TRANSPORT INFRASTRUCTURE AND ITS EMPLOYMENT EFFECTS: A CRITICAL REVIEW OF RESEARCH AND EVIDENCE

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Abstract

Over the past decades, substantial effort has been made to empirically address the question of whether investments in transport infrastructure can foster economic development by generating job opportunities throughout an economy. This paper reviews much of this macro-level research and specifically the application of econometric methods using aggregate level data to analyse the relationship between transport infrastructure investment and employment. We begin with a brief review of the theoretical literature on underlying mechanisms through which transport infrastructure provision can affect employment and other theoretical considerations in modelling this relationship. We then proceed to describe and critique some of the econometric methodologies used in the macro-level studies reviewed, followed by a synthesis of empirical findings on several aspects of the link between transport infrastructure investment and employment. This review also highlights some common problems inherent in the current literature in an attempt to reconcile some emerging contradictory evidence. Finally, we identify and discuss gaps in the empirical knowledge on this topic and fruitful areas for future research.

Keywords: Transport Infrastructure Investment, Employment, Economic Development

1. Introduction

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.[1] The primary incentive for economic development is the employment gain that promoted as a rationale for investment in transport. This is both popular with general public and influences decision makers (Jones 1990). 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.

While the political interest in the importance of transport infrastructure as a prerequisite for employment growth has remained high, exploring statistical 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, a number of macro-level studies have empirically examined the relationship between transport infrastructure investment and employment using aggregate level data. Researchers have applied econometric techniques to estimate the effect of transport infrastructure while controlling for the effects associated with other factors. These studies have used different levels of aggregation, and have used a variety of modelling approaches based on theoretical motivations, assumptions, and focussed on specific questions of interest that may vary. Much of the applied 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 been set out to test whether the impact that transport investment can have on employment varies across regions with different local characteristics. 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.

[1] Useful discussions and reviews of empirical research on transport investment and economic development are immense. For example, see Straszheim (1972), Huddleson and Pangotra (1990), Forkenbrock (1990), Forkenbrock and Foster (1990), Rietveld (1994), Eberts (1999), Weisbrod (2000), OECD (2002), and Bhata and Drennan (2003). For a comprehensive review of this topic, see Rietveld and Bruinsma (1998), SACTRA(1999), Rietveld and Nijkamp (2000) and Banister and Berechman (2000).

This paper 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 as a whole.[2] We begin in Section 2 with a literature survey of the underlying theory through which transport infrastructure is hypothesized to affect employment, followed by an overview of the studies reviewed in this paper. We then provide in Section 3 a review of several modelling techniques used in the empirical literature together with discussions of methodological issues and weaknesses inherent in previous work. In Section 4 we identify and organise the current stage of empirical knowledge obtained to date concerning the effect of transport infrastructure investment on employment. The final section presents concluding comments and highlights some gaps in the understanding of the topic and future research directions.

2. Theoretical considerations and previous research

Provision of transport infrastructure are hypothesized to generate employment throughout an economy in several ways. 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 and how the improvements affect overall productivity.

One strand in the literature primarily emphasises the role that public investments in transport infrastructure can play in affecting the production and location decisions of firms. Improvement in highways and streets is simply seen as a means of stimulating employment growth by encouraging the expansion of existing firms and attracting new industry (e.g. Lichter and Fuguitt 1980, Eagle and Stephanedes 1987, and Munnell and Cook 1990). The fundamental rationale for this idea is expressed in Button (1998) and

[2] 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 opportunities associated with particular transport projects in a defined study area. See, for example, Dodgson (1974), Clay *et a.l* (1992), Linneker and Spence (1996), Bruinsma *et al.* (1997), Bollinger and Ihlanfeldt (1997), and Chalermpong (2004).

Rietveld and Bruinsma (1998) who classify two major ways in which transport infrastructure investment can potentially affect employment. First, they suggest that improvements in infrastructure can be thought of as an increase in the technology of production, and employment changes may occur through substitution and complementary effects. A high quality transport infrastructure can enhance productivity 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. Productivity growth associated with additional investment in infrastructure investments could likewise lead to a decrease in demand for employment as a smaller amount of labour inputs are required for production at a given level of output. However, a complementary effect may also exist because higher productivity could lead to expansion of existing businesses and the establishment of new ones, thereby increasing the local demand for employment. Firms can take advantage of a reduction in production costs to expand their markets, and provision of transport infrastructure can also enhance a region's productivity, which in turn induces more businesses to enter a region. The second issue is that improvements in transport infrastructure could reduce trade barriers, allowing firms in some regions to increase their competitive advantage, although perhaps at the expense of others. This in turn leads to differential impacts on employment across regions. These theoretical notions regarding the employment impact of transport investment are limited to the production side of the economy.

The other approach, which explains the employment effects more extensively, considers the influences of 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. Moreover, 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 (Borjas 1996, SACTRA 1999, Berechman and Paaswell 2001). 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.

Concerning the extent to which public investment in transport infrastructure effects employment, another fundamental premise is that the employment impact of transport infrastructure investments have both a spatial and temporal component. 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 (e.g. Carlino and Mills 1987, Eagle and Stephanedes 1987, Crane *et al.* 1991, Crane and Leatham 1993, Carroll and Wasylenko 1994, Dalenberg and Partridge 1995, Jiwattanakulpaisarn et al, 2009a, 2009b, 2010). The primary reasons behind this idea include adjustment costs incurred by firms and households in response to improved transport facilities, and imperfect information gained by those actors on changed circumstances. The employment effect of transport infrastructure can also be distributed over space. With network characteristics, transport infrastructure can have spatial implications across jurisdictional boundaries, affecting neighbouring regions (e.g. Boarnet 1997, Rietveld and Bruinsma 1998). Of particular importance in our context is therefore the notion that improvements in transport infrastructure in one region could affect local employment of other regions (Dalenberg *et al*. 1998, Cohen and Paul 2004, Jiwattanakulpaisarn et al, 2009b, 2010). This hypothesis, the so-called spatial spillover effects of public infrastructure, has gained attention only recently in the macro-level literature pertaining to the contribution of infrastructure development to regional economic performance (e.g. Holtz-Eakin and Schwartz 1995, Kelejian and Robinson 1997, Boarnet 1998, Mas *et al*. 1996, Perira and Roca-Sagales 2003, and Cantos *et al*. 2005).

