respectively, and the subscript t refers to time period.

Following Mills and Price (1984) who suggest that employment and population may adjust to their equilibrium levels with substantial lags, Carlino and Mills introduce a lagged adjustment process for changes in employment and population:

$$E_t - E_{t-1} = \lambda_E (E_t^* - E_{t-1}) \Rightarrow E_t = E_{t-1} + \lambda_E (E_t^* - E_{t-1}) \quad (4.12a)$$

$$P_t - P_{t-1} = \lambda_P (P_t^* - P_{t-1}) \Rightarrow P_t = P_{t-1} + \lambda_P (P_t^* - P_{t-1}) \quad (4.12b)$$

In equations (4-12a) and (4-12b), actual employment and population are treated as a function of their lagged values and an adjustment to the equilibrium level where λ_E and λ_P are speed-of-adjustment coefficients with $0 \leq \lambda_E, \lambda_P \leq 1$, representing the rate at which employment and population adjust to the desired equilibrium levels. Substituting (4.11) in the lagged adjustment models (4.12), and rearranging terms yields the following structural models:

$$E_t = (1 - \lambda_E) E_{t-1} + \lambda_E \alpha P_t + \lambda_E \beta X_t \quad (4.13a)$$

$$P_t = (1 - \lambda_P) P_{t-1} + \lambda_P \delta E_t + \lambda_P \gamma Y_t \quad (4.13b)$$

where employment and population levels in time period t depend on the other endogenous variable (population or employment), their own lagged value, and a set of exogenous variables. In empirical estimation, Carlino and Mills use employment and population density as the dependent variables and examine the effects of local taxes, racial composition, family income, unionization, and industrial revenue bonds on locations of population or employment. Interstate highway density is also considered to influence the location patterns. Moreover, Carlino and Mills suggest the use of lagged values for all of the exogenous variables in order to avoid simultaneity problems. In their employment equation, for example, employment density in 1979 is related to population density in 1980, employment density in 1970, and other exogenous variables at 1970 values. Many subsequent studies cited below have drawn upon this technique.

The models outlined by equations (4.13a) and (4.13b) are used as a basis for empirical models in the subsequent work of Clark and Murphy (1996), which is similarly based on a countywide dataset, and Duffy-Deno (1998), who studies the effect of wilderness on county growth using a sample of 250 nonurban counties in the eight intermountain states. The models of Clark and Murphy (1996) incorporate several measures (e.g. business conditions, fiscal variables, neighbouring characteristics, and

local amenities) that might affect household residential choices and firm location decisions. Among these variables are the density of highway in each region and highway expenditures by local government. However, Clark and Murphy analyse absolute changes in employment and population density between 1981 and 1989 by simply taking lagged employment and population density to the left hand side. In contrast, Duffy-Deno (1998) follows the Carlino and Mills approach to directly estimate the system of equations with the levels of employment and population density as endogenous variables. The density of highway mileage is used as a measure of accessibility facilitated by transport systems that might attract firms and households. In addition to the linear version, Duffy-Deno also estimates employment and population equations in a log-linear specification that is derived by specifying a multiplicative functional form for equilibrium employment and population equations and using the adjustment equations in log form.

While analysis of population-employment interaction at the level of counties explicitly assume that simultaneous determination of employment and population takes place within a county's jurisdiction, the municipality-level studies including those of Luce (1994) and Boarnet (1994) take account of the fact that employment in one region and population in another may be interrelated because of commuting between these regions. In particular, these studies posit that the labour market areas are larger than the size of the municipality. Luce (1994), who estimates log-linear employment and labour force location models derived by following the Carlino and Mills' (1987) procedure, simply incorporates neighboring variables into labour force and employment equations respectively as exogenous. These variables measure the level of employment and the number of employed labour force outside a municipality but within commuting distance. Based on data for 340 municipalities in the Philadelphia metropolitan area, Luce estimates the effect of access to transport networks, which is captured by a dummy variable denoting whether a municipality had direct access to either an interstate highway or rail services in 1970, on the levels of employment and labour force in 1980.

The empirical work of Boarnet (1994) provides a significant extension of the Carlino-Mills model. He derives a model that allows employment to be influenced not only by the pool of labour living in a given municipality, but also by labour pools located

in other municipalities within the commuting shed. Likewise, population changes are assumed to depend on job opportunities both within and outside a municipality. This results in a simultaneous equations model of spatial interactions between employment and population changes given by

$$E_t - E_{t-1} = a_0 - \lambda_E E_{t-1} + \beta X + a_1(I + W)P_{t-1} + a_2(I + W)(P_t - P_{t-1}) + \varepsilon_1 \quad (4.14a)$$

$$P_t - P_{t-1} = b_0 - \lambda_P P_{t-1} + \gamma_1 Y + b_1(I + W)E_{t-1} + b_2(I + W)(E_t - E_{t-1}) + \varepsilon_2 \quad (4.14b)$$

where E is a $n \times 1$ vector of employment; P is a $n \times 1$ vector of population; the subscript t indexes years; I is an identity matrix of dimension $n \times n$; W is a $n \times n$ matrix of gravity-type weights $1/(d_{ij})^\alpha$ where d_{ij} is the distance between municipalities i and j , and α is a parameter reflecting the extent to which the labour market interaction decreases with distance; and n is the number of regions; X , Y , λ_E , and λ_P are as described; and ε_1 and ε_2 are random disturbance terms. Boarnet's (1994) model is used to explore the determinants of employment and population changes in 365 municipalities in northern New Jersey from 1980 to 1988. Several local characteristics are posited to affect the location choices of households and firms as well as labour demand decisions of firms. Among these is the availability of rail and major highway access in each municipality represented by two separate dummy variables.

In this strand of literature, researchers have estimated the effects of transport infrastructure on the locations of employment and population using simultaneous equations models with various specifications. However, although a number of important factors that may influence the location choices of firms and households have been considered, there remains the possibility that the cross-sectional equations estimated omit some local characteristics that may cause regional differences in population and employment. Examples include topography, geographical location, the quality of environment, and local land use regulations. The recent work of Edmiston (2004) addresses this issue by using a simultaneous model with panel data and fixed effects to control for location-specific and time-specific unobservables that may affect employment and population. In this study, however, transport infrastructure is not considered as a determinant of population and employment growth.

4.3.4 Vector autoregression (VAR)

In the preceding sections, we have reviewed numerous research papers that analyse the effect of transport infrastructure on employment by estimating a system of equations, simultaneous equations models, or single regression models. Applying such approaches, researchers have relied on relevant economic theory or a priori assumptions in order to specify the relationships among transport infrastructure, employment, and other control variables, or which variables are endogenous or exogenous, as well as the lag structures.

Other studies in the literature, although relatively few in number, apply a vector autoregression (VAR) technique that minimises theoretical demands and requires fewer a priori restrictions imposed on the model structure in examining the empirical relationship between transport investment and employment.²¹ The general specification of a vector autoregression, with k different variables, consists of k linear regression equations, one for each of the variables, in which the regressors in all equations are lagged values of all of the variables. When a number of lags in each of the equations is the same and is equal to p , the general form of the VAR(p) model is

$$\mathbf{y}_t = \mathbf{c} + \Pi_1 \mathbf{y}_{t-1} + \Pi_2 \mathbf{y}_{t-2} + \cdots + \Pi_p \mathbf{y}_{t-p} + \boldsymbol{\varepsilon}_t \quad (4.15)$$

where $\mathbf{y}_t$ is a $k \times 1$ vector of time-series variables, the Π_i are $k \times k$ matrices of coefficients, $\mathbf{c}$ is a $n \times 1$ vector of constants, and $\boldsymbol{\varepsilon}_t$ is a $k \times 1$ vector of residuals. For a simple case of a bivariate VAR model in which the order of the VAR, p , is equal to 2, the VAR(2) is a set of two equations

$$y_{1t} = c_1 + \pi_{11}^1 y_{1t-1} + \pi_{12}^1 y_{2t-1} + \pi_{11}^2 y_{1t-2} + \pi_{12}^2 y_{2t-2} + \varepsilon_{1t} \quad (4.16a)$$

$$y_{2t} = c_2 + \pi_{21}^1 y_{1t-1} + \pi_{22}^1 y_{2t-1} + \pi_{21}^2 y_{1t-2} + \pi_{22}^2 y_{2t-2} + \varepsilon_{2t} \quad (4.16b)$$

In equations (4.15) and (4.16) all variables are treated as endogenous, and each variable in the VAR system depends on not only its own lags, but the lags of all other variables. Practically, one may also include deterministic time trends and other exogenous variables in these VAR equations (Johnston and DiNardo, 1997). Therefore, with the advantage of allowing for dynamic feedbacks among all relevant variables, the VAR approach is one way of addressing the question of causality between infrastructure

²¹ Note that the VAR has been considered by econometricians as an atheoretical approach (e.g. Johnston and DiNardo 1997, Gujarati 2003, and Green 2003) in the sense that less prior information or theoretical underpinning is required to explicitly specify structural relationships between various sets of economic variables.

investment and economic growth. In the context we are focusing on, it can be used to analyse the effect of transport infrastructure provision on employment as well as to examine whether there is a reverse link from employment to transport provision.

The earlier work that explored the dynamic relationships between transport infrastructure investment and employment in the VAR framework are Stephanedes (1990) and Zografos and Stephanedes (1992). Using pooled time series and cross-sectional data on highway expenditures and employment for all Minnesota counties, Stephanedes and Zografos estimate the bivariate VAR model that consists of two equations for two sets of variables measuring highway construction expenditure and county employment level. Although this approach has a major advantage in allowing for the simultaneous relationship between transport investment and employment, estimating vector autoregressions with panel data requires particular attention to the orthogonality condition of lagged dependent variables. However, these studies do not demonstrate whether and how this important issue was taken into account.

An important issue in VAR analysis involves choosing an appropriate lag length or order. In principle, it is necessary to specify lags that are long enough to fully capture the dynamics of the system being modelled, but adding additional lags will reduce the degrees of freedom. Because the optimal lag order is typically unknown in empirical applications, sequential testing strategies and information criteria have commonly been used for selecting the number of lags to be included in VAR models. Even though lag length selection can be critical, the work by Stephanedes (1990) and Zografos and Stephanedes (1992) simply relies on an arbitrary choice of lag specification, assuming a 5-year lag for the VAR analysis to capture the delay in the dynamic interactions between transport and employment variables.

A recent and more robust application of VAR in estimating the employment effect of transport infrastructure is found in a national time-series study by Pereira (2000) who has sought to analyse the impact of public capital formation on private-sector performance in the U.S. With a specific objective of addressing the debate about whether or not public capital is a productive input, his estimated VAR models are based on four variables - private output, private capital, employment, and public infrastructure - that are typically considered in the production function literature on the productivity effect of

publicly provided capital. Core infrastructure investment in highways and streets are among the five types of public infrastructure investments considered in his analysis. Pereira accounts for the nonstationary nature of the variables by estimating the models in the first difference of these variables in their logarithmic form. The first-order specification of the VAR models is selected based on the result of Bayesian information criterion (BIC). This research also employs the impulse response function technique to estimate the extent of the effects of shocks to infrastructure investments on private capital investment, output, and employment.

4.3.5 Spatial econometrics

Spatial econometrics have now become an integral part of econometric research dealing with the presence of spatial dependence, the lack of independence among cross-sectional observations in a spatial dataset, which is mainly due to the close spatial proximity or adjacency of spatial observations. The other type of spatial effects that potentially arises in cross-sectional and panel regression models of spatial data is spatial heterogeneity. It specifically refers to the structural instability over space of the behavioural or other relationships under study in the form of non-constant error variances (heteroskedasticity) or varying model coefficients (Anselin 1988). However, much more emphasis in the spatial econometric literature has been on the diagnostics and treatment of spatial dependence (Florax and van der Vlist 2003) because spatial heterogeneity can be addressed by means of standard econometric techniques (Anselin 1988).

Although the empirical relationship between transport infrastructure and employment has been studied extensively using aggregate data for regions or smaller geographical units that are spatially contiguous, the importance of spatial dependence has received little attention. The need for dealing with the issue of spatial dependence, often known as spatial autocorrelation, is driven by two primary reasons (Anselin 1988, and Anselin and Rey 1991). First, there may be measurement errors in observations of contiguous spatial units. This could result from the arbitrary delineation of spatial units of observations and a lack of correspondence between the spatial extent of the phenomenon of interest and the administrative boundaries for which data are collected. For the latter, examples that are relevant to our interest include the spatial spillover effect

of transport infrastructure and the role of interregional commuting in the regional labour market. Moreover, the importance of location and distance in explaining several forms of spatial interdependencies (e.g. spatial interaction, diffusion processes, and spatial hierarchies of place) also suggests the need to account for the possibility that employment at one location is likely to be jointly determined by its value at other locations. Unfortunately, this is a typical shortcoming in the literature based on cross-sectional or panel data. In addition to Boarnet (1994) who incorporates spatial spillover effects in simultaneous equations of population and employment, not many studies have been concerned with the potential existence of spatial dependence. To test whether the error terms are spatially autocorrelated, Bollinger and Ihlanfeldt (2003) apply a Moran's I test, the most commonly used technique for detecting spatial autocorrelation, whereas Dalenberg et al. (1998) use the Kelejian and Robinson (1993) test for spatial autocorrelation. Nonetheless, both studies find no significant evidence of spatially correlated errors.

To deal with the problem of spatial dependence, two alternative modelling approaches have typically been used in the spatial econometric literature. The first, referred to as a spatial error model, is to incorporate a spatial autoregressive process among disturbances into a regression in a similar way to a first-order autoregressive model estimated when serial correlation exists. For example, a fixed effects panel data model with a spatial autoregressive error specification can be specified as

$$y_{it} = X_{it}\beta + u_i + \varepsilon_{it} \quad \text{and} \quad \varepsilon_{it} = \rho W\varepsilon_{it} + v_{it} \quad (4.17)$$

where ρ is a coefficient on the spatially correlated errors, W is a spatial weight matrix, and v_{it} is an independent identically distributed error term. The work by Cohen and Paul (2004) is a major advance in this regard. They estimate a system of cost and input demand functions that allow for spatial error autocorrelation and first-order serial correlation in the stochastic error structure to accommodate spatial and temporal lags. That is, the error term v_{it} in (4.17) is further specified to exhibit first-order autocorrelation over time.

The second approach is to include spatial dependence in a regression model as an additional right-hand side variable in the form of a spatially lagged dependent variable. This is known as a spatial lag model. The cross-sectional analysis by Singletary et al (1995)

and Islam (2003) follow this approach. Apart from running basic regressions using OLS, they estimate a spatial lag model that contains a spatially weighted dependent variable as an additional regressor, taking the form

$$y = \rho W y + X\beta + \varepsilon \quad (4.18)$$

with ρ as a spatial autoregressive coefficient, W as a spatial weight matrix, and ε as an independent identically distributed error term. The findings of these cross-sectional studies confirm the importance of dealing with the presence of spatial dependence which is reflected by the strong significance of the spatial lagged variable.

4.3.6 Common econometric pitfalls

Based on the review of modelling frameworks identified above, we identify some common shortcomings of the existing literature that merit special attention and will be addressed by this dissertation.

Omission of relevant variables

The first common problem is the omission of relevant variables. In many studies reviewed, several important determinants of employment are omitted, and the regression models estimated are not formulated on any coherent theoretical basis. In particular, the choices of variables thought to be relevant to the level or change in employment seems to be made in an ad-hoc fashion. Those studies based solely on cross-sectional data also typically do not account for unobserved regional heterogeneity that may explain spatial differences in employment changes. This is an important issue since the extent to which transport investments affect employment is often dependent upon other characteristics of the region.

To minimise these potential omitted-variables problems, empirical models need to be theoretically formulated. In particular, one promising approach could be to draw upon standard economic theory in deriving employment models that encompasses several other factors that might influence the demand and supply sides of the labour market. In addition, using panel data can help to substantially reduce misspecification problems that may arise when there are omitted or unobserved relevant variables. With information relating to both cross-section and time dimensions, panel regression

techniques are useful to control for unobserved local-specific characteristics that may vary across regions as well as shocks that are common to all regions in each time period (e.g. technological improvements and business cycles).

Potential endogeneity of transport infrastructure

The second problem inherent in the existing literature is the failure to account for the possibility that transport infrastructure could be endogenous to an economy. As the causal direction between transport investments and employment could run in both directions, it seems plausible to contend that estimated results from studies that have ignored or have not effectively addressed the causality issue may be subject to simultaneity bias.

More attention in further work is required to account for the potential endogeneity of transport infrastructure. This could be done by applying econometric techniques that can disentangle the causal relationship between transport infrastructure and employment variables. One approach is to estimate a system of equations in which employment and transport infrastructure are considered as endogenous variables. The vector autoregressive framework is useful in examining the temporal effects of transport infrastructure as well as dynamic responses from employment to changes in transport infrastructure.

In estimating a single-equation regression, one can check for the presence of simultaneity due to transport infrastructure by specification tests (e.g. the Hausman test for endogeneity and the C-test of exogeneity). Instrumental variables (IV) estimation and generalized method of moments (GMM) techniques are viable options if there is simultaneity. It should be emphasised that the major requirement of these approaches is the use of appropriate instrumental variables that satisfy two properties: an instrumental variable must be correlated with the endogenous variable but otherwise independent of the error term. However, it appears that none of previous studies in this literature has checked the validity of their instruments. This is another common pitfall which has to be taken into account in further work.

Endogeneity in dynamic panel models

With panel data, several studies have sought to capture dynamics in the employment impacts of transport infrastructure using various empirical specifications in the form of dynamic panels. The presence of a lagged dependent variable can create an endogeneity problem that can render conventional panel regression techniques (e.g. within-group estimator and random effects estimator) biased and inconsistent. However, this critical issue has not been satisfactorily treated in most studies estimating dynamic panel models. Applying recent advances in dynamic panel econometrics such as GMM estimators developed by Arellano and Bond (1991) and Blundell and Bond (1998) is a useful strategy for dealing with this problem.

Spatial dependence

Another issue that has been typically neglected in the literature is the potential existence of spatial dependence between observations. The majority of studies examining the employment effect of transport infrastructure have used aggregate data for contiguous regions. However, it is very likely that spatial dependencies among cross-sectional observations may exist in the data, which could in turn violate the standard assumption of cross-sectionally uncorrelated errors in their estimation procedures. Ignoring this spatial issue could lead to serious problems of model misspecification. To avoid potentially misleading model estimates and inference, future work analysing spatial data should use spatial econometric techniques to explicitly take into account the issue of spatial dependence. Applying statistical tests for residual spatial autocorrelation can be done as a standard practice. In the presence of spatial error dependence, a natural solution is to incorporate spatial dependence in the form of spatial lag or spatial error models, and then use appropriate econometric methods to estimate these spatial regression models (Anselin, 1988; 2001). Alternatively, one could deal with the problem of spatial dependence by using spatial filtering techniques to remove spatial interdependencies from data and applying conventional estimation techniques to variables that are free of spatial correlation (Getis, 1995; Getis and Griffith 2002).

4.4 Empirical evidence

The econometric methodologies reviewed thus far have been used by many researchers to explore several research questions, and their policy implications could be important and far-reaching. Does transport infrastructure affect overall employment? Does transport investment have a clearly significant impact on employment in particular sectors of an economy? Does the employment impact vary across industrial sectors? Does provision of transport infrastructure in one region have implications for employment in other regions? Is the impact uniform across regions with different characteristics? If not, under which circumstances? Unfortunately, it is not possible to compare their results directly because of the differences in measurements of transport infrastructure and econometric modelling frameworks as demonstrated in the previous sections. Also, the presence of several methodological shortcomings can cast some doubt on what we currently know from these studies. However, it is still instructive to understand the current state of empirical knowledge on this topic. In what follows, we present a synthesis of existing research evidence.

4.4.1 Transport investment and overall employment

Much of the work in the literature has been concerned with the impact of transport infrastructure investment on employment at the aggregate level. However, a diversity of empirical results among different studies has emerged. Of the 18 studies reviewed, the relationship between transport infrastructure and employment is found to be positive and statistically significant in 12 studies, whereas many studies have revealed no significant evidence. Interestingly, some studies reveal a negative employment effect of highway investments. Table 4.2 provides a summary of these results.

Studies using a highway capital stock measure to represent infrastructure obtain mixed results. The VAR analysis by Pereira (2000) reveals a negative association between highway capital and the demand for labour in the private sector. Other studies using regional data to estimate single regression models of employment (i.e. Lombard et al, 1992; Dalenberg, et al, 1998; Haughwout, 1999) or simultaneous equations of employment and population (i.e. Carlino and Mills, 1987; and Clark and Murphy, 1996)

tend to find a positive and significant effect of highway investments. However, Thompson et al (1993) and Duffy-Deno (1998) suggest that the relationship between the density of highways and county employment is insignificant.

Table 4.2. Research evidence on the effect of transport investment on overall employment

Author	Level of analysis	Modelling Approach	Transport investment measure	Effect on overall employment
Pereira (2000)	National	Vector Autoregression (VAR)	Highway capital stock in monetary term	Negative
Dalenberg et al (1998)	State	Static panel regression analysis	Highway capital stock in monetary term	Positive
Jones (1990)	State	Static panel regression analysis	Per capita highway expenditure	Positive
Carroll and Wasylenko (1994)	State	Dynamic panel regression analysis	Highway expenditure per capita	Positive
Dalenberg and Partridge (1995)	Metropolitan	Dynamic panel regression analysis	Highway expenditure per personal income	Negative
Crane et al (1991)	Highway districts	Dynamic panel regression analysis	Highway expenditure	Positive
Haughwout (1999)	County	Cross-sectional analysis	Highway capital stock in monetary term	Positive
Carlino and Mills (1987)	County	Simultaneous equations of employment and population	Interstate highway density	Positive
Clark and Murphy (1996)	County	Simultaneous equations of employment and population	Highway density	Positive
			Percent of public expenditures on highways	Not significant
Duffy-Deno (1998)	County	Simultaneous equations of employment and population	Highway density	Not significant
Lombard et al (1992)	County	Cross-sectional analysis	Highway density	Positive
			Total highway expenditure per square mile	Negative
Thompson et al (1993)	County	Cross-sectional analysis	Highway density	Not significant
Islam (2003)	County	Cross-sectional analysis	Highway capital outlay	Positive
Eagle and Stephanedes (1987)	County	Dynamic panel regression analysis	Highway expenditure	Not significant
Stephanedes (1990)	County	Vector Autoregression (VAR)	Highway expenditure	Not significant
Luce (1994)	Municipality	Simultaneous equations of employment and population	Highway/railroad access	Positive
Boarnet (1994)	Municipality	Simultaneous equations of employment and population	Access to a major highway	Positive
			Access to a commute rail station	Positive
Bollinger and Ihlanfeldt (2003)	Census tract	Static panel regression analysis	Highway expenditure	Positive
			Percentage of a rail station impact area	Not significant

Similarly, those studies examining the employment effect of government spending on transport infrastructure exhibit a tendency to have highly varied results. The work by Crane et al (1991), for example, shows that highway expenditures have both contemporaneous and lagged effects on total employment at the level of highway districts. In contrast, Eagle and Stephanedes (1987) and Stephanedes (1990) who estimate models with lagged variables reveal that highway spending has generally no significant effect on county employment throughout the state. Jones (1990), Islam (2003), and Bollinger and Ihlanfeldt (2003) find that the change in employment over the period is

positively related to the level of highway expenditure at the beginning of the period, whereas this positive relationship is not statistically significant in Clark and Murphy (1996). Two studies that estimate a partial adjustment model in first differences to investigate the employment effect of highway expenditures also yield conflicting results. While state-level estimates of Carroll and Wasylenko (1994) indicate the positive influence of highway spending, Dalenberg and Partridge (1995) find a negative and significant relationship between highway expenditures and metropolitan employment. A cross-sectional analysis by Lombard et al (1992) also suggests that total highway expenditures and changes in county employment over the same period are negatively related. However, the authors argue that this negative relationship may reflect the reverse causation running from declines in employment to highway improvements.

The role of local transport access in generating job opportunities in communities has also remained empirically ambiguous. Luce (1994) and Boarnet (1994) find that the availability of direct access to a major highway and rail transport services is an important determinant of employment growth within municipal areas. On the contrary, a study by Bollinger and Ihlanfeldt (2003) at a smaller scale of analysis reveals that there is no statistically significant effect of rapid rail stations on the growth in employment at the census tract level.

4.4.2 Transport investment and sectoral employment

A large segment of the research on the link between transport infrastructure investment and employment relates to how transport provision affects different sectors of the economy. Some of these studies have focused on the employment impact on certain sectors in the economy, while others have extended their work beyond the analysis of overall employment by applying similar methodology to disaggregated employment data by industry. Table 4.3 summarises the recent studies and their empirical findings concerning the effect of transport infrastructure investment on employment in various sectors of the economy.

Table 4.3 Empirical evidence on the effect of transport investment on employment in disaggregated sectors

Modelling Approach	Author	Transport measure	Effect on aggregate employment	Effect by sector		
				Positive	Negative	Not significant
Cost function	Seitz (1993)	Length of motorways network and the real net capital stock of roads and bridges	-	-	Manufacturing	-
	Nadiri and Mamuneas (1998)	Highway capital stock in monetary term	-	-	All 35 US industries	-
	Cohen and Paul (2004)	Highway capital stock in monetary term	-	-	Manufacturing	-
	Seitz and Licht (1995)	A stock of public road capital in monetary term	-	-	Manufacturing	-
Profit function	Deno (1988)	Highway capital stock in monetary term	-	Manufacturing	-	-
Simultaneous equations of population and employment	Carhino and Mills (1987)	Interstate highway density	Positive	Manufacturing	-	-
	Clark and Murphy (1996)	Highway density	Positive	Manufacturing, construction, services, trade, and FIRE	-	-
		Percent of public expenditures on highways	Not significant	FIRE	Manufacturing	Construction, services, and trade
	Duffy-Deno (1998)	Highway density	Not significant	Resource sector*	-	Non-resource sector*
	Luce (1994)	Highway/railroad access	Positive	Manufacturing, wholesale trade, services, all other private sectors	-	Retail trade and FIRE
Cross-sectional analysis	Lombard et al (1992)	Highway density	Positive	Services	-	Manufacturing
		Total highway expenditure per square mile	Negative	-	Manufacturing and services	-
	Lichter and Fugitt (1980)	Presence of an interstate highway	-	Manufacturing, non-local services, and tourist-related	-	-
	Briggs (1981)	Presence of an interstate highway	-	Manufacturing, tourism, and trucking	Wholesale	-
	Singletary et al (1995)	Two-lane highway density	-	Durable manufacturing	-	Nondurable manufacturing
		Access to an interstate ramp	-	Durable and nondurable manufacturing	-	-
		Access to Interstate highways 85	-	Durable manufacturing	-	Nondurable manufacturing
		Presence of 4-lane highway projects	-	Durable and nondurable manufacturing	-	-
Time-series analysis	Crane and Leatham (1993)	Highway construction and maintenance expenditures	-	Farm and nonfarm	-	-
Panel regression analysis	Mofidi and Stone (1990)	Highway expenditure per personal income	-	Manufacturing	-	-
	Zografos and Stephanedes (1992)	Highway expenditure in counties with major highway corridors	Not significant	Manufacturing	-	Construction, transport, trade, FIRE, and services
		Highway expenditure in counties without major highways corridors	Not significant	-	FIRE	Manufacturing construction, transport, trade, and services
	Carroll and Wasylenko (1994)	Highway expenditure per capita	Positive	Manufacturing	-	Transport, wholesale trade, retail trade, FIRE, and services
	Crane et al (1991)	Highway expenditure	Positive	Mining, manufacturing, construction, wholesale trade, and services	-	-
	Dalenberg and Partridge (1995)	Highway expenditure per personal income	Negative	-	Manufacturing and trade	Transport and public utilities, FIRE, and services
	Bollinger and Ihlanfeldt (2003)	Highway expenditure	Positive	Manufacturing	-	-
		Percentage of a rail station impact area	Not significant	-	-	Manufacturing

*Resource-based employment is the sum of agriculture, mining, and lumber and wood-products employment. Nonresource, non-federal employment consists of all remaining sectors minus military and federal government employment. FIRE denotes finance, insurance, and real estate.

There has been clear evidence on sectoral differences in the employment impacts of transport investments. Some studies, for example, find that a positive effect of transport infrastructure on aggregate employment is associated with positive employment benefits accrued to only some sectors (i.e. Luce, 1994; Lombard et al, 1992; Carroll and Wasylenko, 1994). Other studies show that insignificant evidence at the aggregate level could mask significant effects for specific industrial sectors (Zografos and Stephanedes, 1992; Clark and Murphy, 1996; Duffy-Deno, 1998). In some cases, transport investments are found to benefit some sectors, but also result in employment losses in others (Briggs, 1981; Clark and Murphy, 1996). These general findings, although not unexpected, reinforce the importance of disaggregate analysis in uncovering detailed information that aggregation is not able to show.

For specific industrial sectors, most of the previous research has emphasised the link between transport infrastructure and manufacturing employment, conceivably reflecting the traditional view that transport costs are more relevant in manufacturing activities. Indeed, the employment effect of transport investment has been more frequently found in manufacturing than in other sectors. Many studies have suggested that manufacturing employment tends to be higher in a region with higher levels of highway density (Carlino and Mills, 1987; Clark and Murphy, 1996; and Singletary et al, 1995), direct access to major highways (Lichter and Fuguitt, 1980; Briggs, 1981; Luce, 1994; and Singletary et al, 1995), or greater levels of highway funding (Modifi and Stone, 1990; Carroll and Wasylenko, 1994; Crane et al, 1991; and Bollinger and Ihlanfeldt, 2003).

However, some disaggregate analyses reveal an opposite result. Cost function estimates by Seitz (1993), Seitz and Licht (1995), and Cohen and Paul (2004) suggest that labour demand in the manufacturing sector decreases with an increase in highway capital. The findings of Lombard et al (1992), Dalenberg and Partridge (1995), and Clark and Murphy (1996) suggest that public spending on highway infrastructure could lead to employment losses in the manufacturing sector.

The striking evidence on the negative effect of highway investments has also been found in some other industrial sectors. Nadiri and Manuneas (1998) suggest that increases in highway capital stock have labour saving effects in all U.S. industries, though the magnitude of the elasticity of employment with respect to highway capital

does vary considerably across industries in the economy. In studies of Lombard et al (1992) and Dalenberg and Partridge (1995), it was found that more government spending on highway infrastructure may reduce demand for employment in some service-producing industries. Nevertheless, Lombard et al (1992) find a positive effect of highway density on service employment at the county level as with the work by Clark and Murphy (1996).

4.4.3 Spatial spillover effects of transport investment on employment

Regarding the spatial implications of transport infrastructure investment on regional employment, this area of investigation is not one that has received a great deal of attention. Only a few empirical studies reviewed in this chapter have investigated the spatial spillover effect of transport infrastructure on employment. In Haughwout (1999), the conjecture that infrastructure investments located outside of dense counties affect employment growth in these counties has been tested. To this end, this study relates growth in highway and non-highway infrastructure at the state level to county-level employment growth. Cross-sectional models that include the interaction variable of infrastructure growth and employment density in the beginning period are separately estimated for each group of counties with respect to their urbanisation status. Given that the interaction variable is found to be significantly negative for counties in metropolitan areas, Haughwout concluded that state infrastructure investments tend to reduce regional disparities, leading to the distribution of employment growth within states from higher density counties to less dense counties.

A more direct approach to testing whether transport infrastructure in one region could have implications for employment in other regions is applied in two studies using data for the 48 contiguous US states. Both find evidence confirming the hypothesis of spatial spillovers. Dalenberg et al (1998) have taken into account the potential network effects of the highway system by estimating a panel regression model of state employment growth in which a variable measuring the stock of highway capital in neighbouring states is additionally included. They find positive employment spillovers from highway infrastructure. A more recent analysis by Cohen and Paul (2004) incorporates neighbouring states' highway infrastructure stock as a separate variable in a

cost function model. Unlike the work by Dalenberg et al (1998), their study finds a negative association between manufacturing employment and neighbouring states' highway infrastructure. Cohen and Paul (2004) conclude that this finding lends support to the notion that infrastructure investments could alter competitive advantages across states, leading to the spatial redistribution of input factors of production.

4.4.4 Regional differentials in the employment effects of transport investment

We have reviewed thus far empirical evidence representing the "average" effect of transport infrastructure on employment across regions. However, the extent to which public investments in transport infrastructure affect employment may differ across regions, depending upon specific characteristics of recipient regions. Indeed, it is widely argued that improvements in transport infrastructure can only create a necessary, but not sufficient, condition for growth and development. The effect of transport infrastructure provision on employment likely depends on the extent to which there are other necessary conditions present and a region's capacity for responding to the development opportunities offered by improved transport systems.

There have been some research efforts that explore whether there are certain local conditions under which improvements in transport infrastructure can have implications for a region's employment. In general, the hypothesis tested is that the magnitude and significance of transport's influence on regional employment could vary from one region to another, depending on local characteristics of each region. These studies categorise regions into certain groups according to several different criteria (e.g. the level of urbanization, metropolitan proximity, socioeconomic characteristics, a region's economic well-being, and the existence of major transport facilities), and estimate econometric models using the subsamples of regions. A summary of empirical studies that examine the differential impact of transport investment on employment with respect to the type of region along with their regional classification is presented in Table 4.4.

Focusing on the importance of public infrastructure in manufacturing activities in U.S. metropolitan areas, Deno (1988) finds a larger effect of highway capital on the demand for manufacturing employment in declining regions as compared to growing

regions. Lichter and Fuguitt (1980), who confine their study to non-metropolitan counties in the USA, demonstrate that the positive impact of interstate highways on employment is relatively greater for urbanised and non-urbanised counties located near metropolitan centres. However, Lichter and Fuguitt also find that interstate highways tend to hurt local businesses in remote-rural counties.

Table 4.4 Studies examining regional differentials in the employment effect of transport investment

Author	Level of analysis	Transport measure	Criteria	Regional classification
Deno (1988)	Metropolitan	Highway capital stock in monetary term	Unemployment rates and personal income levels	Two subsamples of metropolitan regions – growing and declining regions
Lichter and Fuguitt (1980)	County	Presence of an interstate highway	Proximity to metropolitan areas and local urbanisation	Four nonmetropolitan county groups: (1) Remote-rural: counties 100 miles or more from the nearest SMSA central city, with the size of the largest place less than 2,500 in population (2) Remote-urban: counties 100 miles or more from the nearest SMSA central city, with the size of the largest place 2,500 or greater (3) Near-rural: counties less than 100 miles from the nearest SMSA central city, with the size of the largest place less than 2,500 in population (4) Near-urban: counties less than 100 miles from the nearest SMSA central city, with the size of the largest place 2,500 or greater
Eagle and Stephanedes (1987)	County	Highway expenditure	Urbanisation status	Five county groups: (1) urban, (2) next-to-urban, (3) regional center, (4) next-to-regional center, and (5) rural counties
Stephanedes (1990)	County	Highway expenditure	Differences in accessibility by roads, population density, average income, and median age of people	Four county groups: (1) regional centre, (2) counties under urban influence, (3) agriculture counties, and (4) national resource counties
Zografos and Stephanedes (1992)	County	Highway expenditure	The presence of a major freeway corridor	Two county groups: (1) counties containing major highways and (2) counties with no major highways.
Crane and Leatham (1993)	County	Highway expenditures	Urbanisation status	Two county groups: (1) Urban: counties in one or more metropolitan statistical area, which contains 50,000 or more population (2) Rural: counties outside a metropolitan statistical area

Based on a similar dataset for all 87 Minnesota counties, Eagle and Stephanedes (1987) and Stephanedes (1990) find no significant evidence of a statewide effect, but have found that highway investments do create employment opportunities for certain types of counties in the state of Minnesota. In Eagle and Stephanedes (1987), regional center counties, which are counties that are economic centres of the state, significantly gain employment benefits from increases in highway expenditures. The work by Stephanedes (1990) that uses more detailed criteria for reclassifying the Minnesota counties yields some additional results. Stephanedes finds that an increase in highway expenditures positively affects employment levels in regional centres and counties under the influence

of urban areas, but tends to reduce employment in other counties adjacent to those counties that are able to take advantage of highway improvements. They conclude that highway investments lead to the spatial redistribution of economic activities, bringing employment benefits to wealthier regions where more businesses and residents are concentrated at the expense of lagging regions from which some economic activities move away.

Looking at the same study area, the more recent work by Zografos and Stephanedes (1992) has concentrated on the importance of the presence of a major highway in each county. They identify that, for counties containing major highway corridors, government spending on highways tends to increase total and sectoral employment. In contrast, counties without highway corridors experience employment losses despite an increase in highway expenditures. However, Zografos and Stephanedes note that their results lend support to the earlier work of Stephanedes (1990) as regional economic centers tend to locate on major highways. The study for Texas by Crane and Leatham (1993) also highlights the relative importance of highway funding across regions as their time-series estimates indicate that expenditures on highway construction and maintenance have larger impacts on employment in urban counties.

4.5 Summary and discussion

The employment impact of transport infrastructure investment has been the focus of substantial research by economists, regional scientists, and transport policy analysts. Over the past decades, a number of macro-level studies have empirically examined the linkage between transport infrastructure investment and employment using various levels of data aggregation and different methodological approaches. Much of the applied econometric research has investigated the effect of transport infrastructure investment on overall employment in an economy, while some has examined the employment impact on different industrial sectors. The notion that the impact of transport investment on employment could geographically spill over across a region's boundary has received some research attention only relatively recently. In addition, some studies have set out to

test whether the impact that transport investment can have on employment varies across regions with different local characteristics.

Despite these research efforts, the general policy question of whether investments in transport infrastructure can generate job opportunities throughout an economy has remained inconclusive. Econometric studies to date have provided inconclusive evidence regarding the significance and quantitative importance of transport infrastructure investment as a factor contributing towards economic development or growth in terms of employment.

Several empirical studies have concluded that transport improvements can help to stimulate employment growth in regional or local economies, whereas other studies have argued that employment changes associated with transport investments are not statistically significant. Interestingly, some studies suggest that transport infrastructure provision does not guarantee positive employment benefits. They have found evidence of employment negatively affected by investments in transport infrastructure.

Empirical evidence has generally agreed with the notion that the employment impact of transport infrastructure does vary considerably among various sectors of an economy, though the work to date has demonstrate no systematic pattern regarding these sector differentials. While a significant role of transport infrastructure provision in affecting employment in an economy may be confined to certain industrial sectors, some research has shown that improved transport services may increase employment in some sectors while reducing it in other sectors. The significance and sign of the employment effect in the manufacturing sector is far from conclusive. In particular, many recent studies find that improvements in transport infrastructure tend to reduce demand for manufacturing employment. The evidence on the negative effect of highway investments in service sectors has also emerged in the empirical literature.

Some research efforts have been devoted to examine the role of transport infrastructure in regional development. Although only few recent studies have attempted to gain insights into the existence of the spatial spillover effect of transport infrastructure on employment, they find evidence supporting the notion that provision of transport infrastructure could produce both positive and negative employment spillovers across neighbouring regions. In addition, studies on the differential effect of

transport infrastructure by region consistently suggest the importance of specific characteristics of a local economy in absorbing employment opportunities induced by transport improvements. The literature shows that transport infrastructure in urbanised areas and other areas that are located near metropolitan regions tend to help local economies to stimulate employment growth. To some extent, these findings confirm that public infrastructure can play an important role in facilitating the benefits of agglomeration. In some studies, however, it was found that such employment gains come at the expense of adjacent regions. These studies point to the spatial implication of transport infrastructure, arguing that some backwash effects take place as agglomerated regions with improved transport services draw economic activities away from their neighbours.

Given the mixed and inconclusive evidence on the effects of transport infrastructure on aggregate and sectoral employment, an important question is what explanations could reconcile such conflicting results? One possible reason is obviously the differences among previous empirical work in scope and methodology. Some emphasise broad spatial dimensions such as nations or states, while others focus on more disaggregated levels such as metropolitan areas, counties, municipalities, or census tracts. To some extent, it makes little sense to compare directly empirical evidence based on different measures of transport infrastructure. This is because they may measure different attributes of the infrastructure. In addition, each measure has its advantages and disadvantages. However, as demonstrated in Section 4.4.1., no clear-cut result has emerged even when grouping research evidence by type of transport infrastructure measure. Furthermore, researchers have applied a variety of methodological approaches with notable differences in theoretical underpinnings, model specifications, control variables incorporated in regression models, and econometric estimation techniques.

While the contradictory evidence in the existing literature would imply that direct use of previous empirical findings in shaping transport policy and supporting particular investment decisions has been rather limited, it is equally important to note that much of the previous work has generally suffered from several methodological drawbacks. Some common issues include the omission of relevant variables, the potential endogeneity of transport infrastructure, the endogeneity problem in dynamic panel models, and the

problem of spatial dependence. Without recognising and taking these issues into account in empirical analysis, the overall understanding of the relationship between transport infrastructure and employment would remain unclear.

In addition to the need to address these methodological issues, there are some gaps in our understanding of this research stream that deserve further empirical investigation.

The first obvious gap in our knowledge is that the empirical literature tells us very little on whether the reverse causation from changes in employment to provision of transport infrastructure does exist. Most of the work has examined long-term employment changes associated with transport investments. Given that the direction of causality may run in both directions, some studies have used instrumental variable estimations to account for the *possibility* that transport infrastructure is endogenous to the economy, with the aim to avoid simultaneity bias in regressions. However, little attention has been given directly to the empirical question of whether additional investments in transport infrastructure are triggered by the need either to provide infrastructure for growing employment or to stimulate employment growth for overall or particular sectors of an economy. Understanding the *existence* of these reverse causal links is as important as evaluating whether and to what extent the job market reacts to improved infrastructure services.

Secondly, additional research is needed to explore whether transport infrastructure investments in one region affect employment in other regions. Very few studies to date have sought to address this spatial spillover hypothesis. Indeed, they have been carried out at highly aggregated levels using state-level data for the United States. As the effects of transport infrastructure generally decays with distance, it is also fruitful to gain insights into the possible existence of employment spillovers from transport investments at smaller scales of analysis such as county, municipality, and census tract.

Finally, a sectoral analysis of the influence of transport infrastructure provision on employment merits further attention. Previous work has reinforced the importance of disaggregate analysis in uncovering the incidence of differential effects on employment over different sectors in an economy. Information on sectoral differences from transport investment could be important to policy makers that are concerned with both the level and composition of total employment. Indeed, one sector's jobs would be valued more

highly than another due to the relative wages or environmental impacts (Dalenberg and Partridge, 1995). For the former, additional jobs created may not lead to overall income increases in an economy unless they are high paying. Much attention in this literature has been largely on manufacturing. While its significant dependence on transport infrastructure has been traditionally acknowledged in the urban and regional economics literature, the existing empirical work has been inconclusive in terms of statistical effects. The service sector constitutes the largest share of gross domestic product and employment in many nations, whereas several others are evolving from a manufacturing-oriented economy into a service-oriented economy. Additional empirical research with emphasis on services could have immediate policy relevance.

This chapter has identified crucial gaps in both econometric methodology and empirical knowledge on this topic. This dissertation sets out to address these issues in an attempt to achieve a better understanding of the causal linkage between highway infrastructure and regional employment. The next chapter presents a dynamic panel regression analysis that examines the direct and spatial spillover effect of highway infrastructure on county-level employment in North Carolina.

