Methods for Estimating the Economic Impact of Transportation Improvements: An Interpretive Review

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June 13, 2013

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Abstract

This chapter reviews several methods of evaluating the economic impacts of transportation improvements. We begin with a discussion of basic project-based methods, such as benefit-cost analysis, and discuss some issues which may complicate the accurate estimation of user benefits over the life of a project, especially the dynamic and recursive relationship between transportation networks and land development. We discuss the possible role of capitalized land value changes as an alternate source of estimated user benefits. We then move on to a discussion of regional economic analysis models as a tool for examining the effects of large-scale projects or packages of transportation improvements. Their linkages with non-traditional sources of benefits, such as agglomeration effects, and also network effects is considered. Lastly, we consider aggregate analysis methods. These include production function analyses, cliometric studies, and other types of empirical investigations of the relationship between transportation and econometric growth at an aggregate scale. We close by commenting on the merits of each approach, and where and how they might usefully be applied.

1 Introduction

Transportation network improvements remain a politically popular means for the promotion of economic growth, even though in most developed countries the opportunities for projects which yield exceptionally large returns are becoming more and more scarce. There are other factors at play, including macroeconomic conditions, education and skills levels, which tend to be more important than transport investment. Hence, from the analyst's perspective estimating the economic impacts from transportation improvements can prove to be a fairly complicated matter, even for projects which are not very large in scope. This chapter reviews some of the more common methods that have been used by practitioners and researchers to analyze transportation improvements of varying scale. We move from basic project-based evaluation techniques like benefit-cost analysis to larger, regional-scale types of analysis which make use of regional economic models, and eventually to aggregate analysis techniques which shift focus from the effect of individual projects to the larger-scale and longer-term relationships between transportation infrastructure and economic growth.

Our discussion of project-based evaluation methods is extended to focus on the unique difficulties of directly estimating the user benefits for a given project over its useful life. Apart from traditional sources of uncertainty encountered in forecasting the demand for a project, the effects of induced demand and the dynamic relationship between transportation network improvement, accessibility changes, and development patterns introduce additional sources of uncertainty which may affect estimates of user benefits. We therefore discuss the possibility of using alternate methods to infer user benefits, such as changes in land values. In the concluding section of this chapter, we discuss some of the practical issues involved with the use of this method and also offer some comments on the merits of the regional and aggregate scale approaches discussed herein.

2 Project-Based Evaluation

2.1 State of Practice and Limitations

The majority of economic impact studies are undertaken using conventional, project-based methods. These methods tend to focus on the direct user impacts of individual projects in terms of travel costs and outcomes, and compare sums of quantifiable, discounted benefits and costs. Inputs to benefit-cost analyses can typically be obtained from readily available data sources or model outputs (such as construction and maintenance costs, and before and after estimates of travel demand, by vehicle class, along with associated travel times). Valuation of changes in external costs of travel (e.g., air pollution and crash injury) can usually be accommodated by using *shadow price* estimates, and many government agencies prescribe a single, standard value based on evidence from recent empirical studies.

The primary benefits included in such studies are those related to reductions in user cost, such as travel time savings and vehicle operating costs (e.g. fuel costs, vehicle depreciation, etc.). Additional benefits may stem from reductions in crash rates, vehicle emissions, noise, and other costs associated with vehicle travel. Project costs are typically confined to expenditures on capital investment, along with ongoing operations and maintenance costs.

Project-based evaluation methods, especially benefit-cost analysis, are favored due to their relative ease of use and employment of readily available or easily acquired data. However, several characteristics inherently limit their effectiveness in practice.

First, there is the general criticism of methods based on benefit-cost analysis that they cannot account for all possible impacts of a project. Project-based methods generally do not describe the economic effects of a project on different user or non-user groups, which are an inevitable outcome of such investments. Winners and losers from a new capacity project cannot be effectively identified and differentiated (Levinson, 2002). Moreover, there is often little consideration given to the extent to which such investments alter patterns of social exclusion, another important distributional concern (Church et al., 2000). There are also concerns that some impacts cannot effectively be quantified, such as impacts on the environment, valued landscapes, and urban environments.