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 linkage between transport infrastructure investment and economic growth could work in both directions. 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. For these reasons, it might be employment that affects provision of transport infrastructure, not the other way around.[3]

Overall, the link between transport infrastructure investment and employment changes has a theoretical basis. The reviewed literature suggests that transport provision could potentially lead to both employment gains and losses throughout an economy, and that time and space dimensions of the employment effect also need to be considered. Given the possibility that transport infrastructure is endogenous to an economy, however, 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.

Table 1 summarises the important features of empirical econometric studies reviewed in this paper using various levels of data aggregation and different modelling approaches. Four basic measures are typically used to capture the role of transport infrastructure; these include (1) monetizing highway capital stock, primarily based on the perpetual inventory technique; (2) physical measures of highway capital stock, such as length or density of highways; (3) transport infrastructure expenditures; and, (4) the use of dummy variables to capture the presence of transport facilities. Principal lines of investigation include: (1) the effect of transport infrastructure on aggregate employment; (2) the employment effect on industrial sectors; (3) the effect of transport infrastructure in one region on employment in other regions; and (4) the differential effect of transport investment on employment across different regions. In the next two sections, we present a technical review of existing modelling techniques used in the literature and discuss some advantages and shortcomings of previous research, followed by empirical findings from all reviewed studies.

[3] 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).

Table 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	Lengths of the total public road network and the total motorway network		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 1. A summary of econometric studies on the impact of transport infrastructure investment on employment (continued)

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		
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		
Jiwattanakulpaisarn et al. (2009a)	Dynamic panel regression analysis	Autoregressive distributed lag model	Panel data, all 100 North Carolina counties, 1985-1997	Highway lane-mile density	x			

Table 1. A summary of econometric studies on the impact of transport infrastructure investment on employment (continued)

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	Highway/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	Access to a major highway and access to a commuter rail station	x			
Pereira (2000)	Vector autoregression (VAR)	Multivariate VAR model	Time-series, the entire US economy, 1956-1997	Highway capital stock in monetary term	x			
Eagle and Stephanedes (1987)	Vector autoregression (VAR)	Bivariate VAR model	Panel data, all 87 Minnesota counties, 1964-1982	Highway expenditure	x			x
Stephanedes (1990)	Vector autoregression (VAR)	Bivariate VAR model	Panel data, all 87 Minnesota counties, 1957-1982	Highway expenditure	x			x
Zografos and Stephanedes (1992)	Vector autoregression (VAR)	Bivariate VAR model	Panel data, all 87 Minnesota counties, 1957-1982	Highway expenditure		x		x
Jiwattanakulpaisarn et al. (2009b)	Vector autoregression (VAR)	Bivariate VAR model	Panel data, 48 US contiguous states, 1984-1997	Highway lane-mile density	x			
Jiwattanakulpaisarn et al. (2010)	Vector autoregression (VAR)	Bivariate VAR model	Panel data, 48 US contiguous states, 1984-1997	Highway lane-mile density		x		

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 organized into five categories. We start Section 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 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 3.3 focuses attention on simultaneous equations 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 3.4 is devoted to the applications of vector autoregression that allow transport infrastructure, employment and other variables of interest to be jointly determined. In the final section, 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.

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 transport 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).[4]

In the cost function studies, it is explicitly assumed that firms are price takers, and the cost function represents the cost-minimizing 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 transport infrastructure is considered a fixed and free input that influences production technology. More transport infrastructure could enhance production possibilities resulting in cost-minimizing firms adjusting their demand and use of inputs, given input prices and the existing output level.

[4] For empirical studies using this approach to explore productivity growth associated with aggregate public investment in infrastructure, see, for example, Berndt and Hansson (1992), Conrad and Seitz (1994), Shah (1992), Lynde and Richmond (1992 and 1993), Nadiri and Mamuneas (1994), Morison and Schwartz (1996), and Crihfield and Panggabean (1996).

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:

$$C = C\left(w, r, z, t, Q, G\right) \tag{1}$$

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 transport infrastructure capital available within a jurisdiction. This cost function is derived by minimizing 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 transport infrastructure capital and firms' input demand decisions, the authors apply Shephard's lemma, which states that the optimal (cost-minimizing) 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:

$$L^* = \partial C\left(w, r, z, t, Q, G\right) / \partial w = L\left(w, r, z, t, Q, G\right) \tag{2a}$$

$$K^* = \partial C\left(w, r, z, t, Q, G\right) / \partial r = K\left(w, r, z, t, Q, G\right) \tag{2b}$$

$$M^* = \partial C\left(w, r, z, t, Q, G\right) / \partial z = M\left(w, r, z, t, Q, G\right) \tag{2c}$$

from which the input demand adjustment effects of transport infrastructure investments can be estimated by differentiating the demand function with respect to G. Consider the demand for labor, $\partial L^*/\partial G > 0$ (<0) which indicates that transport 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 (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 48 contiguous states is given by:

$$C = C\left(w, z, t, Q, K, G, \overline{G}\right) \tag{3}$$

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

For empirical implementation, the cost functions are specified in generalized 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 transport infrastructure investments tend to demonstrate the complementary relationship between transport infrastructure and the demand for private capital, whereas private labour input and infrastructure capital are consistently found to be substitutes.

Nevertheless, there is a shortcoming common 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.

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 maximizers 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 transport infrastructure capital. The profit function derived from the maximization of the firm profit, $pQ - (wL + rK + zM)$, subject to the production function: $Q = f(L, K, M, t, G)$, can be expressed as

$$\Pi = \pi(p, w, r, z, t, G) \tag{4}$$

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

$$L^* = L(p, w, r, z, t, G) \tag{5}$$

Estimation of the *unconditional* demand functions yields the unconditional effect of changes in transport 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 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. Furthermore, 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. 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.