Chapter 5

Roadway Expansions and County Employment in North Carolina: A Dynamic Panel Analysis

5.1 Introduction

The empirical analysis in this chapter investigates the effect of highway investment on county-level employment using data for North Carolina. Our analysis differs from previous work in several aspects. First, we use the density of highway lane-miles to capture the extent and coverage of the highway network. A number of studies to date have analysed the relationship between county employment and the density of highways (e.g. Carlino and Mills, 1987; Lombard et al, 1992; Clark and Murphy, 1996; and Duffy-Deno, 1998). In most of these studies, however, highway density is measured as the total length of highways per unit area of the region, which does not account for regional differences in area-wide roadway capacity (e.g. the number of lanes associated with highways). The use of highway lane-mile density in the present study is far more desirable and particularly important in our context since several major road widening projects in North Carolina were completed during the period of analysis.

Second, we use panel data to analyse the employment effect of highways at the county level. Most studies at this level of aggregation are based on cross-sectional data, which may potentially suffer from omitted-variable bias. Apart from greater efficiency of parameter estimates, unobserved county heterogeneity and time effects that explain spatial differences in county employment can be explicitly taken into account. In addition,

the use of panel data provides flexibility in modelling the nature and the timing of highways' employment impacts. In this analysis, therefore, we consider both static and dynamic panel specifications for the employment model, which accounts for the effects of highways and other potential factors on the supply and demand for labour. To estimate dynamic employment models, we use Generalised Method of Moments (GMM) techniques to control for the endogeneity of lagged employment as well as that of highways and some independent variables, which could bias the coefficients estimated.

Finally, this analysis examines spatial spillover effects of highways on county employment. Aggregate macro-level studies examining the geographical spillover effects of transport infrastructure on employment are few in number, and have been limited to the analysis of state-level data for the United States (e.g. Dalenberg et al, 1998; and Cohen and Paul, 2004). We find evidence of negative employment spillovers from highways between North Carolina counties.²²

In the next section, we derive a simple theoretical model that serves as the basis of our empirical analysis. Section 5.3 describes the econometric models and briefly discusses the estimation techniques applied to estimate the dynamic panel models. The county-level data used for the analysis are outlined in Section 5.4, while estimation results from static and dynamic panel data models of employment as well as the test for employment spillovers from highways are presented in Section 5.5. Finally, we summarise and conclude the chapter in Section 5.6.

5.2 Theoretical framework

A basic weakness of several previous studies is that the regression models estimated are not formulated on any coherent theoretical basis. In particular, the choice of variables thought to be relevant to the level or change in employment in local or regional economies seems to be made in an ad-hoc fashion. We draw upon standard economic theory in deriving a reduced-form employment model that accounts for the effects of

²² Attention in the literature has been given to productivity spillovers from highway infrastructure. For the United States, while previous work using aggregate state-level data including Holtz-Eakin and Schwartz (1995) and Kelejian and Robinson (1997) failed to uncover a clear and significant role of neighbouring states' highways in explaining regional differences in state productivity, the work of Boarnet (1998) explicitly tested and found evidence of negative output spillovers from highways at the county level for California.

highway infrastructure and other potential factors on the supply and demand for labour. This model is based on a simple structural model of labour market equilibrium that consists of three equations, one each for aggregate labour demand, aggregate labour supply, and the equilibrium condition:

$$L^d = f(w, D), \partial L^d / \partial w < 0 \quad (5.1)$$

$$L^s = f(w, S), \partial L^s / \partial w > 0 \quad (5.2)$$

$$L^d = L^s \quad (5.3)$$

where L^d and L^s denote the demand for labour and the supply of labour, w is the wage rate for labour. D and S represent the vectors of factors that determine respectively the aggregate demand and the aggregate supply. The derivation of the reduced-form model of employment is shown below.

5.2.1 Aggregate labour demand model

To derive the aggregate labour demand model, we begin by considering the production possibilities of a region as an aggregate production function. We assume for simplicity that each region produces output using labour and capital services with the Cobb-Douglas production technology.

$$Q = AK^\alpha L^\beta \quad (5.4)$$

where Q is aggregate output of the private sector, K is the input of private capital services, L is labour input, and α and β are parameters. A denotes a technical efficiency parameter in a Hicks-neutral form. It is specified to capture regional differences in productivity which we will discuss later. Applying the duality approach, we assume that firms operating in a competitive market minimise the private production costs (C):

$$C = wL + rK \quad (5.5)$$

where w is the wage rate, and r is the rental rate of private capital services. The minimisation of cost (5.5) subject to the production (5.4) yields the conditional input demand functions. Using the Lagrange method, we specify the Lagrangean (L_g) as the sum of the objective function and the Lagrange multiplier (μ) multiplied by the constraint that the input combination produces the output level:

$$L_g = wL + rK + \mu(Q - AK^\alpha L^\beta) \quad (5.6)$$

Then we differentiate the Lagrangean with respect to L , K and μ , and set the derivatives equal to zero.

$$\partial L_g / \partial L = w - \beta \mu A K^\alpha L^{\beta-1} = 0 \quad (5.7)$$

$$\partial L_g / \partial K = r - \alpha \mu A K^{\alpha-1} L^\beta = 0 \quad (5.8)$$

$$\partial L_g / \partial \mu = Q - A K^\alpha L^\beta = 0 \quad (5.9)$$

Solving these equations, we obtain

$$L^d = Q^{\frac{1}{\alpha+\beta}} A^{-\frac{1}{\alpha+\beta}} \left[\frac{w}{r} \cdot \frac{\alpha}{\beta} \right]^{-\frac{\alpha}{\alpha+\beta}} \quad (5.10)$$

This yields the long-run demand for labour as a function of the output level, the rental price of capital, the wage rate, and the production function shifter. Taking natural logarithms of (5.10), we thus obtain the labour demand (L^d) equation in the following form

$$\ln L^d = \delta_0 + \delta_1 \ln w + \delta_2 \ln r + \delta_3 \ln Q + \delta_4 \ln A \quad (5.11)$$

where $\delta_0 = \alpha\gamma(\ln \beta - \ln \alpha)$, $\delta_1 = -\alpha\gamma$, $\delta_2 = \alpha\gamma$, $\delta_3 = \gamma$, $\delta_4 = -\gamma$, and $\gamma = 1/(\alpha + \beta)$.

Note that we focus on the effect of infrastructure on firms' long run input demands, considering that all factors of production are variable inputs in the cost minimising process, similar to other cost function studies on the role of public infrastructure in influencing firm productivity (e.g. Deno, 1988; Lynde and Richmond, 1992; Seitz, 1993; and Conrad and Seitz, 1994). This approach has often been referred to as a full static equilibrium framework in which the assumption made here is that labour (L) and private capital services (K) adjust instantaneously to their long-run equilibrium levels. It is possible to analyse the relationship between public infrastructure and labour demand in the short run by specifying private capital as a quasi-fixed factor in the short-run cost function framework, as in previous work such as Berndt and Hansson (1992), Shah (1992), and Cohen and Paul (2004). When deriving input demand equations either in the short run or in the long run, however, a more general approach is to consider factor inputs other than labour and capital entering the firm's production. For example, one could relate the gross output (Q) to the services of four inputs: capital (K), labour (L), energy (E), and all other intermediate materials (M). Unfortunately, data availability for unit costs of energy and materials prevents us from the use of multiple factor production functions.

A final issue regarding the aggregate model of labour demand sketched above is the specification of the Hicks-neutral production function shifter (A). Investments in transport infrastructure can be thought of as increases in the level of production technology, thereby enhancing the total factor productivity of firms. Following the studies by Carlino and Voith (1992), Lobo and Rantisi (1999), and Graham (2000), regional variation in productivity may also depend on differences in several location-specific characteristics such as industry composition, government investments in local public services, labour force characteristics, and agglomeration economies and diseconomies. We therefore hypothesise that the production function shifter encompasses the effect of highway infrastructure (H) and other local characteristics (T) on productivity:

$$A = H^\phi \prod_i T_i^{\chi_i} \quad (5.12)$$

where i indexes the number of proxy variables for T . The aggregate labour demand model (5.11) can now be rewritten as:

$$\ln L^d = \delta_0 + \delta_1 \ln w + \delta_2 \ln r + \delta_3 \ln Q + \phi \delta_4 \ln H + \sum_i \chi_i \delta_4 \ln T_i \quad (5.13)$$

According to which the aggregate demand for labour is determined by the wage rate, the rental rate of private capital, the level of output, the availability of highway infrastructure, and other area-specific characteristics that affect productivity.

5.2.2 Aggregate labour supply model

Considering labour supply in aggregate generally requires attention to two aspects: the size of the working-age population in an economy and their labour supply decisions. All else being equal, population evolution, for example, due to births, deaths, and migration will alter the total size of the potential labour force. A large literature in regional science and related disciplines on the determinants of population size exists.²³ Theoretically, it is assumed that the location decision of individuals or households is affected by a variety of factors. In particular, the relative attractiveness of a region has been suggested as depending upon several local attributes, for example, local taxes, other living costs, employment opportunities, availability of local public services (e.g. transportation access,

²³ For example, see Carlino and Mills (1987), Boarnet (1994), Luce (1994), Clark and Murphy (1996), Duffy-Deno (1998), Mark et al (2000), and Henry et al (1997; 1999; 2001).

health, education), climate, recreation opportunities, other aspects of the quality of life, and proximity to urbanised areas, among others.

Taking the size of the working-age population as given, the conventional theory of labour supply maintains that the quantity of labour supplied relates to individuals' labour supply decisions about whether to participate in the labour force and about how many hours to work. The literature has suggested several important determinants of labour supply decisions. The higher the wage rate, other things constant, the more people are willing to work and the greater the number of hours of work supplied. Factors other than the wage rate that alter the amount of labour supplied for a given population can potentially lead to shifts in the labour supply curve. These include, for example, differences in non-labour income and preferences between leisure and income, the availability of transfer payment income, and household structure and the ability or need to have two wage earners. Public aid and social security benefits are thought to discourage persons from labour market entry and job search. The relation between labour force participation and the extent of employment opportunities in the labour market has been the subject of considerable debate through two competing hypotheses: the added-worker hypothesis and the discouraged-worker hypothesis. Most importantly for our analysis, commuting costs could affect individuals' decisions on labour force supply on the grounds that commuting costs raise the reservation wage, which in turn lowers the probability of entering the labour force. Reduced travel time and costs associated with transportation improvements could thus remove this significant barrier to labour-market participation.

Given these theoretical considerations, we posit that highway investments can affect overall labour supply in two primary ways. First, improved highway infrastructure could lead to changes in a region's overall population, *ceteris paribus*. Households viewing local transport services as a residential amenity may be more attracted to a region with better highway infrastructure. Second, for a given size and age-structure of population, an increase in local labour supply may arise if provision of highway infrastructure improves individuals' accessibility to jobs. The reason for this proposition is twofold. Improving highway services can reduce travel time and commuting costs, allowing people to commute a longer distance, which in turn increases the geographical

size of the labour market. In addition, such a decline in commuting costs can lower individuals' reservation wages for jobs; therefore, more people are likely to participate in the labour force.

Based on the above arguments, we assume the straightforward model of aggregate labour supply in the labour market using a log-linear form

$$\ln L^s = \gamma_0 + \gamma_1 \ln w + \gamma_2 \ln H + \sum_j \tau_j \ln S_j + \sum_k \rho_k \ln R_k + \sum_l \nu_l \ln D_l \quad (5.14)$$

where L^s denotes the supply of labour, w represents the wage rate, H is a measure of highway infrastructure that can have impacts on job accessibility and the size of population, D is the vector of demographic variables capturing regional variations in the age structure of population, and S and R are the vectors of other location-specific factors that might affect individuals' labour supply decisions and residential location choice, respectively.

5.2.3 Reduced-form model of employment

The reduced form model for the equilibrium employment level can be obtained by solving the aggregate models of labour demand (5.13) and labour supply (5.14) with the market clearing assumption ($L^d = L^s$). In doing this, we first equate (5.13) and (5.14), and rearrange terms to derive the reduced-form wage model

$$\begin{aligned} \ln W^* = & \beta_0 + \beta_1 \ln r + \beta_2 \ln Q + \beta_3 \ln H + \sum_i \lambda_i \ln T_i + \sum_i \xi_i \ln S_i \\ & + \sum_k \psi_k \ln R_k + \sum_l \vartheta_l \ln D_l \end{aligned} \quad (5.15)$$

where all independent variables are as described previously. By substituting (5.15) into either (5.13) or (5.14), and rearranging terms, we can write the reduced-form model for the equilibrium level of employment (E^*) in the following form

$$\begin{aligned} \ln L^d \text{ or } \ln L^s = \ln E^* = & \alpha_0 + \alpha_1 \ln r + \alpha_2 \ln Q + \alpha_3 \ln H + \sum_i \varphi_i \ln T_i \\ & + \sum_j \zeta_j \ln S_j + \sum_k \mu_k \ln R_k + \sum_l \kappa_l \ln D_l \end{aligned} \quad (5.16)$$

This reduced-form employment model provides an initial theoretical underpinning for our empirical specifications presented in the next section.²⁴

5.3 Empirical models and econometric methods

5.3.1 Static and dynamic panel models

We specify an empirical version for the linear reduced form model of the equilibrium employment level (5.16) taking the general form

$$\ln E_{it}^* = \alpha + \beta \ln H_{it} + \gamma' \ln Z_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (5.17)$$

where E^* is the equilibrium employment level, H is the density of lane miles for major highways, Z represents, for brevity, the vector of other determinants of labour demand and labour supply as previously discussed, ε is an i.i.d. error term, and i and t index regions and years respectively. Owing to difficulties of controlling for all relevant factors that could be important in explaining regional differences in employment, we include the time-invariant region-specific component (μ) to account for unobserved or omitted heterogeneity across counties that does not vary over time (e.g. climate, topography, local land-use policy, geographical location, and initial technological differences) and the county-invariant time-specific component (τ) to account for any shocks to the labour market that are common to all counties but vary across time (e.g. the rate of technological change, business cycle effects, and fiscal policy of central government).

While the static panel specification (5.17) assumes that county employment adjusts instantaneously and/or fully towards its equilibrium during a single year in response to improved accessibility from expansions of highway capacity, there are several reasons to expect that the adjustment process could exhibit considerable time lags. Slow adjustment of employment may be due to the fact that firms usually incur non-recurring fixed costs associated with either upward or downward adjustments to their desired workforce size, for example, hiring, training and firing costs. Due to relocation costs, input factors (e.g. labour and capital) may not be freely mobile across regions in the short run. In addition

²⁴ While it is possible to derive and estimate labour demand and labour supply equations in order to examine the differential effects of highway infrastructure or other shocks on firm and household behaviour in the labour market (see, for example, Eberts and Stone, 1992), we are primarily interested in the net impact of highway infrastructure on employment, which can be analysed using the reduced form employment model as a theoretical basis.

to the adjustment costs, imperfect information on changed circumstances also contributes to lags. Accordingly, assuming a correspondence between the observed level of employment and the equilibrium level of employment may be unrealistic.²⁵

To account for the potential for a lagged response in the labour market, we consider a simple dynamic specification for our employment equation of the form

$$\ln E_{it} = \alpha + \delta \ln E_{it-1} + \beta_0 \ln H_{it} + \beta_1 \ln H_{it-1} + \theta' \ln Z_{it} + \sigma' \ln Z_{it-1} + \mu_i + \tau_t + \varepsilon_{it} \quad (5.18)$$

This dynamic panel specification, which is an autoregressive distributed lag (ARDL) model, explicitly takes into account dynamic responses of employment to changes in highway infrastructure and other factors. The inclusion of the lagged level of employment also allows for potential persistence in the process of adjustment towards an equilibrium, which is reflected by the parameter δ . Regarding the employment effect of highways, the dynamic panel specification (5.18) shows that the current availability of highways could affect the *current* and *future* levels of employment. The coefficient on the highway variable for the contemporaneous period (β_0) measures the short-run effect of highways on employment, while the long run effect can be calculated as $(\beta_0 + \beta_1)/(1 - \delta)$. Note, however, that this dynamic employment specification assumes that the short- and long-run effects of highways on employment are confined within a county's boundary. To test for geographical spillovers in the employment effects, we add highway lane-mile density in neighbouring counties to the employment equation (5.18). Several alternative definitions of neighbouring counties are considered and described in Section 5.5.4.

5.3.2 Dynamic panel model estimation

In estimating dynamic panel regression models, it is well known that the presence of the lagged dependent variable induces substantial complications. The ordinary least squares (OLS) estimator produces biased and inconsistent estimates because of the correlation between the lagged dependent variable and time-invariant individual specific effects, which are ignored, in the disturbance term. In the case of dynamic panel models with fixed effects, the within-group or least-squares dummy variables (LSDV) estimator is problematic because of the correlation between the demeaned lagged dependent variable

²⁵ Some empirical evidence suggests that population and employment only gradually adjust towards equilibrium (e.g. Carlino and Mills, 1987; Clark and Murphy, 1996; and Duffy-Deno, 1998). In addition, Evans (1990), in a survey of research evidence on the role of interregional differences in migration, concludes that regional economies are not in equilibrium.

and the demeaned error term unless the time dimension of the panel is large. The correlation between the lagged dependent variable and the compound disturbance also renders the random effects estimator biased and inconsistent.²⁶

There have been a variety of dynamic panel estimators developed in the literature. A general approach to deal with the endogeneity of the lagged dependent variable in dynamic panel models is to remove the individual-specific effects by the first difference transformation, and then employ instrumental variables for the lagged dependent variable in the first differenced equation to purge the constructed correlation between the transformed lagged dependent variable and the transformed disturbance term. Consider a simple dynamic panel model below

$$y_{it} = \alpha y_{it-1} + \omega' x_{it} + \mu_i + \varepsilon_{it} \quad (5.19)$$

By taking first differences to eliminate the individual-specific effects from equation (5.19), we obtain

$$y_{it} - y_{it-1} = \zeta (y_{it-1} - y_{it-2}) + \omega' (x_{it} - x_{it-1}) + \varepsilon_{it} - \varepsilon_{it-1} \quad (5.20)$$

As the model in first differences is still complicated by the correlation between the lagged dependent variable $y_{it-1} - y_{it-2}$ and the disturbance $\varepsilon_{it} - \varepsilon_{it-1}$, Anderson and Hsiao (1981) suggest using either y_{it-2} or $y_{it-2} - y_{it-3}$ as instruments for $y_{it-1} - y_{it-2}$ in a two-stage least squares (2SLS) framework. This instrumental variable (IV) estimation approach yields consistent estimates but is inefficient because it does not use all the available moment conditions (for example, see Arellano and Bond, 1991).

Our empirical analysis relies on the Generalized Method of Moments (GMM) techniques for dynamic panel estimation suggested by Arellano and Bond (1991) as well as Arellano and Bover (1995) and Blundell and Bond (1998). A key feature of the GMM framework, which has increasingly been applied in dynamic panel analysis, is that it exploits the panel structure of the data to employ all available instruments that satisfy a larger set of relevant moment conditions, and applies the GMM methodology to obtain consistent estimates. Furthermore, estimating a dynamic panel data model in the GMM framework allows us to relax the restrictive assumption of explanatory variables being strictly exogenous.

²⁶ See Hsiao (2003; chapter 4) and Baltagi (2005; pp. 135-136) for comprehensive discussions on estimations issues of dynamic panel data models

Building upon the IV estimation suggested by Anderson and Hsiao (1981), the Arellano and Bond (1991) estimator, which is known as the first-difference GMM estimator, involves taking first differences of the model (5.18) in order to eliminate the individual effects (μ_i) and using all possible lags of $\ln E_{it}$ in time period $t-2$ and earlier ($\ln E_{it-2}, \ln E_{it-3}, \ln E_{it-4}, \dots, \ln E_{it}$) as instruments for $(\ln E_{it-1} - \ln E_{it-2})$ that is correlated with the $(\varepsilon_{it} - \varepsilon_{it-1})$ from the differencing. The same strategy is applied to form instruments for other explanatory variables that are allowed to be endogenous in the sense that they are correlated with contemporaneous and earlier shocks. For our analysis, this enables us to avoid simultaneity bias due to the potential endogeneity of highways. Given the possibility that current and past levels of employment could influence the current level of highway infrastructure, $E(\ln H_{it} \varepsilon_{it}) \neq 0$ for $t \geq s$, the highway variable ($\ln H_{it}$) can be treated as endogenous, which exploits the moment conditions $E(\ln E_{it-s} \Delta \varepsilon_{it}) = 0$ for $s \geq 2$ and $E(\ln H_{it-s} \Delta \varepsilon_{it}) = 0$ for $s \geq 2$.²⁷

However, the first-difference GMM estimator may suffer from a weak instruments problem when time series are highly persistent (e.g. close to a random walk process) or the variance of the individual specific effects (μ_i) is relatively large compared to that of the transitory shocks (ε_{it}) (Blundell and Bond, 1998). In such a case, only weak correlation may exist between the lagged levels of the series and their subsequent first differences, implying that the available instruments used in the GMM estimator in first differences are less informative. Using Monte Carlo simulations, Blundell and Bond (1998) demonstrate that weak instruments can result in large finite-sample biases when using the first-difference GMM procedure to estimate autoregressive models for moderately persistent series from moderately short panels.

The "system GMM" estimator subsequently developed by Arellano and Bover (1995) and Blundell and Bond (1998) is preferable to the first-difference GMM estimator when estimating dynamic models with persistent panel data. Providing that $E(\Delta \ln E_{it} \mu_i) = 0$, the lagged first difference of employment ($\Delta \ln E_{it-1}$) is valid as an instrument for $\ln E_{it-1}$ in the levels equation (5.18), in addition to the instruments that are available after first-

²⁷ Alternatively, due to possible time lags that would rule out direct contemporaneous endogeneity of highways, one might assume $(\ln H_{it})$ as predetermined in the sense that the current level of highway infrastructure could be influenced by previous employment levels only, $E(\ln H_{it} \varepsilon_{it}) \neq 0$ for $t > s$, and use the values of $(\ln H_{it})$ lagged one or more periods as instruments. However, there could be a persistent process with serial correlation that causes this endogeneity. Hence, it makes sense to consider the density of highway lane-miles as endogenous in the regressions.

differencing. The analogous strategy can be applied to any explanatory variable treated as endogenous. Assuming the highway variable $\ln H_{it}$ as endogenous, for instance, we use its lagged first difference ($\Delta \ln H_{it-1}$) as an instrument for $\ln H_{it}$ in the levels equation, providing that $E(\Delta \ln H_{it-1} \mu_{it}) = 0$. This exploits additional moment conditions for equations in levels, $E(\Delta \ln H_{it-1}(\mu_{it} + \varepsilon_{it})) = 0$ and $E(\Delta \ln H_{it-1}(\mu_{it} + \varepsilon_{it})) = 0$ for $t \geq 3$, that are combined with the moment conditions for equations in first differences exploited in the first-difference GMM estimator. The system GMM thus estimates regressions in differences and regressions in levels simultaneously. Blundell and Bond (1998, 2000) show that the use of the system GMM estimator provides dramatic gains in efficiency and reduces the biases of the GMM estimator in first differences if the series is short in time and highly autoregressive.

To assess the validity of instruments adopted in GMM estimations, we have carried out three specification tests. First, we perform the Arellano-Bond test for serial correlation. The consistency of a GMM estimator depends crucially on the assumption of absence of serial correlation. If the errors are not serially correlated in levels, there should be no evidence of second order autocorrelation in differenced residuals. For the GMM estimator in first differences, for instance, the presence of second order autocorrelation implies that $\ln E_{it-2}$ is an invalid instrument as it is correlated with ε_{it-2} in the differenced error term (but $\ln E_{it}$ lagged three periods and earlier may be a valid instrument). Similarly, $\Delta \ln E_{it-1}$ is not a valid instrument for $\ln E_{it-1}$ in levels equations when using the system GMM estimator. Arellano and Bond (1991) derive a test for autocorrelation of order m in the first differenced errors. Failure to reject the null hypothesis of no second order serial correlation gives support to the model. Secondly, we check for the overall validity of the instruments by using the Sargan test for overidentifying restrictions to examine the orthogonality conditions of the set of instruments. If the test fails to reject the null hypothesis of no correlation between instruments and the error, we can reasonably conclude that the instruments used in the GMM estimator are valid. Finally, the Difference Sargan test is employed to assess whether additional moment conditions in levels questions are valid and can be used in the system GMM framework.

In addition to these specification tests, the direction of the bias in the OLS and LSDV estimates could be used to evaluate the performance of the GMM estimators. Due

to the presence of the lagged dependent variable in a dynamic panel model, the OLS estimator tends to bias the coefficient of the lagged dependent variable upwards, while the LSDV estimator produces a downwards-biased estimate of the autoregressive coefficient (e.g. Arellano and Bond, 1991; Hsiao, 2003). Thus, one may expect the OLS and LSDV estimates to form an approximate upper and lower bound, respectively, for the true parameter of the lagged dependent variable. Therefore, we also report OLS and LSDV estimates for comparisons to GMM estimates.

In implementing both GMM estimators for dynamic panel models, it is advisable not to use all available instruments in the sample so as to avoid the overfitting problem due to the use of too many instruments. To deal with endogenous variables, our analysis typically uses three lagged levels in time period $t-2$, $t-3$ and $t-4$ as instruments for GMM estimations in differenced equations, and one period lagged first-differences of variables (e.g. $\ln E_{it-1} - \ln E_{it-2}$) for GMM in levels equations.²⁸ However, this instrument set may not be useful in the likely presence of second order autocorrelation since the lagged levels in time period $t-2$ and the lagged first-differences are correlated with ε_{it-2} . Therefore, we also consider another restricted set of instruments, including three lagged levels in time period $t-3$, $t-4$ and $t-5$ and the second-order lag of the first-difference variable (i.e. $\ln E_{it-2} - \ln E_{it-3}$) for GMM estimations in differenced equations and levels equations respectively. Note that the model results based on the first instrument set, which is likely more informative, are reported unless the test statistics reject its validity.

5.4 Data and variable description

The data consist of annual observations from 1985 through 1997 for all 100 counties of the State of North Carolina. The definitions and sources of all variables as well as their means and standard deviations are presented in Table 5.1. We use data for employment by place of work for the entire private sector from the Regional Economic Information System (REIS) compiled by the U.S. Bureau of Economic Analysis (BEA). Lane-mile data

²⁸ As reported by Judson and Owen (1999), this estimation strategy of using a subset of the available lagged values as instruments could increase computational efficiency for macroeconomic panel GMM estimation without significantly detracting from its effectiveness. The recent findings from Monte Carlo experiments by Bowsher (2002) indicate that the use of a restricted set of instruments could also improve the power of overidentifying restriction tests.

are from Fulton et al (2000). Originally compiled by Energy and Environmental Analysis, Inc. (EEA) for the US Environmental Protection Agency (EPA), the data contain the lane-miles of all interstate highways, all state highways, and other primary roads.

In order that the employment impact associated with highway infrastructure can be statistically distinguished, the theoretical model derived suggests that we also require data and proxy variables for the level of output, the rental rate of private capital, the age structure of population, and other county characteristics that may affect productivity, individuals' labour supply decisions, and the location decisions of households. Each of these independent variables will be discussed in turn.

County-level data for output are generally unavailable. However, we follow the methodology applied by Boarnet (1995 and 1998) in estimating gross county product using readily available data.²⁹ In this regard, gross state product in North Carolina in each year is apportioned to counties based on each county's share of total state personal income in that year.

$$\text{Gross county product}_{c,t} = \frac{\text{County personal income}_{c,t}}{\text{State personal income}_{c,t}} \times \text{Gross state product}_t \quad (5.21)$$

where c and t index counties and years respectively. We obtain data for North Carolina gross state product in private industries and total state personal income from the Department of Commerce, U.S. Bureau of Economic Analysis (BEA). Data for total personal income for each county are taken from the same source.

²⁹ According to Boarnet (1995), this technique is originally used by the Southern California Association of Governments (SCAG) to apportion state gross product to their member counties.

Table 5.1 Description of variables, data source, and descriptive statistics

Variables	Definition	Data Source	Mean	Standard Deviations		
				Overall	Within	Between
Employment	Aggregate private sector employment by place of work	a	32586.930	1.223	0.105	1.224
Highway Density	Lane-miles of highways per square miles of county area	b	0.729	0.381	0.045	0.380
Output	Gross county product in the overall private sector	c	\$1558.051	1.098	0.138	1.094
Property Tax	Effective property tax rates (the total property tax levy for all jurisdictions in the county as a percentage of the total property valuation)	d	0.866	0.265	0.142	0.225
Human Services expenditure	Per capita real public expenditures for human services such as health, mental health, legal aid, subsidies paid to hospitals, social service administration, and assistance programs	e	\$140.730	0.458	0.312	0.337
Public Safety Expenditure	Per capita real public expenditures for public safety such as police and communications, emergency communications, emergency management, fire, inspectors, rescue units, animal control	e	\$86.607	0.435	0.321	0.296
Cultural and Recreation Expenditure	Per capita real public expenditures on recreation, parks, coliseums, museums, libraries, and any other culture and recreation projects	e	\$15.172	1.728	1.230	1.219
Education Expenditure	Per capita real public expenditures on capital outlay and current operations for public schools and community colleges	e	\$183.913	0.776	0.676	0.383
Environmental Protection Expenditure	Per capita real public expenditures for garbage and landfills, drainage and watersheds, cemeteries, and other environmental protection projects	e	\$28.033	1.255	1.015	0.742
Transportation and Public Utility Expenditure	Per capita real public expenditures on public utilities (e.g. water and sewer services, electric power, and natural gas) and for improvements to streets, parking facilities, airports, mass transit, and other transportation	e	\$30.609	5.457	3.306	4.362
Unemployment	County annual unemployment rates	f	5.611	0.411	0.230	0.342
High School	The percentage of the population over 25 years of age who are high school graduates	g	42.274	0.151	0.095	0.117
College	The percentage of the population over 25 years of age who are college graduates	g	8.591	0.408	0.119	0.392
Under 18	The percentage of the population that is under 18 years old	g	24.751	0.101	0.035	0.095
Over 65	The percentage of the population that is over 65 years old	g	13.778	0.246	0.044	0.243
Public Aid	The percentage of the county population who receive public aid assistance	h	3.825	0.618	0.257	0.565
Social Security	The percentage of the county population who receive social security benefits	h	10.940	0.253	0.073	0.244
Urban	1 if a county is a central county of a metropolitan statistical area (MSA), 0 otherwise	g	-	-	-	-
Suburban	1 if a county is an outlying county of a metropolitan statistical area (MSA), 0 otherwise	g	-	-	-	-
Adjacent to Urban	1 if a county is a rural county bordering central county, 0 otherwise	g	-	-	-	-
Adjacent to Suburban	1 if a county is a rural county bordering outlying county, 0 otherwise	g	-	-	-	-

Note: County output and all expenditure variables are in 2000 dollars. Standard deviations were calculated based on variables in their natural logarithms. * Regional Economic Information System (REIS), U.S. Bureau of Economic Analysis (BEA), * U.S. Energy and Environmental Analysis (EEA), * The Department of Commerce, U.S. Bureau of Economic Analysis (BEA). See text for the methodology applied to estimate gross county product., * North Carolina Department of Revenue, * North Carolina Department of State Treasury, * U.S. Bureau of Labour Statistics, * U.S. Census Bureau, * North Carolina Department of Health and Human Services. Most data are available for the entire period of our analysis except for data from the US Bureau of the Census, which have usually been available every 10 years. Interpolation is performed to obtain data for non-census years.

No direct measure for the rental rate of private capital can be included in the empirical models because the data are unavailable. We assume that significant variations in the net rental price of capital are low within the state. Rather, the after-tax rental price of capital should vary among counties by differences in local property tax rates. Therefore, the effective rate of property taxes, based on data from the North Carolina Department of State Revenue, is employed to measure variations in the rental rate of private capital services across counties.³⁰

Given the role of local government expenditures on public services in determining local economic growth, six variables for real public expenditures on several categories of public services (i.e. education, health and human services, cultural and recreation, public safety, transportation and public utility, and environmental protection) are included to control for county-to-county differences in productivity and locational attractiveness as a place of residence.³¹ All of these expenditure variables are measured as percentages of population.

To a large extent, spatial variation in productivity from county to county may be partly due to differences in human capital characteristics. In particular, the education level of population can be an indicator of the quality of the labour force, directly affecting the inherent productivity of human resources. We thus use the percentage of adult population who are high school graduates and the percentage of adult population who are college graduates to control for regional differences in the human capital of the labour force.

Other locational attributes that can influence the local supply of labour are captured by five other variables. We include the percentage of the population under 18

³⁰ More specifically, the after-tax rental rate of private capital could be measured as $q_t(r + \delta) [1 / (1 - \text{tax})]$ where q_t is the private capital investment deflator, r is the discount rate, δ is the capital depreciation rate, and tax is the property tax rate. However, we simply use the property tax rate as a proxy for the rental rate of private capital for two reasons. First, county data on the capital deflator for North Carolina, to the best of our knowledge, is not available. Secondly, q_t and δ are likely to be very similar across counties for each year of our sample period, and their likely variation over time and that of the discount rate could be controlled by time dummies included in our regressions. Note also that the property tax in North Carolina is levied on real property (e.g. land, buildings), personal property (e.g. machinery, equipments, and motor vehicles), and property of public service companies such as electric power companies, gas pipeline companies, telephone companies, and motor freight carriers. The use of the effective property tax rate presumably allows us to generally account for variations in the rental prices for various types of capital services used in the firm production process.

³¹ Given the nature of government budget constraints, the extent of highway lane-miles in each county might be implicitly determined by either or both of expenditures allocated and tax revenues. The inclusion of government fiscal variables including public expenditures and property taxes in our regressions could lead to collinearity that might render the estimates and inferences of the employment impact of highways biased and inconsistent. However, we find that the correlation coefficients between the density of highway lane-miles and each of these fiscal variables are very small. We also experimented with specifications in which all expenditure variables are omitted, but in most cases we could not find any significant change in the coefficients and standard errors for the highway variables.

years of age and the percentage of the population over 65 years of age to control for the age structure of the population. To control for the negative effect of the availability of direct income transfers for labour force participation rates and hence labour supply, we include the percentage of the county population who receive public aid payments or who receive social security benefits. Unemployment rates are used to capture the possibility that high unemployment may affect labour force participation by increasing either discouraged workers or additional workers.

Finally, four dummy variables for (i) central city counties within metropolitan areas, (ii) metropolitan suburban counties, (iii) rural counties that border central city counties, and (iv) rural counties that border suburban counties are included to account for any unspecified county characteristics that vary among urban and rural counties within the state.³² These dummy variables are expected to capture systematic differences in amenities and local circumstances with respect to urbanisation status, for example, agglomeration economies, congestion and environmental quality, costs of living, land use regulations, diffusion of economic benefits from urbanised areas to their neighbouring communities, and the exploitation of resources in less developed areas adjacent to metropolitan regions.

Given this choice of control variables, we are concerned with potential endogeneity of expenditures for public services, output, unemployment, and the proportion of adult population with educational qualifications, which could influence estimation results. Similar to the case of highway infrastructure, provision of other public services is likely to be endogenous (e.g. high-economic-growth economies could have a large tax base, and they can afford to provide more and better schools, hospitals, and public parks, etc.). Treating the level of county output as exogenous is clearly unrealistic since employment and output are simultaneously determined. The typically inverse correlation between unemployment and employment does not imply causality. Finally, counties with greater opportunities for jobs and income could attract more workers with a high educational qualification.³³ Accordingly, in addition to the dynamic employment model (5.18) assuming that all variables except the lagged employment are exogenous, we also

³² Rural counties not adjacent to metropolitan areas are the base case.

³³ This concern relates to a prominent argument in a substantial body of empirical research on the location determinants of employment and population, for example see Carlino and Mills (1987), Boarnet (1994), Henry et al (2001). The basic premise of this literature is that the location decisions of firms and households are simultaneous. In this case, we can argue that people follows jobs.

consider an alternative specification in which the density of highway lane miles and these control variables are treated as endogenous using their lagged values as instruments in the GMM estimation.

5.5 Results

5.5.1 Static employment model estimates

We start by presenting empirical results for the static employment model (5.17) that does not include any lagged variables as regressors in Table 5.2. The first three columns report coefficients estimated by pooled OLS, fixed effects, and random effects estimators. Focusing on the highway density variable, these models consistently provide evidence suggesting that the density of highway lane-miles has a positive and significant impact on overall private sector employment. Based on this finding, one can argue that roadway expansions have important payoffs in terms of private sector employment growth across North Carolina counties. Nevertheless, these estimated results have relied on very restrictive assumptions that the disturbance in equation (5.17) has no serial correlation and that all independent variables are strictly exogenous. Therefore, we relax these assumptions by considering two alternative fixed effects specifications of equation (5.17).³⁴

³⁴ Although fixed county effects in column 2 could be the preferred specification as we include the entire set of North Carolina counties in our sample, we performed the Hausman specification test of the null hypothesis that the individual-specific effects are uncorrelated with one or more of the included regressors. The Hausman test yields a chi-square of 97.86 (32 degrees of freedom), which is far larger than a 1% critical value of 53.47, thereby rejecting the null hypothesis. This confirms that in this case the model with fixed county effects is preferable.

Table 5.2 Estimation results for the static models of employment

Dependent variable: Employment	(1) Pooled OLS	(2) Fixed Effects	(3) Random Effects	(4) Fixed Effects / AR(1)	(5) Fixed Effects / 2SLS	(6) Between Groups
Highway Density	0.091*** (3.45)	0.084** (1.86)	0.135*** (2.98)	-0.020 (-0.62)	-0.033 (-0.38)	0.080 (0.86)
Output	1.150*** (105.99)	0.494*** (11.06)	0.926*** (37.48)	0.301*** (8.65)	0.555*** (15.13)	1.155*** (28.40)
Property Tax	-0.043 (-1.37)	-0.020** (-2.18)	-0.014 (-1.33)	-0.005 (-1.10)	-0.023** (-2.54)	0.003 (0.03)
Human Services Expenditure	-0.005 (-0.32)	-0.004 (-0.50)	-0.005 (-0.58)	0.001 (0.33)	0.003 (0.40)	-0.007 (-0.12)
Public Safety Expenditure	0.094*** (4.82)	-0.003 (-0.33)	-0.011 (-1.06)	0.004 (0.70)	-0.001 (-0.06)	0.059 (0.72)
Cultural and Recreation Expenditure	-0.006** (-2.05)	0.001 (0.98)	0.001 (0.50)	-0.001 (-0.71)	0.001 (0.79)	-0.010 (-0.63)
Education Expenditure	0.015** (2.07)	0.003 (1.10)	0.003 (0.92)	0.0003 (0.35)	0.005 (1.57)	0.083 (1.14)
Environmental Protection Expenditure	0.011* (1.77)	0.0001 (0.12)	0.001 (0.58)	0.0005 (0.68)	0.002 (1.44)	0.036 (0.94)
Transportation and Public Utility Expenditure	-0.001 (-0.55)	0.001* (1.67)	0.001 (1.16)	0.0002 (0.89)	0.001 (1.24)	-0.001 (-0.29)
Unemployment	0.325*** (15.68)	-0.073*** (-7.08)	-0.042*** (-3.91)	-0.052*** (-8.97)	-0.099*** (-11.72)	0.456*** (4.50)
High School	-1.360*** (-13.81)	-0.416*** (-4.88)	-0.202** (-2.34)	-0.031 (-0.20)	-0.169** (-2.12)	-1.553*** (-4.68)
College	0.416*** (11.66)	0.386*** (5.85)	0.262*** (4.63)	-0.004 (-0.04)	0.199*** (4.39)	0.473*** (3.74)
Under 18	-1.041*** (8.96)	-0.251** (-2.42)	-0.114 (-1.15)	-0.116 (-1.03)	-0.183** (-2.16)	1.337*** (2.86)
Over 65	-0.302*** (-3.21)	0.056 (0.65)	0.175* (1.96)	-0.050 (-0.51)	0.234*** (3.75)	-0.316 (-1.02)
Public Aid	-0.234*** (-12.30)	0.010 (0.89)	0.028** (2.29)	-0.049*** (-4.28)	-0.025** (-2.22)	-0.340*** (-4.54)
Social Security	0.724*** (8.65)	0.021 (0.42)	0.004 (0.07)	-0.007 (-0.30)	-0.041 (-1.01)	0.753*** (2.81)
Urban	-0.201*** (-7.82)	0.003 (0.21)	0.021* (1.67)	-0.018 (-1.08)	-0.013 (-0.87)	-0.087* (-1.89)
Suburban	-0.227*** (-10.09)	0.023* (1.74)	0.016 (1.06)	0.010 (0.77)	0.025** (2.12)	-0.248*** (-3.05)
Adjacent to Urban	-0.118*** (-7.24)	0.002 (0.20)	0.014 (1.53)	-0.006 (-0.73)	0.002 (0.25)	-0.116** (-2.05)
Adjacent to Suburban	0.067*** (3.58)	0.056*** (3.56)	0.063*** (3.96)	0.018 (1.35)	0.049*** (3.89)	0.050 (0.72)
Constant	2.935*** (13.16)	6.920*** (20.33)	4.415*** (16.02)	7.293*** (126.01)	6.417*** (21.24)	2.883*** (3.35)
Observation	1300	1300	1300	1200	1000	100
Year dummies	No	Yes	Yes	Yes	Yes	No
R ²	0.977	0.917	0.949	0.917	0.923	0.984
AR(1) coefficient	-	-	-	0.826	-	-

Note: County and year specific constants are omitted for brevity. Numbers in parentheses below the coefficients are t-statistics. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

First, we estimate the fixed effects model in which the error term exhibits first-order autocorrelation:

$$\varepsilon_{it} = \rho\varepsilon_{it-1} + v_{it} \quad (5.22)$$

where ρ is the first-order coefficient of autocorrelation and v_{it} is the stochastic disturbance term. Note that this approach introduces error dynamics in a static panel regression through the errors of equation (5.17), and we can simply derive an autoregressive distributed lag model of the form similar to equation (5.18) using equation (5.22). To some extent, estimating the static employment model with first-order autocorrelated errors allows us to *partially* account for lagged responses of employment through the unobservable error dynamics induced by ε_{it-1} .

Second, we address the potential endogeneity of highways using a two-stage least squares (2SLS) estimator with instrumental variables. An important concern when using this method is the choice of appropriate instruments. Based on diagnostics for instrument relevance and exogeneity, we find that lagged levels of highway lane-mile density in time period $t-2$ and $t-3$ are valid instruments for the current level of highway density. Given that the F -statistic on the joint significance of these instruments in the first-stage regression is 96.73, the problem of weak instruments is not a concern in the 2SLS estimation. The J -test of overidentifying restrictions also does not reject the null hypothesis that these instruments are exogenous.³⁵

The empirical findings from these alternative specifications are reported in columns 4 and 5. Taking into account potential autocorrelation in the disturbance, the results change considerably. The coefficient of the highway variable shown in column 4 is substantially smaller than those reported in the first three columns and, more importantly, becomes statistically insignificant with a negative sign. The high degree of the first order autoregression (0.826) suggests that the static employment equation is seriously misspecified. Treating the density of highway lane-miles as endogenous similarly influences the estimated highway effects. In column 5, the two-stage least squares estimation with the lagged levels of highway density as the instruments reveals

³⁵ We also tested what seemed to be a purely exogenous variable, namely road casualties. Evidence suggests that this should be linked with road infrastructure (Karlaftis and Tarko, 1998; Milton and Mannering, 1998; Noland, 2003; Noland and Oh, 2004) but less likely to be linked with employment. However, results are probably not reliable since the joint F -test statistic on the instruments (4.50) suggests that they might be only weakly correlated with the highway variable. Staiger and Stock (1997) suggest that inference based on 2SLS might be subject to weak instruments problems if the first stage F statistic on instruments is small, particularly less than 10.

no significant relationship between the density of highway lane-miles and county employment. We also perform the Hausman specification test for endogeneity with respect to the highway density variable. The test result confirms that the OLS fixed effects estimates are not consistent; therefore, the endogeneity of highway lane-mile density is an empirical concern in our analysis.