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.

3.2.1 *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 ares 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. This specification is similar to the disequilibrium framework. 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 bias.

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 may contain serious 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 prefererable. 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 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).

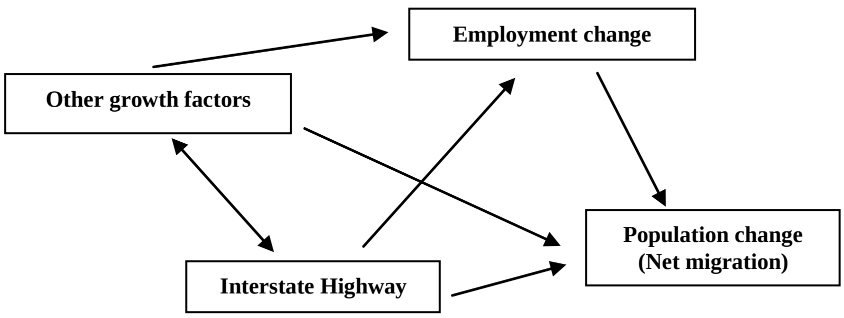

Figure 1. Model of the impact of interstate highways on employment and population changes (Sources: Reproduced from Lichter and Fuguitt (1980) and Briggs (1981))

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 simultaneous 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. In the case that these variables are significant factors contributing to changes in employment, their omission may bias coefficient estimates.

3.2.2 *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.

3.2.3 *Static and dynamic 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 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 the linear fixed effect model of state employment growth in the following form:

$$EGRW_{it} = \alpha + \beta HWY_{it} + \phi NHWY_{it} + \gamma Z_{it} + \sigma_i + \varepsilon_{it} \qquad (6)$$

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 (*NHWY*), 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_i) 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:

$$\Delta E_{it} = \alpha + \beta TRAN_{it-1} + \phi TAX_{it-1} + \gamma Z_{it-1} + \sigma_i + \mu_t + \varepsilon_{it} \quad (7)$$

where ΔE_{it} is the one-year change in a 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 tract; *TAX* is the vector of dummy variables denoting whether 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_i and μ_t 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:

$$Y_{it} - Y_{it-5} = \alpha + \beta(RV_{it} - RV_{it-5}) + \phi(EXP_{it} - EXP_{it-5}) + \delta(Z_{it} - Z_{it-5}) + \eta R + \lambda T + \varepsilon_{it} \quad (8)$$

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 in the following test the relationship between transport infrastructure and employment within a dynamic panel model framework.

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:

$$E_{it} = (1-\lambda)E_{it-1} + \lambda\left[\sum_k \beta^k X_{it}^k + \alpha_i + \mu_t + \varepsilon_{it}\right] \tag{9}$$

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 brackets 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_i and μ_t), 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). As it is well-known in the dynamic panel regression literature, however, the OLS estimates in this research may be biased and inconsistent since there is 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 by Jiwattanakulpaisarn et al (2009a). They empirically investigate the effect of highway lane-mile density on employment in the state of North Carolina using annual observations for all 100 counties from 1985 to 1997. To explicitly take into account dynamic responses of employment to changes in highway infrastructure and other factors, the authors estimate a dynamic panel model of the form:

$$\ln E_{it} = \alpha + \delta \ln E_{it-1} + \beta_0 \ln H_{it} + \beta_1 \ln H_{it-1} + \theta' \ln Z_{it} + \sigma' \ln Z_{it-1} + \mu_i + \tau_t + \varepsilon_{it} \qquad (10)$$

where E is the employment level, H is the density of lane miles for major highways, Z represents the vector of other determinants of labor demand and labor supply, ε is an i.i.d. error term, and i and t index counties and years respectively. The time-invariant county-specific component (μ) is included to account for unobserved or omitted heterogeneity across counties that does not vary over time, while the county-invariant time-specific component (τ) is used to capture any shocks to the labor market that are common to all counties but vary across time. In estimating the dynamic panel data model, the "first-difference GMM" estimator by Arellano and Bond (1991) and the "system GMM" estimator by Blundell and Bond (1998) are used to account for the correlation between unobserved time-invariant county specific effects in the error term and the lagged employment variable. A non-negligible role of slow adjustment processes for employment has been confirmed as the estimated coefficient of the lagged employment level (δ) is fairly large and highly significant.

Unlike other studies, the empirical work by Jiwattanakulpaisarn et al (2009a) has contributed to the literature by employing several alternative modeling frameworks to examine whether and to what extent the estimated effects of highway investment are subject to different econometric specifications. Apart from the dynamic panel model described above, therefore, the basic specification for the static employment model, which contains no lagged variables, is considered. They find that 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.

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 cross-sectional heterogeneity. Analysis of panel data in first-difference form is also performed with the objective of eliminating the fixed effects from the data to avoid omitted variable bias, and controlling for the potential of spurious correlation. Several forms of dynamic panel regressions have also been applied to take into account the dynamic relationships between transport infrastructure provision and evolving patterns of employment, though the estimation results may be criticised on some econometric grounds.

Finally yet importantly, some methodological issues that may exist in previous single-equation studies need to be discussed. Many recent work based on panel data models are likely to have less omitted-variable problems in comparison with the single-equation studies using cross-sectional data. This is due to the use of panel regression techniques to control for the effects of unobserved characteristics across jurisdictions and the inclusion of relevant explanatory variables in the estimated models. More importantly, the potential endogeneity of transport infrastructure variables has often been ignored. Of the seven studies reviewed, only four studies have addressed the latter aspect. Dalenberg and Partridge (1995), Dalenberg *et al*. (1998), and Jiwattanakulpaisarn et al (2009a) have conducted a Hausman test of exogeneity for highways and other variables anticipated to be endogenous and estimated the models using two-stage least squares (2SLS). In Bollinger and Ihlanfeldt (2003), causality tests have been carried out to explore whether changes in employment Granger-cause highway improvements.

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 maximization). 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:

$$E_t^* = \alpha P_t + \beta X_t \qquad (11a)$$

$$P_t^* = \delta E_t + \gamma Y_t \qquad (11b)$$

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:

$$E_t - E_{t-1} = \lambda_E (E_t^* - E_{t-1}) \Rightarrow E_t = E_{t-1} + \lambda_E (E_t^* - E_{t-1}) \qquad (12a)$$

$$P_t - P_{t-1} = \lambda_P (P_t^* - P_{t-1}) \Rightarrow P_t = P_{t-1} + \lambda_P (P_t^* - P_{t-1}) \qquad (12b)$$

In equations (4-12a) and (4-12b), actual employment and population are treated to be 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 (11) in the lagged adjustment models (12), and rearranging terms yields the following structural models:

$$E_t = (1-\lambda_E)\, E_{t-1} + \lambda_E \alpha P_t + \lambda_E \beta X_t \qquad (13a)$$

$$P_t = (1-\lambda_P)\, P_{t-1} + \lambda_P \delta E_t + \lambda_P \gamma Y_t \qquad (13b)$$

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 (13a) and (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

$$E_t - E_{t-1} = a_0 - \lambda_E E_{t-1} + \beta X + a_1(I+W)P_{t-1} + a_2(I+W)(P_t - P_{t-1}) + \varepsilon_1 \quad (14a)$$

$$P_t - P_{t-1} = b_0 - \lambda_P P_{t-1} + \gamma_1 Y + b_1(I+W)E_{t-1} + b_2(I+W)(E_t - E_{t-1}) + \varepsilon_2 \quad (14b)$$

where E is a n x 1 vector of employment; P is a n x 1 vector of population; the subscript t indexes years; I is an identity matrix of dimension n x n; W is a n x n matrix of gravity-type weights $1/(d_{i,j})^{\alpha}$ where $d_{i,j}$ 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. As a matter of course, it is important to highlight some shortcomings common to empirical work cited above. First, even though 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.[5] Second, the technique introduced by Carlino and Mills and followed by others to reduce the simultaneity problem by lagging all independent variables to a base year may not be effective. For instance,

[5] The work of Edmiston (2004) is a recent effort to address 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.

decisions to invest in transport systems are likely to be made in anticipation of future changes in employment and population. To some extent, the coefficients estimated might thus be subject to the endogeneity bias.

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 minimizes theoretical demands and requires less a priori restrictions imposed on the structure of a model in examining the empirical relationship between transport investment and employment.[6] 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. With 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

$$\mathbf{y}_t = \mathbf{c} + \mathbf{\Pi}_1 \mathbf{y}_{t-1} + \mathbf{\Pi}_2 \mathbf{y}_{t-2} + \cdots + \mathbf{\Pi}_p \mathbf{y}_{t-p} + \boldsymbol{\varepsilon}_t \qquad (15)$$

where $\mathbf{y}_t$ =is a *k* x 1 vector of time-series variables, the $\mathbf{\Pi}_i$ are *k* x *k* matrices of coefficients, **c** is a n x 1 vector of constants, and $\boldsymbol{\varepsilon}_t$ is a *k* x 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

$$y_{1t} = c_1 + \pi_{11}^1 y_{1t-1} + \pi_{12}^1 y_{2t-1} + \pi_{11}^2 y_{1t-2} + \pi_{12}^2 y_{2t-2} + \varepsilon_{1t} \qquad (16a)$$

$$y_{2t} = c_2 + \pi_{21}^1 y_{1t-1} + \pi_{22}^1 y_{2t-1} + \pi_{21}^2 y_{1t-2} + \pi_{22}^2 y_{2t-2} + \varepsilon_{2t} \qquad (16b)$$

The illustrations of equations (15) and (16) are that all variables are treated as endogenous, and that 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

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[6] 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.

relevant variables, the VAR approach is one way of addressing the question of causality between infrastructure 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 explore the dynamic relationships between transport infrastructure investment and employment in the VAR framework are Eagle and Stephanedes (1987), Stephanedes (1990) and Zografos and Stephanedes (1992). Using pooled time series and cross-sectional data on highway expenditures and employment for all Minnesota counties, they estimate the bivariate VAR model that consists of two equations for two sets of variables measuring highway construction expenditure and county employment level. The authors simply assume a 5-year lag for the VAR analysis to capture the delay in the dynamic interactions between transport and employment variables. However, although estimating vector autoregressions with panel data requires particular attentions on the orthogonality condition of lagged dependent variables, these studies do not demonstrate if and how this empirical issue had been taken into account. The effects of unobserved characteristics across counties are also ignored.

More recent and sophisticated applications of panel VAR in estimating the employment effect of transport infrastructure are found in Jiwattanakulpaisarn et al (2009b, 2010) who investigate the Granger causality between highway infrastructure and state-level employment in the US. The basis of the empirical models used in these two studies is a panel vector autoregressive model with time dummies and state-specific effects:

$$\Delta E_{it} = \alpha_0 + \sum_{p=1}^{m} \delta_p \Delta E_{i,t-p} + \sum_{p=1}^{m} \beta_p \Delta H_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \qquad (17a)$$

$$\Delta H_{it} = \gamma_0 + \sum_{p=1}^{m} \phi_p \Delta H_{i,t-p} + \sum_{p=1}^{m} \theta_p \Delta E_{i,t-p} + \xi_i + \nu_t + \mu_{it} \qquad (17b)$$

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 optimal lag length (m), which is specified to be identical for all variables, is chosen by information criterion. The authors use time dummies (η_t and ν_t) to account for any unobserved shocks that are common to all states but vary across time, and the time-invariant state-specific effects (f_i and ξ_i) to control unobserved heterogeneity across states. In addition, these VAR models have been estimated using the system GMM estimator (Blundell and Bond, 1998) to take into account the endogeneity due to the presence of lagged dependent variable and individual specific effects. Note that in these two studies some exogenous variables are further added to the employment equation (17a) so as to examine spatial spillover effects of highways as well as to control for the influences of other factors. For example, Jiwattanakulpaisarn et al (2009b) add a variable that captures cross-state spillovers from highways to the employment equation which can be rewritten as

$$\Delta E_{it} = \alpha_0 + \sum_{p=1}^{m} \delta_p \Delta E_{i,t-p} + \sum_{p=1}^{m} \beta_p \Delta H_{i,t-p} + \sum_{p=1}^{m} \lambda_p \Delta \mathbf{W} H_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \qquad (18)$$

The variables $\Delta\mathbf{W}H$ represents growth in highway lane-mile density in other US states:

$$\Delta \mathbf{W} H_{it} = \ln(\sum_{j \neq i} w_{ij} H_{j,t}) - \ln(\sum_{j \neq i} w_{ij} H_{j,t-1}) \qquad (19)$$

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.