While the static panel estimations presented above are concerned with the question of whether changes in highway density have instantaneous effects on employment in the short run, it is also possible to examine the long run effects of highways using the static model of employment (5.17) using the between-groups (BG) estimator. Pirotte (1999; 2003) demonstrates that the BG regression of averages across time performs best in estimating long run effects directly from a static panel model, though the true underlying specification is a dynamic one. The BG estimates as shown in the last column of Table 5.2 tend to be similar to the pooled OLS estimates in column 1. One exception is the elasticity with respect to the highway variable which is not significant, suggesting no evidence of long-run impacts of highways.³⁶

Overall, the above estimation results suggest that the basic specification for the static employment model seems to overestimate the importance of highway infrastructure investments. When controlling for unobservable dynamic processes through first-order autocorrelated errors and the potential endogeneity of highways, the static model estimates find that there is no significant effect of the highway density variable on employment.³⁷ This finding is consistent with other more recent research that suggests that economic impacts from highway and infrastructure improvements tends to disappear when more detailed econometric models are estimated. Our next step is to more explicitly model the dynamics of employment adjustment and determine how this affects the results.

³⁶ The conflicting results are not surprising. Although Monte Carlo simulations by Baltagi and Griffin (1984) indicate that both between and pooled OLS estimators are most appropriate to give long-run estimates, the between estimation results are likely to be more reliable in our context since (1) averaging cross-sectional units across time can reduce the measurement error bias, which again might be a concern in this aggregate study and (2) the Wooldridge (2002) test for serial correlation in panel data models strongly rejects the null hypothesis of no first order autocorrelation in the pooled OLS regression ($F(1,99) = 163.423$; $p\text{-value} = 0.000$). The latter case could be reflected by the fact that the t statistics of most variables in the pooled OLS model are considerably higher than those obtained in the between groups regression.

³⁷ The highway variable is also found to be insignificant when using the Newey and West (1987) standard errors that correct for autocorrelation and heteroscedasticity.

5.5.2 Dynamic employment model estimates

Table 5.3 presents results from various specifications of a dynamic panel employment model that accounts for dynamic responses of county employment to changes in highway density and other variables. In columns 1 and 2, we report, respectively, OLS and LSDV estimates of the employment model in levels. Columns 3 and 5 present coefficient estimates using the first difference GMM and system GMM estimators, respectively, in which only the lagged employment variable is instrumented. The corresponding GMM estimates that also account for the potential endogeneity of highways and other variables, as discussed in Section 5.4, are reported in Columns 4 and 6.

Consider first the GMM estimation results from Columns 3 to 6. The coefficient for the lagged employment variable is positive and statistically significant at the 1% level in all specifications considered, indicating the presence of adjustment processes towards equilibrium. This confirms that the underlying assumption in the static employment specification (5.17) that the observed employment level is at its desired or equilibrium level is incorrect. As a result, the parameter estimates of the static employment model are biased and inconsistent as they may partially pick up the effects of lagged employment. While the validity of instruments used in the GMM estimations is generally accepted at conventional levels of statistical significance, the coefficient for lagged employment obtained from the first-difference GMM estimator is much smaller than the lower bound provided by the LSDV estimator. Despite controlling for the potential endogeneity of highways and some other variables, the coefficient for lagged employment is still lower than the corresponding LSDV estimate.

Table 5.3 Estimation results for the dynamic models of employment

Dependent variable: Employment	(1) Pooled OLS	(2) LSDV	(3) Difference GMM1 (with strictly exogenous explanatory variables)	(4) Difference GMM2 (with endogenous explanatory variables)	(5) System GMM1 (with strictly exogenous explanatory variables)	(6) System GMM2 (with endogenous explanatory variables)	(7) Between Group
Employment (-1)	0.987*** (207.59)	0.782*** (29.71)	0.652*** (4.37)	0.641*** (15.02)	0.969*** (31.93)	0.980*** (123.16)	0.992*** (187.16)
Highway Density	-0.002 (-0.07)	-0.035 (-1.07)	-0.034 (-0.93)	0.006 (0.12)	-0.017 (-0.58)	-0.002 (-0.04)	0.015 (0.11)
Highway Density (-1)	0.003 (0.10)	0.020 (0.58)	0.020 (0.66)	0.046 (0.76)	0.020 (0.70)	-0.002 (-0.05)	-0.011 (-0.08)
Output	0.277*** (5.14)	0.271*** (4.58)	0.150* (1.68)	0.192** (2.48)	0.204*** (2.69)	0.207*** (2.65)	0.467*** (3.02)
Output (-1)	-0.266*** (-4.93)	-0.136** (-2.31)	-0.070 (-0.81)	0.038 (0.51)	-0.174** (-2.21)	-0.187** (-2.41)	-0.462*** (-2.96)
Property Tax	-0.007 (-1.02)	-0.006 (-0.89)	-0.007 (-0.83)	-0.007 (-0.92)	-0.006 (-0.97)	-0.006 (-0.96)	-0.042 (-0.63)
Property Tax (-1)	0.005 (0.79)	0.005 (0.61)	0.002 (0.29)	0.002 (0.25)	0.003 (0.47)	0.004 (-0.55)	0.044 (0.70)
Human Services Expenditure	0.0002 (0.05)	0.002 (0.39)	0.003 (0.75)	-0.002 (-0.33)	0.001 (0.38)	-0.001 (-0.27)	0.014 (0.36)
Human Service Expenditure (-1)	0.001 (0.23)	0.002 (0.51)	0.004 (0.77)	0.004 (0.62)	0.0003 (0.06)	0.003 (0.43)	-0.014 (-0.35)
Public Safety Expenditure	0.007 (1.26)	0.005 (0.94)	-0.002 (-0.42)	0.003 (0.25)	0.003 (0.55)	0.013 (1.57)	0.023 (0.45)
Public Safety Expenditure (-1)	-0.003 (-0.50)	0.0003 (0.06)	0.0002 (0.04)	-0.008 (-0.98)	0.002 (0.33)	-0.008 (-1.03)	-0.022 (-0.44)
Cultural and Recreation Expenditure	-0.001 (-1.12)	-0.001 (-0.93)	-0.002* (-1.86)	-0.001 (-1.35)	-0.001* (-1.83)	-0.002** (-2.22)	-0.003 (-0.61)
Cultural and Recreation Expenditure (-1)	0.001 (1.09)	0.001 (0.86)	0.001 (1.24)	0.001* (1.67)	0.001* (-1.89)	0.001* (1.66)	0.002 (0.49)
Education Expenditure	0.002 (1.61)	0.002 (1.05)	0.004 (1.40)	0.002 (0.87)	0.003* (1.80)	0.002 (0.82)	0.033 (1.21)
Education Expenditure (-1)	0.001 (0.67)	0.001 (0.84)	0.003 (1.30)	0.002 (0.86)	0.002 (1.18)	0.002 (1.02)	-0.031 (-1.12)
Environmental Protection Expenditure	0.0004 (0.47)	0.001 (0.53)	0.00002 (0.03)	0.000002 (0.00)	0.0005 (0.52)	0.001 (0.97)	-0.002 (-0.26)
Environmental Protection Expenditure (-1)	0.00001 (-0.01)	-0.0003 (-0.45)	-0.0001 (-0.24)	0.0001 (0.09)	0.0001 (0.18)	0.0002 (0.43)	0.0002 (0.29)
Transportation and Public Utility Expenditure	0.0001 (0.48)	0.0002 (0.75)	0.0001 (0.41)	-0.0002 (-0.45)	0.0001 (0.39)	-0.0001 (-0.23)	0.003* (1.68)
Transportation and Public Utility Expenditure (-1)	-0.0004 (-1.31)	-0.0003 (-1.02)	-0.0004 (-1.13)	0.0002 (0.55)	-0.0004 (-1.38)	-0.0002 (-0.68)	-0.003* (-1.81)
Unemployment	-0.048*** (-7.22)	-0.066*** (-9.55)	-0.061*** (-7.34)	-0.071*** (-6.70)	-0.045*** (-4.56)	-0.045*** (-4.80)	-0.019 (-0.37)
Unemployment (-1)	0.043*** (6.53)	0.011* (1.77)	0.009 (1.07)	0.004 (0.53)	0.041*** (6.02)	0.033*** (4.00)	0.025 (0.49)
High School	0.236 (1.09)	0.486* (1.81)	0.435 (1.12)	0.098 (0.25)	0.454** (2.40)	0.410* (1.68)	0.040 (0.08)
High School (-1)	-0.202 (-0.95)	-0.526* (-1.95)	-0.512 (-1.41)	-0.168 (-0.42)	-0.434** (-2.24)	-0.370 (-1.54)	-0.003 (-0.01)

Table 5.3 Estimation results for the dynamic models of employment (cont'd)

Dependent variable: Employment	(1) Pooled OLS	(2) LSDV	(3) Difference GMM1 (with strictly exogenous explanatory variables)	(4) Difference GMM1 (with endogenous explanatory variables)	(5) System GMM2 (with strictly exogenous explanatory variables)	(6) System GMM2 (with endogenous explanatory variables)	(7) Between Groups
College	0.020 (0.19)	-0.269** (-2.00)	-0.188 (-1.00)	-0.266 (-1.30)	-0.081 (-0.74)	-0.018 (-0.16)	0.314* (1.77)
College (-1)	-0.020 (-0.19)	0.330** (2.39)	0.284 (1.64)	0.375* (1.79)	0.088 (0.80)	0.020 (0.18)	-0.317* (-1.79)
Under 18	-0.320** (-2.08)	-0.503** (-2.59)	-0.473 (-1.61)	-0.338 (-0.94)	-0.329* (-1.91)	-0.387** (-2.23)	-0.323 (-0.83)
Under 18 (-1)	0.314** (1.97)	0.454** (2.17)	0.410 (1.30)	0.258 (0.69)	0.342* (-1.89)	0.389** (2.17)	0.286 (0.72)
Over 65	-0.250** (-2.45)	0.175 (1.14)	0.200 (1.00)	0.415* (1.68)	-0.263** (-2.52)	-0.278** (-2.32)	-0.168 (-0.54)
Over 65 (-1)	0.210** (2.16)	-0.070 (-0.45)	-0.220 (-0.96)	-0.368 (-1.40)	0.220** (2.28)	0.229** (2.00)	0.113 (0.37)
Public Aid	-0.038*** (-2.66)	-0.025* (-1.83)	-0.022 (-1.29)	-0.019 (-1.04)	-0.039** (-2.27)	-0.037** (-2.38)	0.050 (1.02)
Public Aid (-1)	0.034** (2.40)	0.017 (1.28)	0.008 (0.47)	-0.002 (-0.12)	0.032** (2.12)	0.035** (2.23)	-0.051 (-1.07)
Social Security	0.004 (0.13)	-0.024 (-0.70)	0.015 (0.34)	0.022 (0.62)	0.016 (0.57)	0.020 (0.77)	-0.068 (-0.31)
Social Security (-1)	0.014 (0.44)	-0.024 (-0.74)	-0.010 (-0.23)	-0.017 (-0.49)	0.012 (0.59)	0.010 (0.43)	0.092 (0.44)
Urban	-0.007* (-1.96)	-0.010 (-1.30)	-0.028 (-1.58)	-0.004 (-0.27)	-0.010 (-1.51)	-0.004 (-1.02)	-0.006 (-1.19)
Suburban	-0.005 (-1.47)	0.006 (0.68)	0.003 (0.16)	0.010 (0.67)	-0.008 (-1.01)	-0.005 (-1.12)	-0.003 (-0.68)
Adjacent to Urban	-0.004* (-1.66)	-0.004 (-0.76)	-0.018 (-1.52)	-0.011 (-1.22)	-0.006 (-1.52)	-0.003 (-1.32)	-0.002 (-0.67)
Adjacent to Suburban	-0.007** (-2.26)	-0.005 (-0.63)	-0.001 (-0.08)	-0.012 (-0.92)	-0.006 (-1.43)	-0.004 (-0.89)	-0.009** (-2.38)
Observations	1200	1200	1100	1100	1200	1200	100
Test of the joint hypothesis that $\beta_0 = \beta_1 = 0$ (p-value)	0.970	0.514	0.631	0.574	0.628	0.801	0.676
Test of the hypothesis that $\beta_0 + \beta_1 = 0$ (p-value)	0.818	0.502	0.676	0.296	0.537	0.506	0.381
Sargan test of over-identifying restrictions (p-value)	-	-	0.062	1.000	0.280	1.000	-
Difference Sargan test (p-value)	-	-	-	-	1.000	1.000	-
Second order serial correlation (p-value)	-	-	0.090	0.075	0.148	0.190	-

Note: 1) In Columns 1 to 6, year specific constants are omitted for brevity, and the Wald statistics suggest that we can reject the null hypothesis that all the coefficients of year dummies are zero. 2) Numbers in parentheses below the coefficients are t-statistics, which are heteroscedasticity consistent. 3) *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. 4) In columns 3 to 6, the results reported are from one-step robust GMM estimators, which are consistent with possible heteroscedasticity. For inference on the coefficients, one-step robust GMM estimates have been considered to be more reliable than GMM estimates in the two-step version (see Arellano and Bond, 1991; Blundell and Bond, 1998, 2000). 5) We consider two restricted instrument sets as described in Section 5.3.2. In columns 3, 4, and 6, we report the GMM estimates obtained from the first instrument set as both instrument sets give similar results for the specification tests. The model results presented in column 5 are based on the second instrument set because the test statistics reject the validity of the first one.

These results raise concerns regarding the problem of weak instruments when using the standard GMM estimator in first differences with persistent series. Column 1 shows that employment is highly persistent since the OLS estimate for the autoregressive parameter is positively significant and close to unity. Moreover, by simply estimating first-order autoregressive models for each of the other variables considered in this study using OLS and LSDV, we find that many, such as the density of lane-miles, county output, the percentage of high school and college graduates, and unemployment, are highly persistent. As such, the strong persistence of the panel data used in this analysis is likely to result in poor performance of the first difference GMM estimator.

The system GMM estimator, which exploits additional moment conditions in the levels equations, appears more appropriate. We find evidence supports the work by Blundell and Bond (1998 and 2000) which suggests that due to weak instruments one can expect first-difference GMM estimates tend to be biased in the direction of the LSDV. Either under the strict exogeneity assumption on all explanatory variables (SYSGMM1) or considering the potential endogeneity of highways and several other variables (SYSGMM2), the system GMM estimates of the first-order autoregressive coefficient as shown in columns 5 and 6 are considerably higher than the difference GMM results (0.652 and 0.641) and lies in the interval between the OLS and LSDV estimates, which forms a lower and upper bound from 0.782 to 0.987. Moreover, a test for second-order serial correlation is more comfortably passed, and the Difference Sargan tests do not reject the validity of instruments that are additionally employed in the system GMM framework. Apart from this, we test for instrument relevance of the level instruments used in the first difference equations as well as the first-difference instruments used in levels equations by regressing each of the regressors specified as endogenous on its corresponding instruments and time period dummies.³⁸ For most variables the results, which are reported in Table 5.4, show clearly that although the instruments used in both first-difference and levels equations are jointly significant, the *F* statistics for the first-difference instruments tend to be much higher. Based upon this evidence, therefore, the system GMM estimator is in our case preferable to the first-difference GMM estimator.

³⁸ A similar approach to testing for instrument relevance in the system GMM estimator can be found in Hämäläinen and Böckerman (2004).

Table 5.4 Test of instrument relevance for GMM estimations

Variables considered as endogenous	1 st Instrument Set				2 nd Instrument Set			
	First Difference Equations		Levels Equations		First Difference Equations		Levels Equations	
	F test	R ²	F test	R ²	F test	R ²	F test	R ²
Lagged Employment	18.68 (0.000)	0.428	48.67 (0.000)	0.999	10.98 (0.000)	0.431	70.91 (0.000)	0.999
Highway Density	6.69 (0.000)	0.187	26.76 (0.000)	0.993	4.80 (0.003)	0.174	17.06 (0.000)	0.993
Output	7.69 (0.000)	0.592	21.77 (0.000)	0.999	6.92 (0.000)	0.612	15.54 (0.000)	0.999
Human Services expenditure	4.54 (0.004)	0.189	15.98 (0.000)	0.822	0.32 (0.813)	0.122	7.89 (0.005)	0.815
Public Safety Expenditure	12.34 (0.000)	0.147	45.10 (0.000)	0.873	0.396 (0.008)	0.082	9.14 (0.003)	0.857
Cultural and Recreation Expenditure	1.48 (0.218)	0.199	7.39 (0.007)	0.580	0.59 (0.620)	0.079	2.17 (0.141)	0.565
Education Expenditure	2.38 (0.068)	0.232	1.04 (0.307)	0.473	1.08 (0.359)	0.192	0.37 (0.545)	0.449
Environmental Protection Expenditure	1.26 (0.287)	0.020	2.63 (0.105)	0.393	0.03 (0.993)	0.009	0.03 (0.861)	0.389
Transportation and Public Utility Expenditure	5.15 (0.002)	0.094	14.34 (0.000)	0.675	2.81 (0.039)	0.092	7.67 (0.006)	0.694
Unemployment	29.21 (0.000)	0.635	155.02 (0.000)	0.881	7.86 (0.000)	0.609	30.53 (0.000)	0.873
High School	20.77 (0.000)	0.640	38.68 (0.000)	0.978	17.53 (0.000)	0.625	51.25 (0.000)	0.980
College	29.13 (0.000)	0.663	128.82 (0.000)	0.993	20.84 (0.000)	0.725	199.86 (0.000)	0.994
Instruments used in GMM estimations	Lagged levels in time period t-2, t-3, and t-4		Lagged first-differences dated t-1		Lagged levels in time period t-3, t-4, and t-5		Lagged first-differences dated t-2	

Note: Numbers in parentheses are p-values corresponding to the test of the null hypothesis that coefficients of all instruments used are jointly zero.

Of particular importance to us is the employment effect of highway investments. Taken as a whole, the picture presented in columns 1 to 6 shows no statistical relationship between the density of highway lane-miles and county employment across several specifications of the dynamic panel data model. In our preferred system GMM specification with highways and other variables treated as endogenous, the coefficients on the highway variables are very small and not individually significant. Even though the collinearity between the contemporaneous highway variable and its lag is likely to cause the individual coefficients to be statistically insignificant, we also cannot reject the joint test of their significance ($\beta_0 = \beta_1 = 0$) as well as the hypothesis that the sum of the coefficients is zero ($\beta_0 + \beta_1 = 0$). This suggests that expanding capacity of highway infrastructure does not have long-run impacts on North Carolina county employment in the private sector.

In contrast, we find evidence for other determinants of private sector employment in North Carolina counties, many of which are consistent with our expectations. The

system GMM estimates suggest that the effects of county output in private industries and unemployment rates on private sector employment persist over time. The coefficients on the proportion of the population that receive public aid assistance are consistent with the notion that the availability of direct income transfers negatively affects the labour market. As also expected, the percentages of the population under the age of 18 and over 65 years of age have negative effects on employment since a greater share of young and senior persons could be associated with a lower share of working-age population. In addition, the positive relationship between employment and the share of the population above the age of 25 who have completed four or more years of high school tends to support the notion that the quality of the labour force plays an important role in generating employment. The negative coefficient on the share of the adult population who are college graduates is surprising, but it is fairly small and not statistically significant. Likewise, the coefficient on property tax is also negative and insignificant. Of the fiscal variables only the coefficients on public spending for education are jointly different from zero at the 10% level (p -value = 0.087). This supports the hypothesis that improving education is a prerequisite for long-term employment in a region.

5.5.3 Robustness of dynamic panel estimation results

We perform several robustness checks for the dynamic regression results with respect to the employment effects of highways. The first robustness check refers to the sensitivity of the results to other alternative lag specifications of the dynamic employment model. We experimented with autoregressive distributed lag models of employment with more general lag structures, estimating ARDL(2,2) and ARDL(3,3) where the first and second numbers in the parentheses denote the lag orders of the dependent variable and the vector of explanatory variables respectively. The main results were basically unchanged. Based on the difference GMM estimation, we found that some of the lagged highway variables are individually different from zero at the 10% level. Nevertheless, they were statistically insignificant in the system GMM framework that was again found to be preferable.

The collinearity that is often associated with autoregressive distributed lag models could possibly mask the significance of individual coefficients, we consider another

dynamic specification in which the current level of employment is related to its lag(s) as well as the density of highways and other variables during the contemporaneous period:

$$\ln E_{it} = \alpha + \sum_{r=1}^p \delta_r \ln E_{it-r} + \beta_0 \ln H_{it} + \theta' \ln Z_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (5.23)$$

This specification, which imposes less flexible lag structures, has the advantage of reducing the number of coefficients to be estimated and the multicollinearity which may render the standard errors of the short run coefficient (β_0) in the ARDL models to be large.³⁹ As the tests for second-order autocorrelation based on the GMM estimates tend to reject the validity of the specification with the inclusion among covariates of a lagged employment variable ($r = 1$), we instead consider the estimation results from the dynamic model (5.23) with two lags of employment ($p = 2$). The results are consistent with those obtained from the autoregressive distributed lag models in that the estimated short run coefficient of the highway density variable is always insignificant.

There is also concern that highway investments, despite having no *marginal* contribution both in the short run and in the long run, may have an *average* effect on employment. Thus, the second robustness check involves estimating the dynamic employment model (5.18) using a between-groups (BG) estimator, which is based on only the cross-sectional variation in the data.⁴⁰ Given that the density of highway lane-miles in our sample varies considerably *between* counties, one might anticipate that North Carolina's highway density could have long-run cross-sectional effects on county employment. That is, for example, a road-less county would likely have considerably less employment. The BG estimates reported in column 7 of Table 5.3, however, do not support these expectations as the coefficients of highway lane-mile density are not individually and jointly significant. To some extent, these findings confirm the evidence from the dynamic panel estimates that in the long run, highway infrastructure investment has no impact on county employment in North Carolina.

³⁹ The multicollinearity could make the test of significance for an individual coefficient unreliable when estimating the autoregressive distributed lag model of county employment (5.18) in levels by means of the pooled OLS and the within groups estimator. In the GMM framework, however, the first difference transformation may alleviate the problem of multicollinearity as the pair-wise correlation between the first differenced highway variables is very low (0.014).

⁴⁰ The BG estimator may be useful in disentangling long run influences of variables with small time-series variation. This is likely to be a concern in our case as the descriptive statistics reveal that for the highway variable the within group variation is smaller than the between groups variation. In the difference GMM framework, first differencing the equations may diminish the influence of time invariant highway density. Adding the equations in levels, the system GMM estimator could alleviate this problem. For dynamic panel models, the BG estimator has also been found to be more accurate than the fixed effects estimator and the Arellano-Bond model in the presence of measurement error (e.g. Griliches and Mairesse, 1995; Hauk and Wacziarg, 2004), which might be the case in our aggregate analysis.

As a final robustness check on our dynamic panel results, we test for the presence of spatial error autocorrelation using the Moran's I test of the residuals obtained from the system GMM estimates for each time period. Three different weighting schemes are used to construct spatial weight matrices. The first one is a simple contiguity measure where a weight of 1 is assigned if two counties share a border, and zero otherwise. The second is a distance-based measure relying on the inverse of geographical distance between the centres of all counties. The last one is based on the combination of the first two weighting schemes. The results of the Moran's I test, which are robust across three spatial weight matrices considered, indicate that residual spatial dependence appears not to be a concern. As shown in Table 5.5, there is practically no evidence of spatial autocorrelation as we cannot reject the null hypothesis of no spatial error autocorrelation at the 5% level for most yearly observations. The one major exception is the 5% level for 1997. Estimates of the model omitting the year 1997, however, resulted in no substantive differences in the parameter estimates. In addition, the Moran's I test is applied to check for the presence of spatial dependence among residuals from the BG estimation, and the test results in all cases consistently suggest no problem of spatial error autocorrelation.

In summary, the results from estimating the dynamic panel models of employment consistently indicate that provision of highways has no significant impact on county private sector employment. Despite being fairly robust to changes in model specifications, this evidence is based on dynamic modelling frameworks that do not take into account the possibility of employment spillovers from highways located in other North Carolina counties. Thus, while the density of highway lane-miles is found to have no employment impact locally, an unresolved issue is whether neighbouring county highways matter. To investigate this, we turn to dynamic employment models that account for highway lane-mile density in neighbouring counties.

Table 5.5 Moran's I test for spatial autocorrelation

Year	System GMM specification (with strictly exogenous explanatory variables)			System GMM specification (with endogenous explanatory variables)		
	Contiguity weight matrix	Distance-based weight matrix	Distance-based contiguity weight matrix	Contiguity weight matrix	Distance-based weight matrix	Distance-based contiguity weight matrix
1986	0.274	- 0.079	0.223	0.163	- 0.170	0.092
1987	0.151	0.577	0.154	- 0.050	0.415	- 0.017
1988	1.329	0.868	1.360	1.284	0.862	1.300
1989	- 0.247	0.238	- 0.176	- 0.380	0.053	- 0.344
1990	- 0.550	- 0.118	- 0.508	- 0.421	0.018	- 0.358
1991	0.858	0.812	0.543	0.821	0.832	0.474
1992	1.591	1.267	1.543	1.778 *	1.511	1.743 *
1993	- 0.043	0.186	0.088	- 0.003	0.199	0.104
1994	1.113	1.069	1.015	1.109	0.987	1.024
1995	- 0.553	- 0.017	- 0.611	- 0.567	- 0.095	- 0.697
1996	0.759	0.689	0.414	0.863	0.774	0.534
1997	2.377 **	2.078 **	2.280 **	2.140 **	1.942 *	2.059 **

Note: * and ** indicate significance at the 10% and 5% level.

5.5.4 Employment spillovers from highway infrastructure

We attempt to capture spillover effects of highways by adding the current and lagged levels of highway lane-mile density in neighbouring counties to the dynamic employment model of equation (5.18), which can be rewritten as

$$\ln E_{it} = \alpha + \delta \ln E_{it-1} + \beta_0 \ln H_{it} + \beta_1 \ln H_{it-1} + \beta_2 \ln HO_{it} + \beta_3 \ln HO_{it-1} \quad (5.24)$$

$$\theta' \ln Z_{it} + \sigma' \ln Z_{it-1} + \mu_i + \tau_t + \varepsilon_{it}$$

where HO as a variable representing the density of highways in other counties: $HO_{it} = \ln(\sum w_{ij} H_{jt})$ where i indexes the own-county, t indexes time, j indexes other counties in the dataset, and w_{ij} denotes the elements of a spatial weight matrix W that defines the connecting counties or geographic neighbours.

We consider four different definitions of the W matrix. The matrix $W1$ is based on a simple contiguity definition where $w_{ij} = 1$ if counties i and j share a common border and zero otherwise. The matrix $W2$ is also restricted to take account of spatial spillovers among immediately adjacent counties, but the weights are assigned with respect to the degree of connectivity by major highways between any pair of contiguous counties. In particular, the weighting scheme of $W2$ is a weighted average of the number of major highways crossing the border.⁴¹

⁴¹ Major highways include interstate highways, US federal highways and state highways. The data are obtained from a map of North Carolina's primary road system published by the North Carolina Department of Transport (NCDOT) in 2005. In constructing the weight matrix, we exclude cross-border highways that were completed and open to traffic during the years 1998-2004. Detailed information on 750 sections of 349 major highway projects constructed over the period 1990-2004 are available in Hartgen (2004) who constructed this extensive database using NCDOT records and contacts with metropolitan planning organisations in major regions.

Given that highways in non-geographically contiguous counties could also produce spatial spillover effects, the last two weight matrices are concerned with the importance of spatial externalities from highway lane-mile density in all other counties in North Carolina. For the matrix **W3**, the elements w_{ij} are set equal to the inverse of the distance between the counties, with a distance decay effect. Finally, we consider the possibility of negative economic spillovers from highway infrastructure due to competition for mobile factors of production among counties with similar urban characteristics, as suggested by Boarnet (1998). Thus, the matrix **W4** is constructed to measure cross-county similarity in urbanisation, with greater weight assigned to any pair of counties with similar population density. Formally, the weights in the matrix **W4** are defined as:

$$w_{ij} = (1 / |popden_i - popden_j|) / S_i \text{ where } S_i = \sum 1 / |popden_i - popden_j|$$

To construct this weight matrix, we use population density data for the year 1990 that is approximately in the midpoint of our sample.

The estimation results are shown in Table 5.6, which reports results based upon system GMM estimation. For brevity, we present only the regression results for lagged employment and highway density variables. All specification tests do not reject the validity of these system GMM estimates, either under the assumption of strictly exogenous explanatory variables or taking into account the potential endogeneity of highways and several other regressors. The estimation results for own-county highway density variables are similar to what was previously found when spillover effects are omitted (Table 5.3). For alternative model specifications, the current and lagged levels of own-county highway density are individually and jointly significant, confirming the earlier evidence of no employment effect from highways located within a county's border.

Turning to neighbouring highway variables, the results based on all the weight matrices reveal the existence of employment spillovers from highways in other counties. For the first three matrices **W1**, **W2** and **W3**, although the individual coefficients on highway density in neighbouring counties are not statistically significant (perhaps due to collinearity), the Wald tests clearly indicate their joint significance at the conventional levels. Focusing on the long-run coefficient for the density of highway lane miles in

neighbouring counties, the results consistently show that highways create long-run negative employment spillovers. However, the magnitude of the spatial spillovers varies across specifications, as expected because of differences in the definition of the neighbour relationship between counties.

Table 5.6 System GMM estimates of employment spillovers from highways

Variables	System GMM1 (with strictly exogenous explanatory variables)				System GMM2 (with endogenous explanatory variables)			
	W1 Binary contiguity	W2 Connectivity by highways	W3 Inverse distance	W4 Similarity in population density	W1 Binary contiguity	W2 Connectivity by highways	W3 Inverse distance	W4 Similarity in population density
E (-1)	0.958 *** (30.75)	0.935 *** (26.13)	0.951 *** (28.83)	0.970 *** (33.74)	0.976 *** (97.17)	0.972 *** (90.83)	0.977 *** (107.40)	0.979 *** (100.55)
H	-0.014 (-0.49)	-0.015 (-0.52)	-0.018 (-0.61)	-0.019 (-0.65)	-0.002 (-0.04)	-0.009 (-0.15)	-0.024 (-0.39)	-0.025 (-0.40)
H (-1)	0.021 (0.76)	0.026 (0.93)	0.024 (0.85)	0.023 (0.80)	0.007 (0.12)	0.013 (0.21)	0.023 (0.40)	0.023 (0.38)
HO	-0.016 (-0.27)	0.012 (0.23)	0.235 (0.89)	-0.181 ** (-2.27)	-0.059 (-0.90)	-0.022 (-0.39)	-0.042 (-0.15)	-0.199 ** (-2.52)
HO (-1)	-0.001 (-0.01)	-0.043 (0.81)	-0.266 (-1.02)	0.177 ** (-2.30)	0.039 (0.61)	-0.001 (-0.03)	0.008 (0.03)	0.195 *** (2.62)
<u>Test of joint significance</u>								
H	0.375	0.231	0.317	0.503	0.768	0.835	0.923	0.910
HO	0.081	0.028	0.000	0.072	0.033	0.006	0.000	0.031
<u>Long run effect</u>								
H	0.172	0.175	0.134	0.128	0.196	0.126	-0.018	-0.097
HO	-0.404	-0.472	-0.645	-0.138	-0.807	-0.849	-1.506	-0.161
AR2	0.148	0.137	0.144	0.153	0.230	0.201	0.198	0.227
Sargan	0.254	0.297	0.270	0.288	1.000	1.000	1.000	1.000
Diff Sargan	0.978	0.997	0.990	0.999	1.000	1.000	1.000	1.000

Note: The results reported are from one-step GMM estimators, which are consistent with possible heteroscedasticity. Numbers in parentheses below the coefficients are t-statistics, which are heteroscedasticity consistent. ** and *** indicate significance at the 5% and 1% level. For system GMM1 specifications, we use three lagged levels of employment as instruments for GMM estimations in differenced equations as described in Section 3. In estimating system GMM2 specifications, we use only two lagged levels of all endogenous variables in time period t-2 and t-3 as instruments in differenced equations in order to reduce the number of instruments and thereby avoid potential overfitting problems. P-values are reported for the Wald test of joint significance, the Arellano and Bond test of second order autocorrelation, the Sargan test, and the Difference Sargan test.

Regardless of the variations in the strength of the negative spillovers, these findings provide evidence suggesting that spatial spillovers in highways' economic impacts could be driven by two important sources. The first is the network characteristics of highway infrastructure. The results based on the matrix **W2** which contains information on highway network connectivity imply that reduced transport costs (and possibly associated productivity effects) in one county more likely spread out to neighbouring counties that have good connections to the county that receives the increased lane-mileage. As labour saving and output expansion effects associated with

productivity improvements can work simultaneously in opposing directions, the *a priori* expectation of a net employment impact from highway improvements could be either positive or negative. In our case, the net negative employment effect of neighbouring counties' highways implies that the labour saving effect may have a dominant role.

The second reason as argued by Boarnet (1998) is that highway infrastructure investments likely alter the comparative advantage across locations, drawing economic activities from elsewhere to those regions with such investments taking place. The findings based on the spatial matrices **W3** and **W4** lend support to this idea. While the distance weighted matrix **W3** likely captures the widespread productivity effects that are posited to diminish with distance, it could also account for the role of geographic proximity in the migration of factors of production. Compared to a more distant county, a geographically nearby county is potentially a stronger rival in competing for mobile labour and capital. Moreover, the results based on the matrix **W4** are consistent with those found in Boarnet's empirical work which reports negative output spillovers from street and highway capital in California counties. Using the dataset for North Carolina, this study reveals evidence of negative employment spillovers from highways across counties of similar population density, confirming that similarity in urbanisation could facilitate spatial competition in factors of production and future private sector investments in a local economy.

While the evidence on the existence of spatial spillover effects of highways on county economic performance is in line with those reported elsewhere in the literature (e.g. Rephann and Isserman, 1994; Boarnet, 1998; and Chandra and Thompson, 2000), we directly address the economic policy of enhancing employment. Since the density of highway lane miles is found to have no impact on private sector employment locally but create negative spillover effects across North Carolina counties, this implies net negative effects on employment from highway infrastructure. This finding is consistent with previous studies for the United States which have revealed the negative employment effect of highways more broadly at the national level (Nadiri and Mamuneas, 1998; and Pereira, 2000) and the state level (Cohen and Paul, 2004). While these studies point to the substitution of reduced transport costs for labour services, this research suggests that the negative association between highway capital and employment when observed at the

state level could be partly attributable to the redistribution of jobs from one county to another.

5.6 Summary and discussion

The findings reported in this chapter cast some doubt on the conventional wisdom that expansion of highway infrastructure is an effective method of boosting employment. Based on panel data for 100 North Carolina counties from 1985 to 1997, the results obtained from several alternative modelling frameworks consistently suggest that highway investments, measured in terms of the density of highway lane miles, do not affect overall private sector employment within a county. The opposite conclusion would have been drawn if the dynamic adjustment of employment or the potential endogeneity of highways had not been taken into account in our empirical analysis. In the static specification framework, our results clearly reveal that estimates of highway infrastructure impacts on employment will have a positive and strongly significant impact on employment when either of these econometric issues is ignored. The results based on several dynamic modelling frameworks, which account more explicitly for lagged adjustment of employment, consistently show that there is no discernible effect from own-county highways on private sector employment. The coefficient of lagged employment is found to be fairly large and highly significant, confirming a non-negligible role of slow adjustment processes for employment.

When extending the dynamic panel model of employment to account for highways in other counties, the results suggest that provision of highway infrastructure, despite having no significant effect on employment locally, tend to produce negative employment spillovers across North Carolina counties. It is found that such spillovers could be driven by both network externalities of highway infrastructure and its role in altering the comparative advantage across locations which could in turn draw economic activities from regions with relatively poor highway infrastructure to those with better highway systems. For the latter, we find that potential competitors for mobile factors of production and future private sector investments in a local economy could be from geographically nearby counties as well as counties with similar urban characteristics.

One possible policy implication from this research is that additional provision of highways may not be an appropriate policy measure if the aim is to increase overall county employment. Like many types of public infrastructure, highways are certainly necessary, but may not be sufficient to foster job growth. It is also plausible that the effects of highways have already changed from what were previously occurring. As the highway systems nowadays are very extensive and increasingly saturated, additional highway investments in a mature economy may have no discernible development effects. There could be potentially different effects from new highway links as opposed to just capacity enhancements of existing links, but we do not address this issue. However, highway improvements may still increase personal mobility and to some extent alter the comparative advantages across regions, leading to a relocation of employment rather than stimulating employment growth overall. Even though reduced transport costs associated with highway improvements could occur, growth in overall production and hence the demand for employment which would arise from productivity improvements might balance out the substitution away from labour services, leaving the net impact of highways on local employment within a county unchanged. However, these notions overlook an economy's industrial structure and hence the possibility that the effects from highways on employment can vary considerably among various sectors. Highway investments may benefit some sectors, but also result in employment losses in others. This will certainly affect the overall employment impact.

In the next two chapters we present spatial econometric analyses that address the issue of causality more explicitly using data at the state level. The temporal dynamics of the causal relationship between highway and employment growth are modelled in a panel vector autoregressive framework with the possibility of cross-state employment spillovers from highways also being taken into account. An innovative approach for dealing with the problem of spatial autocorrelation in dynamic panel models is applied and demonstrated. Chapter 6 analyses data for the aggregate state economy, whereas Chapter 7 presents the disaggregate analysis by sector that is set out to examine whether and how additional investments in highways could affect the structure of employment in US private industries.

Chapter 6

Highway Infrastructure and State-level Employment: A Causal Spatial Analysis

6.1 Introduction

The provision of transport infrastructure has been hypothesised to have economic development impacts that may not only exist in an area directly served but could also spatially extend to neighbouring areas. However, it is also possible that both regions with a growing economy or, alternatively, lagging economic performance, could both be targets for public investment in transport infrastructure, albeit for different reasons. A major reason for the latter investment is to stimulate employment, while the former is intended to provide infrastructure for growing employment. Little research effort to date has been given to examine the causal direction of transport infrastructure and employment.

This chapter attempts to contribute to the literature by examining the existence and direction of causal links between highway infrastructure investment and regional employment in the United States. In particular, we test for Granger causality between the regional supply of highway infrastructure, represented by the density of highway lane-miles, and private sector employment using panel data for the 48 contiguous states (excluding Alaska, Hawaii, and the District of Columbia). This analysis is also extended to examine the possibility of employment spillovers from highway investments in a Granger causality framework.

The next section reviews empirical studies exploring whether public infrastructure is endogenous to an economy using a variety of econometric approaches. In Section 6.3, we describe dynamic panel models for Granger causality testing and the estimation methodology applied in this analysis, followed by a discussion of data in Section 6.4. Section 6.5 presents the results obtained from the Granger causality tests, and Section 6.6 presents some robustness checks of our findings. We conclude this chapter in the final section.

6.2 Previous work on the endogeneity of public infrastructure

While the impact on economic development from infrastructure investments has been extensively studied in a macroeconomic or aggregate context over the past decades, research efforts to gain insights into the potential reverse causation of development on public infrastructure, particularly transport infrastructure, have been relatively limited. A simple approach used in the existing literature has been to estimate a single-equation model with public infrastructure specified as a function of economic development measures and other control variables. For example, Thompson et al (1993) estimate a simple cross-sectional model in which the growth rate in highway lane-mile density is related to population and job growth using data for Florida counties. They find that neither population nor jobs have significant impacts on growth in highway lane-miles. Rietveld and Boonsta (1995) and Rietveld and Wintershoven (1998) study the determinants of transport infrastructure supply for European regions using a single-equation framework, and provide evidence of a reverse link from regional development to transport infrastructure. Population density and the level of gross domestic product per capita are found to have positive and significant effects on the regional supply of transport infrastructure.

While these single-equation studies have focused on the reverse relationship, another stream of research has considered simultaneity between public infrastructure and economic development in a multi-equation framework. Most studies based on this approach have attempted to identify the effects of infrastructure investment while dealing with the issue of causality. Duffy-Deno and Eberts (1991), for example, estimate

simultaneous equations to test if public infrastructure (broadly defined) affected economic growth across 28 US metropolitan areas during the first half of the 1980s, and find that causality between infrastructure and personal income runs both ways. More recent studies have used a vector autoregression (VAR) approach to explicitly account for the dynamic feedbacks among infrastructure and other variables by treating all variables as jointly determined. Based on U.S. national time-series data, the VAR estimation by Pereira and Flores de Frutos (1999) reveals that public capital is productive but its contribution to private sector output is substantially smaller than that found in the work of Aschauer (1989). However, their estimated results also confirm the endogeneity of public capital. Its growth rate is found to be positively related to the growth rate of output lagged by one and two periods and negatively related to the growth rate of employment lagged by one period. A subsequent analysis by Pereira (2000) using a VAR analysis shows that changes in the evolution of highways and streets are positively related to lagged changes in private output and negatively to lagged changes in employment, adding to the consistency of the results using VAR models. Otto and Voss (1996) analysing annual data for Australia in the VAR framework find a significant effect of aggregate public capital on output. In contrast to the VAR studies using US national data, however, Otto and Voss find no evidence that public capital is endogenous in the Australian context.

Another widely used approach to sort out the direction of causality (or at least precedence) between public infrastructure and economic development has been to perform a Granger causality test. Examples of studies applying this approach are Tatom (1993) and Sturm et al (1999). Empirical work by Tatom (1993) analyses U.S. annual data covering the period 1949 to 1991, and reveals a reverse Granger causal relationship between public capital and business-sector total factor productivity (TFP). Tatom finds that an increase in public capital does not temporally precede a change in private sector productivity, whereas TFP growth in the private sector Granger causes public capital formation. Sturm et al (1999) finds that in the Dutch economy there was a two-way directional relationship between transport infrastructure investment and economic growth during the second half of the nineteenth century. Based on time-series data from 1853 to 1913, the results indicate that not only have investments in transport

infrastructure in the Netherlands contributed positively towards GDP growth, but increases in GDP also negatively influenced transport infrastructure over this time period.

Some previous work in the literature has tested for Granger causality between infrastructure and economic development using panel data. Basically, an application of the Granger causality test requires a long time series, such as in the work by Tatom (1993) and Sturm et al (1999). However, the combination of time series and cross-sectional information allows the use of a Granger causality test with panel data sets where the availability of time series observations for each cross-sectional unit is fairly short. In addition, an increase in the number of observations generates additional degrees of freedom, thereby improving the efficiency of Granger causality tests. Stephanedes and Eagle (1987) perform Granger causality tests to investigate the dynamic relationship between highway construction expenditures and county employment in Minnesota. Using pooled time-series and cross-sectional data for all 87 counties over the years 1964 to 1982, they find that total county employment does Granger cause highway expenditures, but there is no causality running in the opposite direction. A study by Seitz (1995) using panel data for 99 large cities in Western Germany from 1980 to 1989 employs the Granger causality test to analyse the causal links between public infrastructure and private sector economic activity. Unlike the US studies by Stephanedes and Eagle, Seitz finds evidence suggesting that public infrastructure induces local employment growth, whereas the reverse causality is not statistically significant. A more recent study by Zhang and Fan (2004) has sought to test for Granger causality between agricultural productivity growth and road infrastructure development, using data from 1971 to 1994 for 290 rural districts in India. However, the results provide weak support for the notion of bi-directional causality between infrastructure development and productivity growth. Zhang and Fan find that Granger causality runs from road density to total factor productivity, but not vice versa.