The studies discussed above have relied on bivariate VAR models in establishing the relationship between highway and employment variables. To allow more interactions among variables, a national time-series study by Pereira (2000), which analyses the impact of public capital formation on private-sector performance in the USA, estimates multivariate VAR models based on four variables - private output, private capital, employment, and public infrastructure. Core infrastructure investment in highways and streets are among the five types of public infrastructure investments considered in this 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 the Box Information Criterion (BIC) test. This research also employs the impulse response function (IRF) technique to estimate the extent of the effects of shocks to infrastructure investments on private capital investment, output, and employment.

3.5 *Spatial econometric models*

Spatial econometric models 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 due to the close spatial proximity or adjacency of spatial observations. Other type of spatial effect 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 contiguous, the importance of spatial dependence, often known as spatial autocorrelation, 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). For instance, 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, the reviewed studies based on cross-sectional regressions tend to rely on an implicit, but very restricted, assumption that error terms are uncorrelated across geographical observations. Likewise, most of the studies using panel data do not consider the potential existence of spatial dependence. In addition to Boarnet (1994) who incorporates spatial spillover effects in the simultaneous equations of population and employment, others dealing with this issue include Singletary *et al*. (1995), Dalenberg *et al*. (1998), Bollinger and Ihlanfeldt (2003), Islam (2003), Cohen and Paul (2004), and Jiwattanakulpaisarn et al (2009b, 2010).

The use of specification tests for the possibility that disturbance terms in regression models are spatially autocorrelated has been found in the studies using panel data.

Bollinger and Ihlanfeldt (2003) and Jiwattanakulpaisarn et al (2009b, 2010) apply a Moran's *I* test, the most commonly used technique for detecting spatial autocorrelation, while Dalenberg and his colleagues use a test for spatial autocorrelation suggested by Kelejian and Robinson (1993). Nonetheless, only the studies by Jiwattanakulpaisarn et al (2009b, 2010) find significant evidence of spatially correlated errors and address it econometrically.

In the spatial econometric literature, the problem of spatial dependence has typically been taken into account using two alternative approaches. The first 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 traditional OLS regressions, they estimate spatial lag models that contain the spatially weighted dependent variable as an additional regressor, taking the form

$$y = \rho Wy + X\beta + \varepsilon \qquad (20)$$

with ρ as a spatial autoregressive coefficient, W as a spatial weight matrix, and ε_{it} as an independent identically distributed error term. The application of panel VAR models by Jiwattanakulpaisarn et al (2009b) also applies this approach to the employment question (18), resulting in the time-space dynamic specification (Anselin, 2001) of the form:

$$\Delta E_{it} = \alpha_0 + \sum_{p=0}^{m} \sigma_p \Delta \mathbf{W}_e E_{i,t-p} + \sum_{p=1}^{m} \delta_p \Delta E_{i,t-p} + \sum_{p=1}^{m} \beta_p \Delta H_{i,t-p} + \sum_{p=1}^{m} \lambda_p \Delta \mathbf{W} H_{i,t-p} + f_i + \eta_t + \varepsilon_{it} \qquad (21)$$

where $\mathbf{W}_e$ is the weight matrix for spatial lags of employment growth. The findings of these studies confirm the importance of dealing with the presence of spatial dependence as the coefficients estimated for spatial lagged variables are strong and statistically significant.

The second, 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

$$y_{it} = X_{it}\beta + u_i + \varepsilon_{it} \quad \text{and} \quad \varepsilon_{it} = \rho W \varepsilon_{jt} + \upsilon_{it} \qquad (22)$$

where ρ is a coefficient on the spatially correlated errors, W is a spatial weight matrix, and υ_{it} is an independent identically distributed error term. Cohen and Paul's (2004) work 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 structure to accommodate spatial and temporal lags. That is, the error term υ_{it} in (17) is further specified to exhibit first-order autocorrelation over time.

There is another approach to dealing with spatial autocorrelation in regression analysis, namely spatial filtering. It 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 (Getis and Griffith, 2002). Jiwattanakulpaisarn et al (2009b, 2010) are the studies found that apply the spatial filtering approach in a panel VAR framework to examine the causal linkages between highway and employment.

4. Empirical evidence

The econometric methodologies outlined above have been applied to explore several research questions, and their policy implications could be important and far-reaching. Does transport infrastructure affect employment in the aggregate economy? Does transport investment have a clearly significant impact on employment in specific sectors of the 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? A synthesis of research evidence along these lines of investigation is presented below.

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 in the economy as a whole. However, a diversity of empirical results among different studies has emerged. Of the 20 studies reviewed, the relationship between transport infrastructure and employment is found to be positive and statistically significant in 13 studies, whereas many studies have revealed no significant evidence or even a negative relationship. Table 2 provides a summary of these results.

Table 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
Jiwattanakulpaisarn et al (2009b)	State	Panel Vector Autoregression (VAR)	Highway lane-mile density	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	Vector Autoregression (VAR)	Highway expenditure	Not significant
Stephanedes (1990)	County	Vector Autoregression (VAR)	Highway expenditure	Not significant
Jiwattanakulpaisarn et al (2009a)	County	Dynamic panel regression analysis	Highway lane-mile density	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

Studies that investigate the relationship between the stock of highway infrastructure and employment obtain mixed results. A VAR analysis by Pereira (2000) identifies a negative association between highway capital and the demand for labour in the private sector. However, this national-level analysis strictly focuses on the role of highway infrastructure from the firm perspective as an unpaid input for production. Other studies using regional data to estimate single regression models of employment (i.e. Lombard *et al*. 1992, Dalenberg *et al*. 1998, Haughwout, 1999), simultaneous equations of employment and population (i.e. Carlino and Mills 1987, and Clark and Murphy 1996), or panel VARs models (Jiwattanakulpaisarn et al, 2009b) tend to find a positive and significant effect of highway investments. However, Thompson *et al.* (1993), Duffy-Deno

(1998), and (Jiwattanakulpaisarn et al, 2009a) suggest that the relationship between the density of highways and county employment is insignificant.

Similarly, those studies examining the employment effect of government spending on transport infrastructure exhibit the general tendency of 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. The authors note, however, that this negative association may reflect the reverse causation running from employment decreasing 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.

4.2 *Transport investment and sectoral employment*

A large segment of the research on the link between transport infrastructure investment and employment relates to an empirical investigation of whether transport provision has differential effects on industrial sectors in an economy. For a variety of reasons, the employment effect of transport improvements may vary by industry.

Different industries have several distinct characteristics such as the share of transport costs in total production costs, the extent to which transport infrastructure is involved in the production process, the cost structure, mobility of capital and labour, and market for finished goods and services. Also considerably different could be the strength and weakness of the backward-forward linkage between industries. Thus, some or all of these factors could be attributable to differentials in the impact of transport investments on employment among industrial sectors. As noted by Dalenberg and Partridge (1995: 618), information on sectoral differences in the impact of transport investment could be important to policy markers that are concerned with both the level and composition of total employment, and that may value one sector's jobs more than another due to the relative wages or environmental impacts.

Table 3 summarises the recent studies and their empirical findings concerning the effect of transport infrastructure investment on employment in various sectors of the economy. As can be seen, some of these studies have specifically focused on the employment impact on certain sectors in the economy, while others have extended their work beyond analysis of overall employment by applying similar methodologies to disaggregated employment data by industry.

In general, the research evidence has revealed that the relationship between transport investments and private sector employment varies across sectors, and that a significant role of transport infrastructure in affecting employment in the economy is confined to some sectors. For instance, some authors who find a positive effect of transport infrastructure on aggregate employment (i.e. Luce 1994, Lombard *et al*. 1992, Carroll and Wasylenko 1994) discover that only certain industrial sectors appear to gain significant benefits from the presence of or improvements in transport facilities. In some cases, disaggregate analyses also find that transport infrastructure improvements are negatively related to employment in particular sectors of the economy.

Table 3. Empirical evidence on the effect of transport investment on sector-level employment

Modelling Approach	**Author**	**Transport measure**	**Effect on aggregate employment**	**Effect by industry**		
				Positive	**Negative**	**Not significant**
Cost function	Seitz (1993)	Length of the total motorway 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)	Lengths of the total public road network and the total motorway network	-	-	Manufacturing	-
Profit function	Deno (1988)	Highway capital stock in monetary term	-	Manufacturing	-	-
Simultaneous equations of population and employment	Carlino and Mills (1987)	Interstate highway density	Positive	Manufacturing	-	-
	Clark and Murphy (1996)	Highway density	Positive	Manufacturing, construction, services, trade, and finance, insurance, and real estate	-	-
		Percent of public expenditures on highways	Not significant	Finance, insurance, and real estate	Manufacturing	Construction, services, and trade
	Duffy-Deno (1998)	Highway density	Not significant	Resource sector[a]	-	Non-resource sector[a]
	Luce (1994)	Highway/railroad access	Positive	Manufacturing, wholesale trade, services, all other private sectors	-	Retail trade, and finance, insurance, and real estate
Cross-sectional analysis	Lombard *et al.* (1992)	Highway density	Positive	Services	-	Manufacturing
		Total highway expenditure per square mile	Negative	-	Manufacturing and services	-
	Lichter and Fuguitt (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	-	-
	Carroll and Wasylenko (1994)	Highway expenditure per capita	Positive	Manufacturing	-	Transport, wholesale trade, retail trade, finance, insurance, and real estate, 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, finance, insurance, and real estate, and services
	Bollinger and Ihlanfeldt (2003)	Highway expenditure	Positive	Manufacturing	-	
		Percentage of a rail station impact area	Not significant	-	-	Manufacturing
Panel VAR	Jiwattanakulpaisarn et al (2010)	Highway lane-mile density	-	Service, Construction	Manufacturing	

[a]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.

The influence that public investments in transport infrastructure have on employment in the manufacturing sector has been more frequently found than in other sectors, although the direction of the effect is uncertain. Cost function estimates by Seitz (1993), Seitz and Licht (1995), Nadiri and Mamuneas (1998), and Cohen and Paul (2004) indicate that labour demand in the manufacturing sector decreases with an increase in highway capital, whereas Deno (1988) who estimates the profit function finds that the unconditional relationship between highway capital and the demand for manufacturing workers is complementary. A number of estimated results of regression models of employment suggest 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 an interstate highway or presence of major highways (Lichter and Fuguitt 1980, Briggs 1981, Luce 1994, and Singletary *et al*. 1995), or greater levels of government expenditures on highways (Modifi and Stone 1990, Carroll and Wasylenko 1994, Crane *et al*. 1991, and Bollinger and Ihlanfeldt, 2003). However, the findings of Lombard *et al*. (1992), Clark and Murphy (1996), and Dalenberg and Partridge (1995) suggest that public spending on highway infrastructure could lead to employment losses in the manufacturing sector. Recently, Jiwattanakulpaisarn et al (2010) find evidence that lane-mile additions of own-state major highways could increase state employment growth in the service sector while reducing growth in manufacturing. However, the causal relationship is also found to work the other way around.