Summing up, the research evidence on the question of whether infrastructure subsequently induces growth or growth influences infrastructure has been mixed. Although few studies have found economic growth temporally affected by public infrastructure provision, there is a considerable degree of consistency in that many studies find the causal relationship is reversed or even works in both directions. In this

analysis we follow Stephanedes and Eagle (1987), Seitz (1995), and Zhang and Fan (2004) in implementing the Granger causality test with panel data. Apart from allowing the use of a short time series, another advantage of testing for Granger causality in the panel regression framework is to control for heterogeneity across individual cross-sectional units. However, the presence of lagged dependent variables on the right hand side of typical Granger-causality models introduces substantial complications in model estimation. In particular, the difficulty arises from the correlation between such lagged variables and individual specific effects. Seitz (1995) and Zhang and Fan (2004) estimate their dynamic panel models using the Generalized Method of Moments (GMM) technique.

In addition, the cross-sectional and panel data models estimated in most studies reviewed above have a restrictive assumption that the disturbances are uncorrelated across spatial observations. Although many of these studies employ aggregate data for contiguous regions, there is a possibility that spatial dependence (i.e. the lack of independence among cross-sectional observations in spatial data) may exist. Unfortunately, this issue of spatial dependence has been typically ignored in the literature, which could lead to potentially misleading results. In the next section, we describe our dynamic panel models to test for Granger causality between highway infrastructure and employment, and discuss estimation techniques applied in this analysis. We also describe spatial econometric methods that are applied to deal with the potential problem of spatial dependence, which is our point of departure from previous work in this area.

6.3 Methodology

6.3.1 A Granger causality test in a panel vector autoregressive framework

In a seminal paper by Holtz-Eakin et al (1988), a traditional time-series model for Granger causality tests was adapted to panel data. In particular, the authors introduced a vector autoregressive model with individual effects allowing for heterogeneity across cross-sectional units through an individual-specific intercept. Given the importance of controlling for unobserved time-variant attributes that could affect all states in the same

manner, we consider in this analysis the following dynamic panel models with time dummies and state-specific effects:

$$\Delta E_{it} = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p} + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \quad (6.1)$$

$$\Delta H_{it} = \gamma_0 + \sum_{p=1}^m \phi_p \Delta H_{i,t-p} + \sum_{p=1}^m \theta_p \Delta E_{i,t-p} + \xi_i + \nu_t + \mu_{it} \quad (6.2)$$

where the variables ΔE and ΔH denotes growth rates of employment in the entire private sector and the density of highway lane miles respectively, which are obtained by taking the first difference of their natural log levels. The subscripts i and t index states and time periods respectively, and ε_{it} and μ_{it} are white noise residuals. The number of lags is m , which is specified to be identical for all variables. Time dummies are η_t and ν_t , accounting for any unobserved shocks that are common to all states but vary across time, whereas unobserved individual heterogeneity is controlled by the time-invariant state-specific effects (f_i and ξ_i).

To examine whether employment growth in a given state is temporally influenced by highway infrastructure investments taking place elsewhere, we add a variable that captures cross-state spillovers from highways to the employment equation (6.1) which can be rewritten as

$$\Delta E_{it} = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p} + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + \sum_{p=1}^m \lambda_p \Delta WH_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \quad (6.3)$$

The variables ΔWH represents growth in highway lane-mile density in other US states:

$$\Delta WH_{it} = \ln\left(\sum_{j \neq i} w_{ij} H_{j,t}\right) - \ln\left(\sum_{j \neq i} w_{ij} H_{j,t-1}\right) \quad (6.4)$$

where i indexes a state under investigation, j indexes other states in the dataset, and w_{ij} denotes the elements of a spatial weight matrix $\mathbf{W}$ that accounts for geographical proximity which is usually considered as the primary reason for the existence of spillovers. We consider two definitions to define our spatial weight matrices. The first is based on a binary contiguity matrix $\mathbf{W}_{\text{bin}}$ such that w_{ij} is set to one if states i and j share a border and zero otherwise. To account for higher-order spillovers effects, we specify the distance-decay matrix $\mathbf{W}_{\text{dis}}$ that includes the density of highway lane-miles in all other

states. The elements w_{ij} are set equal to the inverse of the squared distance between the states, given that geographical spillovers in highway impacts decay with distance.⁴²

To test whether highways Granger cause employment simply involves estimating the employment equation (6.1) and testing the joint hypothesis that $\beta_1 = \beta_2 = \beta_3 = \dots = \beta_m$ are equal to zero. If this null hypothesis is rejected, then highways can be said to Granger cause employment. The spatial spillover effects of highways on employment can be said to exist if the joint significance test indicates that all the coefficients of lagged lane-mile density growth in other states are significantly different from zero ($\lambda_1 = \lambda_2 = \dots = \lambda_p = 0$). Similarly, Granger causality from employment to highways can be said to exist if we can reject the hypothesis that all the coefficients of lagged employment in the highway equation (6.2) are equal to zero.

Granger causality test results may depend crucially on the choice of lag specification, and it is not advisable to rely on an arbitrarily chosen lag length. For each equation, we initially consider the maximum lag order of 3 years and determine the optimal lag specification based on a combination of sequential test, Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQ). While the chosen maximum lag order of three could be justified by likely anticipation effects, we also experimented with a maximum lag order of five. The optimal lag length is not found to be longer than three in all cases; we therefore choose the models with common lags up to 3 years to report the causality test results.

6.3.2 Estimation issues

The correlation between lagged dependent variables and time-invariant state specific effects in both employment and highway equations causes the problem of endogeneity that requires special attention and appropriate treatments. Our empirical implementation relies on the system GMM estimation framework. A first-differenced version of the GMM estimator might be viewed as an alternative because our panel dataset does not contain highly persistent time series. However, the system GMM estimator could provide more efficient estimates because it combines moment conditions obtained from equations in

⁴² The binary contiguity matrix W_{bin} is row-standardised such that the sum of row elements is equal to unity. However, the standardisation is not carried out for the distance-decay matrix W_{dis} since the absolute distance has a meaningful interpretation in our context.

first differences with additional moment conditions exploited from equations in levels. To avoid the problem of overfitting due to the use of too many moment conditions, we use a restricted set of instruments for GMM estimates.⁴³ In addition, we perform several specification tests to ensure that instruments used in the system GMM framework are valid. These include the Arellano-Bond test for serial correlation, the Sargan test for overidentifying restrictions, and the Difference Sargan test. Of particular importance for the system GMM estimation is the Difference Sargan test that assesses the validity of additional moment conditions in the levels equations. While these specification tests are generally concerned with the exogeneity of instruments, we test for instrument relevance of the level instruments used in the first difference equations as well as the first-difference instruments used in the levels equations by regressing each of the endogenous variables on its corresponding instruments and time period dummies. The *F* statistics from the joint significance test for the instruments are used to examine whether the problem of weak instruments is a concern in our system GMM estimations.

Another estimation issue is the potential for spatial dependence in regression residuals. We perform the Moran's *I* test of residual spatial dependence for each time period. The elements of the spatial weight matrix are simply based on contiguity in that a weight of 1 is assigned if two states share a common boundary, and zero otherwise. The matrix is row-standardised such that the row sum equals unity. Expressions for the expected value and the variance of the Moran's *I* statistic under a normal approximation (Cliff and Ord, 1981; pp. 202-303) are used to determine statistical inference for the Moran's *I*. The dynamic panel estimation methodology described above could be biased and inconsistent if the standardised Moran's *I* statistics indicate the presence of spatial error autocorrelation. Ignoring this issue would lead to serious problems of model misspecification.

To overcome the problem of spatial dependence, one approach is to rely on spatial panel estimation methods, which have increasingly received attention in recent years (e.g. Kelejian and Prucha, 1999; Elhorst, 2003; Druska and Hoxby, 2004; Baltagi and Li, 2006;

⁴³ The number of instruments is set to three for GMM estimations in differenced equations in that we use three lagged levels in time period *t*-2, *t*-3 and *t*-4 as instruments, while we use one period lagged first-differences of variables for GMM in levels equations. The results reported in this analysis are based on a one-step robust system GMM estimator, which is consistent with possible heteroscedasticity. For inference on the coefficients, one-step GMM estimates have been considered to be more reliable than GMM estimates in the two-step version (see Arellano and Bond, 1991; Blundell and Bond, 1998, 2000).

Kapoor et al., 2007). However, estimation methods that are robust to spatial dependence in the error terms and that account for the additional econometric complications of dynamic panel data models are less well developed, and their applications are restricted by the complexity and the limited availability of practical tools.⁴⁴ In this study, we employ an alternative approach to dealing with the problem of spatial autocorrelation. This involves filtering out spatial dependence embedded in spatially autocorrelated variables and applying estimation methods that are based on the assumption of cross-sectional independent errors to variables that are free of spatial autocorrelation.⁴⁵ Badinger et al (2004) recently applied this two-step estimation procedure using dynamic panel regressions to estimate regional convergence in the European Union. An estimation strategy that explicitly incorporates spatial dependence in the panel VAR model is also considered as a robustness check. The spatial filtering technique adopted in this analysis is briefly described in the next section.

6.3.3 Getis's spatial filtering approach⁴⁶

We utilise the spatial filtering method as devised by Getis (1990, 1995) that relies on the G_i local spatial autocorrelation statistic (Getis and Ord, 1992):

$$G_i(d) = \frac{\sum_j w_{ij}(d)x_j}{\sum_j x_j}, i \neq j \quad (6.5)$$

where w_{ij} are the elements of the binary weight matrix with ones for all links being within distance d of a given i and zero for all other links. The filtering is based on the comparison between the observed value of $G_i(d)$ and its expected value that represents the realisation of the variable X at a location i when no autocorrelation exists. Let x_i be an original variable with spatial dependence embedded in it. The filtered variable (x_i^F) can be obtained as

$$x_i^F = \frac{x_i \left[\frac{\sum_j w_{ij}(d)}{n-1} \right]}{G_i(d)} \quad (6.6)$$

⁴⁴ For recent contributions on spatial dynamic panel data estimation, see Elhorst (2001), Mutl (2006)

⁴⁵ See Getis and Griffith (2002) for a recent review of filtering techniques in spatial regression analysis.

⁴⁶ An alternative filtering technique, which is based on an eigenfunction decomposition associated with Moran's I statistics, is developed in Griffith (2000). Given its similar effectiveness we use the Getis filtering approach which is simpler to implement (Getis and Griffith, 2002).

where the expression in the bracket represents the expected value of the $G_i(d)$ statistic and n denotes the number of observations. The original value x_i and the filtered variable x_i^F will have the same value if there is no autocorrelation at i with distance d . As such, the difference between x_i and x_i^F represents a spatial component which is filtered out from the original variable.

A practical issue when applying this filtering approach is to identify an appropriate choice of distance d within which nearby geographical observations are spatially dependent. If an appropriate distance d is chosen, there will be no spatial autocorrelation in a filtered variable. We use the criterion suggested by Getis (1995) in that the value represents a distance within which spatial dependence is maximised and corresponds to the maximum absolute sum of the standardised G_i statistics for all observations of a variable.

6.4 Data

The database employed consists of state-level data for the 48 contiguous US states, covering the period 1984 to 1997. Data for employment by place of work for the entire private sector are collected from the Regional Economic Information System (REIS), which is compiled by the US Department of Commerce, Bureau of Economic Analysis (BEA). The availability of highway lane-mile data allows the use of highway lane-mile density, measured as roadway lane-miles per square miles of the region, to account for regional differences in the coverage and capacities of highway network supply. Lane-mile data was compiled from the Federal Highway Administration *Highway Statistics* series.⁴⁷ State data on lane-miles are available in aggregate and disaggregated by type of roads, including interstate highways, arterial roads, collector roads, and local roads. This enables us to perform Granger causality tests using aggregate data on road types as well as to examine whether the causal pattern differs across various road categories. Roadway lane-mile data for Alaska and Hawaii are not included.

Figure 6.1 displays the time series for employment and roadway lane miles data for the 48 contiguous states. Overall employment in the private sector grew very rapidly

⁴⁷ This data is the same series used by Noland (2001).

by about 32.6% from 1984 to 1997. While time-series for lane miles both in aggregate and disaggregated by road type also tend to exhibit upward trends over the 13 years of the sample, a major exception is the case of collector lane miles which tend to decline over time with approximately a 1.5% reduction overall (see Figure 6.1d). This downward trend is probably due in part to reclassification as arterials for which roadway lane miles are found to increase steadily over the period by about 11.8%.⁴⁸ Given this opposite trend, using data for either arterial or collector lane miles separately to estimate the models could yield potentially misleading results. Therefore, we combine lane miles of arterial roads with those of collector roads so as to measure the density of lane miles for *non-interstate major roads*. This also allows us to analyse and explore likely differences in the causal effects between major highway systems that are designed to provide mobility for interstate travel and those primarily serving intrastate travel. By taking the reclassification into account, we find that the aggregate lane-mile stock for these major roads grew by about 3.1% over the period 1984-97 (see Figure 6.1e).

In addition to the time trends, it is also of interest to explore if there is some degree of spatial interdependency in employment growth as well as in lane-mile density growth that would exist in our spatial data. Table 6.1 shows the Moran's *I* coefficients used to measure the extent of spatial correlation for employment growth (ΔE) and highway growth (ΔH) variables for each year of our sample. As one would expect, growth in private sector employment exhibits very strong spatial dependence as the standardised Moran's *I* coefficients are very highly significant for most sample years. The positive values of Moran's *I* suggest that nearby states tend to have similar employment growth. The global pattern of spatial dependence varies from one year to another. In particular, the spatial dependence tends to reach its maximum value in 1990-91.

⁴⁸ It should be noted that the decline in collector lane miles is also likely because some other collector roads were downgraded to lower order roads (e.g. local roads and streets). Nevertheless, the negative correlation coefficient between growth in collector lane miles and growth in local roads is relatively small (-0.11), compared with that between growth rates of arterials and collectors (-0.33).

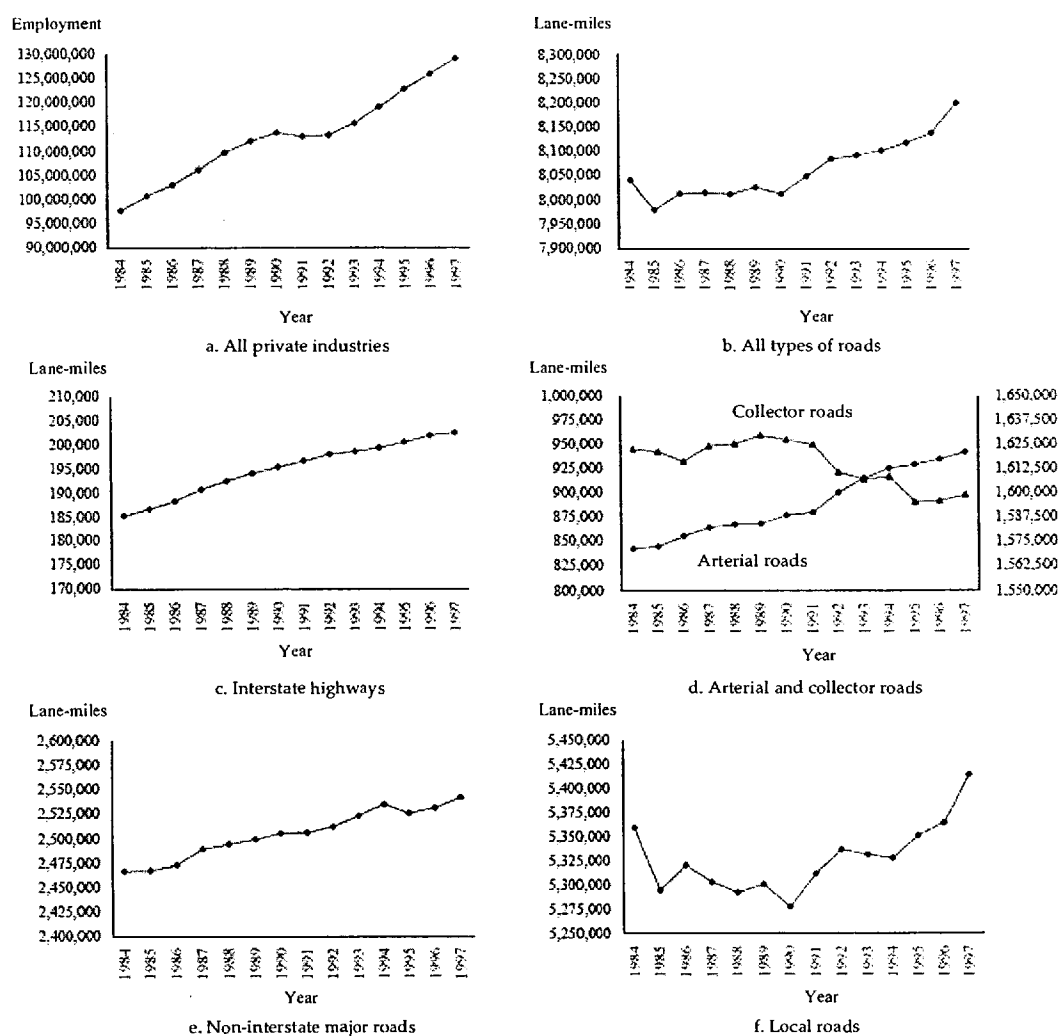


Figure 6.1 Private sector employment and roadway lane miles in the 48 contiguous US states, 1984-1997

In contrast, we do not find similar Moran's I test results for the highway variables. As can be seen in Table 6.1, there is practically no evidence of spatial correlation for all roads and each of the road categories over the sample period. Cross-boundary road construction projects and the need for additional roadway capacity could mean that there is spatial correlation amongst these variables. However, strong evidence of this at the state level emerges only for some years as shown by the Moran's I coefficients for local roads, arterials, interstate highways, and aggregate non-interstate major roads.

Table 6.1 Moran's I coefficient of spatial correlation in employment and highway growth

Year of data	ΔE	ΔH					
		All roads	Interstate highways	Arterial roads	Collector roads	Non-interstate major roads	Local roads
1985	3.537**	-0.230	0.382	1.043	0.090	0.915	-0.242
1986	4.338***	2.249**	0.033	0.639	-1.779*	0.800	2.761***
1987	1.731*	-0.656	0.046	1.070	-0.005	1.656*	-0.214
1988	3.923***	1.372	-0.366	-0.150	-0.299	-0.565	1.327
1989	4.483***	-0.173	-0.210	0.260	0.798	0.079	-0.139
1990	7.175***	0.001	1.216	2.025**	0.402	1.336	0.055
1991	8.071***	0.759	1.193	3.191***	0.349	0.159	0.603
1992	2.104*	-0.373	0.011	-0.269	-0.387	0.203	0.495
1993	4.512***	1.419	0.102	-0.131	1.622	2.537**	0.993
1994	5.641***	-1.013	0.120	0.691	0.777	1.300	-0.838
1995	4.427***	-0.532	2.751***	-1.908*	0.022	0.123	0.083
1996	4.445***	0.604	-0.297	-0.055	-1.177	-1.105	0.354
1997	3.733***	-0.315	0.722	-0.484	-0.767	-0.710	-0.239

Note: Standardised Moran's I statistics (z-scores) are reported based on the row-standardised weight matrix with first-order contiguity are reported. Significance at 10%, 5%, and 1% levels is indicated by *, **, and ***, respectively.

Granger causality tests require that the variables under examination are stationary so as to avoid spurious regression results. Using both time-series and cross-sectional information has a certain advantage in that the assumption of time stationarity can be relaxed for panel datasets that contain a large number of cross-sectional units over a short period of time. Given that the time dimension of our panel dataset is large relative to the size of cross-sectional units ($T = 14$, $N = 48$), we examine whether employment and highway variables are stationary using the panel data unit root test suggested by Levin et al (2002), which is generally considered to be a pooled version of the Dickey-Fuller test. The test statistics indicate that the null hypothesis of nonstationarity can be rejected for all the variables at the 1% level of significance. The results of the unit root tests are presented in Table 6.2.

Table 6.2 The results of the Levin-Lin-Chu test for panel unit roots

Variables	Lags		
	1	2	3
ΔE			
Private sector employment growth	-12.878***	-12.992***	-13.708***
ΔH			
Growth in total lane-mile density	-18.582***	-18.750***	-19.698***
Growth in interstate lane-mile density	-33.118***	-33.018***	-33.821***
Growth in arterial lane-mile density	-21.222***	-21.445***	-22.274***
Growth in collector lane-mile density	-20.910***	-21.121***	-21.972***
Growth in arterial and collector lane-mile density	-20.882***	-21.103***	-21.975***
Growth in local lane-mile density	-17.627***	-17.652***	-18.591***

Note: Constant and time trend are included in the models. *** indicates significance at the 1% level.

6.5 Results

6.5.1 Application of spatial filtering to deal with spatial autocorrelation

To test whether road lane-mile density growth Granger causes employment growth, we begin with estimating the employment equation (6.1) using data for all road lane-miles and those disaggregated by functional category. The results are reported in Table 6.3. Although the system GMM estimates reveal evidence of state employment growth temporally influenced by growth in non-local roads (i.e. interstate highways, arterial roads, and collector roads), we find that these results are subject to model misspecification problems due to spatial error autocorrelation. For all specifications, the Moran's I test applied to the residuals clearly reveals strong spatial autocorrelation in the regression residuals throughout the years of our sample period, as 89.39% of the standardised Moran's I statistics across all models are statistically significant at the 5% level (see Appendix A).

The inclusion of the variable ΔWH in the employment equation (6.3) would help to alleviate this problem since the presence of spatial error autocorrelation is largely due to the omission of relevant variables that might include neighbouring state road densities. However, the Moran's I test on residuals obtained from estimating the employment equation (6.3) still indicate that a strong degree of spatial autocorrelation in regression residuals exists across the model specifications considered.

Table 6.3 Test of Granger causality from highways to employment using original variables

Type of roads	Lags	First order contiguity matrix W_{lin}				Distance decay matrix W_{dis}			
		Lagged ΔH		Lagged ΔWH		Lagged ΔH		Lagged ΔWH	
		Long-run coeff.	Joint test (p-value)	Long-run coeff.	Joint test (p-value)	Long-run coeff.	Joint test (p-value)	Long-run coeff.	Joint test (p-value)
All roads	1	-0.048	0.115	-0.037	0.513	-0.048	0.121	-0.001	0.996
	2	-0.027	0.676	-0.102	0.440	-0.028	0.657	0.106	0.828
	3	-0.066	0.812	-0.251	0.124	-0.079	0.753	-0.141	0.134
Interstate highways	1	-0.106	0.052 [*]	-0.332	0.000 ^{***}	-0.108	0.054 [*]	-0.349	0.000 ^{***}
	2	0.045	0.005 ^{***}	0.010	0.001 ^{***}	0.058	0.004 ^{***}	0.276	0.000 ^{***}
	3	0.010	0.061 [*]	-0.457	0.000 ^{***}	-0.016	0.077 [*]	-0.282	0.000 ^{***}
Arterial roads	1	0.064	0.012 ^{**}	0.032	0.626	0.065	0.010 ^{**}	0.075	0.488
	2	0.033	0.034 ^{**}	0.175	0.372	0.035	0.032 ^{**}	0.184	0.647
	3	0.127	0.065 [*]	0.416	0.141	0.122	0.060 [*]	0.811	0.154
Collector roads	1	-0.066	0.003 ^{***}	0.162	0.176	-0.063	0.005 ^{***}	0.350	0.004 ^{***}
	2	0.047	0.002 ^{***}	0.259	0.191	0.051	0.003 ^{***}	0.428	0.011 ^{**}
	3	0.005	0.010 ^{**}	0.290	0.199	-0.001	0.010 ^{**}	0.579	0.000 ^{***}
Non-interstate major roads	1	-0.056	0.167	0.247	0.300	-0.054	0.152	0.469	0.074 [*]
	2	0.040	0.283	0.505	0.150	0.049	0.370	0.644	0.164
	3	0.054	0.007 ^{***}	0.756	0.192	0.027	0.508	1.393	0.002 ^{***}
Local roads	1	-0.026	0.229	-0.042	0.325	-0.026	0.232	-0.047	0.629
	2	-0.024	0.736	-0.128	0.153	-0.022	0.760	-0.065	0.830
	3	-0.077	0.928	-0.270	0.034 ^{**}	-0.054	0.900	-0.344	0.221

Note: Results are based on original employment and highway variables. p-values are reported for the joint significance test for Granger causality. The results from the Arellano and Bond test for second-order serial correlation, the Sargan test, and the Difference Sargan test, which are not reported here, do not reject the validity of instruments used in GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively.

Given that it is only employment growth that exhibits very strong spatial dependencies throughout the sample period, as demonstrated in the preceding section, it is likely that the presence of spatial autocorrelated residuals is primarily due to spatial correlation embedded in the employment data. Therefore, we apply spatial filtering to the employment variable. Due to the nature of the G statistic of Getis and Ord (1992) given in equation (6.5), the Getis's filtering approach requires that a spatial autocorrelated variable to be transformed has a natural origin and be positive. We thus filter employment data in levels (E) instead of the growth rate (ΔE).

For each year of the sample, we identify a critical distance d where spatial association of employment in nearby states is at a maximum. This is done by evaluating the absolute sum of the standardised G statistics for all states at a series of increasing geographical distances between the centroids of states, initially starting at a distance of 50 miles and proceeding by 50 miles increments up to 1000 miles. However, the spatial

autocorrelation G statistics are not available for the distances ranging from 50 miles to 300 miles because they are not sufficiently large enough to cover at least one nearest state for some states. As such, we compare the absolute sum of standardised G statistics among different distances from 350 miles to 1000 miles. The results, which are presented in Figure 6.2 for some selected years, indicate that for all sample years spatial dependence declines with distance and is maximised when distance d is equal to 350 miles. With the critical d value of 350 miles, filtered employment levels (E^F) for all states in each year are calculated from equation (6.6), and the filtered employment growth variable (ΔE^F) is obtained by first differencing the natural logarithm of E^F .

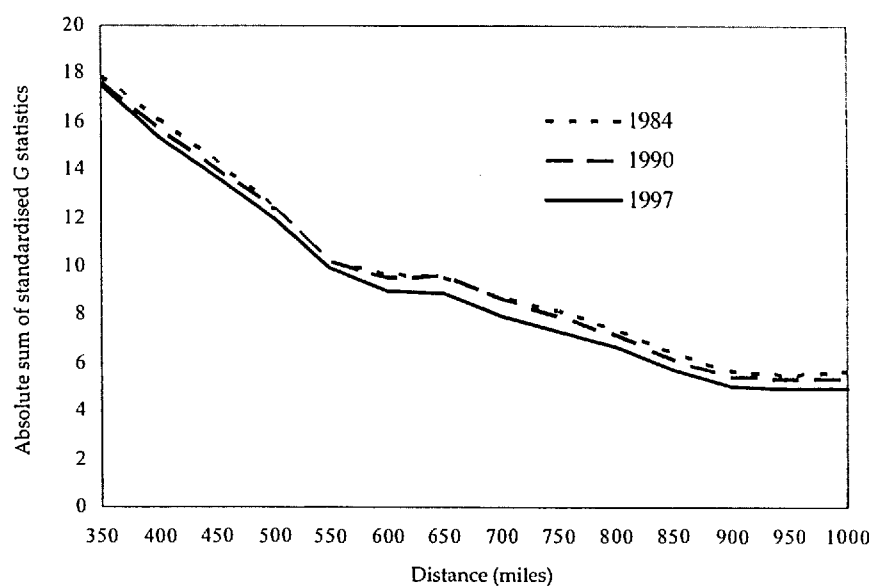


Figure 6.2 Absolute sum of standardised G statistics for state employment in 1984, 1990, and 1997

Prior to reestimating the models, we examine whether there remains spatial dependence embedded in the filtered employment growth variable (ΔE^F). The results reported in Table 6.4 indicate that the filtering technique performs fairly well in removing spatially correlated components from the original employment variable (ΔE) as the previously large values of standardised Moran's I statistics are considerably reduced.

Generally, we find that the ΔE^f variable is free of strong spatial autocorrelation for most years of observations.⁴⁹

Table 6.4 Moran's I test for original and filtered employment variables

Year of data	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ΔE	3.537	4.338	1.731	3.923	4.483	7.175	8.071	2.104	4.512	5.641	4.427	4.445	3.733
	***	***	*	***	***	***	***	*	***	***	***	***	***
ΔE^f	-0.811	-1.201	-0.761	0.030	-1.130	0.239	0.024	-0.840	-1.757	-1.112	-1.730	-2.212	-1.787

Note: Standardised Moran's I statistics (z-scores) based on the weight matrix with first-order contiguity are reported. Significance at 10%, 5%, and 1% levels is indicated by *, **, and ***, respectively.

Using the filtered employment and original highway variables we reestimate the employment equations (6.1) and (6.3) and test whether spatial autocorrelation exists in the regression residuals. The results of the Moran's I test illustrate that the problem of spatial autocorrelated errors has been effectively alleviated by the spatial filtering approach. For the employment equation (6.1) with spatial spillovers omitted, the Moran's I statistics are substantially smaller and significant at the 5% level for only 9.60% of all yearly observations (see Appendix A1). Similarly, the Moran's I test results do not indicate the problem of spatial error autocorrelation for the employment equation (6.3) that accounts for neighbouring states' highways. Since both equations yield similar results for the employment effect of highways within the state, we report and discuss Granger causality test results obtained from estimating the employment equation (6.3) with the filtered employment and original highway variables.

⁴⁹ While the filtering technique employed above is based on a simple binary weighting scheme, we also apply the same procedure to separate spatial dependence from the original employment variable (ΔE) but using a spatial weighting scheme based on distance decay. For all states within a radius of distance d from a given state i , $w_i(d)$ in equations 6.5 and 6.6 is redefined as the inverse of their distance to state i . The spatial filtering based on this distance-based weighting scheme yields very similar results. The critical d value is also found to be 350 miles for every year of observations and the Moran's I test results generally indicate no strong degree of spatial correlation in the corresponding filtered employment growth variable (ΔE^f). Given that the absolute values of the standardised Moran's statistics are relatively much higher than those reported in Table 6.4, however, we use the filtered employment growth variable obtained from the filtering procedure based on the binary weighting scheme to reestimate the employment equations.

6.5.2 Granger causality from highway infrastructure to state employment growth

Table 6.5 presents a summary of the main results of the Granger causality test for own-state and neighbouring states' highways based on the binary contiguity matrix W_{bin} and the distance-decay matrix W_{dis} . The joint significance test for lagged highway variables is reported along with long-run coefficients of highway variables. The long run coefficient of lagged ΔH is calculated as $(\beta_1 + \beta_2 + \dots + \beta_m) / (1 - (\delta_1 + \delta_2 + \dots + \delta_m))$ where β_m and δ_m are, respectively, the coefficients of highway and employment variables lagged m^{th} period. We calculate the long-run coefficient of lagged ΔWH in a similar manner. As shown in the last three columns, all the specification tests for the exogeneity of instruments generally do not reject the validity of moment conditions employed in the system GMM framework. The results from the test of instrument relevance (Table 6.6) also do not indicate that our GMM estimates are subject to weak instruments problems.

Beginning with the test of whether growth in highway lane-mile density Granger causes employment growth within a state's border, it is evident that for all roads there is no causality running from the density of total highway lane-miles to overall state employment growth. These results are counter-intuitive to the conventional wisdom that job growth is one of several economic development benefits stemming from constructing new highways or widening major roads. Breaking down the sample according to road category, however, we obtain evidence of the employment effect, and find noticeable differences in temporal associations. We would expect those roads that are expressly designed to provide linkages between regions (such as interstate highways and arterials) to have a stronger effect than functionally lower road categories, such as collector and local roads. The results in Table 6.5 tend to suggest that the density of lane-miles for non-local roads is a significant source of state-wide variations in private sector employment growth, whereas the importance of local road lane-miles is rejected in all specifications. For the latter case, this may explain the similar result for all roads, since local roads form the bulk of the total road network (i.e. total lane mileages for local roads account for 65% of those for all road categories in our sample).

Table 6.5 Granger causality from highways to employment:
Spatial filtering applied

Type of roads	Lags	Lagged ΔH		Lagged ΔWH		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
Binary contiguity matrix W_{bin}								
All roads	1	- 0.036	0.432	- 0.052	0.394	0.158	0.436	0.996
	2	0.039	0.441	- 0.046	0.503	0.941	0.573	1.000
	3	0.054	0.792	0.002	0.612	0.795	0.309	0.746
Interstate highways	1	- 0.072	0.032 [~]	- 0.144	0.090 ⁺	0.101	0.438	0.999
	2	0.059	0.030 [~]	0.099	0.055 ⁺	0.727	0.480	1.000
	3	0.070	0.022 [~]	- 0.174	0.017 [~]	0.675	0.302	0.995
Arterial roads	1	0.019	0.617	- 0.070	0.227	0.089	0.479	1.000
	2	0.013	0.952	0.026	0.459	0.744	0.418	0.983
	3	0.052	0.795	- 0.119	0.321	0.522	0.473	0.855
Collector roads	1	- 0.099	0.002 [~]	0.040	0.676	0.149	0.548	0.999
	2	- 0.043	0.039 [~]	0.037	0.895	0.737	0.596	1.000
	3	- 0.041	0.052 ⁺	0.131	0.520	0.603	0.445	1.000
Non-interstate major roads	1	- 0.148	0.001 [~]	0.033	0.814	0.183	0.443	1.000
	2	- 0.068	0.002 [~]	0.144	0.502	0.915	0.447	1.000
	3	- 0.050	0.007 [~]	0.199	0.694	0.777	0.572	1.000
Local roads	1	- 0.002	0.965	- 0.042	0.327	0.122	0.484	1.000
	2	0.051	0.435	- 0.043	0.321	0.977	0.555	1.000
	3	0.067	0.796	- 0.033	0.508	0.723	0.357	0.603
Distance decay matrix W_{dis}								
All roads	1	- 0.035	0.435	- 0.039	0.736	0.113	0.514	1.000
	2	0.036	0.422	0.058	0.906	0.678	0.503	1.000
	3	0.045	0.769	0.214	0.530	0.679	0.456	0.989
Interstate highways	1	-0.073	0.035 [~]	- 0.161	0.017 [~]	0.121	0.437	1.000
	2	0.070	0.022 [~]	0.083	0.020 [~]	0.680	0.376	1.000
	3	0.076	0.027 [~]	- 0.369	0.000 [~]	0.565	0.363	0.981
Arterial roads	1	0.017	0.650	- 0.123	0.123	0.089	0.430	0.998
	2	0.013	0.959	- 0.113	0.393	0.678	0.358	0.955
	3	0.053	0.803	- 0.113	0.738	0.489	0.509	0.886
Collector roads	1	- 0.097	0.002 [~]	0.161	0.220	0.143	0.441	0.938
	2	- 0.044	0.042 [~]	0.131	0.434	0.746	0.630	1.000
	3	- 0.047	0.054 ⁺	0.253	0.105	0.627	0.513	1.000
Non-interstate major roads	1	- 0.148	0.000 [~]	0.156	0.477	0.164	0.422	0.995
	2	- 0.066	0.004 [~]	0.198	0.830	0.991	0.460	1.000
	3	- 0.061	0.011 [~]	0.518	0.392	0.589	0.497	0.983
Local roads	1	- 0.001	0.966	- 0.005	0.534	0.097	0.590	1.000
	2	0.050	0.454	- 0.013	0.882	0.474	0.429	1.000
	3	0.061	0.815	0.077	0.869	0.600	0.512	0.999

Note: Results are based on filtered employment and original highway variables. *p*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively.

Table 6.6 Test of instrument relevance: Employment equation

Endogenous variable	First difference equations		Levels equations	
	F test	R ²	F test	R ²
Lagged growth in private sector employment (filtered)	71.22 (0.000)	0.493	103.62 (0.000)	0.457
Instruments used in GMM estimations	Lagged levels in time period t-2, t-3, and t-4		Lagged first-differences dated t-1	

Note: Numbers in parentheses are p-values corresponding to the test of the null hypothesis that coefficients of all instruments used are jointly zero.

Spatial filtering to account for the issue of spatial dependence noticeably affects some estimation results for non-local roads. Compared with the results without spatial filtering applied as shown in Table 6.3, Table 6.5 indicates no evidence of Granger causality for the density of arterial roads, and the long-run coefficients for collector roads which are also found to Granger cause employment become negative for all lag specifications. The results based on aggregate lane-mile data for arterial and collector roads (i.e. non-interstate major roads) also tend to reveal consistent evidence of Granger causality regardless of the number of lags included in the model when taking into account the spatial autocorrelation. Given the possibility of confounding or misleading results due to road reclassification as discussed in Section 6.4, we focus our discussion on the results based on aggregate data for arterial and collector roads for which interpretations are more meaningful.

The negative coefficients for the one-year lagged effect of interstate highways and for non-interstate major roads in all lag specifications might seem counterintuitive. In the case of interstate highways, this may simply represent a lagged response of the state economy gaining employment benefits from improved major transportation systems. If road improvements are considered as an improvement in production technology, additional investments in highway infrastructure could enhance the productivity of firms, allowing the use of a smaller quantity of labour inputs at existing output levels. This would be consistent with our finding of a short-run negative effect.⁵⁰ Longer run productivity growth associated with better highway systems could lead to increases in employment growth. In particular, higher productivity would not only enable existing

⁵⁰ This finding is consistent with cost-function studies (e.g. Seitz, 1993; Seitz and Licht, 1995; Nadiri and Mamuneas, 1998; and Cohen and Paul, 2004) that focus on the short run effects of public infrastructure on private sector production, and find that labour demand in the manufacturing sector decreases with an increase in highway infrastructure capital.

firms to expand their markets but induce more businesses to enter a region, which in turn leads to a rise in output and hence labour demand. Given these two opposing effects, the overall impact of improved highway infrastructure depends on which effect dominates. Due to adjustment costs associated with the process of obtaining a desired workforce size and the immobility of input factors in the short run, however, the positive effect on employment may exhibit considerable time lags. This could be the case in our analysis as the long-run coefficients for interstates are positive for the models with lags of order 2 and 3.

The extent to which aggregate lane-mile additions for arterial and collector roads could attract new establishments and generate expansion of employment activity may be relatively less substantial compared to the effect of additional interstate highway capacity. This is probably due to the fact that the functional characteristics and magnitude of services provided by intrastate road networks are limited to smaller scales. Our results suggest that for growth in non-interstate major lane miles the labour-saving effect persistently dominates regardless of lag specification, as indicated by our negative coefficients.

6.5.3 Test for employment spillovers from highway infrastructure

Turning to the causality test for employment spillovers from highways, the top part of Table 6.5 displays the results based on the binary contiguity matrix W_{bin} which measures the importance of lane-mile addition in *adjacent* states. While no evidence of spillovers is found when using aggregate lane-mile data for all functional road categories, we find negative spillovers from neighbouring interstate highways in the models with lag order of one and three. Indeed, these negative spillover effects are generally stronger than the employment effects of interstate highways located within the same state. For other road types, there appears to be no statistically significant evidence of either positive or negative spillovers. The Granger causality evidence of no spillovers from arterial roads is surprising. This is because one would expect major arterial roads, which are designed to provide linkages between cities and major towns as well as facilitate interstate and intercounty travel, to have spillover effects. The case of collector roads is somewhat analogous as the joint hypothesis for all lagged coefficients for the lane-mile density of

collector roads in adjacent states cannot be rejected in all specifications. Even using aggregate lane-mile data for arterial and collector roads does not reveal evidence of employment spillovers. The absence of spillover effects from local roads is not unexpected since the productivity effects of local infrastructure are very likely confined within local areas that they directly serve.

The use of the distance-decay matrix W_{dis} to take into account the density of highway lane-miles in *all other* states does not change the basic nature of the Granger causality results. As can be seen in the bottom part of Table 6.5, we find that only lane-mile additions for interstate highways generate spatial spillovers effects across neighbouring states. However, compared with the results from the contiguity matrix W_{bin} , the long-run coefficients for the ΔWH variable are considerably higher in most specifications when accounting for interstate lane-miles both in immediately adjacent and all other states. This implies that the negative spillover effects of interstate highways could spread out over a very large geographical area. Estimates without spatial filtering found positive spillovers from non-interstate major roads (see Table 6.3), thus this demonstrates the need to carefully control for spatial autocorrelation.

The estimated negative spillover effects of growth in the density of interstate highways is consistent with Cohen and Paul (2004) who reveal evidence of negative associations between intrastate labour demand in the manufacturing sector and highway capital stocks in neighbouring states. This finding also lends support to Boarnet's (1998) model of spatial competition on factor inputs associated with regional differences in public infrastructure, which predicts negative output spillovers. The state-level analysis by Cohen and Paul estimates a short-run cost function to empirically investigate the contemporaneous relationship between state highway capital and private production inputs. Thus, our analysis contributes to this strand of the literature by showing that the spatial spillover effects of major highway infrastructure could be persistent over time.

Previous work that examined spillover effects includes Dalenberg et al (1998). Their research relates annual state employment growth to highway infrastructure stock levels and other factors in a static panel framework and reports the existence of spillovers, but provides somewhat contradictory evidence that highway capital of neighbouring states tends to increase employment growth in the state. This is likely to reflect the fact

that productivity growth associated with improved highway infrastructure spatially extends to neighbouring states where the resulting output expansion and increased labour demand largely dominate the labour saving effect. This is consistent with our estimation results in Table 6.5 showing the overall positive impact of other states' interstate highway density when allowing only two-year lagged effects. Alternatively, as suggested by Boarnet (1998), a state where improved highways are located could also be a strong competitor for factors of production. Thus, there are two potential spillover effects that work in opposing directions. Empirically we find negative spillover effects; that is, highway infrastructure in neighbouring states diminishes own-state employment growth.

6.5.4 Causal and spatial effects of highways: Further corroboration of the results

Based on the employment equation (6.3) with spatial filtering applied, the results from estimating aggregate data for all types of roads indicate no evidence of Granger causality. However, the analysis of data disaggregated by functional road categories shows that state employment growth is temporally influenced by annual growth in the provision of interstate highways and non-interstate major roads. The test of Granger causality also provides evidence of employment spillovers from interstate highways. Since the extent of these temporal and spatial effects depend on the time lags considered, we determine the optimal lag structure that could capture or represent the overall effect of lane-mile additions for both interstate and non-interstate major roads. All information criterion considered (AIC, BIC, and HQ) yield slightly different results. While either 2-lags (BIC and HQ) or 3 lags (AIC) are found to be appropriate, we focus on the results based on the longest optimal lag order of three which has an advantage of taking into account the temporal dynamics of the effects for a longer period.

Given the magnitude of long-run coefficients in the three-year lag specification, we find that the long-run positive effect of interstates is higher than the long-run negative effect of non-interstate major roads. While these findings provide evidence supporting the view that additional provision of major highway facilities precedes increased employment growth in private industries, it is important to note that the effects may

differ markedly according to the type of roads. Despite not being the main focus in this analysis, the evidence on the net positive effect from major highways on employment growth also lends support to the hypothesis of induced travel associated with expanding highway capacity (e.g. Noland, 2001) as road utilization will increase as employment increases (i.e. there is likely some induced traffic growth represented by the increase in employment activity).

For the case of interstate highways, the results from the models with lag order of three suggest that additions of interstate lane-miles not only have a positive impact on employment growth within the state, but produce negative employment spillovers across states. As the magnitude of the latter effect is larger, however, the net long run impact of growth in the density of US interstate highways on private sector employment growth is negative. This evidence suggests that public investments in interstate highways could generate employment opportunities within a state served directly, but could also be associated with negative employment spillovers that can unintentionally lead to declines in state employment growth in private industries.

6.5.5 Granger causality from state employment growth to highway infrastructure

Results of the Granger causality test from estimating the highway equation (6.2) is summarised in Table 6.7. Throughout all model specifications, the results from the Arellano-Bond test of second order autocorrelation, Sargan test, and Difference Sargan test consistently indicate that the instruments used in system GMM estimations satisfies the required orthogonality conditions. The F statistics from the test of instrument relevance also does not reject the validity of the instruments as shown in Table 6.8. More interestingly, we find that the Granger causality test results in Table 6.7 do not exhibit the problem of spatial autocorrelation. Unlike the estimation of the employment equations with the original variables, the Moran's I test indicates practically no evidence of strong spatial autocorrelation in regression residuals, given that 92.42% of the standardised Moran's I statistics across all model specifications are not significant at the 5% level (see Appendix A). Although highly significant Moran's I values at the 1% level are found in a

single year of observations, 1991 for arterial roads and 1995 for interstate highways, we do not expect these to affect the estimations for the whole sample.

Table 6.7 Granger causality from employment to highways

Type of roads	Lags	Lagged ΔE		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
All roads	1	-0.046	0.357	0.528	0.300	0.900
	2	-0.018	0.374	0.959	0.231	0.989
	3	-0.050	0.627	0.677	0.267	0.237
Interstate highways	1	0.039	0.198	0.247	0.432	1.000
	2	-0.027	0.421	0.480	0.505	0.640
	3	-0.096	0.532	0.895	0.239	0.620
Arterial roads	1	-0.011	0.895	0.211	0.774	0.620
	2	0.177	0.123	0.831	0.603	0.953
	3	0.121	0.418	0.424	0.601	0.817
Collector roads	1	-0.124	0.341	0.188	0.462	0.381
	2	-0.002	0.381	0.541	0.794	1.000
	3	0.115	0.294	0.733	0.265	0.121
Non-interstate major roads	1	-0.105	0.186	0.362	0.805	0.481
	2	0.040	0.028**	0.998	0.906	0.936
	3	0.080	0.009***	0.874	0.895	0.783
Local roads	1	-0.019	0.793	0.589	0.440	0.943
	2	-0.039	0.631	0.972	0.488	0.806
	3	-0.080	0.671	0.748	0.430	0.986

Note: Results are based on original employment and highway variables. *p*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively. The detailed tables of individual coefficients estimated are provided in Appendix B.

Table 6.8 Test of instrument relevance: Highway equation

Endogenous variable	First difference equations		Levels equations	
	<i>F</i> test	<i>R</i> ²	<i>F</i> test	<i>R</i> ²
Lagged growth in total lane-mile density	29.81 (0.000)	0.419	15.04 (0.000)	0.348
Lagged growth in interstate lane-mile density	116.92 (0.000)	0.450	55.66 (0.000)	0.541
Lagged growth in arterial lane-mile density	61.61 (0.000)	0.611	45.18 (0.000)	0.564
Lagged growth in collector lane-mile density	112.75 (0.000)	0.510	11.51 (0.001)	0.521
Lagged growth in arterial and collector lane-mile density	65.73 (0.000)	0.501	8.38 (0.004)	0.514
Lagged growth in local lane-mile density	31.37 (0.000)	0.412	19.32 (0.000)	0.366
Instruments used in GMM estimations	Lagged levels in time period t-2, t-3, and t-4		Lagged first-differences dated t-1	

Note: Numbers in parentheses are *p*-values corresponding to the test of the null hypothesis that coefficients of all instruments used are jointly zero.

The joint significance test of lagged employment growth seems to suggest that Granger causality does not run from employment to road lane-mile density during the period of analysis. The null hypothesis that the coefficients of the lagged employment

variables are jointly different from zero is generally not rejected, either for all roads or for any individual road category. An exception is, however, the case of aggregate arterial and collector lane miles where there is some evidence of reverse causality. For the models with lag order of two or three, the results indicate that private sector employment growth precede growth in the density of aggregate lane miles for arterial and collector roads. The long-run coefficients for lagged employment growth are indeed positive, which implies that growth in the demand for travel associated with increases in employment activity could lead to new construction and capacity expansion of these major roads. This positive causal effect in the Granger sense can be confirmed by the fact that AIC and HQ suggest the longest optimal lag order of two. These findings reinforce the concern in the literature that investments in transport infrastructure could be endogenous to the economy; and therefore the causal relationship could also run in the reverse direction, as found in this analysis.⁵¹

6.6 Checks for robustness

The results thus far suggest that additions of lane miles for interstates and non-interstate major roads can have temporal dynamic effects on state employment growth. However, there is clearly no doubt that highway infrastructure is not the only factor contributing to employment growth. The evidence of the spatial spillover effects of interstate highways is also based on the two common and broad definitions of spatial proximity. More importantly, since the employment equations are estimated using spatially filtered employment variables, we are also concerned with the possibility that the filtering technique applied to remove spatial dependencies in the data may omit or filter away any important information which would affect our model estimates and inferences. This section provides some robustness checks to see whether the results we have reported in Table 6.5 would be affected by inclusion of control variables, some alterations to spatial

⁵¹ It is also of interest to address the question of whether highway investments in a given state are temporally influenced by neighbouring states' employment growth. However, adding a variable measuring employment growth in contiguous states induced problems of collinearity (correlation coefficient of 0.715) due to the very strong spatial interdependencies in employment growth between nearby states. Given the difficulty in disentangling the spatial effects, we excluded this analysis from the scope of this analysis.

weight matrices, and a change in estimation strategy for dealing with the issue of spatial autocorrelation.

6.6.1 Control variables

Although the presence of state- and time-specific effects as well as the autoregressive terms in the panel VAR models can substantially diminish the potential omitted-variables problem, we examine the robustness of our findings by adding lagged variables for growth in state output (ΔQ) and growth in private sector capital stock (ΔK) to the employment equation (6.3). These control variables are chosen on the basis of the classical theory of the firm. Similar to employment, both private sector output and capital variables are found to exhibit strong patterns of spatial correlation across the years of the sample. Before reestimating the models, we thus filter out spatial dependencies in the data using the same filtering strategy applied to the employment growth variable.⁵²

The results show that the evolution of both state output and private capital stock Granger causes the evolution of employment as expected, and that the sign of their long-run coefficients is also consistent with theoretical expectations. While the growth rate of private employment is found to be positively related to lagged output growth, the long-run coefficients of the lagged private capital variables are negative, suggesting that labour and private capital are substitutes. Despite the significance of these control variables, the findings on Granger causality for all the highway variables are basically unchanged. For an illustrative purpose, we report in Table 6.9 detailed estimation results for the cases of interstate and non-interstate major roads based on the model with the distance decay matrix.

⁵² Data on gross state product for the entire private sector are obtained from the Bureau of Economic Analysis (BEA). Data on private capital for individual states are not readily available. We estimate state private capital stocks by apportioning total U.S. private fixed capital to states, based on the ratio of returns to capital, represented by the total value added net of total labour costs (i.e. wages and salaries), for a given state to national total in each year. All data used to construct private capital estimates are from the BEA. Both state output and private capital are measured in 2000 dollars.

Table 6.9 A panel VAR model of employment growth with spatial spillovers and control variables

Variable	Interstate highways			Non-interstate major roads		
	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
ΔE_{it-1}	0.361 (6.10)	0.365 (6.57)	0.359 (6.57)	0.366 (6.24)	0.364 (6.68)	0.350 (6.56)
ΔE_{it-2}		0.110 (3.16)	0.071 (1.90)		0.113 (3.40)	0.073 (2.14)
ΔE_{it-3}			0.098 (2.26)			0.117 (2.42)
ΔH_{it-1}	-0.035 (-2.07)	-0.008 (-0.34)	-0.008 (-0.28)	-0.071 (-3.41)	-0.054 (-2.62)	-0.051 (-2.24)
ΔH_{it-2}		0.047 (3.10)	0.048 (2.86)		0.025 (0.80)	0.036 (1.26)
ΔH_{it-3}			-0.005 (-0.22)			-0.010 (-0.26)
ΔWH_{it-1}	-0.083 (-2.62)	-0.055 (-0.64)	-0.110 (-1.02)	0.089 (0.85)	0.101 (0.88)	0.132 (1.21)
ΔWH_{it-2}		0.068 (1.76)	0.008 (0.13)		0.014 (0.14)	0.054 (0.55)
ΔWH_{it-3}			-0.078 (-2.78)			0.103 (2.12)
ΔQ_{it-1}	0.228 (2.73)	0.193 (2.22)	0.286 (2.74)	0.227 (2.65)	0.195 (2.20)	0.285 (2.83)
ΔQ_{it-2}		-0.181 (-2.48)	-0.099 (1.72)		-0.186 (-2.55)	-0.117 (-1.99)
ΔQ_{it-3}			-0.014 (-0.19)			-0.034 (-0.44)
ΔK_{it-1}	-0.108 (-2.53)	-0.067 (-1.40)	-0.116 (-2.18)	-0.107 (-2.41)	-0.068 (-1.39)	-0.113 (-2.20)
ΔK_{it-2}		0.115 (2.34)	0.044 (1.34)		0.119 (2.40)	0.057 (1.71)
ΔK_{it-3}			-0.041 (-0.76)			-0.029 (-0.55)
Joint test						
Lagged ΔH	0.038	0.005	0.022	0.001	0.001	0.014
Lagged ΔWH	0.009	0.009	0.001	0.396	0.671	0.168
Long-run coeff						
Lagged ΔH	-0.054	0.074	0.076	-0.112	-0.057	-0.056
Lagged ΔWH	-0.130	0.026	-0.382	0.140	0.219	0.630
AR2	0.476	0.849	0.693	0.437	0.909	0.402
Sargan	0.396	0.541	0.788	0.614	0.721	0.797
Diff Sargan	0.998	1.000	1.000	1.000	1.000	1.000
No. of observations	576	528	480	576	528	480

Note: ΔQ and ΔK denote annual growth of output and private capital respectively. Spatial filtering is applied to employment, output and private capital variables. The weighing scheme used to capture the spatial spillovers effects of highways is based on the distance-decay matrix W_{dis} . p-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. Numbers in parentheses below the coefficients are robust t-statistics.

6.6.2 Alternative spatial weight matrices

We experimented with three alternative spatial weight matrices that measure spillovers across contiguous states. First, the two weight matrices considered previously are simply combined to construct the contiguity matrix with distance decay W_{dis} , which takes into account the geographical proximity between adjacent states. Second, we attempt to capture employment spillovers due to network effects of highway infrastructure by taking into account the connectivity of the highway network between states. The contiguity matrix with highway network connectivity W_{hwy} is specified with the weighting scheme as a weighted average of the number of highways in the category under investigation that cross the state border. Finally, we consider the contiguity matrix with population density weighted average W_{pop} so as to capture some spatial aspects of both population and geographical size of neighbouring states (Kelejian and Robinson, 1997). The population in a neighbouring state can be viewed as ‘points of contact’ between states, whereas its geographical size is also important in the sense that highways in the most distant parts of a neighbouring state may not be as accessible as those closer to the border. As the density of population can also serve as a proxy for agglomerations, this spatial matrix also allows us to implicitly examine whether the combined effects of highway infrastructure provision and urbanisation economies have some implications for employment growth in neighbouring states.⁵³

Using these alternative weight matrices to reestimate the employment equation (6.3) with and without the control variables, we find that broadening the scope of spatial weighting schemes does not change the basic nature of our findings. Table 6.10 reports the results of this experiment for interstate and non-interstate major highways, based on the three-year lag specification with the control variables. The corresponding estimates obtained from the weight matrices W_{bin} and W_{dis} are also presented for comparison. As can be seen, the results strongly confirm the evidence that growth in the density of interstate lane miles in neighbouring states does matter for state employment growth. The sign of its long-run coefficients is also consistently negative across specifications,

⁵³ Geospatial information for highway networks from North American Transportation Atlas Database 1998 is used in constructing the matrix W_{hwy} . Note that this matrix is only applied to the test of spatial spillovers effects from interstate highways and non-interstate major roads. For the latter road category, we count the total number of federal and state highways that cross the border. To construct the spatial matrix W_{pop} , we use state population data for each year from the REIS.

supporting the hypothesis of negative spillovers. However, substantial variation of the long-run coefficients across the weighting schemes we consider suggests that the scale of the negative spillovers depends on how spatial proximity is defined.

Table 6.10 Test of employment spillovers from highways:
Alternative weight matrices considered

Spatial weighting scheme	Lags	Lagged ΔH		Lagged ΔWH		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
<i>Interstate highways</i>								
W_{bin} : Binary contiguity	3	0.070	0.018 [~]	- 0.187	0.073 [~]	0.476	0.612	1.000
W_{dis} : Distance-decay	3	0.076	0.022 [~]	- 0.382	0.001 ^{***}	0.693	0.788	1.000
W_{dis} : Contiguity with distance decay	3	0.073	0.028 [~]	- 0.127	0.025 [~]	0.996	0.715	1.000
W_{hwy} : Contiguity with highway connectivity	3	0.066	0.028 [~]	- 0.089	0.022 [~]	0.592	0.683	1.000
W_{pop} : Contiguity with population density weighted average	3	0.070	0.023 [~]	- 0.124	0.099 [~]	0.435	0.635	1.000
<i>Non-interstates major roads</i>								
W_{bin} : Binary contiguity	3	- 0.039	0.009 ^{***}	0.240	0.653	0.700	0.856	1.000
W_{dis} : Distance-decay	3	- 0.056	0.014 [~]	0.630	0.168	0.402	0.797	1.000
W_{dis} : Contiguity with distance decay	3	- 0.037	0.009 [~]	0.270	0.757	0.611	0.651	1.000
W_{hwy} : Contiguity with highway connectivity	3	- 0.044	0.009 ^{***}	0.278	0.706	0.572	0.781	1.000
W_{pop} : Contiguity with population density weighted average	3	- 0.050	0.011 [~]	0.310	0.142	0.660	0.883	1.000

Note: Results are based on filtered employment and original highway variables. State output and private capital are also included in the regressions, and spatial filtering is applied to these variables. p-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively.

Examining different spatial weighting schemes also provides better insight into the channels in which employment spillovers from highways take place. The hypothesis that spatial spillovers from highway infrastructure could be partly driven by network externalities is supported by the result based on the weight matrix W_{hwy} where information on the connectivity provided by the highway network is incorporated. In this case, however, the negative long-run coefficient for neighbouring interstate highways is considerably lower than those derived from other weighing schemes. One reason may be that the highway connectivity matrix is likely to better capture positive

network spillovers of interstate highways, though such spillovers would not be so strong that they outweigh the negative spatial effects.

Regardless of how well geographically adjacent states are connected by the road network, the evidence of negative employment spillovers emerging from other spatial weight matrices point to the view that improving interstate highways could lead to the redistribution of economic activities across regions and also potentially influence the path of future private investments. Although the matrices $\mathbf{W}_{dis}$ and $\mathbf{W}_{edis}$ likely capture the widespread productivity effects which diminish with distance, they could also capture the role of geographical proximity in the spatial competition for mobile factors of production. The results from the matrix $\mathbf{W}_{pop}$ which is based on weighted population density seem to suggest that close competitors are adjacent states with urbanisation economies. This is probably because expanding capacities for interstate highways can promote agglomeration benefits, which could in turn draw factors of production away from nearby states or making a population-dense state with improved interstate highways relatively more attractive to inward investments.⁵⁴

6.6.3 Time-space simultaneous model

While the basic idea of spatial filtering involves removing spatial dependence embedded in spatially correlated variables, another viable option for dealing with the problem of spatially correlated errors is to incorporate spatial dependence into regression models. We consider a *spatial lag* specification adding contemporaneous employment growth in neighbouring states to the employment equation (6.3), which still retains the autoregressive model structure. In this form, employment growth is related to not only its *temporal* lag but also its *spatial lag*, in addition to lagged growth in lane-mile density and state- and time- specific effects:

$$\Delta E_{it} = \alpha_0 + \alpha_1 \Delta \mathbf{W}_e E_{it} + \sum_{p=1}^m \delta_p \Delta E_{it-p} + \sum_{p=1}^m \beta_p \Delta H_{it-p} + \sum_{p=1}^m \lambda_p \Delta \mathbf{W} H_{it-p} + f_i + \eta_t + \varepsilon_{it} \quad (6.7)$$

⁵⁴ Alternatively, one might interpret the finding of negative spillovers from the matrix $\mathbf{W}_{pop}$ as a partial consequence of trade competition. Since lane mile additions for interstate highways could reduce transport costs *to* and *from* other states, it is natural to expect that such highway improvements could allow firms within the state to expand their market as well as lead them to encounter competition from other firms located elsewhere. Given that firms located in agglomeration areas tend to operate more efficiently, it might be such firms that take advantage of the combined benefits of urbanisation and interstate highway improvements in their own state at the expense of those based in adjacent states. This interpretation is merely speculation and requires further empirical investigation using more detailed datasets and explicit modeling framework.

Given that spatial interaction could take place between non-contiguous states, the elements of the weight matrix for spatially lagged employment growth (W_t) are set to one for all the states j being within a certain distance from state i and zero otherwise. Based on the G local spatial autocorrelation statistics as demonstrated in Section 6.5, we choose the cut-off distance of 350 miles where spatial correlation of employment growth is found to be at a maximum. This matrix is also normalised such that the row sum equals one. In estimating the model (6.7) which can be referred to as a time-space simultaneous model (Anselin, 2001), both temporal and spatial lags of employment growth are treated as endogenous in the system GMM estimation framework.⁵⁵ Note that all variables used in the regressions are non-filtered.

Using the time-space simultaneous specification gives results that are similar in terms of the sign and significance pattern to those obtained from estimating the employment model (6.3) with spatially uncorrelated variables (see Appendix C). The introduction of the spatial lag variable, which is found to be highly significant, as expected, also substantially reduces the problem of spatial error dependence. The Moran's I test generally indicates that no spatial correlation exists in the regression residuals for most yearly observations in all specifications. As for the evidence of Granger causality, we find that in some cases the long-run effects from interstate and non-interstate major roads are considerably smaller than those based on the models with spatial filtering applied. This might be partly due to collinearity between the spatial lag employment growth and the one-year lagged employment growth variable, the latter of which is used to calculate the long-run coefficients. Despite this minor difference, our main conclusions regarding the relative importance of these two different types of highways are robust. The results are also unchanged even after controlling for the temporal influence of state output and private capital stock.

⁵⁵ For GMM estimations in differenced equations, we use only lagged levels in time period $t-2$ as instruments for both the endogenous variables so as to avoid overfitting problems that could result from the use of too many moment conditions.

6.7 Summary and discussion

This chapter attempts to disentangle the causal relationship between highway infrastructure and private sector employment within the US economy. While the analysis of data for all road lane-miles does not identify a statistically significant effect, the results based on disaggregation of the data into individual road categories indicates that annual growth in lane-mile density of US interstate highways tends to have a positive and significant impact on private sector employment growth in the Granger causal sense. Short-run, one-year lagged effects, were found to be negative, but off-set by a positive effect in the second year lag. However, we find in all lag specifications a negative employment impact of non-interstate major road lane mile additions (i.e. aggregate arterial and collector roads).

Our analysis also provides evidence supporting the spatial spillover hypotheses for the case of interstate highway provision, which is often considered as among the most likely potential source of economic spillover effects. We find lane-mile additions of interstate highways in one state produce negative long-run employment spillovers across all other states. The results based on the optimal lag specification suggest that growth in the density of interstate highways has both positive and negative spillover effects on state employment growth, but the net employment effect is negative. This evidence suggests that interstate highways could generate employment opportunities within a state they serve directly, but could also be associated with negative employment spillovers that can unintentionally lead to declines in state employment growth in private industries.

Although it is evident that the causal linkage between highway infrastructure investment and employment could be established, this analysis confirms the view that one cannot make a clear-cut prediction for the direction of causality. Using aggregate data for arterial and collector lane miles, we find evidence of state employment being temporally influenced by growth in non-interstate major roads, as well as the other way around. For the latter temporal effect, the Granger causality test results suggest that increases in employment activity could lead to adding roadway capacity to serve growth

in travel. This implies that highways can be either a cause or a consequence of regional employment.

What remains to be seen is the sectoral incidence of these causal effects. Is the positive and significant effect of own-state interstate highways evenly distributed to all private sectors or is it sector-specific? Does provision of non-interstate major roads have negative employment effects throughout the economy? Or has sectoral aggregation hidden some long-term employment benefits that accrue to specific industries? Is there any evidence of employment spillovers from each type of highways that the aggregate analysis is unable to discover? Should state development policy be directed towards increasing highway capacities if the primary interest is to generate job opportunities in the service sector? Could the data tell us about any likely response from state transportation authorities to the general decline in manufacturing employment during the period of this analysis? We have given our attention to these questions in the next chapter.

Chapter 7

Causal Linkages between Highways and Sector-Level Employment

7.1 Introduction

In the last chapter we sought to disentangle the causal relationship between annual growth in the density of highways and employment growth using aggregate state-level data for the entire private sector in the United States. The results show that overall employment growth is temporally influenced by annual growth in the provision of interstate and non-interstate major roads within the same state and all other states, as well as the other way around. Additional insights into these causal effects can be gained through an analysis of sector-level data. In this chapter we test for Granger causality and examine employment spillovers from interstate and non-interstate major roads at the sectoral level, focusing on three major industrial sectors: manufacturing, construction, and services.

As with many other developed economies, the United States has experienced a major structural shift from manufacturing employment towards service employment over the past decades. Growth in the productivity of manufacturing firms, shifts in demand from manufacturing goods to services, competition from countries with lower production costs, and changes in the structure of manufacturing employment have been viewed as among long-term factors attributed to substantial declines in manufacturing jobs in the United States (Congressional Budget Office, 2004). Given the traditional view

on the significant role of transport costs of moving inputs and goods in the economic performance of manufacturing, a key policy question is whether previous state investments in major highways have helped curtail the loss of manufacturing jobs since its historical peak in 1979.

Although research efforts on the importance of highway infrastructure investments in states' manufacturing employment have been minimal, a synthesis of findings tends to suggest that the employment effects of highways vary considerably among time periods. Using historical data for 48 states from the 1960s to the early 1980s, Modifi and Stone (1990) and Carroll and Wasylenko (1994) find that increasing spending on highways increased state-level manufacturing employment. Evidence has emerged in the latter work that uncovers the presence of a structural change in the relationship between state and local expenditures and manufacturing employment in the year 1983. State expenditures on highways are found to have a negative impact on manufacturing employment during the period 1984-1988 when the downsizing in manufacturing occurred among states, though the adverse effect is not significant. Using a longer-period data set, Cohen and Paul (2004) reveal significant evidence of a negative association. Based on 1982-1996 state-level U.S. manufacturing data, their cost function estimates indicate that increases in monetary stocks of highways reduced overall demand for manufacturing workers.

While this would imply that state investments in highways entailed the slowdown in state manufacturing employment, very little is known whether such investments similarly deterred growth in services employment in the state economy or worked in an opposite way. Given the increasing importance of the services sector, the emphasis on services employment is of interest to state policymakers. To our knowledge, only the work by Carroll and Wasylenko (1994) seeks to examine the employment effects of highway expenditures on service-producing industries but does not find any statistically significant evidence.

In the following section, we describe econometric models used to investigate the causal relationship between highway infrastructure and sectoral employment. Section 7.3 presents data and some descriptive statistics. The evolution of the U.S. industrial structure during the period of analysis is also highlighted. Section 7.4 demonstrates how

we deal with the problem of spatial dependence which also requires an appropriate treatment. Section 7.5 presents results from Granger causality tests, and the final section summarises the chapter and presents some concluding remarks.

7.2 Econometric methodology

In an attempt to reveal sectoral differences in the temporal and spatial effects that could be hidden at the aggregate level, we use empirical strategies similar to those applied with aggregate data for the entire private sector. To implement Granger causality tests, we consider a panel vector autoregressive model for each industrial sector in the following form:

$$\Delta E_{it}^s = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p}^s + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \quad (7.1)$$

$$\Delta H_{it} = \gamma_0 + \sum_{p=1}^m \phi_p \Delta H_{i,t-p} + \sum_{p=1}^m \theta_p \Delta E_{i,t-p}^s + \xi_i + \nu_t + \mu_{it} \quad (7.2)$$

where the variable ΔE denotes employment growth, ΔH denotes growth in the density of highway lane miles, the superscript s denotes sector, and the subscripts i and t index states and time periods respectively. The number of lags (m) is specified to be identical for all variables. f_i and ξ_i are vectors representing time-invariant state-specific characteristics, and η_t and ν_t are year-specific intercepts controlling for any unobserved shocks that are common to all states but vary across time. In order to capture the possibility of employment spillovers from highways, we introduce a variable measuring the density of highways in other US states (ΔWH) to equation 7.1 which can be expressed as

$$\Delta E_{it}^s = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p}^s + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + \sum_{p=1}^m \lambda_p \Delta WH_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \quad (7.3)$$

where W denotes a spatial weight matrix that is defined to capture the spatial effects from highways in all other states. However, it is unlikely that highways from more distant states create spatial spillovers effects as strongly as those in geographically nearby states. Therefore, the distance decay matrix (W_{dis}) is used to take account of distance decay by setting the elements of the matrix equal to the inverse of the squared distance between the states.

The above empirical modelling framework is analogous to that has been applied to explore the causal linkages between highway density and private sector employment growth at the aggregate level (Chapter 6). As Dodgson (1974) and Seitz (2000) point out, one complication when examining the influence of infrastructure on employment in a particular sector of an economy is the interaction of the demand for labour between various industrial sectors. This can work via the input and output linkages between sectors, suggesting that provision of infrastructure can affect employment in one sector not only directly but also indirectly through its effects on employment in other sectors. Given that the employment effect of infrastructure emerges throughout the economy because of these sectoral links, Seitz (2000) derives and estimates a reduced-form labour demand equation that relates employment in one sector to employment in other sectors. We follow this approach in our empirical implementation by including employment growth of other sectors as explanatory variables. To avoid simultaneity bias and allow time lags due to adjustment costs, employment growth of other sectors enters equation 7.3 with a lag of one period in the following form:

$$\Delta E_{it}^s = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p}^s + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + \sum_{p=1}^m \lambda_p \Delta WH_{i,t-p} + \sum_{r \neq s} \varpi_r \Delta E_{i,t-1}^r + f_i + \eta_t + \varepsilon_{it} \quad (7.4)$$

where r denotes other sectors in the dataset. By estimating this model, we can examine whether there is evidence of intersectoral spillovers. Apart from this, we also estimate a model including lagged variables for industry output growth (ΔQ) as a robustness check.

$$\Delta E_{it}^s = \alpha_0 + \sum_{p=1}^m \delta_p \Delta E_{i,t-p}^s + \sum_{p=1}^m \beta_p \Delta H_{i,t-p} + \sum_{p=1}^m \lambda_p \Delta WH_{i,t-p} + \sum_{p=1}^m \delta_p \Delta Q_{i,t-p}^s + \sum_{r \neq s} \varpi_r \Delta E_{i,t-1}^r + f_i + \eta_t + \varepsilon_{it} \quad (7.5)$$

Despite the fact that lagged values of output growth are introduced as control variables, equation 7.5 could be viewed simply as a labour demand model in a vector autoregression framework, given that the influence of factor input prices are captured by state- and time-specific components.⁵⁶

To deal with endogeneity due to the presence of lagged dependent variables, our estimation strategy for the employment and highway equations specified above is based on the system GMM estimator for dynamic panel models. For GMM estimation of the

⁵⁶ Unlike the analysis in Chapter 6, our control variables here do not include lagged growth in private capital investment because industry data needed for estimating state-level capital stocks are not available.

differenced equations, we use restricted sets of instruments so as to avoid overfitting problems. Three specification tests including the Arellano-Bond test for serial correlation, the Sargan test for overidentifying restrictions, and the Difference Sargan test are employed to assess whether the instruments are exogenous and thus valid to be used in the system GMM estimation. To test whether the instruments are weakly correlated with the endogenous variables in the model, we consider the F test for the joint significance of the instruments from regressions that relate each of the endogenous variables to its corresponding instruments. In addition, we check whether the problem of spatial error dependence is a concern in this analysis using the Moran's I test for residual spatial autocorrelation. If correcting for spatial autocorrelation is required, we apply the Getis's spatial filtering to spatially correlated variables. The Moran's I test is then performed again to ensure that system GMM estimation results based on spatially uncorrelated variables are not subject to misspecifications from spatial error autocorrelation.

Tests for the appropriate number of lags to include in regressions are performed using Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQ). A maximum of three and five lags is considered in searching for the optimal lag structure on the basis of these information criteria. In addition, we perform the sequential Wald test using statistical significance at the 5% level to determine the optimal lag length for each equation. In the case that these lag length selection methods suggest different optimal lag lengths, we dismiss parsimonious specifications and choose the longest optimal lag specification for reporting Granger causality test results.

7.3 Data

This analysis uses pooled cross-section time-series data for the 48 contiguous US states for the period 1984-1997. Data on sectoral employment are obtained from the Regional Economic Information System (REIS) compiled by the US Bureau of Economic Analysis (BEA). While employment data for manufacturing and construction sectors are extracted from the REIS and used directly, data on employment for the services sector are the sum of employment for service-producing industries including transportation,

communication, and public utility (TCPU), wholesale trade, retail trade, finance, insurance, and real estates (FIRE) and other services. We use data on real gross state product (GSP) by industry in constant 2000 dollars to measure output growth for each of the three sectors. These GSP data are obtained from the BEA website (<http://www.bea.gov>).

Table 7.1 shows that employment for the entire private sector from 1984 to 1997 grew by 32.6%. Overall 1984-1997 growth was faster in services and construction which constitute approximately 74.3% and 6.3% of the total in 1990, respectively. In contrast, the number of manufacturing jobs which stood at 19.3 million in 1997 declined by about 0.5 million, or 2.6% overall since 1987.

Table 7.1 Employment in services, manufacturing and construction sectors for the 48 contiguous states in 1984, 1990, and 1997

Industrial sector	Employment by place of work			Percent share 1990	Overall growth (1984-1997)
	1984	1990	1997		
Services	69,175,658	84,443,958	98,919,047	74.25%	43.00%
Manufacturing	19,832,121	19,634,683	19,313,301	17.27%	-2.62%
Construction	6,032,490	7,189,716	8,284,881	6.32%	37.34%
Overall private sector	97,490,036	113,724,203	129,283,930	100.00%	32.61%

Note: Data for the services sector include transport, communication, and public utility (TCPU), wholesale trade, retail trade, finance, insurance, and real estates (FIRE) and other services. Figures for the overall private sector also include employment in agriculture and mining sectors.

A structural shift from manufacturing employment towards service employment during this period is displayed in Figure 7.1. The vertical axis is the ratio of sector-level employment to overall private employment. Figures for the services sector are shown on the right vertical axis, and those for the manufacturing and construction sector are on the left axis. As can be seen, there was a steady decline in manufacturing's share of overall private sector employment, whereas the services sector had a clearly opposite trend. For the construction sector which also experienced substantial job growth, its share of total employment was roughly constant over the period.

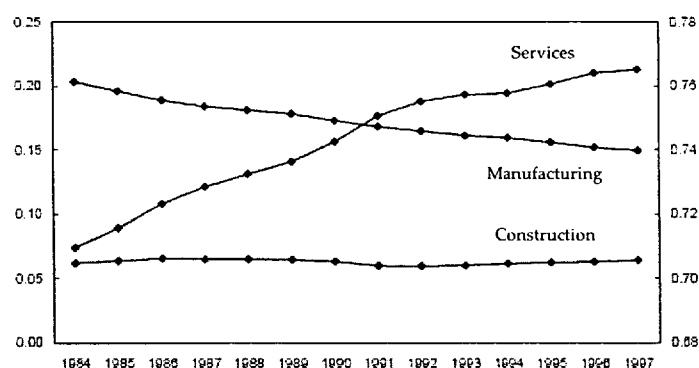


Figure 7.1 The ratio of sectoral employment to total private employment, 1984-1997
(Note: Left vertical axis for manufacturing and construction, and right vertical axis for services)

7.4 Spatial autocorrelation and spatial filtering

In the likely case that the problem of spatial autocorrelation exists in our analysis of spatial data, Granger causality test results would be potentially misleading if no effective treatment for this is undertaken. We find clear and strong evidence of spatial error dependence when estimating the employment equation (7.1) to test for Granger causality from highways to sectoral employment. As shown in Table 7.2, the standardised Moran's I statistics generally indicate strong spatial autocorrelation in residuals throughout the yearly observations.⁵⁷ The most serious problem is found in the employment model for the services sector where 10 out of 12 Moran's I values are highly significant at the 1% level.

For the GMM estimation of the highway equation, however, the Moran's I test reveals practically no evidence of spatial autocorrelation throughout the sample period. Table 7.3 reports the standardised Moran's I statistics based on the models that relate annual growth in the density of highways to its own lags and lagged employment growth in the services sector, which tend to be not significant for most yearly observations. Similar results are obtained when examining the reverse causality from construction and manufacturing employment.

⁵⁷ We apply the Moran's I test to residuals from the panel VAR models with one-year, two-year and three-year lag orders. As the findings are similar across model specifications, we present the Moran's test results and the treatment of spatial error dependence for the models with the one-year lag order.

Table 7.2 Moran's *I* test for residual spatial autocorrelation: Employment equations

Year of residuals	Testing for Granger causality from interstate highways to sectoral employment (Employment eq. 7.1)			Testing for Granger causality from non-interstate major roads to sectoral employment (Employment eq. 7.1)		
	Services	Manufacturing	Construction	Services	Manufacturing	Construction
1986	4.696 ***	1.375	3.875 ***	4.783 ***	1.071	4.033 ***
1987	1.635	2.992 **	2.508 **	1.775 *	3.085 ***	2.496 **
1988	2.913 ***	2.415 **	1.825 *	2.910 ***	2.505 **	1.929 *
1989	3.825 ***	1.410	6.428 ***	3.726 ***	1.449	6.406 ***
1990	5.092 ***	3.815 ***	4.660 ***	5.135 ***	3.885 ***	4.702 ***
1991	6.763 ***	2.285 **	3.753 ***	6.762 ***	2.345 **	3.911 ***
1992	5.561 ***	2.784 ***	2.929 ***	5.537 ***	2.878 ***	2.955 ***
1993	3.505 ***	1.973 **	1.852 *	3.603 ***	2.013 **	1.851 *
1994	4.746 ***	3.863 ***	4.797 ***	4.821 ***	3.946 ***	4.909 ***
1995	2.897 ***	1.012	3.941 ***	2.923 **	1.039	3.940 ***
1996	2.108 **	4.147 ***	1.263	2.068 **	4.173 ***	1.287
1997	2.613 ***	0.818	1.425	2.701 ***	0.734	1.539

Note: The row-standardised binary contiguity matrix is used for the Moran's *I* test. *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. Results are based on the models with the one-year lag order.

Table 7.3 Moran's *I* test for residual spatial autocorrelation: Highway equations

Year of residuals	Testing for Granger causality from services employment to highways (Highway eq. 7.2)		Testing for Granger causality from manufacturing employment to highways (Highway eq. 7.2)		Testing for Granger causality from construction employment to highways (Highway eq. 7.2)	
	Interstate highways	Non-interstate major roads	Interstate highways	Non-interstate major roads	Interstate highways	Non-interstate major roads
1986	-0.072	1.319	-0.036	0.943	-0.239	1.080
1987	0.304	1.502	0.329	1.764 *	0.247	1.457
1988	-0.050	-0.535	0.029	-0.652	-0.216	-0.086
1989	-0.064	0.252	-0.058	0.245	-0.092	0.187
1990	1.135	1.868 *	1.218	2.740 ***	1.160	1.752 *
1991	1.195	0.607	1.269	1.741 *	1.277	0.576
1992	1.232	0.655	1.197	0.534	1.505	0.505
1993	0.305	2.396 **	0.483	2.884 ***	0.895	2.579 ***
1994	0.128	1.758 *	0.224	2.115 **	0.140	1.537
1995	2.922 ***	0.176	2.961 ***	0.163	3.005 ***	0.251
1996	-0.021	-0.792	-0.017	-0.873	-0.040	-0.901
1997	0.081	-0.676	0.604	-0.119	0.129	-0.635

Note: The row-standardised binary contiguity matrix is used for the Moran's *I* test. *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. Results are based on the models with the one-year lag order.

To deal with the issue of spatial autocorrelation in the employment equation, we use the Getis's spatial filtering method to remove spatial dependencies embedded in spatially correlated variables that could have considerable potential for the presence of residual spatial autocorrelation. While growth in the density of lane miles for both interstate and non-interstate major roads does not exhibit spatial correlation throughout the years of our sample (See Chapter 6, pp. 147), we find strong evidence of spatial interdependencies in sectoral employment growth among nearby states. For all three sectors, the Moran's *I* coefficients reported in Table 7.4 are positive and highly significant

across the sample period. As such, it is very likely that spatial error autocorrelation we have detected from estimating the employment equations arises mainly from spatial dependencies embedded in the employment data.

Table 7.4 Spatial correlation of sectoral employment growth
(original and filtered variables)

Year of data	Services		Manufacturing		Construction	
	Original	Filtered	Original	Filtered	Original	Filtered
1985	4.555 ***	- 0.382	1.777 *	- 1.370	4.079 ***	- 1.315
1986	5.093 ***	- 0.360	1.497	- 2.569 **	6.129 ***	- 1.625
1987	1.208	- 0.927	4.502 ***	- 1.864 *	4.812 ***	- 0.912
1988	4.894 ***	1.550	5.678 ***	- 0.337	3.408 ***	- 1.838 *
1989	3.694 ***	- 0.617	5.682 ***	- 1.032	4.167 ***	- 2.067 **
1990	5.588 ***	- 0.323	6.903 ***	- 0.368	6.647 ***	0.257
1991	7.809 ***	- 0.492	5.680 ***	- 1.329	6.523 ***	- 0.830
1992	1.585	- 0.548	4.764 ***	- 0.702	3.722 ***	- 1.045
1993	3.754 ***	- 2.102 **	3.398 ***	- 1.485	2.145 ***	- 1.876 *
1994	4.863 ***	- 1.103	4.159 ***	- 1.689 *	5.705 ***	- 1.614
1995	4.241 ***	- 1.330	3.521 ***	- 1.746 *	3.705 ***	- 1.794 *
1996	3.961 ***	- 1.823 *	5.748 ***	- 0.373	1.656 *	- 2.650 **
1997	3.573 ***	- 1.614	3.818 ***	- 0.899	1.610	- 1.337

Note: Filtered employment growth variables are based on the Getis's spatial filtering technique. All variables are stationary, according to the Levin-Lin-Chu test for panel data unit root.

We apply the spatial filtering to the employment growth variable. For each sector, the filtered employment variable is obtained using the critical distance of 350 miles at which the absolute sum of the standardised *G* statistics for all observations is consistently found to be maximised. The results from the Moran's *I* test for spatial correlation applied to the filtered employment variable suggests that the filtering performs fairly well in screening out spatially correlated components from the original employment variable. There are only few cases that the Moran's *I* coefficients become negative and significant, which should not be a problem.⁵⁸ Compared with the original employment growth variable, the Moran's coefficients of the filtered variable for all the three sectors are generally lower and not statistically insignificant at the 5% level across yearly observations.

By reestimating the employment equation with the filtered employment growth variable and the original highway variable, we can check whether the strong degree of residual spatial autocorrelation no longer exists. In doing so, we apply the Moran's *I* test for spatial autocorrelation on the new residuals, and the results are reported in Table 7.5.

⁵⁸ This could happen when applying spatial filtering as found in Getis (1995) and Badlinger et al (2004).

As expected, the problem of spatial error autocorrelation, which is previously found when using the original employment and highway variables to estimate the employment equations, generally disappears. The Moran's I statistics of the new residuals based on the employment equation for all the three sectors are generally not significant at the 5% level. In addition, compared with the results based on the unfiltered data in Table 7.2, the degree to which residuals are spatially correlated is lower in most cases.

Table 7.5 Moran's I test for residual spatial autocorrelation: spatial filtering applied

Year of residuals	Testing for Granger causality from interstate highways to sectoral employment (Employment eq. 7.1)			Testing for Granger causality from non-interstate major roads to sectoral employment (Employment eq. 7.1)		
	Services	Manufacturing	Construction	Services	Manufacturing	Construction
1986	-0.467	-1.786*	-1.645	-0.337	-1.791*	-1.437
1987	-1.042	-0.910	-1.135	-0.994	-0.887	-1.140
1988	0.144	-0.293	-1.865*	-0.198	-0.276	-1.828*
1989	-1.159	-1.315	-0.947	-1.278	-1.369	-1.178
1990	-0.038	-1.113	0.036	-0.017	-1.032	0.010
1991	-0.765	-1.156	-1.722*	-0.693	-1.095	-1.615
1992	0.609	-0.615	-0.229	0.708	-0.525	-0.190
1993	-2.385**	-1.719*	-2.244**	-2.195**	-1.680*	-2.193**
1994	-1.006	-1.758*	-1.302	-0.946	-1.694*	-1.043
1995	-0.899	-2.208**	-0.991	-0.880	-2.194**	-0.956
1996	-1.846*	-1.290	-2.268**	-1.921*	-1.195	-2.243**
1997	-1.533	0.007	-1.539	-1.514	-0.122	-1.452

Note: The row-standardised binary contiguity matrix is used for the Moran's I test. *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. Results are based on the models with the one-year lag order.

In conclusion, the strong evidence of spatial autocorrelation in the residuals derived from estimating the employment equation suggests that the system GMM estimator would yield potentially misleading results for Granger causality. As demonstrated above, filtering out the spatial interdependencies embedded in the original data on sectoral employment can be a viable solution to this problem. Therefore, our empirical test for Granger causality from highways to sectoral employment relies on filtered employment data. In testing for the reverse causality from sectoral employment to highways, the spatial filtering technique is not applied since we find that the residuals based on the system GMM estimation of the highway equation generally exhibit no spatial correlation. The causality test results are presented in the next section.

7.5 Empirical findings

7.5.1 Causality from highways to sectoral employment

Preliminary results

Table 7.6 presents the results from examining whether growth in the density of interstate lane miles significantly determines future growth in sectoral employment. The results in the first column for each panel are limited to address the question of whether lane-mile additions for interstate highways within the state temporally influence sectoral employment growth, whereas the last three columns present the results from the test for employment spillovers from interstate highways in all other states. The long-run coefficients for each set of lagged interstate highway variables are reported, the sign of which indicates whether the dynamic effects of interstate highways on employment are positive or negative. For the test of the joint significance of lagged variables, p -values are presented in rectangular brackets, which provide a test for Granger causality. The tests for instrument exogeneity (AR2, Sargan, and Diff Sargan) and instrument relevance (Table 7.7) do not reject the validity of the instruments used in the system GMM estimations.

Results of the Granger causality tests indicate that lane mile growth of interstate highways plays a significant role in determining future state employment growth in the services sector. The null hypothesis of no Granger causality from interstate highways within the state is clearly rejected, and the sign of the long-run coefficient is positive across specifications. This suggests that growth in own state's interstate lane-mile density could Granger cause an increase in services employment growth.