Overall, empirical evidence has generally agreed with the notion that the employment impact of transport infrastructure does vary considerably among various sectors of an economy. Moving beyond an aggregate picture, the literature has revealed that improved transport infrastructure may have significant effects only in certain sectors. More important, transport improvements are found to benefit some sectors, but also result in employment losses in others. Unfortunately, the work to date has demonstrated no systematic pattern regarding these sectoral differences. However, there are common differences among studies with respect to research methodology, the use of transport measures, the scale of analysis, and industrial classification. Perhaps, the most important implication of these findings is to reinforce the importance of disaggregate analysis in uncovering the incidence of differential effects on employment over different sectors in an economy.

4.3 *Spatial spillover effects of transport investment on employment*

Regarding the spatial implications of transport infrastructure investment in regional employment, this area of investigation is not one which has received a great deal of attention. Among the econometric studies reviewed in this paper, only a few empirical studies have investigated the spatial spillover effect of transport infrastructure on employment. These attempts, however, provide consistent evidence confirming the spatial aspect of transport infrastructure.

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, Haughwout relates growth in state highway and non-highway infrastructure to employment growth among counties with respect to their urbanization status. The results indicate that state infrastructure growth has led to the distribution of employment growth within state from higher density counties to less dense counties.

More formal investigations of whether transport infrastructure in one region could have implications for employment in other regions are found in the state level studies of Dalenberg *et al.* (1998), Cohen and Paul (2004), and Jiwattanakulpaisarn et al (2009a, 2010). Dalenberg *et al*. (1998) and Jiwattanakulpaisarn et al (2009a, 2010) have taken into account the potential network effects of the highway system by further estimating panel regression models of state employment growth in which a variable measuring the stock of highway capital in neighbouring states is additionally included. Likewise, Cohen and Paul (2004) incorporate neighbouring states' highway infrastructure stocks as a separate variable in the cost function model. Both studies find significant evidence that the employment impact of highway infrastructure geographically spills over across a state's jurisdiction.

4.4 *Regional differentials in the employment effect of transport investment*

Most of the research evidence reviewed in the preceding sections represents the "average" effect of transport investment on employment across regions. It is based on analysis of regional data at different levels of geographical aggregation, and the models estimated implicitly assume that all regions behave the same in response to changes in transport infrastructure. However, the theoretical and empirical literature have consistently suggested that the extent to which public investments in infrastructure affect a region's economic development may differ across regions because the effects of infrastructure investment on the economy are subject to dependence upon specific characteristics of recipient regions (e.g. Hansen 1965, Looney and Frederikson 1981, Biehl 1991, Bergman and Sun 1996, SACTRA, 1999). One fundamental reason behind this evidence 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 only create a necessary, but not sufficient, condition for growth and development (e.g. Nijkamp 1986, Deno 1988, Huddleson and Pangotra 1990, Fox and Murray 1993, World Bank 1994). In other words, infrastructure provision alone does not guarantee that growth will occur but they act as a prerequisite for local economic development. Therefore, the effect of transport infrastructure provision on economic growth and development 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 to explore if there are certain local circumstances under which transport infrastructure can have implications for a region's employment (i.e. Deno 1988, Lichter and Fuguitt 1980, Eagle and Stephanedes 1987, Stephanedes 1990, Zografos and Stephanedes 1992, and Crane and Leatham 1993). In general, the hypothesis tested is that the magnitude and significance of transport's influence on regional employment might 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 the 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.

Most studies have provided consistent evidence suggesting that the effect of transport infrastructure improvements on employment vary considerably across regions. 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 urbanized and non-urbanized 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. Studies examining regional differentials in the employment effect of transport investment

Author	**Level of analysis**	**Transport measure**	**Specifying 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 urbanization	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	Urbanization 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	Urbanization 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, two empirical works by Eagle and Stephanedes (1987) and Stephanedes (1990), who find no significant evidence on the statewide effect, have revealed that highway investments do create employment opportunities only 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 urban influence of the state, but tends to reduce employment in other counties adjacent to those counties that are able to take advantage of highway improvements.

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. A more recent Texas study by Crane and Leatham (1993) also highlights the relative importance of highway funding across regions as the time-series estimates indicate that expenditures in highway construction and maintenance have larger impacts on employment in urban counties.

In summary, the empirical evidence on the differential effect of highway investments by region suggests the importance of specific characteristics of a local economy in absorbing employment opportunities arising from highway improvements. The literature shows that highway developments in urbanized areas and other regions that are located near metropolitan regions tend to help local economies to stimulate employment growth. To some extent, these results confirm that public infrastructure can play a crucial role in facilitating the benefits of agglomeration. Nonetheless, some studies reviewed suggest that there are also losers due to improvements in highways. As pointed out by Stephanedes (1990) and Zografos and Stephanedes (1992), highway improvements could lead to the spatial redistribution of economic activities, bringing economic benefits to wealthier regions where more businesses and residents are concentrated at the expense of lagging regions from which a certain amount of such economic activities move away.

5. Concluding remarks

The relationship between transport investment and employment as a measure of the economic development impact stemming from transport infrastructure has received considerable attention from econometric analysts for several decades, but it is still not well understood and hence remains a challenging subject of empirical research. Despite tremendous research efforts, econometric studies to date have provided an archive of inconclusive evidence regarding the significance and quantitative importance of transport infrastructure investment as a factor contributing towards overall employment growth. Several empirical studies have revealed significant evidence that transport improvements help to stimulate employment opportunities in regional or local economies, whereas other studies have argued that the employment effect is statistically insignificant or even negative. In contrast, the literature tends to consistently suggest that sectoral differences in employment changes associated with transport investment could be expected. The research evidence clearly shows that a significant role of transport infrastructure provision in affecting employment in an economy may be confined to certain industrial sectors, and that improved transport services could increase employment in some sectors while reducing it in other sectors. Note, however, that empirical evidence on the direction and significance of the employment effect in the manufacturing sector is far from being conclusive. Few recent studies that have attempted to gain insights into the existence of the spatial spillover effect of transport infrastructure also obtain similar results supporting the notion that provision of transport infrastructure in one region can affect local employment in other regions. In addition, it is often found in this literature that regional differences in the effect of transport infrastructure investment on employment are attributable to differences in the economic characteristics and the urbanisation status of recipient regions. The completed studies find that government spending on highway infrastructure brings about employment benefits to regions in which economic performance is influenced by agglomeration economies. They also reveal that such employment gains might come at the expense of other regions.