Table 7.6 Granger causality from interstate highways to sectoral employment

Variable	Services				Manufacturing				Construction			
	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5
<i>Granger causality</i>												
Lagged ΔH	0.039 [0.015]	0.039 [0.010]	0.045 [0.026]	0.046 [0.043]	- 0.038 [0.931]	- 0.047 [0.910]	- 0.050 [0.911]	- 0.087 [0.872]	0.142 [0.403]	0.199 [0.052]	0.211 [0.031]	0.106 [0.100]
Lagged ΔWH		- 0.082 [0.001]	- 0.109 [0.003]	- 0.198 [0.002]		- 0.517 [0.428]	- 0.532 [0.418]	- 0.513 [0.447]		- 0.504 [0.008]	- 0.132 [0.004]	- 0.425 [0.012]
Lagged ΔQ				0.221 [0.009]				- 0.061 [0.000]				0.352 [0.000]
<i>Sectoral spillovers</i>												
$\Delta E_{\text{serv}(t-1)}$							0.004 (0.06)	0.016 (0.20)			0.278 (0.96)	0.217 (0.96)
$\Delta E_{\text{manuf}(t-1)}$			0.111 (2.67)	0.117 (3.84)							0.499 (3.54)	0.431 (4.57)
$\Delta E_{\text{const}(t-1)}$			0.062 (2.09)	0.046 (1.58)			- 0.003 (- 0.14)	0.002 (0.08)				
Optimal lag order	3	3	3	3	2	2	2	2	2	3	3	3
AR2	0.370	0.286	0.839	0.973	0.699	0.711	0.767	0.805	0.745	0.299	0.256	0.155
Sargan	0.310	0.396	0.228	0.127	0.304	0.191	0.263	0.404	0.219	0.264	0.419	0.320
Diff Sargan	0.999	0.999	0.950	0.994	0.537	0.297	0.471	0.832	0.554	0.855	0.981	0.948
No. of observations	480	480	480	480	528	528	528	528	528	528	480	480

Note: The long-run coefficients are reported for highway and output variables. Numbers in rectangular brackets under the long-run coefficients are p -values from the test for joint significance of lagged variables (Granger causality). Numbers in round brackets under the estimated parameters for sectoral spillover variables are robust t -stat. The weighing scheme used to capture the spatial spillovers effects of highways is based on the distance-decay matrix W_{dis} . AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. P -values are reported for these specification tests.

Table 7.7 Test of instrument relevance: sector-level employment equations

Endogenous variable	First difference equations		Levels equations	
	F test	R ²	F test	R ²
Lagged growth in services employment (filtered)	145.02 (0.000)	0.475	165.52 (0.000)	0.478
Lagged growth in manufacturing employment (filtered)	62.50 (0.000)	0.412	133.37 (0.000)	0.403
Lagged growth in construction employment (filtered)	107.31 (0.000)	0.526	105.23 (0.000)	0.511
Instruments used in GMM estimations	Lagged levels in time period t-2, and t-3		Lagged first-differences dated t-1	

Note: Numbers in parentheses are *p*-values corresponding to the test of the null hypothesis that coefficients of all instruments used are jointly zero.

Nevertheless, we find that interstate highways also produce negative employment spillovers across states. The negative long-run coefficients exhibit some substantial variation across specifications and tend to increase when extending the basic model in the second column to include the intersectoral spillover variables (i.e. employment growth in manufacturing and construction) and lagged variables for output growth of the services sector. Parameter estimates for employment growth in the manufacturing sector with one period lag are positive and highly significant, implying that manufacturing employment growth positively determines future employment growth in the services sector. There is also evidence of employment spillovers from construction to services, though the inclusion of lagged output variables results in a slightly lower significant level for the parameter of construction employment growth. More importantly, the strongest degree of negative employment spillovers from interstate highways is found after controlling for the influence of service output growth which is positively associated with future growth of employment in the services sector.

The central panel of Table 7.6 displays the results for the manufacturing sector, indicating no significant evidence of manufacturing employment growth temporally influenced by provision of interstate highways that take place both within and outside the state. Although the negative long-run coefficients would imply the predominance of the labour saving effect associated with expanding capacity of interstate highways, the null of no joint significance cannot be rejected at any conventional levels. None of the intersectoral spillover variables are also found to be statistically significant. For the last specification, the negative and significant long-run coefficient of lagged output growth

variables should not be overstressed, given that we find evidence of positive causality from output to employment which is theoretically consistent when introducing contemporaneous growth of manufacturing output into equation 7.5.

The Granger causality test results for the construction sector in the right panel are similar to those for the service sector, though they are somewhat sensitive to changes in model specifications. In the first column the model with two-year lags reveals no evidence of causality running from interstate highways to construction employment within a state served directly. However, the three-year lag specification is found to be more appropriate in capturing the temporal and spatial effects of interstate highways. Using the models with lag order of three, we find that growth in the density of interstate highways has both positive and negative spillover effects on future employment growth in the construction sector. Although there is wide variation in the magnitude of the long-run coefficients, the results tend to show that the negative spillover effects are relatively stronger than the positive effects of own state's interstate highways. The specification in the last column, that accounts for the temporal influences of industry output and intersectoral employment spillovers, finds significant evidence that growth in manufacturing employment is positively associated with future employment growth in the construction sector.

Turning to the results for non-interstate major roads in Table 7.8, we find evidence of annual growth in services employment to be Granger-caused by aggregate lane mile additions for arterial and collector roads within the state border. The fact that the long-run coefficient is positive in most specifications, albeit much lower than those obtained for interstate highways, implies that additional investments in such non-interstate major roads also precedes increased state employment growth in the services sector. The negative long-run coefficient in the second column is perhaps due to multicollinearity. However, the model without the spatial spillover variable in the first column appears to be preferable, given that the spillover variables are jointly insignificant.

Table 7.8 Granger causality from non-interstate major roads to sectoral employment

Variable	Services				Manufacturing				Construction			
	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5	Eq. 7.1	Eq. 7.3	Eq. 7.4	Eq. 7.5
<i>Granger causality</i>												
Lagged ΔH	0.015 [0.067]	- 0.019 [0.077]	0.009 [0.018]	0.004 [0.036]	- 0.591 [0.070]	- 0.679 [0.016]	- 0.676 [0.009]	- 0.655 [0.009]	- 0.231 [0.103]	- 0.140 [0.100]	- 0.172 [0.021]	- 0.078 [0.000]
Lagged ΔWH		0.370 [0.555]	0.205 [0.719]	0.209 [0.403]		1.341 [0.096]	1.282 [0.080]	1.158 [0.091]		1.122 [0.034]	0.747 [0.027]	0.365 [0.026]
Lagged ΔQ				0.202 [0.013]				- 0.016 [0.000]				0.335 [0.000]
<i>Sectoral spillovers</i>												
$\Delta E_{serv(t-1)}$							0.124 (1.58)	0.138 (1.64)			0.229 (0.79)	0.169 (0.82)
$\Delta E_{manuf(t-1)}$			0.110 (2.78)	0.116 (3.91)							0.471 (3.59)	0.416 (4.63)
$\Delta E_{const(t-1)}$			0.062 (2.11)	0.045 (1.54)			- 0.014 (- 0.60)	- 0.010 (- 0.39)				
Optimal lag order	3	3	3	3	3	3	3	3	2	3	3	3
AR2	0.224	0.366	0.999	0.891	0.919	0.962	0.960	0.841	0.736	0.266	0.268	0.262
Sargan	0.239	0.299	0.207	0.063	0.353	0.330	0.363	0.455	0.271	0.178	0.327	0.230
Diff Sargan	0.966	0.999	0.970	0.815	0.987	0.903	0.999	0.999	0.905	0.447	0.747	0.651
No. of observations	480	480	480	480	480	480	480	480	528	480	480	480

Note: The long-run coefficients are reported for highway and output variables. Numbers in rectangular brackets under the long-run coefficients are p -values from the test for joint significance of lagged variables (Granger causality). Numbers in round brackets under the estimated parameters for sectoral spillover variables are robust t -stat. The weighing scheme used to capture the spatial spillovers effects of highways is based on the distance-decay matrix $W_{\Delta\Delta}$. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. P -values are reported for these specification tests.

We find that manufacturing and construction jobs are negatively affected by additional provision of non-interstate major roads within the same state, whereas in both sectors there are some employment gains induced by such highway investments elsewhere. The negative long-run coefficient for own state's non-interstate major roads simply means that additional provision of arterial and collector roads Granger cause a reduction in manufacturing employment. This finding is consistent with other studies (e.g. Seitz, 1993; Seitz and Licht, 1995; and Cohen and Paul, 2004) which reveal a negative relationship between highway capital stocks and the demand for labour in manufacturing industries. Given that the direction of the employment effect depends on whether and the extent to which total demand for manufactured products can keep pace with increased productivity associated with improvements in highway facilities, the evidence of negative Granger causality could imply that the productivity effect of major roads may not result in substantial increases in sales. Rather, improvements in arterial and collector roads could be linked more closely to improved access to a better skilled and experienced labour force living within or just near the state. This could lead to increases in labour productivity and higher wage bills, thereby reducing demand for manufacturing workers.

The fact that manufacturing products are also traded regionally and later nationally should not be discounted. Basically, improving the capacity and accessibility of the highway infrastructure network could facilitate access to material sources and market areas outside the state border as well as intermodal transportation facilities (e.g. airports and ports) that are located in other states. For manufacturing industries in a state, highway improvements in its neighbouring states or in the rest of the economy could primarily lead to a substantial decrease in transport costs of moving inputs and goods, which might be translated into a rise in the demand for manufacturing goods and thus employment.

As one would expect interstate highways which are expressly designed to provide linkages between states to be important to manufacturing, the absence of Granger causality evidence as shown in Table 7.6 is surprising. Nevertheless, the results for the manufacturing sector in Table 7.8 consistently indicate the long-run positive effect of growth in the density of arterial and collector roads located in other states. While this

finding may underline the importance of these major highways in supplementing and augmenting the interstate highway system, another possible explanation could be that some principal arterial roads also serve interstate travel and provide direct access to and from major cities located in adjacent states.

Changes in the area-wide capacity and coverage of the highway network may not affect construction activities as directly as could be expected in manufacturing. In addition, the market areas that they serve are notably different in spatial scale. Improvements in arterial and collector roads could extend the effective labour market for construction businesses in a state. Despite the fact that the potential increase in labour productivity could enable them to expand, this may not be so sufficient that the number of construction jobs would increase overall as we find that growth in non-interstate major highways has a negative impact on future growth in construction employment within the state. It is not immediately clear how to interpret the evidence of positive employment spillovers for the construction sector. While expanding roadway capacities for principal arterials could improve access to construction sites located in nearby states, one might argue that the majority of construction firms are more likely to serve residents and businesses locally.

The evidence on the sectoral link between manufacturing and construction has led us to an alternative interpretation. Consider the estimates from the models that include the intersectoral variables as presented in the last two columns of Table 7.8. The estimated parameters for the manufacturing employment variable are positive and highly significant, implying that growth in manufacturing employment is, *ceteris paribus*, a significant determinant of future employment growth for construction. Given the temporal and spatial spillover effects of non-interstate major roads on manufacturing, the Granger causality evidence for the construction sector is likely to mirror some indirect effects that emerge through the linkage between these two sectors. In other words, growth in aggregate arterial and collector lane miles within the state, for instance, has an indirect negative impact on construction employment growth through its negative effect on the demand for manufacturing employment. The positive spillover effect can be interpreted in an analogous manner.

Alternative spatial weighting schemes

As for the test for employment spillovers from highways, the results thus far are based on a spatial weighting scheme that accounts for the employment effects of highways in all other states. While a key merit of this approach is to account for higher-order spillovers in spatial processes, we also consider a common practice in the literature by emphasising the spillover effect of highways among states that share a common border. Four alternative definitions of spatial proximity as previously defined in Chapter 6 are also used.

In order to test whether the employment effects of highways spill over into geographically neighbouring states under with these different definitions, we reestimate our preferred specification that accounts for the temporal dynamic effects of intersectoral spillovers and industry output (eq. 7.5). The summary of Granger causality test results for interstate highways and non-interstate highways are presented in Tables 7.9 and 7.10 respectively, including the corresponding results based on the distance decay matrix (W_{dis}) for comparison. Since the estimation results for output and sectoral spillover variables are basically unchanged, only p -values from the tests for the exogeneity of instruments used in the GMM estimation are reported.

For the case of interstate highways, the results are consistent across different definitions of spatial proximity, confirming the existence of negative spillover effects on services and construction employment. However, there is wide variation in the long-run coefficients for interstate highways located outside the state boundary. This implies that the magnitude of negative employment spillovers is dependent upon how we define the spatial scale of impact areas as well as how we define states as close neighbours. For both sectors, the higher long-run coefficients based on the distance decay matrix, which is defined to capture the spatial effects from all other states' interstate highways, lends support to the view that spatial externalities of interstate highways are not necessarily confined to geographically nearby states. In addition, the results tend to confirm the net negative effect of interstate highways, regardless of different criteria used to define spatial weight matrices. However, there is an exception in the case of the services sector using the highway network matrix (W_{hwy}). Assuming that the presence of spillovers depends on the extent to which states are connected by the interstate highway network,

we find an opposite result in that the positive effect of interstate highways in a state served directly is larger than the negative spillover effect.

Table 7.9 Testing for sectoral employment spillovers from interstate highways

Spatial weighting scheme	Lags	Lagged ΔH		Lagged ΔWH		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
<i>Services</i>								
W_{dis} : Distance-decay	3	0.046	0.043 ^{***}	- 0.198	0.002 ^{***}	0.973	0.127	0.994
W_{bin} : Binary contiguity	3	0.042	0.059 [*]	- 0.082	0.085 [*]	0.904	0.137	0.999
W_{edis} : Contiguity with distance decay	3	0.044	0.054 [*]	- 0.071	0.091 [*]	0.999	0.138	0.999
W_{hwy} : Contiguity with highway connectivity	3	0.039	0.063 [*]	- 0.027	0.075 [*]	0.820	0.100	0.994
W_{pop} : Contiguity with population density weighted average	3	0.042	0.058 [*]	- 0.055	0.066 [*]	0.922	0.077	0.975
<i>Manufacturing</i>								
W_{dis} : Distance-decay	2	- 0.087	0.872	- 0.513	0.447	0.805	0.404	0.832
W_{bin} : Binary contiguity	2	- 0.099	0.848	- 0.013	0.426	0.768	0.483	0.933
W_{edis} : Contiguity with distance decay	2	- 0.090	0.870	- 0.066	0.546	0.755	0.461	0.921
W_{hwy} : Contiguity with highway connectivity	2	- 0.109	0.829	- 0.086	0.160	0.758	0.484	0.927
W_{pop} : Contiguity with population density weighted average	2	- 0.090	0.876	- 0.119	0.439	0.754	0.492	0.927
<i>Construction</i>								
W_{dis} : Distance-decay	3	0.106	0.100	- 0.425	0.012 ^{**}	0.155	0.320	0.948
W_{bin} : Binary contiguity	3	0.113	0.059 [*]	- 0.308	0.022 ^{**}	0.227	0.280	0.848
W_{edis} : Contiguity with distance decay	3	0.112	0.081 [*]	- 0.290	0.017 ^{**}	0.173	0.190	0.693
W_{hwy} : Contiguity with highway connectivity	3	0.109	0.068 [*]	- 0.240	0.011 ^{**}	0.190	0.219	0.763
W_{pop} : Contiguity with population density weighted average	3	0.106	0.058 [*]	- 0.204	0.009 ^{***}	0.215	0.243	0.789

Note: *P*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged highway variables at the 10%, 5%, and 1% levels, respectively.

Table 7.10 Testing for sectoral employment spillovers from non-interstate major roads

Spatial weighting scheme	Lags	Lagged ΔH		Lagged ΔWH		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
<i>Services</i>								
W_{dis} : Distance-decay	3	0.004	0.036**	0.209	0.403	0.891	0.063	0.815
W_{bin} : Binary contiguity	3	0.007	0.029**	0.093	0.652	0.670	0.055	0.805
W_{dis} : Contiguity with distance decay	3	0.009	0.033**	0.091	0.815	0.800	0.059	0.800
W_{hwy} : Contiguity with highway connectivity	3	0.006	0.027**	0.095	0.660	0.926	0.053	0.763
W_{pop} : Contiguity with population density weighted average	3	0.0003	0.030**	0.142	0.143	0.901	0.068	0.891
<i>Manufacturing</i>								
W_{dis} : Distance-decay	3	-0.665	0.009***	1.158	0.091*	0.841	0.455	0.999
W_{bin} : Binary contiguity	3	-0.647	0.021**	0.877	0.108	0.939	0.554	1.000
W_{dis} : Contiguity with distance decay	3	-0.669	0.008***	0.833	0.139	0.835	0.479	0.999
W_{hwy} : Contiguity with highway connectivity	3	-0.658	0.011**	0.930	0.040*	0.914	0.568	1.000
W_{pop} : Contiguity with population density weighted average	3	-0.640	0.015**	0.859	0.118	0.930	0.519	1.000
<i>Construction</i>								
W_{dis} : Distance-decay	3	-0.078	0.000***	0.365	0.026**	0.262	0.230	0.651
W_{bin} : Binary contiguity	3	-0.052	0.001***	0.130	0.218	0.215	0.224	0.678
W_{dis} : Contiguity with distance decay	3	-0.065	0.000**	0.156	0.481	0.294	0.269	0.756
W_{hwy} : Contiguity with highway connectivity	3	-0.065	0.001***	0.189	0.291	0.291	0.247	0.713
W_{pop} : Contiguity with population density weighted average	3	-0.059	0.002***	0.149	0.394	0.182	0.389	0.907

Note: *P*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged highway variables at the 10%, 5%, and 1% levels, respectively.

For the manufacturing sector, the finding of no spillover effect from interstate highways remains unchanged. It is again surprising as we do not find significant evidence of employment spillovers even limiting our attention to the possibility that interstate highways could have spillover effects across states that are geographically contiguous.

The causality test results for non-interstate major roads are relatively less conclusive. While we find consistent evidence suggesting that improvements in arterial and collector roads do not have spatial spillovers effects on services employment, the results for non-service sectors are affected by changes in the spatial weight matrices. It is previously found that state manufacturing employment growth is positively influenced by growth in all other states' non-interstate major highways. However, the only significant evidence of employment spillovers across geographical contiguous states in Table 7.10 comes from the use of the highway connectivity matrix (W_{hwy}) which contains information on the connectivity of the intrastate highway network. The result based on the population density matrix (W_{pop}) that is expected to capture the relative importance of market potentials just fails to reject the null of no Granger causality at the 10 percent level.

Given the differences in the significance of Granger causality evidence across different spatial weighting scenarios, we assess which spatial matrix has produced better results in terms of model fit using information criteria.⁵⁹ In most cases, all the information criteria we consider (i.e. AIC, BIC, and HQ) tend to reach minimum values for the model using the highway connectivity matrix, and the population density matrix is generally found to be the second best. Based on this evidence, it is plausible to conclude that adding lane miles for arterial and collector roads can produce positive network spillovers that induce growth in manufacturing jobs across neighbouring states. Note however that this finding of positive spillovers is not in line with the recent work by Cohen and Paul (2004) which finds the negative effect of neighbouring states' highway capital on state manufacturing employment.

For the case of construction industries in which our previous results indicate the existence of spillover effects of non-interstate major roads from all other states, we find an opposite and, perhaps, contradictory result when focusing on the spatial interaction between states that share a common border. In particular, we cannot reject the null hypothesis of no employment spillovers even when trying different spatial weighting scenarios. This finding does not seem to support the earlier interpretation that gains in

⁵⁹ In several cases there are also substantial variations in the magnitude of the long-run coefficient of highways located outside the state, depending on the definitions of spatial weight matrices. In those cases, applying information criteria tends to yield results in favour of either the highway connectivity matrix or the population density matrix. However, the results from other spatial matrices are also important because they have different but meaningful interpretations.

construction employment in a state could stem from improved accessibility provided by intrastate highways located just outside its border. Given generally similar patterns in the causality test results for manufacturing and construction sectors, it would still make sense that non-interstate major roads may have both direct and indirect effects on construction employment; the latter is probably due to the effects of highways on manufacturing. However, our finding in Table 7.10 suggests that construction industries may be unable to capitalise on induced growth in manufacturing employment which arises from expanding capacities of arterial and collector roads in surrounding states that are strongly connected by the intrastate highway network.

7.5.2 Reverse causality

By estimating the highway equation 7.2, we can examine whether the evolution of employment for each sector Granger causes additional investments of highway infrastructure. Table 7.11 reports the summary of causality test results based on the system GMM estimator with valid instruments (See Table 7.12 for the test of instrument relevance). As can be seen, there are some dynamic feedbacks from sectoral employment growth to growth in the density of non-interstate major highways. For the services sector, the null of no reverse causality cannot be rejected at the 5% level, and the long-run coefficient for lagged growth in services employment is positive. The reverse causal link is also statistically evident in the case of manufacturing employment, but the sign of its long-run coefficient indicates negative Granger causality.

Two important implications stand out from these empirical findings. The evidence of positive feedback from growth in services employment supports the view that state government decisions to expand or improve highway capacities are usually taken in response to growth in the demand from road users. Since the demand for travel is a derived demand, a rapid expansion of service activities that generally exhibit the largest growing employment in the state economy could lead to substantial increases in road traffic which may in turn cause congestion and delays. Our results confirm the existence of the reverse causal link, suggesting that new construction and expansions for arterial and collector roads are likely undertaken in order to remove gridlock on roads and serve growing volumes of individual and business journeys.

Table 7.11 Granger causality from sectoral employment to highways

Industry	Lags	Lagged ΔE		Tests of instrument exogeneity		
		Long-run coeff.	Joint test	AR2	Sargan	Diff Sargan
<i>Interstate highways</i>						
Services	1	0.024	0.535	0.239	0.176	0.339
Manufacturing	3	- 0.036	0.365	0.852	0.134	0.170
Construction	3	- 0.033	0.205	0.843	0.130	0.198
<i>Non-interstate major roads</i>						
Services	2	0.064	0.049**	0.962	0.703	0.423
Manufacturing	3	- 0.005	0.016**	0.944	0.728	0.690
Construction	1	- 0.018	0.224	0.317	0.826	0.864

Note: *P*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. *, **, and *** indicate the joint significance of coefficients on lagged highway variables at the 10%, 5%, and 1% levels, respectively.

Table 7.12 Test of instrument relevance: highway equations

Endogenous variable	First difference equations		Levels equations	
	<i>F</i> test	<i>R</i> ²	<i>F</i> test	<i>R</i> ²
Lagged growth in interstate lane-mile density	227.51 (0.000)	0.468	55.66 (0.000)	0.541
Lagged growth in non-interstate major lane-mile density	129.28 (0.000)	0.489	8.38 (0.004)	0.514
Instruments used in GMM estimations	Lagged levels in time period t-2, and t-3		Lagged first-differences dated t-1	

Note: Numbers in parentheses are *p*-values corresponding to the test of the null hypothesis that coefficients of all instruments used are jointly zero.

Given the economic slowdown in manufacturing, the finding of negative Granger causality from manufacturing employment possibly reflects state governments' efforts that were made to stimulate growth and attract inward investments in manufacturing by improving streets and highways (Forkenbrock and Plazak, 1986). However, the data analysis in this chapter seems to suggest that this strategy did not lead to increased employment in manufacturing.

7.5.3 Comparison between aggregate and sector-specific results

To highlight the importance of disaggregate analysis by industrial sector in revealing sectoral differences in the causal relationship between highway infrastructure and employment in both directions, we compare the general findings of Granger causality

that are obtained using sector-specific employment data with those based on aggregate data for all private sectors (Chapter 6).

Table 7.13 summarises the evidence of Granger causality along with the sign of the temporal effects of highways on employment.⁶⁰ As can be seen, analysing disaggregate data by sector has uncovered significant variations in the effects of interstate and non-interstate major highways on employment in the various sectors of the economy. We find that the aggregate positive effect of interstate highways within the state and their negative spillover effects are confined to services and construction sectors. Interestingly, provision of non-interstate major roads with a state served directly also has a positive effect on service employment. This result is masked by aggregation from which the overall effect in the entire private sector is found to be negative. The sectoral analysis also reveals that own state's lane mile additions for arterial and collector roads negatively affect growth in manufacturing and construction jobs. In addition, it enables us to discover the evidence of positive spillover effects on manufacturing and construction employment which were not found using aggregate data.

Table 7.13 Granger causality from highways to private sector employment

Type of highways	All private sectors	Services	Manufacturing	Construction
<u>Interstate highways</u>				
Within the state	$\Delta H \rightarrow \Delta E$ (+)	$\Delta H \rightarrow \Delta E$ (+)	None	$\Delta H \rightarrow \Delta E$ (+)
Adjacent states (spillovers)	$\Delta WH \rightarrow \Delta E$ (-)	$\Delta WH \rightarrow \Delta E$ (-)	None	$\Delta WH \rightarrow \Delta E$ (-)
All other states (spillovers)	$\Delta WH \rightarrow \Delta E$ (-)	$\Delta WH \rightarrow \Delta E$ (-)	None	$\Delta WH \rightarrow \Delta E$ (-)
<u>Non-interstate roads</u>				
Within the state	$\Delta H \rightarrow \Delta E$ (-)	$\Delta H \rightarrow \Delta E$ (+)	$\Delta H \rightarrow \Delta E$ (-)	$\Delta H \rightarrow \Delta E$ (-)
Adjacent states (spillovers)	None	None	$\Delta WH \rightarrow \Delta E$ (+)	None
All other states (spillovers)	None	None	$\Delta WH \rightarrow \Delta E$ (+)	$\Delta WH \rightarrow \Delta E$ (+)

The comparison for the findings of reverse causality is displayed in Table 7.14. While the evolution of aggregate lane miles for non-interstate major roads is found to be positively associated with lagged changes in aggregate private employment, the tests for

⁶⁰ Owing to differences in datasets and specifications, the specific values of the long-run coefficients cannot be compared directly and thus not reported.

Granger causality using disaggregated data reveal that it could be employment growth in the services sector, the largest sector in the economy, which seems to drive the significant positive effect at the aggregate level. Moreover, the finding of positive feedback from employment growth in all private sectors hides the significant but opposite result for the manufacturing sector. Breaking down the sample by sector, we find evidence of negative causality from manufacturing employment to non-interstate major roads.

Table 7.14 Granger causality from private sector employment to highways

Industrial sector	Interstate highways	Non-interstate major roads
Services	None	$\Delta E \rightarrow \Delta H$ (+)
Manufacturing	None	$\Delta E \rightarrow \Delta H$ (-)
Construction	None	None
All private sectors	None	$\Delta E \rightarrow \Delta H$ (+)

7.6 Summary and discussion

The chapter has reported evidence that there were notable differences in the causal relationship between provision of major highway infrastructure and employment growth across U.S. industrial sectors. We find additional investments in interstate and non-interstate major roads as important determinants of state employment growth in the services sector. Adding capacity of interstate highways also tends to boost long-term local construction jobs. However, our results suggest that such employment gains from improvements in interstate highways in the state may come at the expense of the same industries in the rest of the economy. We find that interstate highways create negative employment spillovers, shifting services and construction jobs away from other states. This evidence is robust across different assumptions of spatial interactions.

Previous studies indicate that investments in highway infrastructure could lead to a reduction in the demand for manufacturing workers. The common argument is that improved highway facilities may induce large substitution away from the intensity of labour usage in manufacturing industries. This analysis reveals supporting evidence for

the case of improvements in non-interstate major highways within a state. Nevertheless, we also find evidence of positive employment spillovers which suggests that adding lane miles for arterial and collector roads outside of the state where the industry is based has contributed towards state manufacturing employment growth. Similar results are obtained for the construction sector, though they may to a certain extent capture some indirect effects of non-interstate major highways through its sectoral link with the manufacturing sector.

Over the past decades, a shift from manufacturing to services employment has characterised the economic restructuring of several nations, including the United States. Based on data for the 48 contiguous US states from 1984-1997, this analysis brings forward econometric evidence suggesting that additional investments in highways played a significant role in this structural realignment of the state economy during that period. As already mentioned, the results indicate that expanding capacity and coverage of the major highway network in the state Granger causes increased employment growth in the services sector while reducing manufacturing employment growth. Although not usually framed in the context of the modern literature on infrastructure and economic development, one could certainly view the evolution of regional employment in these two major industrial sectors as a function of prior investments in highway infrastructure. By taking into account the potential reverse causation, we can empirically identify that such relationships are bi-directional. While state government efforts to increase lane-mile capacity of arterial and collector roads are likely made in response to a rapid expansion of service employment, such highway improvements are also likely intended to attract replacements for lost manufacturing jobs. For the latter, however, empirical evidence shows that the effect of lane-mile additions tends to run counter to that aim.

Chapter 8

The Impact of Highway Infrastructure on Private Sector Production

8.1 Introduction

In the last three chapters, the question that has been addressed is whether building new capacity for highways is an effective policy instrument if it is designed to generate employment. In Chapter 6, the results show that the net impact of own-state lane-mile additions for non-local roads on overall private employment is positive but tends to be very small. In addition, employment growth associated with the provision of interstate highways is found to be at the expense of neighbouring and remote states, which in turn raise doubts about the total employment effect of interstate highways from a nationwide perspective. While the latter finding lends to support the justification of improving capacity for interstate highways as a “competitive” tool for attracting employment-generating activity (Forkenbrock and Plazek, 1986), the former seems to be less favourable for overall highway infrastructure programmes aimed at creating jobs for state and local communities. The question that remains unsolved and that could be of importance to policy makers is whether the allocation of highway improvement funding can be justified through the pursuit of the economic returns from highway capacity expansions.

The purpose of this chapter is therefore to examine whether and to what extent increasing capacity for the highway network can foster economic development by increasing gross domestic product for the entire private sector at the state level.

Prompted by the debate arising from the seminal work of Aschauer (1989), research efforts devoted to examining the contribution of highway infrastructure to private sector productivity in the United States have been immense. As a brief review of the literature in Chapter 2 has pointed out, much attention has been given to identify the “true” elasticity of output with respect to infrastructure capital and reconciling inconclusive findings from previous research. In almost all the research on this topic, highway infrastructure is measured as the monetary value of the capital stock, primarily based on the perpetual inventory method. As discussed in Chapter 4, the accuracy of the monetary stock in measuring the services provided by highway infrastructure has been subject to several criticisms, including the validity of assumptions regarding prices used to value capital stock, depreciation rates, the difference between actual government spending on infrastructure and its economic costs, and estimating or benchmarking the level of capital stock for an initial year. Using physical measures of highway infrastructure is a viable option to avoid these difficulties. Yet, empirical evidence based on this alternative approach has rarely emerged in the literature.

In this chapter we examine the effect of highway infrastructure investment on private sector output using panel data for the 48 contiguous US states from the years 1984 through 1997. To contribute further evidence to the existing literature, this analysis utilises data on roadway lane miles to measure the physical stock of highway infrastructure. We begin with a static Cobb-Douglas production function framework, and systematically test for the most appropriate econometric specifications. While this approach is generally consistent with typical empirical settings in the literature, we consider a dynamic production function model to capture temporal lags in the impact of highway capacity expansion on state output. The hypothesis of output spillovers from highway infrastructure located in other states is also addressed using several different criteria of spatial interaction. Notwithstanding these empirical extensions, Cribfield and McGuire (1997) argue that the sign and significance of coefficients from regressions do not offer the compelling evidence for policy direction indicated by alternative criteria, such as maximisation of the net present value in project evaluation. Given that this is another limitation in much of the previous research, we calculate the present value of future output gains from adding a one-time increase in a lane-mile of highways which

policy makers could use to make investment decisions. Distinction is also made between the long-term accumulated output effects of highways by different category.

Section 8.2 presents the theoretical framework for the analysis. Section 8.3 discusses the data set, followed by Section 8.4 that contains some preliminary results from estimating static production functions. Section 8.5 presents the results from dynamic production function estimates, followed by the test for the spatial spillover effect of highways in Section 8.6. Policy implications regarding the marginal benefits of highway capacity expansion are discussed in Section 8.7. Section 8.8 concludes with a summary of results and discussion.

8.2 Model

Assuming that production technology at the firm level is homogenous, we specify the same general production function for each state, containing labour and private capital as the inputs. A simple aggregate production function used as a theoretical basis for the analysis is then defined as:

$$Q_{it} = g(H_{it}, Urban_{it}, \mu_i, \tau_i) \cdot f(L_{it}, K_{it}) \quad (8.1)$$

where Q is the private sector output, K is the private capital stock, and L is the private labour. Subscript i and t denote states and years, respectively. The variable H represents the physical measure of highway capital stock that is modelled to affect productivity through the Hick-neutral production function shifter (g). Given that the theoretical link between infrastructure, agglomeration, and productivity is well established in the literature (e.g. Eberts and McMillen, 1999; Rosenthal and Strange, 2004), we also include the variable $Urban$ as a shift factor to account for regional heterogeneity in productivity due to differences in the degree of state urbanisation, represented by each state's share of population in metropolitan areas.⁶¹ μ_i and τ_i denote, respectively, state-specific

⁶¹ This measure of urbanisation is as used in Carlinio and Voith (1992) who analyse the effects of agglomeration economies on state productivity in the US. As argued by Graham (2007b), sources of agglomeration economies are not only city size or scale, but the spatial proximity of economic activities. We have experimented with more appropriate measures of agglomerations including population density and employment density. However, there are problems of multicollinearity as both of these are found to be highly correlated with our highway density variable ($r = 0.89$). Given that this is not the main objective of the analysis, we use the share of population living in urban areas to control for the influence of agglomerations on state economic performance. Since such density measures are very persistent over time, their agglomeration effects could be captured by the state-specific component.

characteristics and time-varying factors that can influence the overall state production technology. The Hicks-neutral shifter is assumed to take the following form:

$$g(\cdot) = H_i^{\beta_H} e^{\beta_u \text{Urban}_i} e^{\mu_i} e^{\tau_i} \quad (8.2)$$

Assuming that labour and private capital are combined in a Cobb-Douglas relationship, the logarithmic transformation produces a log-linear production function that can be estimated in the following form:

$$\ln Q_i = \alpha + \beta_L \ln L_i + \beta_K \ln K_i + \beta_H \ln H_i + \beta_u \text{Urban}_i + \mu_i + \tau_i + \varepsilon_i \quad (8.3)$$

where ε is an error term.⁶² All variables are in the natural logarithm except for *Urban*. One may reduce the number of parameters to be estimated and collinearity by assuming that the production technology exhibits constant returns to scale in labour and private capital (i.e. $\beta_L + \beta_K = 1$), though this restriction is not necessarily appropriate. The main focus in this context is on the coefficient β_H that gives the elasticity of output with respect to highways. It should be noted that this specification is to some extent consistent with typical empirical settings in much of the literature relying on the production function approach. However, it imposes an untenable restriction that output fully adjusts to changes in highway capital in a contemporaneous period. Since time lags may come into play, this implies the need to model the contribution of highway capital to output dynamically. To characterise dynamic adjustments of state output in response to increased highway capital, we therefore consider a general dynamic model specification based on the simple production function model (8.3). We describe this empirical extension in Section 8.5.

8.3 Data

Data on private capital stocks at the state level are not readily available. We thus apportion BEA national stock estimates of private fixed capital among the states, using

⁶² The Cobb-Douglas specification has some limitations. For example, it imposes the restriction of constant output elasticities of the inputs. Also, it does not provide information about whether any two inputs are complements or substitutes. Taking these limitations into account, some studies in the literature use a translog functional form for aggregate production. However, this flexible functional form involves estimation of a large number of independent parameters. Another concern is multicollinearity due to the inclusion of many variables. We thus follow much of the empirical infrastructure research in using the simple Cobb-Douglas functional form. A key contribution of this analysis is to assess whether and how introducing dynamic components into the production function could affect the estimated impact of highway infrastructure.

the size of private capital stock in a given state relative to that of the entire nation.⁶³ The share of state population in metropolitan statistical areas (MSAs) is used as a proxy for the level of state urbanisation. We calculate the sum of population living in counties located in MSAs based on the 1990 definition of the US Census Bureau, and divide it by the number of state population. Data on state and county population are taken from the REIS.

Table 8.1 presents descriptive statistics of the data. Prior to estimation, we check whether the data are stationary series so as to avoid spurious regression results. The Levin-Lin-Chu test for panel unit root is conducted under the null hypothesis of non-stationary. As reported in the same table, the test results indicate that, for all variables, the null hypothesis is strongly rejected at the 1% level. In empirical implementation, therefore, we do not consider the first-difference transformation that alters the interpretation of regression results, and that disregards long-run information in the data.

Table 8.1 Descriptive statistics and tests for panel unit root

Variable	Mean	Standard deviations			Levin-Lin-Chu test for panel unit root		
		Overall	Between	Within	1 lag	2 lags	3 lags
$\ln Q$	11.207	1.048	1.049	0.136	-8.755 ***	-9.331 ***	-9.297 ***
$\ln K$	12.169	1.006	1.009	0.121	-8.791 ***	-9.464 ***	-9.418 ***
$\ln L$	14.202	0.997	1.002	0.102	-8.801 ***	-9.382 ***	-9.370 ***
$\ln H$	1.151	0.634	0.639	0.038	-6.023 ***	-6.668 ***	-6.708 ***
<i>Urban</i>	0.656	0.217	0.220	0.007	-4.330 ***	-4.679 ***	-4.699 ***

Note: For the test for panel unit root, the constant term and a time trend are included. This can be viewed as an Augmented Dickey-Fullter (ADF) test for unit root.

8.4 Static production function estimates

To begin, we apply several estimation techniques to the log-linear production function equation 8.3. The results are reported in Table 8.2. Column 1 presents OLS estimates that ignore the importance of state-specific effects. Column 2 presents Within Group estimates based on the fixed effects specification, whereas results from the estimation of

⁶³ The private capital stock in a state is given by the following formula:

$$K_{s,t} = \frac{VADD_{s,t} - WS_{s,t}}{VADD_{n,t} - WS_{n,t}} \times K_{n,t}$$

where K is private capital stock, $VADD$ is total value added of all private industries, WS is total wages and salaries for all private industries, s indexes state, n indexes the nation, and t indexes years. The term $(VADD - WS)$ represents returns to capital that is used as a proxy for the size of private capital stocks. This procedure is similar to one outlined in Yilmaz et al (2002). Data on $VADD$ and WS are obtained from the BEA website (<http://www.bea.gov>). State-level private capital stocks are measured in 2000 dollars.

an alternative random effects specification by the Feasible Generalised Least Squares (FGLS) estimator are reported in column 3. Column 4 contains results based on the Between Group (BG) estimator that involves applying the OLS to a cross-section of all variables averaged over time. Tests for the hypothesis of constant returns to scale (CRTS) in the private inputs and Moran's I residual spatial autocorrelation are also reported.

All variables are statistically significant with expected signs. The output elasticities of labour and private capital are positive and highly significant. There is also strong and consistent evidence on the positive influence of urbanisation on state productivity which is consistent with Carlino and Voith (1992) and Ciccone and Hall (1996) using data from US states. Of particular interest to this analysis is the contribution of highway infrastructure to state output. The results for the coefficient on highways are generally robust across model specifications in terms of sign and significance. However, there are major differences in the magnitude of the highway variable, ranging from 0.017 to 0.041.

Table 8.2 Static production function estimates

Dependent variable: ln Q	(1) OLS	(2) Within	(3) FGLS	(4) BG
ln L	0.331 (26.43)	0.348 (23.02)	0.334 (22.98)	0.331 (8.15)
ln K	0.679 (54.26)	0.684 (44.38)	0.680 (45.67)	0.679 (16.37)
ln H	0.017 (7.02)	0.041 (2.65)	0.021 (2.42)	0.017 (1.95)
Urban	0.197 (22.83)	0.306 (2.67)	0.185 (6.97)	0.197 (6.14)
State effects	No	Fixed	Random	No
Time effects	Yes	Yes	Yes	No
CRTS	0.000	0.055	0.003	0.138
Moran's I (W_{bin})	1.349	1.714	1.834	1.203
Moran's I (W_{inv})	1.108	1.482	1.589	0.976
R ²	0.999	0.998	0.999	0.991
Obs.	672	672	672	48

Note: Numbers in parentheses are robust t -statistics. CRTS is a test of the constant returns to scale under the null hypothesis that $\beta_L + \beta_K = 1$. The null hypothesis for the Moran's I test is that there is no spatial autocorrelation in regression residuals. Two spatial weight matrices are used: the binary contiguity (W_{bin}) where the elements are set to one if two states share a border and zero otherwise, and the inversed distance matrix (W_{inv}) where the elements are set equal to the inverse of distance between any pair of states if they have a common border, and zero otherwise. These two matrices are row-standardised. Average values of standardised Moran's I statistics across time period are reported. The estimated results for time and state fixed effects are omitted for brevity. The inclusion of time dummies cannot be rejected at the 1% level in all specifications.

Compared with OLS estimates in column 1, the coefficient for highway capital is higher when controlling for state-specific effects. This is in contrast to some state-level studies which found that the estimated coefficient on public infrastructure becomes

smaller in either fixed effects or random effects specification (e.g. Holtz-Eakin, 1994; and Garcia-Mila et al, 1996). However, the Hausman test for the fixed effects model versus the random effects model yields a similar result, in that the state-specific effects are likely correlated with the explanatory variables. The test statistic is 245.88, which is significant at the 1% level. Based on this, the fixed state effects specification is preferable, and yields the output elasticity of 0.041 for highway capital. In column 4 which reports Between Group estimates, however, the estimated elasticity of output with respect to highways is much lower (0.017).

Imposing CRTS in labour and private capital ($\beta_L + \beta_K = 1$) into equation (8.3), we find that this does not have discernible effects on these results (see Table 8.3). However, the appropriateness of this coefficient restriction in the OLS, fixed effects, and random effects models is rejected statistically. In these three specifications, we find the existence of increasing returns to scale in labour and private capital. Only the results from Between Group regressions satisfy the assumption of CRTS in the private inputs, which suggests that in the long run the state production technology likely exhibits constant returns to scale. Note also that the results from the Moran's I test do not indicate that spatial autocorrelation seems to be a problem.

For static panel estimations, it is a common practice to distinguish between time series and cross sectional estimates when interpreting regression results. The Within Group estimator is usually thought to capture *short-run* responses of explanatory variables, whereas the Between Group estimates could yield the *long-run* responses (e.g. Baltagi and Griffin, 1984; Pirotte, 1999, 2003; Egger and Pfaffermayr, 2004). Although this could explain the difference between the estimated elasticities of output with respect to highways, what seems to be difficult to reconcile is their relative size. Providing that the Within Group regression would yield the short-run effect of highway capital on output, the lower magnitude for the long-run effect of highways which would be indicated by the Between Group estimates seems to be unrealistic.

Although this could indicate misspecification problems, some econometric issues are not taken into account. For specifications using time-series information in the data, the null hypothesis of no first-order autocorrelation (AR1) is consistently rejected by the Wooldridge (2002) test and the Arellano and Bond (1991) test. More importantly, the

estimates may suffer from simultaneity bias due to the feedbacks from output to labour and private capital.

Table 8.3 Static production function estimates:
Assuming CRTS restriction and testing the type of returns to scale

Dependent variable: ln Q/L	Imposing constant returns to scale (CRTS)				Testing the type of returns to scale			
	OLS (a)	Within (a)	FGLS (a)	BG (a)	OLS (b)	Within (b)	FGLS (b)	BG (b)
ln K/L	0.677 (55.68)	0.684 (42.72)	0.680 (45.27)	0.677 (17.60)	0.679 (54.26)	0.684 (44.38)	0.680 (45.67)	0.679 (16.37)
ln L					0.010 (4.78)	0.032 (1.93)	0.015 (2.93)	0.010 (1.25)
ln H	0.019 (8.62)	0.035 (2.40)	0.023 (2.58)	0.019 (2.47)	0.017 (7.02)	0.041 (2.65)	0.021 (2.42)	0.017 (1.95)
Urban	0.225 (31.11)	0.375 (2.99)	0.227 (9.60)	0.225 (8.56)	0.197 (22.83)	0.306 (2.67)	0.185 (6.97)	0.197 (6.14)
State effects	No	Fixed	Random	No	No	Fixed	Random	No
Time effects	No	Yes	Yes	No	No	Yes	Yes	No
Moran's I (W_{bin})	1.219	1.651	1.782	1.077	1.349	1.714	1.834	1.203
Moran's I (W_{mv})	1.070	1.409	1.529	0.954	1.108	1.482	1.589	0.976
R ²	0.928	0.879	0.928	0.924	0.931	0.850	0.930	0.928
Observations	672	672	672	672	672	672	672	672

Note: Numbers in parentheses are robust t -statistics. The null hypothesis for the Moran's I test is that there is no spatial autocorrelation in regression residuals. Average values of standardised Moran's I statistics across time period are reported. See notes below Table 8.2 for the definitions of the spatial weight matrices. The estimated results for time and state fixed effects are omitted for brevity. The inclusion of time dummies cannot be rejected at the 1% level in all specifications. Model specifications (a) and (b) are $\ln(Q_t/L_t) = \alpha + \beta_K \ln(K_t/L_t) + \beta_H \ln(H_t) + \beta_U \ln(Urban_t) + u_{it}$ and $\ln(Q_t/L_t) = \alpha + (\beta_1 + \beta_1 - 1) \ln(L_t) + \beta_K \ln(K_t/L_t) + \beta_H \ln(H_t) + \beta_U \ln(Urban_t) + u_{it}$, respectively, where u is the error term of the generic form. For the latter, the statistical significance of the coefficient on labour will reject the CRTS restriction, whereas its sign indicates the type of returns to scale.

Table 8.4 presents the C-test of exogeneity of each explanatory variable in the production function models.⁶⁴ Using valid instruments, the test suggests that labour and private capital variables have to be treated as endogenous in the fixed effects specification. For the Between Group specification which relies solely on the variation between cross-sectional units, it is only the treatment of private capital as exogenous that could render OLS biased and inconsistent. While these findings reinforce the common criticism of production function estimations in that output and factor inputs are likely to be simultaneously determined, the rejection of the null for private capital may also result from measurement error in the data on capital estimates. As widely emphasised in the literature, another potential source of simultaneity bias could be highway infrastructure. Given that more prosperous states are likely to have a greater stock of highway capital

⁶⁴ The C-test is implemented under the null hypothesis that the suspect regressor can be treated as exogenous. Distributed as chi-squared with degrees of freedom equal to the number of regressors tested, the C-statistic is calculated as the difference of two Sargan statistics: one from the equation with smaller set of instruments and the other from the equation with the larger set of instruments.

endowments, the causal relationship could be bi-directional. We are also concerned with the endogeneity of urbanisation. To the extent that firms and households could be drawn to high-productive states could give rise to the degree of urban concentration (Graham et al, 2008). However, the C-statistics indicate that we cannot reject the null hypothesis that these two variables are exogenous in both specifications.

Table 8.4 Tests for exogeneity of explanatory variables

Model specification	$\ln L$	$\ln K$	$\ln H$	<i>Urban</i>
<i>Fixed effects</i>				
C-test	8.722(1)	15.272(1)	0.153(1)	1.186(1)
(Difference-in-Sargan)	***	***		
F-test from first-stage regressions	28.22	30.88	69.72	27.70
	***	***	***	***
Sargan test of overidentifying restrictions	3.361(2)	3.226(2)	0.053(1)	0.135(1)
Instrument set	$\Delta \ln L_{t-1}, \Delta \ln L_{t-2}, \Delta \ln L_{t-3}$	$\Delta \ln K_t, \Delta \ln K_{t-1}, \Delta \ln K_{t-2}$	$\ln H_{t-1}, \ln H_{t-2}$	$\%urban_vmt_t, (\%urban_vmt_t)^2$
<i>Cross-section of individual means</i>				
C-test	1.028(1)	3.006(1)	0.158(1)	0.222(1)
(Difference-in-Sargan)		*		
F-test from first-stage regressions	38.84	50.97	1532.45	141.15
	***	***	***	***
Sargan test of overidentifying restrictions	0.000(1)	0.092(1)	0.470(1)	0.081(1)
Instrument set	$\ln L_{i,1984}, (\ln L_{i,1984})^2$	$\ln K_{i,1984}, (\ln K_{i,1984})^2$	$\ln H_{i,1984}, (\ln H_{i,1984})^2$	$\%urban_vmt_{i,1984}, (\%urban_vmt_{i,1984})^2$

Note: Results reported are based on 2SLS estimations. Using GMM, we also obtain similar results. For the fixed-effects specification, 2SLS estimates are corrected for autocorrelation. C-test is chi-square distributed under the null hypothesis that a variable is exogenous. Under the joint hypothesis that the instruments are uncorrelated with the error term, the Sargan test of overidentifying restrictions is distributed as chi-squared. * indicates significance at the 10% level. *** indicates significance at the 1% level. %urban_vmt denotes the share of vehicle-mile travel (VMT) on urban highways and streets within the state. The variable on the share of urban population is very highly time-series persistent. The lagged values of *Urban* cannot be used as instruments because the test of instrument exogeneity is rejected.

To correct for the endogeneity of private inputs, we apply two-stages least squares (2SLS) and generalised method of moments (GMM) estimators using the instrumental variables listed in Table 8.4. The problem of AR1 autocorrelation is addressed using the Newey and West (1987) procedure in order to obtain standard errors that are consistent with heteroscedasticity and autocorrelation. Table 8.5 presents 2SLS and GMM estimates along with *t* statistics calculated from the Newey-West standard errors. Columns 1 and 2 contain the results from estimating the fixed effects specification with labour and private capital specified as endogenous. Columns 3 and 4 report the results that take into account the endogeneity of private capital in the single cross-sectional specification of all

variables averaged over time.⁶⁵ Compared with the results from the Within Group and Between Group regressions in Table 8.2, the estimated elasticities of output with respect to highway capital do not change in terms of their relative magnitude. Based on the fixed effects specification, the GMM estimation yields the short-run output elasticity of 0.063 which is even higher than that based on the Within Group estimator (0.041). For the cross section estimates which could capture the long run responses, the long-run elasticity is not markedly altered (0.016) but still lower even after controlling for the endogeneity. As previously found, these results are also unaffected by either the use of invalid instruments or misspecifications due to spatial autocorrelation.

Table 8.5 Static production function estimates:
Correcting for autocorrelation and the endogeneity of private inputs

Dependent variable: ln Q	Fixed effects		Cross-section of individual means	
	2SLS (1)	GMM (2)	2SLS (3)	GMM (4)
ln L	0.367 (9.95)	0.382 (10.72)	0.364 (7.02)	0.361 (7.10)
ln K	0.535 (26.19)	0.538 (26.66)	0.646 (12.52)	0.649 (12.71)
ln H	0.060 (2.31)	0.063 (2.47)	0.016 (1.81)	0.016 (1.78)
Urban	0.553 (2.83)	0.625 (3.33)	0.199 (5.99)	0.199 (5.99)
State effects	Fixed		No	
Time effects	Yes		No	
C-test of exogeneity of ln L and ln K	14.003(2) ***		-	
C-test of exogeneity of ln K	-		3.006(1) *	
F-test from first-stage regressions of ln L	10.56 ***		-	
F-test from first-stage regressions of ln K	15.73 ***		50.07 ***	
Sargan test of overidentifying restrictions	5.029(4)		0.092(1)	
Moran's I (W_{bin})	0.941	0.758	0.912	0.967
Moran's I (W_{inv})	0.785	0.663	0.675	0.724
R ²	0.994	0.995	0.999	0.999
Observations	480		48	

Note: Numbers in parentheses below estimated coefficients are *t*-statistics that are heteroscedasticity-autocorrelation consistent. C-test is chi-square distributed under the null hypothesis of exogeneity. Under the joint hypothesis that the instruments are uncorrelated with the error term, the Sargan test of overidentifying restrictions is distributed as chi-squared. * indicates significance at the 10% level. *** indicates significance at the 1% level. The null hypothesis for the Moran's *I* test is that there is no spatial autocorrelation in regression residuals. Average values of standardised Moran's *I* statistics across time period are reported. See notes below Table 8.2 for the definitions of the spatial weight matrices. The estimated results for time and state fixed effects are omitted for brevity. The inclusion of time dummies cannot be rejected at the 1% level in all specifications.

⁶⁵ We also applied the C-test to examine the null hypothesis of exogeneity of the remaining variables. To perform the test, we use instruments listed in Table 8.4, the validity of which are again confirmed by the *F*-statistics from first-stage regressions and the Sargan test of overidentifying restrictions. However, the C-statistics do not reject the null hypothesis of exogeneity, given a 10% critical value of 2.71. The test statistics for ln *H* and *Urban* are, respectively, 0.292 and 1.650 in the fixed-effects specification, whereas those for ln *L*, ln *H*, and *Urban* in the cross-section specification are 0.187, 0.269, and 0.026, respectively.

The static production function estimates thus far consistently indicate that additions of highway lane miles can have a positive and significant impact on private sector output in states. This general finding is robust to the presence of temporal autocorrelation and endogeneity of the private inputs. In more detail, however, we find that elasticity estimates involving highway capital are very sensitive to the choice of estimation method. More importantly, the specifications that can be expected to capture short-run and long-run responses of state output to changes in highway infrastructure appear to yield opposing results. Regardless of labour and private capital endogeneity, the short-run elasticity of output obtained from the Within Group estimator (0.041) is much higher than the long-run elasticity from the Between Group regression (0.017) which makes use of the cross-sectional variation in the data.

Recent work by Egger and Pfaffermayr (2004) has reported estimation biases of static panel models with respect to short run and long run parameters when the true specification is "dynamic". For static panels with a short time series dimension, their Monte Carlo simulations show that the Within Group and Between Group estimators could perform poorly in capturing short-run and long-run responses, depending crucially on the memory of the data generating process. This could be the most plausible explanation for these elasticity estimates from the static Cobb-Douglas production function in which the absence of a lagged dependent variable does not account for dynamic adjustments of output. As previously shown, AR1 error is present in the data. An implication on this ground also comes from the existence of temporal autocorrelation as already reported. Although one possible solution to dealing with autocorrelation could be to estimate the static panel model with temporally autocorrelated errors using GLS, this approach is only appropriate when its underlying coefficient restrictions are consistent with the data (Johnston and DiNardo, 1997; and Green, 2003).

In the light of these concerns, we proceed in the next section by specifying a general dynamic specification for the Cobb-Douglas production function. Dynamic panel data analysis is applied to derive short-run and long-run elasticities of output with respect to highway capital. While the underlying reason for this is to seek improvements in elasticity estimates, the dynamic modelling results suggest that research evidence from static models are unreliable.

8.5 Dynamic production function approach

To incorporate temporal dynamics into the production function, we begin by specifying a first-order autoregressive (AR1) disturbance term in the static production function model (8.3), which can be expressed as:

$$\ln Q_{it} = \alpha + \beta_L \ln L_{it} + \beta_K \ln K_{it} + \beta_H \ln H_{it} + \beta_U \text{Urban}_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (8.4)$$

with

$$\varepsilon_{it} = \delta \varepsilon_{it-1} + v_{it}$$

where $|\delta| < 1$ and v_{it} is an i.i.d. error term. This model which introduces error dynamics can be rewritten as:

$$\begin{aligned} \ln Q_{it} = & (1 - \delta)\alpha + \delta \ln Q_{it-1} + \beta_L \ln L_{it} - \delta\beta_L \ln L_{it-1} + \beta_K \ln K_{it} - \delta\beta_K \ln K_{it-1} \\ & + \beta_H \ln H_{it} - \delta\beta_H \ln H_{it-1} + \beta_U \text{Urban}_{it} - \delta\beta_U \text{Urban}_{it-1} + (1 - \delta)\mu_i + \tau_t - \delta\tau_{t-1} + \varepsilon_{it} \end{aligned} \quad (8.5)$$

This specification is a first-order autoregressive distributed lag model (ARDL) of the generic form:

$$\begin{aligned} \ln Q_{it} = & \alpha^* + \delta \ln Q_{it-1} + \pi_1 \ln L_{it} + \pi_{1a} \ln L_{it-1} + \pi_2 \ln K_{it} + \pi_{2a} \ln K_{it-1} \\ & + \pi_3 \ln H_{it} + \pi_{3a} \ln H_{it-1} + \pi_4 \text{Urban}_{it} + \pi_{4a} \text{Urban}_{it-1} + \mu_i^* + \tau_t^* + \varepsilon_{it} \end{aligned} \quad (8.6)$$

where there are four common factor restrictions: $\pi_{1a} = -\delta\pi_1$, $\pi_{2a} = -\delta\pi_2$, $\pi_{3a} = -\delta\pi_3$, and $\pi_{4a} = -\delta\pi_4$. Providing that these restrictions are valid, one could rely on the more parsimonious specification (8.4) and proceed to estimate it. On the other hand, by directly estimating the unrestricted dynamic specification (8.6), we can derive short run and long run effects of the independent variables. With respect to highway capital, the estimated coefficient π_3 gives the short-run output elasticity (ϕ_H^{SR}) while the long-run elasticity (ϕ_H^{LR}) is given by $(\pi_3 + \pi_{3a})/(1 - \delta)$. Testing for these common factor restrictions, we find that they are rejected by the data.⁶⁶

Table 8.6 reports the results from estimating equation (8.6) using OLS, Within, and GMM estimators. While OLS and Within estimates for dynamic panel models are known to be biased and inconsistent, they could represent an upper and lower bound of the true autoregressive coefficient (δ). In Column 3, we report results based on a system GMM

⁶⁶ We use a Stata routine given by Frank Windmeijer to perform a minimum distance test of the non-linear common factor restrictions imposed in the restricted production equation (8.4). Based on system GMM estimates, the test rejects the appropriateness of the non-linear coefficient restrictions at the 5% level.

estimator (Arellano and Bover, 1995; Blundell and Bond, 1998) that accounts for the endogeneity of the lagged output variable. In this specification, however, the C test rejects the null of exogeneity of labour and private capital.⁶⁷ We thus report another set of system GMM estimates that take into account the endogeneity of the private inputs in column 4. For both specifications, the validity of instruments used in the GMM estimations is not rejected by the Arellano and Bond test of second-order autocorrelation, and the Sargan test of overidentifying restrictions. The coefficients of lagged output (0.839 and 0.725) fall within the upper bound (0.968) and the lower bound (0.691). While this indicates the reliability of the system GMM estimations, the strong significance of the autoregressive coefficient implies that the static production function model (8.3), which strictly imposes the value of a lagged dependent variable as zero, may be seriously misspecified. We also estimate the models using the first-differenced GMM estimator (Arellano and Bond, 1991). However, the results (not shown) exhibit weak instruments problems as the difference GMM estimates for the coefficient on lagged output (0.479 and 0.590) are lower than those obtained from the Within estimator which are downward biased (Blundell and Bond, 1998; 2000). While this suggests that the system GMM estimates reported in Table 8.6 could be more efficient, the Difference-Sargan test also does not reject the validity of instruments used in the levels equations in the system GMM framework. In addition, the results from the Moran's test are satisfactory as the null of no spatial autocorrelation cannot be rejected at any conventional levels.

Focusing on system GMM estimates reported in columns 3 and 4, we find similar results for highway infrastructure from both specifications. While there is apparently no significant effect of highways in the short run, the long-run estimates for the output elasticity of highway capital are positive and statistically significant. The insignificance of the short-run elasticity may be due to very high collinearity between contemporaneous and lagged terms of the highway variables ($r=0.99$). Despite being individually insignificant, the F -test indicates that the coefficients are jointly different from zero ($\pi_3 = \pi_{3a} \neq 0$). This is also the case for the variables on urbanisation as the correlation coefficient equals about one. The short-run elasticity of output with respect to urbanisation is

⁶⁷ The C-statistics from tests of exogeneity of labour and private capital are 4.32 and 5.35, respectively, which reject the null at the 5% level. However, the C-test indicates that we cannot reject the null hypothesis of exogeneity of highways and urbanisation (i.e. the C-statistics equal 1.69 and 1.66, respectively).

significant, but appears to have a wrong sign. In the presence of the strong collinearity, however, the sign and statistical inference of individual coefficients are not precisely estimated.

Table 8.6 Dynamic production function estimates

Dependent variable:	OLS	Within	SYSGMM	SYSGMM	SYSGMM	SYSGMM
ln Q	(1)	(2)	(3)	(4)	(5)	(6)
ln Q (t-1)	0.968 (97.23)	0.691 (17.13)	0.839 (18.03)	0.725 (10.89)	0.876 (20.77)	0.749 (11.09)
ln L (t)	0.503 (20.72)	0.404 (16.45)	0.436 (13.00)	0.523 (8.82)	0.461 (12.89)	0.511 (8.22)
ln L (t-1)	- 0.484 (-20.07)	- 0.271 (- 7.86)	- 0.399 (- 9.35)	- 0.411 (- 5.80)	- 0.409 (- 9.50)	- 0.408 (- 5.27)
ln K (t)	0.552 (43.84)	0.543 (53.09)	0.554 (38.67)	0.573 (23.95)	0.553 (37.35)	0.570 (20.78)
ln K (t-1)	- 0.540 (- 37.42)	- 0.354 (- 13.05)	- 0.455 (- 11.42)	- 0.408 (- 7.80)	- 0.479 (- 13.05)	- 0.423 (- 8.06)
ln H (t)	- 0.003 (- 0.44)	0.008 (0.85)	- 0.003 (- 0.35)	0.003 (0.25)	0.004 (2.87)	0.008 (2.11)
ln H (t-1)	0.007 (0.83)	- 0.004 (- 0.54)	0.008 (0.84)	0.005 (0.48)		
Urban (t)	- 0.209 (- 0.81)	- 0.606 (- 1.88)	- 1.003 (- 2.73)	- 1.505 (- 2.52)	0.029 (2.84)	0.064 (2.25)
Urban (t-1)	0.218 (0.85)	0.841 (2.69)	1.037 (2.80)	1.562 (2.65)		
Long-run elasticities						
ϕ_L^{LR}	0.630 (6.05)	0.430 (14.76)	0.401 (11.18)	0.405 (8.00)	0.418 (9.86)	0.407 (7.34)
ϕ_K^{LR}	0.387 (3.78)	0.612 (32.45)	0.611 (16.44)	0.601 (9.85)	0.593 (13.61)	0.588 (9.05)
ϕ_H^{LR}	0.100 (3.17)	0.013 (0.50)	0.029 (2.85)	0.027 (2.07)	0.033 (2.79)	0.030 (2.13)
ϕ_{Urban}^{LR}	0.305 (3.82)	0.760 (3.49)	0.206 (5.24)	0.209 (2.30)	0.234 (5.77)	0.255 (2.48)
AR2			0.946	0.493	0.923	0.772
Sargan			0.306	0.716	0.130	0.420
Diff Sargan			0.997	1.000	0.694	1.000
Moran's I ($W_{highway}$)	1.215	1.220	0.817	0.645	1.065	0.782
Moran's I ($W_{distance}$)	1.146	1.203	0.601	0.415	0.901	0.632
Observations	624	624	624	624	624	624
Endogenous regressors	None	None	Lagged Q	Lagged Q, L , and K	Lagged Q	Lagged Q, L , and K

Note: Numbers in parentheses are robust t-statistics. The null hypothesis for the Moran's I test is that there is no spatial autocorrelation in regression residuals. Average values of standardised Moran's I statistics across time period are reported. See notes below Table 8.2 for the definitions of the spatial weight matrices. The significance of long-run elasticities is obtained from the delta method. P -values are reported for AR2, Sargan, and Diff Sargan tests. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the levels equations.

To deal with the collinearity problems, we estimate another dynamic panel model that excludes the lagged terms of highway capital and urbanisation. The results are

reported in columns 5 and 6. Once the source of collinearity has been removed, we find the contemporaneous highway variable statistically significant as expected. Taking account of the endogeneity of the private inputs, the output elasticity of highway capital for the short run is 0.008 which is very small. The short-run elasticity of output with respect to urbanisation becomes positive in both specifications, though its magnitude is sensitive to the assumption of exogenous regressors. The system GMM estimates indicate the short-run output elasticity of 0.064 when labour and private capital are instrumented and 0.029 otherwise. Also, the long-run elasticity of output with respect to urbanisation varies across specifications. For highway capital, assuming the coefficient on its lag is zero does not affect the system GMM estimates for the long-run output elasticity of highways. As generally indicated, a 1% increase in highway lane-mile density could lead to a 0.03% increase in state output in the long run.

We proceed to compare these elasticity estimates for highway capital with those previously found from the static production function estimations. As shown in Table 8.7, we find a reverse and more reasonable order for the short-run and long-run output elasticities of highway capital when the dynamic adjustment of state production is explicitly modelled. In other words, these two elasticities obtained from the static production function estimations appear to be biased in opposing ways. For static panel models, Egger and Pfaffermayr (2004) have shown that the short-run effect from the Within regression is heavily upward biased if an explanatory variable has highly persistent time-series. For the long-run effect, the Between specification always produces downward-biased estimates, and the bias is very large when the dependent variable is highly persistent. Based on simulation experiments, Egger and Pfaffermayr point out that the amount of these biases could be several hundred percent.

Table 8.7 Static and dynamic production function estimates for output elasticities of highways

Modelling framework	The elasticity of output with respect to highway capital	
	Short run	Long run
Static production function	0.041 – 0.063	0.016 – 0.017
Dynamic production function	0.004 – 0.008	0.027 – 0.033

Using the dataset, our estimation results reveal that the biases of the short-run and long-run responses of state output to highway capital exhibit a pattern that is consistent with these predictions. In particular, we find that, on average, the static production function models tend to overestimate the short-run effect of highways by approximately 767% while underestimating the long-run effect by about 45%. These distortions can be characterised by the fact that the memory of the data is quite high. Based on the system GMM estimations, the autoregressive coefficients (δ) ranging from 0.725 to 0.876 imply a “slow” speed of adjustment for private sector output. Given the within standard deviation of 0.038, the variable on highway capital has a small degree of time variation. We have also observed a similar pattern of biases for the urbanisation variable which is also highly persistent. When dynamics are explicitly specified, the short-run elasticity of output with respect to the degree of urbanisation becomes much smaller. The output elasticity of 0.064 in column 6 of Table 8.6 is close to that found in Ciccone and Hall (1996) who analyse data for US states and estimate an elasticity of 0.060), though they use the density of employment as a proxy for agglomerations and do not consider dynamics in agglomeration effects.

By focusing on the dynamic production function estimates, we can identify how state output responds to changes in highway capital endowments in a given year. Figure 8.1 illustrates the dynamic effects of highway infrastructure on private sector output, based on the system GMM estimates (i.e. $\delta = 0.749$, and $\phi_H^{SR} = 0.008$). As one would expect, the total output effect of highway infrastructure investments comes over several years. To fully adjust to a doubling of the density of total lane miles, state output is predicted to take approximately 15 years to increase by 3%. In this regard, the speed of output adjustments as a response to improved network capacities tends to be relatively fast within the first 5 years. Despite relying on the underlying assumption of lag distributions from the dynamic modelling framework, this demonstrates that increases in overall highway capacity in states can have a positive and long-lasting effect on private sector output. However, the short-run and long-run output elasticities with respect to highway capital are lower than those reported in most studies that estimate the returns from highway capital using static production function models. More discussion on the comparisons is presented in Section 8.7.

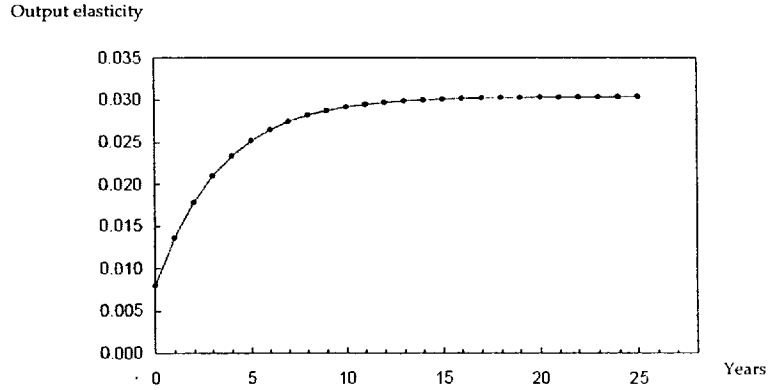


Figure 8.1 Dynamic effects of highway infrastructure on state output

Despite being small in magnitude, an increase in the capacity of the highway network could be said to have a positive and significant impact on private sector output in states. Another question that has not been addressed is whether there could be some leakages of the productivity effect from highway improvements that take place outside the state border. We extend our dynamic modelling framework to address this issue in the next section.

8.6 Spatial spillovers in highways' output effects

Following a common approach in the literature examining the spatial spillover effects of public infrastructure, we introduce an additional variable into the dynamic production function (8.6) in order to examine the spatial effects from highway capital located in other states. Given the collinearity problems due to the time-series persistence of highway and urbanisation variables, their lagged terms are dropped from the specification. This yields another dynamic production function model of the form:

$$\ln Q_{it} = \alpha' + \delta \ln Q_{it-1} + \pi_1 \ln L_{it} + \pi_{1a} \ln L_{it-1} + \pi_2 \ln K_{it} + \pi_{2a} \ln K_{it-1} + \pi_3 \ln H_{it} + \pi_{3s} \ln \sum_{j \neq i} w_{ij} H_{jt} + \pi_4 \text{Urban}_{it} + \mu_i' + \tau_t' + \varepsilon_{it} \quad (8.7)$$

where w_{ij} are the elements of a spatial weight matrix (W) that can be defined to capture the relative importance of highway capital in other states. As the literature offers little guidance in the choice of correct weighting schemes, we consider the same weight matrices defined and applied previously in Chapters 6 and 7.

According to equation (8.7), the significance of the coefficient on the spatial highway variable (π_{3s}) indicates the existence of output spillovers from highway capital, whereas the coefficient on own-state highways (π_3) captures the output effect of highways within the same state. Our preliminary results across different spatial weight definitions show that these coefficients are difficult to interpret individually. This is because the variables for own-state and neighbouring states' highway capital are highly collinear (i.e. the pair-wise correlation coefficients range from 0.77 to 0.87).

Table 8.8 presents system GMM estimates with endogeneity of lagged output and the private inputs taken into account. The estimated coefficient for highways in other states is positive and significant across specifications, suggesting the presence of positive output spillovers. In contrast, the coefficient for own-state highways is negative and statistically insignificant with lower magnitude (in absolute terms), compared to that of highway capital located elsewhere. While the latter contradicts our earlier finding of the positive and significant contribution of highway capital to private sector output in states, the evidence of such collinearity implies that the significant coefficient for other states' highways may partially capture the positive effect of own-state highways. When dropping own-state highways from equation (8.7), the significant and positive results for the spatial highway variable (not shown) are basically unchanged. However, the estimated coefficient on other states' highway capital is possibly biased and inconsistent. This is due to the absence of the own-state highway variable that is collinear and belongs theoretically and statistically in the regression.

Since the question of whether highway infrastructure has spatial spillover effects on state output appears to be solved incompletely, we have sought to address this issue in two steps. We first calculate the short-run and long-run output elasticities with respect to highways located within and outside of the state border by combining estimated coefficients of the two variables: the short-run output elasticity (ϕ_{HWH}^{SR}) is obtained from the straight sum ($\pi_3 + \pi_{3s}$) and the long-run output elasticity (ϕ_{HWH}^{LR}) from $(\pi_3 + \pi_{3s})/(1 - \delta)$. Then, we compare these two elasticity estimates to those based on the dynamic panel specification with spatial spillover omitted, as presented in Section 8.5. A higher value of ϕ_{HWH}^{SR} will be interpreted as evidence of positive output spillovers from highway capital

in the short run. Similarly, we could conclude that these spillovers can persist in the long run if the value of ϕ_{HWH}^{LR} is significant and higher than ϕ_H^{LR} .

Table 8.8 Dynamic production function estimates: Testing for output spillovers from highways

Dependent variable: ln Q	Binary contiguity (W_{bin})	Contiguity with highway connectivity (W_{hwy})	Contiguity with population density weighted average (W_{pop})	Contiguity with distance decay (W_{dis})	Distance-decay (W_{dis})
ln Q (t-1)	0.694 (7.60)	0.687 (7.60)	0.670 (5.36)	0.704 (8.46)	0.711 (8.33)
ln L (t)	0.525 (8.83)	0.514 (8.19)	0.509 (7.90)	0.517 (8.49)	0.529 (8.56)
ln L (t-1)	-0.397 (-4.82)	-0.386 (-4.55)	-0.374 (-4.26)	-0.394 (-4.79)	-0.407 (-5.16)
ln K (t)	0.568 (21.83)	0.571 (22.55)	0.572 (21.48)	0.570 (22.44)	0.566 (21.37)
ln K (t-1)	-0.382 (-5.76)	-0.378 (-5.66)	-0.364 (-4.02)	-0.390 (-6.20)	-0.393 (-5.97)
ln H (t)	-0.012 (-1.46)	-0.011 (-1.34)	-0.012 (-1.21)	-0.008 (-1.05)	-0.004 (-0.54)
ln WH (t)	0.025 (2.41)	0.024 (2.36)	0.025 (1.83)	0.019 (2.24)	0.020 (1.73)
Urban (t)	0.056 (2.28)	0.058 (2.29)	0.055 (2.26)	0.057 (2.25)	0.055 (2.24)
AR2	0.634	0.611	0.571	0.753	0.692
Sargan	0.691	0.631	0.596	0.657	0.627
Diff Sargan	0.606	0.359	0.452	0.359	0.890
Moran's I (W_{binary})	1.492	1.370	0.916	1.225	1.121
Moran's I ($W_{distance}$)	1.314	1.272	0.814	1.228	1.085
Observations	624	624	624	624	624

Note: Numbers in parentheses are robust t-statistics. The null hypothesis for the Moran's I test is that there is no spatial autocorrelation in regression residuals. Average values of standardised Moran's I statistics across time period are reported. See notes below Table 8.2 for the definitions of the spatial weight matrices. P-values are reported for AR2, Sargan, and Diff Sargan tests. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the levels equations.

The comparisons of output elasticity estimates in Table 8.9 tend to reaffirm that investments in highway infrastructure could produce positive spillover impacts on private sector performance. Both short-run and long-run elasticities of output with respect to own-state and other state's highways are higher than those obtained from the model that disregards the possibility of output spillovers. This implies that some productivity benefits of highway improvements in a given state are accrued to its neighbours. Of particular interest is the output elasticities based on the distance decay matrix (W_{dis}) that are greater relative to those based on all other spatial weight definitions. This finding lends support to the argument that provision of transport infrastructure in one region could affect the economic performance of other regions, including quite

remote from it (e.g. Vickerman, 1991b; Holtz-Eakin and Schwartz, 1995; and Pereira and Andraz, 2004).

Table 8.9 Short-run and long-run output elasticities with respect to highway capital

Spatial weight matrix	Short-run elasticity of output with respect to highways		Long-run elasticity of output with respect to highways	
	ϕ_H^{SR}	ϕ_{HWH}^{SR}	ϕ_H^{LR}	ϕ_{HWH}^{LR}
None (assuming no output spillover)	0.008**		0.030**	
W_{bin} : Binary contiguity		0.013***		0.041***
W_{hwy} : Contiguity with highway connectivity		0.012***		0.039***
W_{pop} : Contiguity with population density weighted average		0.013**		0.041***
W_{dis} : Contiguity with distance decay		0.011***		0.037***
W_{dis} : Distance-decay		0.015***		0.054***

Note: ** and *** indicate significance at the 5% and 1% levels, respectively. The significance levels of short-run and long-run elasticities are derived from the delta method.

Figure 8.2 illustrates the long-term accumulated effect on state output from highway improvements within and outside of the state border. To calculate the dynamic effects of own-state and adjacent states' highways, we use the short-run output elasticity and the coefficient on lagged output from the specification based on the contiguity matrix with distance decay (W_{dis}). Assume that the long-run contribution of own-state highways to output is 0.03 and that the productivity effect of highway infrastructure installed elsewhere decays with geographical distance in a polynomial form. The long-run output elasticity of 0.054 implies that one would need to double the density of total lane miles for the rest of the economy in order to stimulate private sector output of a given state by 2.4% in the long run.

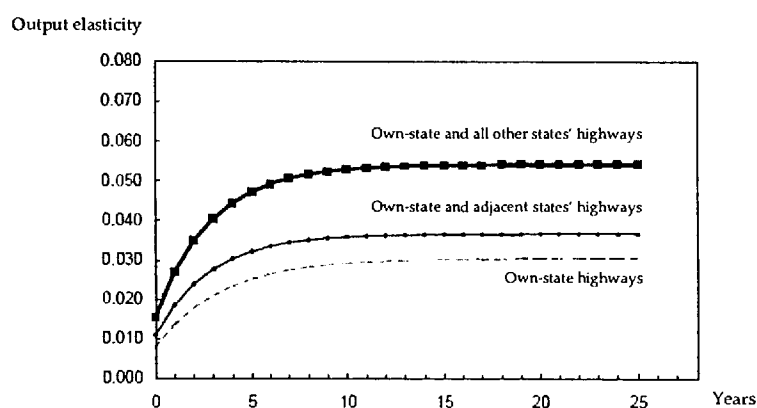


Figure 8.2 Dynamic effects of own-state and other states' highways

8.7 Marginal impacts

Our estimates support the view that there is a positive relationship between the highway infrastructure network and state economic performance. The results indicate that increasing highway capacity can have both direct and spillover effects on state output. What could be of importance to the state policy community is the amount of increased state output in dollar terms that may result from building new capacity, which is usually targeted to reduce congestion and facilitate development. Would lane-mile additions provide substantial productivity benefits, or could they just contribute a small percent to a state's gross domestic product?

Using the results from the dynamic production function analysis, we address these questions by estimating the long-term accumulated effects (in present dollars) of a one-time increase in a lane-mile of highways on state output as

$$\frac{\partial Q_{t+n}}{\partial LM_t} = \phi_H^{SR} \frac{Q_t}{LM_t} + \frac{\phi_H^{SR} \delta}{(1+r)} \frac{Q_t}{LM_t} + \frac{\phi_H^{SR} \delta^2}{(1+r)^2} \frac{Q_t}{LM_t} + \dots + \frac{\phi_H^{SR} \delta^n}{(1+r)^n} \frac{Q_t}{LM_t} \quad (8.8)$$

that can be generalised to the form:

$$\frac{\partial Q_{t+n}}{\partial LM_t} = \frac{Q_t}{LM_t} \times \left[\phi_H^{SR} \times \left\{ \sum_{n=0}^k \frac{1}{(1+r)^n} \times \delta^n \right\} \right] \quad (8.9)$$

where Q denotes gross state product, and LM denotes own-state lane-mileage. The terms ϕ_H^{SR} and δ are, respectively, the short-run output elasticity of own-state highway lane-mile density and the autoregressive coefficient on lagged state output that are obtained from the system GMM estimations in Section 8.5.⁶⁸ The variable r denotes a discount rate, which is used to calculate the present value of future output gains from adding one lane-mile of highways in the present year. The expression in the rectangular parenthesis will correspond to the long-run output elasticity of own-state highways ($\phi_H^{SR} / [1 - \delta]$) when setting r and k as zero and infinity, respectively.

The analysis thus far has concentrated on the total system effect of highway infrastructure on state output. However, it could also be useful to examine differentials

⁶⁸ Using the output elasticity of highway capital directly given by the dynamic production function estimates, we can calculate the marginal product of the density of highway lane miles. Since the emphasis is on changes in output associated with lane-mile additions, both sides of equations 8.7 and 8.8 are multiplied by land area. For each state, the time average of the ratio of gross state product to lane miles is used to calculate the marginal product of lane miles.

in the productivity effect between different types of roads. We thus replicate the dynamic production function estimation as presented in column 6 of Table 8.6, using disaggregated lane-mile data for interstate highways, non-interstate major roads (i.e. arterial and collector roads), and local roads. The coefficient estimates as shown in Table 8.10 are taken to identify the accumulated long-term marginal product of own-state highway lane miles for various categories, using the formula outlined above.

Table 8.10 Dynamic production function estimates by types of road

Dependent variable: ln Q	Interstate highways	Non-interstate major roads	Local roads
ln Q (t-1)	0.737 (9.33)	0.756 (11.34)	0.754 (11.20)
ln L (t)	0.532 (8.79)	0.522 (8.32)	0.503 (8.07)
ln L (t-1)	-0.416 (-5.26)	-0.421 (-5.43)	-0.404 (-5.17)
ln K (t)	0.563 (19.71)	0.566 (19.66)	0.574 (21.54)
ln K (t-1)	-0.412 (-6.62)	-0.426 (-8.14)	-0.428 (-8.26)
ln H (t)	0.008 (2.86)	0.007 (2.02)	0.007 (2.10)
Urban (t)	0.046 (2.02)	0.065 (2.17)	0.063 (2.30)
Long-run elasticities			
ϕ_L^{LR}	0.4385 (8.48)	0.417 (7.35)	0.402 (7.25)
ϕ_K^{LR}	0.577 (12.33)	0.576 (8.02)	0.593 (9.52)
ϕ_H^{LR}	0.031 (3.52)	0.028 (1.96)	0.029 (2.12)
ϕ_{Urban}^{LR}	0.173 (2.32)	0.268 (2.39)	0.258 (2.48)
AR2	0.745	0.648	0.748
Sargan	0.483	0.563	0.426
Diff Sargan	0.234	0.811	0.488
Observations	624	624	624
Endogenous regressors	Lagged Q, L, and K	Lagged Q, L, and K	Lagged Q, L, and K

Note: Numbers in parentheses are robust t-statistics. The significance of long-run elasticities is obtained from the delta method. P-values are reported for AR2, Sargan, and Diff Sargan tests. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the levels equations.

Table 8.11 presents the estimated effects of an additional lane-mile of highways on gross state product that accumulate over various time intervals. These figures are state averages. The first row of each panel reports the accumulated marginal product of highway lane miles without taking into account opportunity costs. Given uncertainty in

the discount rate, we simply use the two values of 4% and 8% to convert state output gains in future years into their present monetary values. The accumulated productivity benefits from adding a lane-mile are measured in 2000 dollars.

Table 8.11 The accumulated long-term marginal product of one lane mile addition

Type of roads	Discount rate	Time intervals			
		0 - 5 yrs	0 - 10 yrs	0 - 15 yrs	0 - 20 yrs
All roads ($\delta = 0.749$, $\phi_H^{SR} = 0.008$)	0%	\$19,957.91	\$23,228.87	\$24,000.22	\$24,182.11
	4%	\$18,707.80	\$21,154.48	\$21,628.37	\$21,720.22
	8%	\$17,640.80	\$19,495.58	\$19,793.05	\$19,841.11
Interstate highways ($\delta = 0.737$, $\phi_H^{SR} = 0.008$)	0%	\$767,528.19	\$882,120.15	\$907,048.17	\$912,456.85
	4%	\$720,580.82	\$806,374.55	\$821,711.17	\$824,451.57
	8%	\$680,508.48	\$745,556.91	\$755,196.39	\$756,614.66
Non-interstate major roads ($\delta = 0.756$, $\phi_H^{SR} = 0.007$)	0%	\$60,280.94	\$70,698.84	\$73,270.75	\$73,905.60
	4%	\$56,455.61	\$64,241.91	\$65,820.87	\$66,141.00
	8%	\$53,190.98	\$59,089.03	\$60,080.17	\$60,248.38
Local roads ($\delta = 0.754$, $\phi_H^{SR} = 0.007$)	0%	\$30,072.80	\$35,194.29	\$36,442.26	\$36,746.78
	4%	\$28,171.38	\$31,999.59	\$32,766.32	\$32,920.39
	8%	\$26,549.11	\$29,449.26	\$29,930.51	\$30,010.26

Note: Gross state products measured in 2000 dollars

Regardless of marked differences in the contribution to state economic growth by road category that are hidden by the aggregate estimates, the long-term economic returns from highway capacity expansion do not appear to be substantial. With the discount rate of 4%, the output gains accumulated over the time horizon of 20 years range from a low of \$32,920 in present dollars for local roads to a high of \$824,452 for interstate highways. In our sample, the overall mean of gross state product for all private industries is \$125,646.7 million in 2000 dollars. This implies that adding a lane-mile of interstate highways, despite having the strongest effect, could lead to a long-term accumulated increase in a state's GDP for the entire private sector by only 0.0007%.

By having information on the cost per lane per mile for interstate construction on an average basis, we can roughly estimate the returns from spending a dollar on adding lane miles for interstate highways. The Federal Highway Administration (1997) has reported that, on average, interstate highways cost \$20.6 million per mile in 1996 dollars.

Assuming a typical 4-lane interstate highway, an average cost per lane per mile would be \$5.5 million in constant 2000 dollars. Given this figure and the discount rate of 4%, we estimate that a \$1 increase in expanding capacity for interstate highways could be roughly equivalent to a \$0.15 increase in private sector output in the long run. This is merely a crude approximation, so it has to be interpreted with caution. Also, this estimate may not be applicable to any particular project since the costs of building new capacity vary tremendously.⁶⁹ From our macro-level estimates, nevertheless, we conclude that the long-term productivity benefit of capacity expansion might be trivial for interstate highways and could be even smaller for lane-mile additions in lower categories.

The analysis presented above suggests additional highway infrastructure investments may not produce sizable returns, but these results should be viewed along with empirical evidence from other research. Table 8.12 shows that state-level studies examining the productivity effect of highway investments has reported mixed evidence, ranging from very strong and positive effects to no statistically significant effect. Our estimates for the long-run accumulated effect of highway infrastructure on state output is small in comparison with the previous literature. Although some earlier attempts in the literature (e.g. Munnell, 1990b; Garcia-Mila and McGuire, 1992; Williams and Mullen, 1992) report higher output elasticities of highways, subsequent studies demonstrate that these estimates suffer from several econometric problems (e.g. Evans and Karras, 1994; Holtz-Eakin and Schwartz, 1995; Garcia-Mela et al, 1996). Another possible explanation could be that investments in highway capital are subject to decreasing marginal productivity. However, our elasticity estimates are still lower than those reported in Pereira and Andrzej (2004) and Berechman et al (2006) that analyse state-level data for the time periods similar to those covered here.

Given the different measures of highway infrastructure investments, it might be more useful to compare the absolute effects on state output in dollar terms rather than comparing the relative percent changes. As already presented, our roughly estimated marginal product of interstate highways indicates a \$0.15 increase in output for every dollar increase in interstate capital investments. Despite a very strong assumption on construction costs imposed for the approximation and the difference in modelling

⁶⁹ Both the costs and benefits are likely to be much higher in urban areas.

framework, this marginal product estimate is very similar to the findings of Pereira and Andraz (2004). They examine the long-run effect of public spending on highways using VAR models that account for endogeneity and dynamic adjustments of state output. These issues have also been addressed in our production function estimations. Note that this VAR analysis focuses on long-term accumulated changes in output in response to changes in the amount of monetary flow in each year.