Given the disagreement over the effect of transport infrastructure on overall and manufacturing employment in the economy, one might raise an important question regarding possible explanations that could reconcile such conflicting results. One possible reason for the variation in the estimated effect could be the common differences among previous empirical work in scope and methodology. Some emphasise broad spatial dimensions such as nation or states, while others focus on more disaggregated levels such as metropolitan areas, counties, municipalities, or census tracts. In addition, researchers have used different measures of transport infrastructure and have applied a variety of econometric approaches with notable differences in theoretical underpinnings, model specifications, and control variables incorporated in the estimated models. Another possibility is that much of the previous work has generally suffered from several methodological drawbacks. Given this, criticisms might be not only on such piece of contradictory evidence but also on the overall understanding of the relationship between transport infrastructure and employment in the existing empirical literature.

Based on the exhaustive review of modelling frameworks used in the completed research work, we identify three major shortcomings of the previous literature that merit special attention in future research.

The first common problem of this literature is the general failure to account for the possibility that the direction of causality is reversed. As the causal direction between transport infrastructure investment and economic growth could run in both ways, it seems plausible to contend that the estimated results from studies that have ignored or have not effectively addressed this causality issue may be subject to simultaneity bias. More attention in further work is therefore required to applications of econometric techniques that can disentangle the causal relationship between transport infrastructure and employment variables. One rigorous approach is to simultaneously estimate a system of equations in which employment and transport infrastructure measure are both treated as endogenous. Extending this to model the effect of transport investment in the vector autoregressive framework enables researchers to account for the problem of endogeneity as well as dynamic responses of employment to changes in transport infrastructure. In estimating a single-equation regression, an instrumental variables approach is presumably an ideal technique for dealing with the causality issue, although searching for appropriate instrument variables is a substantial complication.

The second crucial issue is the omission of relevant variables. As the complexity of most economic systems, transport infrastructure is only one of numerous factors contributing to changes in employment. In many studies reviewed, however, several important determinants of employment growth are omitted and the choices of control 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. To minimise this problem, 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 labour demand and supply as it is fundamentally clear that employment theoretically relates to the demand and supply sides of the labour market. In addition, analysis of a panel data set can be useful to control for unobserved characteristics over space and time.

The third basic but serious weakness in the literature is that the majority of studies using aggregate data for contiguous regions have generally ignored the potential existence of spatial dependence between observations. Under the assumption that the disturbances are uncorrelated across spatial observations, previous studies estimating cross-sectional or panel data models may suffer from a misspecification problem. This could in turn undermine their credibility of finding statistically significant evidence on the employment impact of transport infrastructure. To improve our understanding of the relationship between transport investment and employment, further work needs to explicitly take into account this spatial aspect using spatial econometric techniques when analysing spatial data. Examples of these include the use of diagnostics to detect spatially correlated residuals in regression analysis (e.g. the Moran's I test, the Lagrange multiplier test for the spatial error, by Burridge (1980), and the Kelejian Robinson's (1992, 1993) specification robust test), and the implementation of filtering processes to separate spatial interdependencies from data (Getis and Griffith 2002) or the application of spatial lag and spatial error models once the presence of spatial dependence is discovered.

In addition to the need to addressing these methodological issues, there remain some gaps in knowledge that deserve further empirical investigation. First, additional research is needed to explore whether transport infrastructure investments in one region affect employment in other regions. Very few studies to data have attempted to test this hypothesis. Indeed, they have been carried out at the highly aggregated level using state databases. As the effects of transport infrastructure generally decay with distance, it is also fruitful to analyse the spatial spillover effect of transport investments on employment at smaller scales of analysis such as county, municipality, and census tract.

Secondly, a sectoral analysis of the influence of transport infrastructure provision on employment merits further attention. Apart from the impact across industrial sectors with respect to different activities in which they are engaged (i.e. manufacturing, trade, finance, and service), attention should also be paid to investigating whether exporting sectors in a region are influenced in a different way by improved transport infrastructure compared with other sectors. The theory of trade maintains that while reduced transport costs associated with transport improvements allow industries whose products are traded regionally to expand market areas, such improvements also expose firms in other industries to stronger competition from firms based elsewhere. As a result, transport infrastructure improvements are likely to cause firms in tradable sectors to be better off at the expense of other firms in non-tradable sectors. However, remarkably little research has been devoted to empirically assess this theoretical expectation.

Finally, it is extremely important to consider that the implications of transport infrastructure development for employment may vary not only over different sectors, but also over space. As discovered by the historical literature reviewed above, the magnitude and significance of the employment impact of highway infrastructure provision are subject to dependence upon specific local circumstances of the recipients regions (i.e. proximity to agglomerations, economic conditions, the urbanization status, and socioeconomic characteristics). However, the empirical work to date gives us little insight into whether the effect of transport investment on employment may differ across regions with respect to the levels of transport infrastructure already in place. While transport economists and many research scholars have been concerned that further investments in transport infrastructure in the presence of a well-developed and extensive transport network are likely to have a less discernible impact (e.g. Evers *et al*. 1987, Rietveld 1994, Forkenbork and Foster 1996, SACTRA 1999, Banister and Berechman 2000, and Rietveld and Nijkamp 2002), one may infer that the effect on local employment is likely to be greater in a region where the level of transport infrastructure is relatively small than in other regions with more ubiquitous transport systems. Nevertheless, despite a fundamentally compelling hypothesis, its supporting evidence is very scant. As transport infrastructure investments are widely considered as necessary, "but not sufficient", for economic development, a lack of empirical knowledge on this important concern limits our understanding of how transport infrastructure investments can contribute towards regional employment growth in a modern economy.

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