Table 8.12 A summary of empirical evidence on the output effect of highway infrastructure investment for the 48 contiguous US states

Author(s)	Data	Methodology	Measure of highway investments	Output elasticity	Marginal product of highway investment (constant 2000 dollars) ^a
Munnell (1990b)	Panel, 1970-1986	Static production function (Cobb-Douglas)	Highway capital (\$)	0.060	\$ 0.57
Garcia-Mila and McGuire (1992)	Panel, 1969-1983	Static production function (Cobb-Douglas)	Highway capital (\$)	0.045	N/A
Williams and Mullen (1992)	Cross-section, 1970, 1980, and 1986	Static production function (Translog)	Highway capital (\$)	0.185 – 0.479 ^b	\$ 2.08 – \$ 4.12 ^b
Evans and Karras (1994)	Panel, 1970-1986	Static production function (Cobb-Douglas)	Highway capital (\$)	Not significant ^c	Not significant ^c
Baltagi and Pinnoi (1995)	Panel, 1970-1986	Static production function (Cobb-Douglas)	Highway capital (\$)	Not significant ^c	Not significant ^c
Hotiz-Eakin and Schwart (1995)	Panel, 1969-1986	Static production function (Cobb-Douglas)	Highway capital (\$)	Not significant ^c	Not significant ^c
Garcia-Mila et al (1996)	Panel, 1970-1983	Static production function (Cobb-Douglas)	Highway capital (\$)	Not significant ^c	Not significant ^c
Pereira and Andraz (2004)	Time-series, 1977-1999	Time-series VAR model for each state	Highway spending	0.056 – 0.043 ^d	\$ 0.14 – \$ 0.16 ^d
Berechman et al (2006)	Panel, 1990-2000	Static production function (Cobb-Douglas)	Highway capital (\$)	0.047	\$ 0.37

Note: ^a Only Berechman et al (2006) report the result in constant 2000 dollars in their paper. For the others, original estimates are in either 1982 or 1987 dollars. We use the GDP deflator for the conversion. ^b Output elasticities are given by averaging the estimates for the states reported in Table 2 of the authors' paper. We calculate the corresponding values for the marginal product of highway capital using these averaged output elasticities and data for the ratio of gross state product to highway capital from Munnell (1990b). ^c Results are based on preferred specification(s) in each study. Some other models show positive and significant effects of highways. See details in the authors' papers. ^d To obtain these numbers, we take the average of the 48 state-specific results reported in Table 1 of the authors' paper.

The recent work by Berechman et al (2006) that has an estimate of a log-linear Cobb-Douglas production function using monetary highway capital stocks is comparable. Although the estimated marginal product of aggregate highway capital itself could be considered as a small return to investment (\$0.37), it is much more than the figure that we approximate for the case of interstate highways. This would imply that the use of

physical measures of highway infrastructure might be unable to capture the role of government spending on maintenance activities that could partially result in differentials in the quality of services provided by infrastructure. To some extent, disaggregating highway capital into various categories would also yield some even higher estimates.

Nonetheless, estimating a static production function similar to what has been done by these authors could produce biased and inconsistent estimates. This is because for this sort of analysis (1) a more appropriate specification requires dynamic components and (2) data on highway capital stocks are persistent over time, as demonstrated earlier in this chapter. Moreover, two common econometric problems, which have been very well recognised since the debate on this research topic was sparked, are surprisingly ignored (e.g. Evans and Karras, 1994; Holtz-Eakin, 1994; Andrews and Swanson, 1995; and Garcia-Mila et al, 1996). Despite using state panel data, Berechman et al (2006) do not consider any form of error component models to control for unobserved state-specific characteristics. The potential endogeneity of the private inputs and highway capital is also not taken into account. These issues could also be likely sources of the conflicting evidence.

8.8 Summary and discussions

While the objective of this dissertation is to examine whether there is any empirical relationship between highway investments and regional employment, this chapter has attempted to address a different, but related, issue of whether highway investments contribute significantly to regional output. The use of roadway lane-mile data for the 48 contiguous US states has led us to focus on the ongoing policy debate on building new capacity for the existing highway network and its potential to induce development which is measured here as gross domestic product in the private sector. A key issue which is gaining considerable attention from infrastructure policy analysts is also examined, that is the possibility of output spillovers from highway investments.

Estimates of dynamic production functions have generally revealed evidence of positive output effects of lane-mile additions within the same state and outside the state border. However, the scale of both short-run and long-run effects of increases in highway

lane miles on a state's private sector production is small even after including positive output spillovers from highways located in all other states. For the output effect of own-state highways in the long run, the results indicate that state output would take more than a decade to increase by 0.03% in response to a 1% increase in the capacity of the highway network. The long-term accumulated benefits from lane-mile additions of interstate highways are found to be relatively large, compared with capacity improvements in other road categories. Despite this, building new capacity for interstates may still not produce sizable economic returns. Given a discount rate of 4%, the estimates indicate that the present value of 20-year accumulated increases in state output by adding one lane-mile for the interstate network is about \$0.824 million in 2000 dollars. This long-term economic benefit is trivial, as one would expect, when comparing with the costs per mile of typical interstate highway construction.

The estimated effects of highways on private sector output are also generally small, compared to previous state-level studies that find a positive and statistically significant effect of highway capital when estimating static production functions. Apart from the failure to address common econometric issues which are well known in the literature, our analysis shows that the underlying assumption in the static modelling framework could also lead to misspecification and serious biases. Given that it is untenable to expect that output will fully adjust to increases in highway capital without time lags, a more appropriate specification requires dynamic components to capture temporal responses of economic activity to improved infrastructure. Not only does it allow researchers to distinguish between the short-run and long-run effects of highways, but it can help to avoid considerable and unfavourable distortions in model estimates when the "true" specification is a dynamic one (Egger and Pfaffermayr, 2004).

One of the primary aims of this dissertation is to provide evidence that could be essential for improving road infrastructure policy towards economic development. Using data from US states, the results thus far provide general support for the hypothesis that highway capital investments have a positive influence on state economic performance, as measured by private sector employment, or alternatively, output. However, these wider economic benefits of adding highway capacity are not of a considerable magnitude. This finding is hardly any comfort to those who would expect that allocating funding to build

new highways or roadway widening projects can make a strong contribution to growth and development in the economy. But this finding is also hardly surprising as the stage of development of the US highway system has been physically mature.

In the next chapter we conclude this dissertation with a summary of the main findings and their implications for policy and future research. The limitations of this dissertation are also discussed.

Chapter 9

Conclusions

This chapter concludes the dissertation. We begin with a summary of the main findings from the empirical analyses. This is followed by a discussion of implications on policy and econometric issues for future research. Finally, we acknowledge the limitations of our empirical analyses and discuss some fruitful avenues for future work.

9.1 Summary of the main findings

This dissertation has sought to enhance the current state of knowledge on the relationship between highway infrastructure investment and regional employment. Particular attention is given to the issue of causality between highways and employment. This is done by using statistical techniques that go beyond mere association and attempt, as far as is possible statistically, to allow for a causal interpretation. This thesis also examines the possibility of employment spillovers from highways, and identifies differentials in the employment effect of highways between manufacturing and service sectors. To provide insights into these empirical gaps, several econometric analyses are performed using panel data for the 48 contiguous states and at the county level for North Carolina in the United States. Recent advances in dynamic panel and spatial econometric techniques are applied to investigate the employment effect of highway infrastructure that could take place at several points in time and space while accounting for methodological issues inherent in much of the previous work such as the endogeneity of highways, omitted variable bias, the dynamic adjustment of employment, and spatial

error dependence. Given the link between employment and output which is also regarded as a measure of the wider economic impacts of transport infrastructure, the impact of highway infrastructure on private sector production is also examined. The main results from all the empirical chapters is briefly summarised in the following.

The work presented in Chapter 5 estimates dynamic panel models to investigate the effect of highway infrastructure investment on aggregate private sector employment within the same county and in neighbouring counties in the State of North Carolina. Investments in highway infrastructure, measured by the density of aggregate lane-miles for all major highways, are found to have no significant impact on overall private sector employment locally, but create negative spillover effects across North Carolina counties. Based on several alternative spatial modelling approaches, the results suggest that such negative spillovers in a local economy could be driven by both network characteristics of highway infrastructure and spatial competition in factors of production and future private sector investments. For the latter, we find that potential competitors could be from geographically nearby counties as well as counties with similar urban characteristics.

Another contribution of this chapter is an analysis of different modelling techniques to understand why estimates vary. The results suggest that the employment effect of highway infrastructure depends critically on the model specification considered, and it is essential to account for the dynamics of employment adjustment and potential endogeneity of highway infrastructure to avoid biases in the estimated effect of highways. The static panel estimations, which ignore endogeneity and lagged responses, indicate that own-county investments in highways can have a positive and significant impact on employment, whereas fully specified dynamic models are found to give insignificant results as discussed above. Based on the robust GMM estimations, the large and highly significant coefficient on lagged employment has confirmed the non-negligible role of slow adjustment processes for employment.

Chapter 6 analyses data for the 48 contiguous US states to disentangle the causal direction between highway infrastructure investment and private employment growth. Employment spillovers from highway investments are also examined. The analysis reveals significant evidence of Granger causality for non-local roads. The results indicate

that additions of interstate lane-miles could temporally lead to increased employment growth within a state served directly while reducing employment growth in both geographically contiguous and remote states. Adding roadway capacity for non-interstate major roads (i.e. aggregate arterial and collector roads) is not found to produce spillovers, but there is evidence of its negative impact on employment growth within the same state. We also find evidence of the reverse causality, suggesting that increases in overall private employment growth could stimulate demand for travel and hence the addition of capacity for the non-interstate major road network. The fact that we find reverse causality provides a real justification for the use of econometric techniques such as the dynamic panel GMM that controls for endogenous variables.

This chapter has also emphasised the importance of accounting for spatial interdependencies of employment between regions that can lead to misspecification problems and hence misleading results. The Moran's I coefficients used to measure the extent of spatial correlation indicate that nearby states tend to have similar employment growth, and the issue of spatial dependence is found to exist in our basic Granger causality models. When the spatial filtering technique is applied to address these problems, some significant results for the dynamic effect of major highways on state employment growth disappear.

An extension of Chapter 6 is the analysis presented in Chapter 7 that has sought to identify sectoral differences in the causal and spatial effects of interstate and non-interstate major roads for three major industrial sectors: manufacturing, construction, and services. The results indicate that additional investments in interstate and non-interstate major roads positively determine employment growth in the services sector while the employment benefit from improved interstate highways also accrues to the construction sector. However, such employment gains from interstate highways may come at the expense of other states as there is also evidence of negative employment spillovers from interstate lane-mile additions.

There is evidence of manufacturing employment growth being negatively affected by own-state investments in non-interstate major roads. This labour saving effect on the manufacturing sector is consistent with the results reported in the literature. However, the results indicate a positive spillover effect on a state's manufacturing growth from

improvements in non-interstate facilities outside the state border. Similar results are obtained for the construction sector. The evidence of sectoral spillovers from manufacturing to construction tends to suggest that such investments could influence growth in construction employment, both directly and indirectly through the multiplier effect.

These results suggest that lane-mile additions of own-state major highways could increase state employment growth in the services sector while reducing growth in manufacturing. Based on this evidence, a plausible interpretation is that highway investments played a significant role in the structural shift from manufacturing towards service employment in a state economy. However, the causal relationship is also found to work the other way around. The causality test results suggest that both the rapid growth in services employment and the slowdown in manufacturing jobs can temporally lead to increases in roadway capacity of non-interstate major roads.

Given the link between employment and output which is also regarded as a measure of wider economic impacts of transport infrastructure, Chapter 8 examines the impact of highways on private sector production using the same state-level data. Dynamic production function estimations indicate that additions of highway lane-miles within and outside the state border have positive effects on state output. However, the contribution of highway infrastructure to output both in the short run and in the long run is small in magnitude even after including the positive spillover effect of highways in all other states. The differential effects by road type are also examined. We find that the long-term accumulated benefits from lane-mile additions of interstate highways are large relative to those of other types of highways. However, the results indicate that adding capacity for interstates does not produce sizable economic returns. In addition, the estimated output impact from highway investments is found to be relatively small when compared with many other studies estimating static production functions. However, the work presented in this chapter has shown that for this application the static panel models could lead to considerable biases, possibly indicating that some of the previous research derived incorrect conclusions.

9.2 Policy implications for highway infrastructure policy

The empirical evidence from this dissertation has important implications for highway infrastructure policy towards increasing employment, and more broadly promoting economic development.

The effectiveness of expanding highway capacity as a policy instrument to foster economic development is likely overstated. At the mature stage of development of the highway system, additional investments in highway infrastructure may not produce sizeable economic benefits, as measured by private sector output and employment. While highway infrastructure policy towards economic development may be defined in the context of multiple objectives (e.g. a combination of employment generation and output growth), assessing the direct user benefits of highway investments in a traditional cost-benefit framework is of prime importance when making investment decisions.

Adding capacity for the existing highway network may not be an appropriate policy measure if the aim is to increase overall employment. All else being equal, the impact of transport improvement on employment is uncertain as there could be both positive and negative effects occurring simultaneously. *In this regard, more attention should be given to the possibility that improvements in highway infrastructure could have adverse impacts on employment.* While the allocation of funding to transport improvement programmes is often justified on the basis of *anticipated* or *predicted* job creation, there are theoretically possible ways in which highway investments can negatively affect local employment as discussed in the reviewed literature. This research finds empirical evidence suggesting that adding capacity for non-interstate major roads could lead to a reduction in a state's overall employment growth.

It is essential to distinguish clearly between growth and distributive effects when defining policy objectives for capital investments in highway infrastructure. For state-level highway infrastructure policy, the stimulation of jobs might be on the grounds of the investment decisions for highway improvement programmes that involve lane-mile additions for interstate highways. There is also empirical evidence of negative spillovers in that such employment gains tend to be redistributive, drawing employment growth from one state to another. Even though this suggests that state-level investments for the existing

interstate highway network are important to a state's competitiveness, this also lends support to the view that highway investments may not stimulate overall economic growth nationwide through net increases in employment.

Highway infrastructure investment could also create a redistribution of employment at the sectoral level, which could possibly leave its effect on overall employment growth unclear. The sectoral analysis at the state level has shown that expanding highway capacity could stimulate additional jobs in some sectors while reducing job growth in other sectors. Indeed, there is evidence suggesting that improvements in highways could play a role in the economic restructuring from manufacturing to services. Although this finding appears to be preliminary and tentative, it suggests that policy initiatives aimed at retaining or stimulating manufacturing jobs by investing in highway infrastructure have unintentional effects, and that the pursuit of employment gain in service industries might be considered as an alternative. On the other hand, the uneven distribution of employment benefits associated with government spending on highway infrastructure can also raise public concerns on the grounds of social welfare and equity. Accordingly, the link between financial responsibilities and economic benefits should also be a policy matter that needs to be closely examined.

9.3 Implications for empirical modelling strategies

The empirical work of this dissertation has also demonstrated the need to account for several issues when modelling the relationship between highway infrastructure and economic development. Some broad and important implications for methodologies used to estimate the economic development impacts from transport investments can be drawn.

First, the possibility that transport infrastructure can be endogenous to an economy should not be discounted in empirical analysis. Despite focusing on the time-precedence of variables, i.e. Granger causality, the evidence in this dissertation has confirmed the importance of disentangling the causal nature of infrastructure impacts so as to avoid simultaneity bias in the presence of reverse causality. As also demonstrated in this

dissertation and some other studies, a Granger causality test in the vector autoregression framework is a viable approach for sorting out the direction of causality.

Second, a temporal context of the economic impacts from transport infrastructure has to be taken into account more seriously. In much of the previous work in this area, the underlying assumption that economic activities will immediately and fully respond to changes in accessibility and services provided by transport infrastructure is overly restricted. Rather, an adjustment process usually occurs over time. The failure to account for this could limit and distort our understanding of the role of transport infrastructure on an economy. We find strong evidence that incorrect conclusions could be drawn if the economic development impacts of highway infrastructure are modelled with dynamic adjustments excluded.

Finally, considerable attention must also be given to the importance of *space*. The existence and complexity of spatial interdependencies and interaction are well-documented in the regional science literature. The results reported in this dissertation indicate that some significant evidence of causal effects disappear when the problem of spatial autocorrelation is taken into account. From a statistical analysis point of view, this reinforces the importance of accounting for likely spatial dependencies in cross-sectional observations in order to avoid potentially biased inferences on the significance of the estimated coefficients. This could be the case in previous work in the literature using cross-sectional or panel data. It is worth considering the state-of-the-art of modelling time and space simultaneously that exists in the spatial econometric literature. In practice, spatial filtering can also be used as an alternative to deal with the issue of spatial autocorrelation in dynamic panel models. Despite the complexity of these spatial issues, the possibility that the economic effects of transport infrastructure could spatially extend to immediately contiguous regions or even more distant regions needs to be addressed explicitly. This dissertation provides evidence that supports both the positive and negative spillover hypotheses. The contribution of transport infrastructure to economic development could be either underestimated or overestimated if the spatial dimension of impacts is ignored. It is also essential to ensure that impact areas are not too narrowly defined.

9.4 Limitations of the analyses

As with all empirical analyses, there are various limitations and constraints imposed by the data available and the ability to develop theoretically plausible models. The results should be interpreted with these caveats in mind.

- The causality tests do not capture the possibility that firms and households may react in anticipation of changes in accessibility and improvements in transport services before completion of infrastructure (e.g. Rietveld and Bruinsma, 1998; Vickerman, 2007). This could be very likely in the case of major transport projects since prior information about the projects are often widespread among the general public and the period of construction is very lengthy.
- As the empirical analyses in this dissertation use the county or the state as a spatial unit of analysis, there is potentially concern about aggregation biases of coefficient estimates. This is because the underlying assumptions of the theoretical economic models are based on microeconomic linkages and optimising behaviours that are relevant at the firm level. While this is a common practice in econometric analysis at macro scales, one important advantage of an aggregate analysis in transport infrastructure research is that spatial effects of infrastructure within study areas can be captured more effectively. Also, the data available at more aggregate levels tend to be more comprehensive in scope. On the other hand, using firm-based data could provide important insights into the relationship and clearer pictures on how firms respond to changes in transport services available with respect to either upward or downward adjustments to their desired workforce size. Micro-level data would provide a fruitful avenue for future research.
- Compared with making use of monetary data to measure the influence of highway investments, the physical measurement of highway infrastructure supply used in this dissertation may not capture to some extent the quality and condition of highway infrastructure (See Section 4.2 of Chapter 4 for discussions).
- The magnitude of coefficients based on the VAR analysis and Granger causality tests cannot be inferred directly since VAR models are non-structural. The individual coefficients are difficult to interpret, and the sum of coefficient estimates is typically

used to examine the *sign* and the *relative* extent of the causal effects from each variable as done in this dissertation. However, this approach does not impose a prior theoretical assumption on the model structure, but allows the data to tell us the relationship between variables.

- Another difficulty in interpreting the true coefficient estimates could come from the application of spatial filtering to deal with the problem of spatial dependence. Although the robustness check shows that the general findings of Granger causality are unaffected when comparing with those obtained from the time-space simultaneous model using unfiltered data (see Section 6.6 of Chapter 6), there is variation in the long-run coefficients of the variables, as already mentioned, making it difficult to fully interpret absolute effects.
- Testing spatial spillover effects of highway infrastructure has proven to be a difficult task. Apart from the choice of spatial weight definitions and the issue of collinearity, spatial spillover effects between regions are not necessarily symmetrical, which in turn confound accurate interpretation.

9.5 Directions for future research

Although the empirical analyses in this dissertation have contributed to the study on the relationship between transport infrastructure and regional employment, more research in this area is clearly needed and a well-ground econometric methodology is required when modelling this relationship. There are several fruitful avenues for future research that could be carried out.

- Future work should be more disaggregate. Given the use of highly aggregate data in our Granger causality analysis, a further research question could be whether the causation depends upon the level of geographical aggregation in the data. Future research in this area should also be devoted to providing insights into the microeconomic linkage between transport infrastructure improvements and how the job market will respond to changes in accessibility and infrastructure services using firm-based data. Additional empirical analysis to explore spatial spillover effects at small regional units is essential for improving our understanding of the spatial

dimension of infrastructure impacts and how these spatial effects decline with distance.

- A promising additional area of research might be to focus on differential effects of transport investments on employment in tradable and non-tradable sectors. The theory of trade maintains that to the extent that transport infrastructure improvements help to remove trade barriers is likely to cause firms in tradable sectors to be better off at the expense of some other firms in non-tradable sectors. However, remarkably little research has been devoted to empirically identify the extent of this effect.
- An appealing extension of this dissertation is to examine the linkage between congestion and local economic development. The standardisation of lane-miles by population could capture accessibility as well as some degree of congestion. Also, data on vehicle-km travelled (VKT) in aggregate and disaggregated by types of road, which are available at the state level, can be combined with the stock of highway lane-miles in order to construct a crude measure of congestion.
- Further research attention should be given to the concept of accessibility in order to better capture spatial differences in the quality of infrastructure services (Rietveld and Bruinsma, 1998), given that more detailed data on travel times between zones or links are available and sufficient for conducting panel econometric analysis.
- As this dissertation and many other studies find that additional investments in highway capital have limited impacts in the presence of ubiquitous highway systems, this implies the need for additional empirical research into the wider economic benefits of highway maintenance which is likely to be a cost-effective strategy for policies towards promoting local development. An essential step could be to obtain sufficient data on pavement condition or maintenance expenditures.
- Another fruitful area of research is to examine whether the economic development impacts of transport investments may differ across regions with respect to the levels of transport infrastructure already in place. Given the possibility of diminishing returns to continued infrastructure investments, a potential hypothesis is that the economic effect is likely to be greater in a region where the level of transport infrastructure is relatively small, compared with other regions that have a well-

provided and more extensive transport system. An empirical test of this hypothesis, although it is fundamentally compelling, has never been conducted. This could offer important insight into how transport infrastructure investments can contribute towards regional employment growth in a modern economy as well as in developed countries.

- Finally, the empirical literature on the link between transport investment and economic development has focused on econometric analyses using data for developed and industrialised nations. Future research exploring evidence on the economic development impacts of transport infrastructure investments in developing countries is clearly needed.

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Appendix A

Moran's *I* Test for Residual Spatial Autocorrelation

Type of roads	Year	Employment equation (original variables)			Employment equation (spatial filtering applied)			Highway equation (original variables)		
		m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
All roads	1986	3.860***			-1.311			2.015**		
	1987	3.193***	3.292***		-0.385	-0.500		-0.734	-0.054	
	1988	2.157**	1.985**	1.545	-1.098	-1.178	-1.181	1.261	1.202	1.160
	1989	4.832***	4.822***	4.979***	-1.190	-1.385	-1.338	-0.323	-0.362	-0.185
	1990	6.494***	6.339***	5.902***	0.773	0.891	0.766	0.089	0.428	0.609
	1991	6.405***	6.149***	5.774***	-0.658	-0.585	-0.470	0.864	0.932	0.947
	1992	5.001***	5.125***	5.389***	0.369	0.417	0.314	-0.244	-0.435	-0.648
	1993	4.780***	4.137***	3.879***	-2.159**	-1.963**	-1.902*	1.447	1.432	1.551
	1994	5.837***	5.644***	5.314***	-0.811	-0.919	-0.890	-0.799	-0.689	-0.480
	1995	3.557**	3.500**	3.504**	-0.710	-0.799	-0.772	-1.296	-0.802	-0.396
Interstate highways	1996	3.471***	3.050***	2.835***	-1.999**	-2.030**	-1.950*	0.600	0.959	0.907
	1997	2.159*	1.879*	1.885*	-1.484	-1.587	-1.523	-0.139	-0.104	-0.064
	1986	3.873**			-1.368			-0.089		
	1987	2.963**	2.885**		-0.466	-0.651		0.274	0.074	
	1988	2.193*	1.794*	1.444	-0.938	-1.339	-1.304	-0.079	-0.193	-0.152
	1989	5.007**	5.150**	4.986**	-1.040	-1.088	-1.008	-0.087	-0.101	-0.028
	1990	6.481***	6.581***	6.117***	0.721	0.879	0.740	1.140	1.304	1.352
	1991	6.429***	6.125***	5.761***	-0.714	-0.675	-0.610	1.240	1.336	1.295
	1992	5.051***	5.186***	5.407***	0.304	0.478	0.377	1.353	0.141	0.071
	1993	4.673**	4.068**	3.937**	-2.172**	-2.081**	-1.981**	0.400	0.035	0.347
Arterial roads	1994	5.782**	5.614**	5.234**	-0.817	-0.893	-0.851	0.141	0.026	0.782
	1995	3.518**	3.427**	3.452**	-0.664	-0.773	-0.777	2.997**	2.693**	2.497**
	1996	3.404**	3.039**	2.974**	-1.935*	-1.938*	-1.911*	-0.024	-0.196	-0.189
	1997	1.862*	1.905*	2.040*	-1.535	-1.504	-1.449	0.266	1.424	1.405
	1986	3.879**			-1.300			0.575		
	1987	3.098**	3.127**		-0.431	-0.489		1.118	1.151	
	1988	1.818*	1.732*	1.411	-1.013	-1.117	-1.001	0.305	1.436	1.167
	1989	4.923**	5.094**	5.151**	-1.107	-1.294	-1.246	0.308	0.601	0.710
	1990	6.701***	6.557***	6.076***	0.710	0.805	0.682	2.131**	2.204**	2.179**
	1991	6.438***	6.216***	5.886***	-0.572	-0.543	-0.448	3.310***	3.344***	3.217***
Collector roads	1992	5.087***	5.142***	5.309***	0.450	0.550	0.455	0.009	0.047	0.137
	1993	4.755***	4.090***	3.828***	-2.185**	-2.024**	-1.886*	-0.127	0.173	0.237
	1994	5.839***	5.691***	5.430***	-0.802	-0.905	-0.835	0.822	0.257	0.478
	1995	3.482**	3.394**	3.415**	-0.694	-0.721	-0.703	-1.736*	-1.199	-1.085
	1996	3.468**	3.061**	3.047**	-2.020**	-1.974**	-1.888*	-0.001	-0.288	-0.052
	1997	2.204**	1.924*	1.972*	-1.510	-1.593	-1.485	-0.386	-0.394	-0.310
	1986	3.895**			-1.299			-1.382		
	1987	3.069**	3.137**		-0.469	-0.527		-0.378	-0.087	
	1988	2.100**	1.932*	1.570	-1.012	-1.163	-1.142	-0.272	0.742	1.524
	1989	4.953**	5.018**	5.285**	-1.110	-1.270	-1.187	1.067	1.035	1.380
	1990	6.717***	6.492***	6.091***	0.668	0.773	0.623	0.366	0.537	0.532
Collector roads	1991	6.457***	6.173***	5.844***	-0.562	-0.525	-0.407	0.785	0.574	0.774
	1992	5.070***	5.092***	5.237***	0.417	0.481	0.360	-0.036	-0.052	-0.089
	1993	5.052**	4.198**	3.916**	-1.836*	-1.927*	-1.819*	1.626	1.163	0.744
	1994	6.042**	5.696**	5.359**	-0.642	-0.828	-0.843	1.528	1.189	0.892
	1995	3.558**	3.457**	3.518**	-0.654	-0.681	-0.655	0.111	0.180	0.275
	1996	3.226**	3.016**	2.913**	-2.036**	-1.998**	-1.950**	-1.035	-0.574	-0.191
	1997	2.120*	0.244	0.457	-1.575	-1.776*	-1.691*	-0.737	-0.578	-0.434

Note: Standardised Moran's *I* statistics (z-scores) based on the row-standardised binary contiguity matrix are reported. Significance at 10%, 5%, and 1% levels is indicated by *, **, and ***, respectively.

Appendix A

Moran's *I* test for residual spatial autocorrelation (cont'd)

Type of roads	Year	Employment equation (original variables)			Employment equation (spatial filtering applied)			Highway equation (original variables)		
		m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
Non-interstate major roads (arterial and collector roads)	1986	3.917***			-1.264			1.262		
	1987	3.147***	2.824***		-0.397	-0.461		1.488	1.522	
	1988	2.299**	2.329**	2.092**	-1.154	-1.205	-1.157	-0.567	0.444	0.654
	1989	4.939***	4.644***	4.745***	-1.240	-1.406	-1.306	0.142	0.500	0.729
	1990	6.611***	6.508***	6.193***	0.819	0.876	0.763	2.180**	2.128**	2.009**
	1991	6.470***	6.464***	6.252***	-0.581	-0.540	-0.435	1.043	0.668	0.976
	1992	5.058***	4.603**	4.585**	0.454	0.530	0.444	0.725	0.356	0.348
	1993	4.870***	3.972**	3.695**	-1.846*	-1.882	-1.772*	2.481**	1.369	1.027
	1994	5.873***	5.583***	5.208**	-0.694	-0.845	-0.870	1.836	1.594	1.294
	1995	3.554***	3.381**	3.372**	-0.626	-0.644	-0.608	0.188	0.276	0.381
Local roads	1996	3.386**	3.185**	3.083**	-1.987**	-1.950*	-1.869*	-0.772	-0.638	-0.495
	1997	2.181*	1.251	0.885	-1.606	-1.825*	-1.748*	-0.595	-0.454	-0.335
	1986	3.875***			-1.326			2.207**		
	1987	3.201***	3.241***		-0.391	-0.498		-0.113	0.334	
	1988	2.143*	2.000*	1.597	-1.094	-1.173	-1.145	1.200	1.191	1.162
	1989	4.884***	4.869***	5.037***	-1.111	-1.267	-1.220	-0.316	-0.386	-0.155
	1990	6.520***	6.352***	5.904***	0.736	0.851	0.749	0.180	0.348	0.482
	1991	6.401***	6.139***	5.758***	-0.623	-0.547	-0.439	0.733	0.772	0.795
	1992	5.001***	5.129***	5.374***	0.405	0.462	0.341	0.328	0.182	0.024
	1993	4.737***	4.088**	3.827**	-2.160**	-1.959**	-1.912*	1.248	1.444	1.577
	1994	5.804***	5.666***	5.348**	-0.801	-0.870	-0.833	-0.629	-0.455	-0.320
	1995	3.539***	3.487**	3.520**	-0.726	-0.820	-0.769	0.084	0.214	0.358
	1996	3.454***	3.049**	2.923**	-1.973**	-1.996**	-1.918**	0.398	0.545	0.661
	1997	2.186**	1.932*	1.940*	-1.514	-1.555	-1.503	-0.083	-0.003	0.024

Note: Standardised Moran's *I* statistics (z-scores) based on the row-standardised binary contiguity matrix are reported. Significance at 10%, 5%, and 1% levels is indicated by *, **, and ***, respectively.

Appendix B

System GMM estimates of the highway equation

Dependent variable (ΔH)	All roads			Interstate highways			Arterial roads		
	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
$\Delta H_{(t-1)}$	0.101 (1.42)	0.164 (1.86)	0.168 (1.87)	-0.139 (-1.06)	0.036 (0.99)	0.054 (1.51)	-0.080 (-2.71)	-0.105 (-4.09)	-0.089 (-2.55)
$\Delta H_{(t-2)}$		-0.042 (-0.61)	-0.086 (-1.02)		0.013 (0.33)	0.009 (0.17)		-0.135 (-2.07)	-0.118 (1.89)
$\Delta H_{(t-3)}$			-0.015 (-0.21)			0.037 (1.11)			0.046 (2.54)
$\Delta E_{(t-1)}$	-0.041 (-0.92)	-0.098 (-1.30)	-0.095 (-1.06)	0.044 (1.29)	0.034 (0.97)	0.015 (0.50)	-0.012 (-0.13)	-0.051 (-0.44)	-0.087 (-0.68)
$\Delta E_{(t-2)}$		0.082 (1.06)	0.110 (1.15)		-0.060 (-1.21)	-0.039 (-1.02)		0.270 (2.02)	0.189 (1.56)
$\Delta E_{(t-3)}$			-0.062 (-0.86)			-0.062 (-1.42)			0.037 (0.57)
Joint test									
Lagged ΔE	0.357	0.374	0.627	0.198	0.421	0.532	0.895	0.123	0.418
Long-run coefficient									
Lagged ΔE	-0.046	-0.018	-0.050	0.039	-0.027	-0.096	-0.011	0.177	0.121
AR2	0.528	0.959	0.677	0.247	0.480	0.895	0.211	0.831	0.424
Sargan	0.300	0.231	0.267	0.432	0.505	0.239	0.774	0.603	0.601
Diff Sargan	0.900	0.989	0.237	0.520	0.640	0.620	0.620	0.953	0.817
No of observations	576	528	480	576	528	480	576	528	480

Note: *p*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. Numbers in parentheses below the coefficients are robust *t*-statistics.

Dependent variable (ΔH)	Collector roads			Non-interstate major roads			Local roads		
	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
$\Delta H_{(t-1)}$	-0.019 (-0.99)	-0.020 (-0.93)	-0.021 (-0.95)	-0.005 (-0.18)	-0.004 (-0.12)	-0.017 (-0.44)	0.114 (1.55)	0.174 (2.18)	0.178 (2.32)
$\Delta H_{(t-2)}$		-0.027 (-1.36)	-0.028 (-1.31)		-0.028 (-0.81)	-0.014 (-0.48)		-0.031 (-0.48)	-0.059 (-0.66)
$\Delta H_{(t-3)}$			0.017 (0.48)			0.043 (0.92)			-0.003 (-0.05)
$\Delta E_{(t-1)}$	-0.126 (-0.95)	-0.137 (-0.84)	-0.147 (-0.73)	-0.105 (-1.32)	-0.133 (-1.34)	-0.160 (-1.31)	-0.016 (-0.26)	-0.083 (-0.78)	-0.058 (-0.47)
$\Delta E_{(t-2)}$		0.135 (1.39)	0.121 (1.29)		0.174 (2.63)	0.134 (1.87)		0.050 (0.49)	0.092 (0.72)
$\Delta E_{(t-3)}$			0.145 (1.48)			0.105 (1.68)			-0.105 (-1.17)
Joint test									
Lagged ΔE	0.341	0.381	0.294	0.186	0.028	0.009	0.793	0.631	0.671
Long-run coefficient									
Lagged ΔE	-0.124	-0.002	0.115	-0.105	0.040	0.080	-0.018	-0.039	-0.080
AR2	0.188	0.541	0.733	0.362	0.998	0.874	0.589	0.972	0.748
Sargan	0.462	0.794	0.265	0.805	0.906	0.895	0.440	0.488	0.430
Diff Sargan	0.381	0.999	0.121	0.481	0.936	0.783	0.943	0.806	0.986
No of observations	576	528	480	576	528	480	576	528	480

Note: *p*-values are reported for the joint significance test for Granger causality, AR2, Sargan, and Diff Sargan. AR2 is the Arellano and Bond test for second-order serial correlation. Sargan is a test of the overidentifying restrictions for the GMM estimations. Diff Sargan is a test of the additional moment conditions used in the system GMM estimations. Numbers in parentheses below the coefficients are robust *t*-statistics.

Appendix C

Test of Granger causality from highways to employment using VARs with a spatial lag (time space simultaneous)

C1: Granger causality tests based on equation 6.7

Type of roads	Lags	W_{bin} : Binary contiguity matrix				W_{dis} : Distance decay matrix			
		Lagged ΔH		Lagged ΔWH		Lagged ΔH		Lagged ΔWH	
		Long-run coeff.	Joint test	Long-run coeff.	Joint test	Long-run coeff.	Joint test	Long-run coeff.	Joint test
All roads	1	-0.019	0.370	0.005	0.873	-0.019	0.378	0.001	0.987
	2	0.006	0.448	0.030	0.945	0.004	0.447	0.087	0.636
	3	0.007	0.781	0.012	0.679	0.002	0.760	0.090	0.368
Interstate highways	1	-0.048	0.069 *	-0.135	0.008 ***	-0.048	0.073 *	-0.177	0.000 ***
	2	0.051	0.005 ***	0.068	0.006 ***	0.060	0.004 ***	0.046	0.000 ***
	3	0.048	0.030 **	-0.163	0.001 ***	0.049	0.033 **	-0.321	0.000 **
Arterial roads	1	0.024	0.383	-0.034	0.304	0.023	0.412	-0.097	0.092 *
	2	0.013	0.518	0.035	0.769	0.014	0.559	-0.115	0.522
	3	0.053	0.574	0.052	0.692	0.055	0.530	0.049	0.846
Collector roads	1	-0.063	0.003 ***	0.014	0.832	-0.061	0.004 ***	0.102	0.278
	2	-0.010	0.026 **	0.026	0.927	-0.011	0.026 **	0.116	0.400
	3	-0.025	0.035 **	0.064	0.713	-0.027	0.042 **	0.207	0.251
Non-interstate major roads	1	-0.079	0.001 ***	0.003	0.979	-0.079	0.002 ***	0.065	0.711
	2	-0.023	0.005 ***	0.098	0.754	-0.021	0.011 **	0.123	0.743
	3	-0.024	0.018 **	0.201	0.625	-0.027	0.051 *	0.488	0.477
Local roads	1	-0.001	0.971	0.004	0.884	-0.001	0.973	-0.006	0.916
	2	0.017	0.644	0.013	0.971	0.016	0.650	0.026	0.947
	3	0.023	0.955	-0.018	0.650	0.020	0.910	-0.016	0.704

Note: p-values are reported for the joint significance test for Granger causality. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively.

Appendix C

Test of Granger causality from highways to employment using VARs with a spatial lag (time space simultaneous)

C2: Granger causality tests based on equation 6.7 with control variables

Variable	Interstate highways			Non-interstate major roads		
	m = 1	m = 2	m = 3	m = 1	m = 2	m = 3
ΔE_{it-1}	0.098 (1.46)	0.144 (1.67)	0.155 (2.01)	0.100 (1.67)	0.119 (1.70)	0.093 (1.61)
ΔE_{it-2}		-0.010 (-0.17)	-0.010 (-0.17)		-0.013 (0.23)	-0.037 (-0.73)
ΔE_{it-3}			0.188 (1.99)			0.223 (1.96)
ΔH_{it-1}	-0.040 (-2.23)	-0.010 (-0.43)	-0.002 (-0.08)	-0.048 (-2.82)	-0.028 (-1.74)	-0.034 (-1.98)
ΔH_{it-2}		0.046 (3.02)	0.047 (2.62)		0.024 (0.83)	0.031 (1.30)
ΔH_{it-3}			-0.004 (-0.19)			-0.009 (-0.25)
ΔWH_{it-1}	-0.129 (-4.29)	-0.104 (-1.49)	-0.076 (-0.94)	0.103 (0.92)	0.117 (0.91)	0.166 (1.40)
ΔWH_{it-2}		0.071 (2.11)	-0.049 (-0.75)		0.044 (0.35)	0.156 (1.20)
ΔWH_{it-3}			-0.078 (-3.31)			0.172 (1.81)
ΔQ_{it-1}	0.304 (5.92)	0.244 (2.73)	0.258 (2.57)	0.297 (5.21)	0.257 (3.04)	0.307 (2.96)
ΔQ_{it-2}		-0.024 (-0.32)	0.006 (0.07)		-0.009 (-0.12)	0.017 (0.22)
ΔQ_{it-3}			-0.188 (-1.99)			-0.226 (-2.08)
ΔK_{it-1}	-0.136 (-4.36)	-0.090 (-1.76)	-0.092 (-1.78)	-0.132 (-3.86)	-0.099 (-2.05)	-0.115 (-2.17)
ΔK_{it-2}		0.026 (0.49)	-0.0003 (-0.01)		0.016 (0.34)	-0.002 (-0.05)
ΔK_{it-3}			0.067 (1.18)			0.088 (1.48)
ΔWE_{it}	0.642 (4.52)	0.604 (3.91)	0.509 (3.37)	0.655 (4.58)	0.619 (3.92)	0.511 (3.27)
Joint test						
Lagged ΔH	0.020	0.002	0.043	0.005	0.014	0.040
Lagged ΔWH	0.000	0.000	0.000	0.360	0.650	0.345
Long-run coeff						
Lagged ΔH	-0.044	0.042	0.063	-0.053	-0.004	-0.016
Lagged ΔWH	-0.143	-0.038	-0.344	0.114	0.180	0.685
AR2	0.755	0.386	0.339	0.974	0.446	0.337
Sargan	0.548	0.561	0.719	0.525	0.490	0.663
Diff Sargan	0.998	0.984	0.855	0.995	0.987	0.862
Obs.	576	528	480	576	528	480

Note: The weighing scheme used to capture the spatial spillovers effects of highways is based on the distance-decay matrix W_{hs} . Others are as described in Table 6.9.

Appendix C

Test of Granger causality from highways to employment using VARs with a spatial lag (time space simultaneous)

C3: Test of employment spillovers from highways based on equation 6.7 with control variables: Alternative weighted matrices considered

Spatial weighting scheme	Lags	Lagged ΔH		Lagged ΔWH	
		Long-run coeff.	Joint test	Long-run coeff.	Joint test
<i>Interstate highways</i>					
W_{bin} : Binary contiguity	3	0.059	0.027 **	- 0.187	0.006 ***
W_{dis} : Distance-decay	3	0.063	0.043 **	- 0.344	0.022 **
W_{dis} : Contiguity with distance decay	3	0.061	0.036 **	- 0.143	0.000 ***
W_{hwy} : Contiguity with highway connectivity	3	0.057	0.027 **	- 0.111	0.002 ***
W_{pop} : Contiguity with population density weighted average	3	0.057	0.030 **	- 0.116	0.020 **
<i>Non-interstate major roads</i>					
W_{bin} : Binary contiguity	3	- 0.008	0.021 **	0.318	0.303
W_{dis} : Distance-decay	3	- 0.016	0.040 **	0.685	0.345
W_{dis} : Contiguity with distance decay	3	- 0.010	0.022 **	0.340	0.587
W_{hwy} : Contiguity with highway connectivity	3	- 0.013	0.021 **	0.345	0.266
W_{pop} : Contiguity with population density weighted average	3	- 0.012	0.030 **	0.371	0.181

Note: *p*-values are reported for the joint significance test for Granger causality. *, **, and *** indicate the joint significance of coefficients on lagged variables at the 10%, 5%, and 1% levels, respectively.

Publications

- JIWATTANAKULPAISARN P., NOLAND R.B., GRAHAM D.J. AND POLAK J.W. (2008) Highway infrastructure investment and county employment growth: A dynamic panel regression analysis, *Journal of Regional Science* (in press).
- JIWATTANAKULPAISARN P., NOLAND R.B., GRAHAM D.J. AND POLAK J.W. (2008) Highway infrastructure and state-level employment: A causal spatial analysis, paper under review for publication in *Papers in Regional Science*.
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- JIWATTANAKULPAISARN P., NOLAND R.B., GRAHAM D.J. AND POLAK J.W. (2007) A Granger causality test of highway infrastructure investment and regional employment growth, paper presented at the 11th World Conference on Transport Research, Berkley, USA.
- JIWATTANAKULPAISARN P., NOLAND R.B., GRAHAM D.J. AND POLAK J.W. (2007) Highway infrastructure investment and regional employment growth: A dynamic panel regression analysis, paper presented at the 38th Annual Meeting of Transportation Research Board, Washington D.C., USA.
- JIWATTANAKULPAISARN, P., NOLAND, R.B., GRAHAM, D.J. AND POLAK, J.W. (2006) Do roadway expansions contribute towards county employment growth? Evidence from North Carolina, paper presented at the 38th Annual Conference of the Universities' Transport Study Group (UTSG), Dublin.