Second, a significant amount of uncertainty and risk is involved in the employment of project-based methods. Methods that use benefit-cost techniques to calculate B/C ratios, rates of return, and/or net present values are often sensitive to certain assumptions and inputs (Ashley, 1980). With transportation infrastructure projects, the choice of discount rate is often critical, due to the long life of projects and large, up-front costs. Also, the presumed value of travel time savings is often pivotal, since it typically reflects the majority of project benefits. Valuations of travel time savings vary dramatically across the traveler population as a function of trip purpose, travel mode, traveler wage, household income, and time of day (Hensher, 2001; Brownstone et al., 2003; Hensher and Rose, 2007; Abrantes and Wardman, 2011). It is often useful to test several plausible values. More recently, interest has also extended to other dimensions of travel behavior, such as the reliability of travel time (Noland and Polak, 2002; Brownstone and Small, 2005; Carrion and Levinson, 2012), which may figure in to the estimation of project benefits.

Two of the most important inputs to any project evaluation, forecasts of demand and project costs, are also among the primary sources of risk. Reviews of forecast versus actual traffic volumes for road projects have shown evidence of both systematic overprediction (Flyvbjerg et al., 2005) and underprediction (Parthasarathi and Levinson, 2010) of traffic volumes, often by large margins. Evidence of demand forecasts for urban rail projects have shown a consistent trend toward overprediction of demand, both in the USA and internationally (Pickrell, 1992; Richmond, 2001; Flyvbjerg et al., 2005). Perhaps more worrisome, the evidence suggests that these errors become amplified in the case of large-scale infrastructure projects, or “mega-projects” (Flyvbjerg et al., 2003).

Uncertainty and risk may also arise from other sources apart from the technical analysis components of project evaluation. For example, Mackie and Preston (1998) identify 21 distinct sources of error in project evaluation. Some of these include the sources listed above, both others are more broadly embedded in the planning process itself, such as unclear objectives, prior political commitments, and optimism bias.

2.2 Induced Demand and Induced Development

One particular challenge which confronts nearly all evaluations of projects of any significant size, and hence merits additional attention, is the response of travelers, firms and households to network improvements over extended periods of time. Short-run travel behavior responses, often characterized as "induced demand" and longer-term location decisions in response to new patterns of accessibility, may complicate the estimation of project benefits over the economic life of a project.

2.2.1 Induced Demand

Since so many assessments of project benefits are based on travel-time savings, the issue of induced or "elastic" demand merits special attention. Since Hansen and Huang (1997) provided evidence of an elasticity of 0.9 between road supply (capacity) and the demand for road use (VMT) among California's counties, there has been a great deal of concern over how the provision of new highway capacity might affect travel behavior and whether new capacity policies might be self-defeating. Such findings may have important implications for the long-term economic and social effects of highway capacity provision.

However, there is still a great deal that is not known about the fundamental causal structure underlying the phenomenon of induced demand. Research attempting to decompose the complex issue of induced demand (Hills, 1996; Lee et al., 1999) has emphasized that there are both short-run and long-run effects of highway capacity additions. Specifically, in the short run, movements along the demand curve for road use are observed, as travelers may switch routes or substitute destinations. In the longer term, fixed adjustments by travelers and location decisions by households and firms in response to changes in travel time and accessibility may affect levels of overall travel, leading to an overall *shift* in the demand curve. Recent research has only begun to address these issues in practice by substituting micro-level data and methods for macroscopic analyses (Goodwin et al., 1998; Levinson and Kanchi, 2002; Mokhtarian et al., 2002; Parthasarathi et al., 2003) and addressing the reciprocal relationship between supply and demand (Cervero, 2002; Levinson and Karamalaputi, 2003; Levinson and Chen, 2005).

Perhaps the greatest difficulty in substantiating and quantifying the effects of induced demand is the task of estimating the amount of "latent" demand that may emerge from a network improvement. The concept of latent demand was popularized by Downs (1962, 1992), along with the related concept of "triple convergence", which suggests that there are (at least) three types of substitution effects which may lead to greater flows on an improved road link following the introduction of the improvement. As its name implies, latent demand is particularly difficult to estimate due to the absence of knowledge about which types of substitutions are most likely to materialize, and in what magnitude. One may also hypothesize further types of behavioral response, such as changes in trip generation and destination choice, in response to lower generalized costs of travel. To the extent that these types of adjustments cannot be modeled accurately, they may lead to overestimates of travel time savings and hence user benefits.

2.2.2 Induced Development

Over the course of a project's lifetime, it may generate secondary impacts beyond its direct, short-term effects on travel. By changing the level of accessibility of locations served by the improved network link, a project may bring about additional development in those locations. This spatial reorganization of activities may then feed back to the demand for travel and alter network flows accordingly. We might call this process "induced development" in order to differentiate it from induced demand. This process is illustrated below in Figure 1.

Figure 1: Conceptual representation of co-evolution of transportation networks and land use

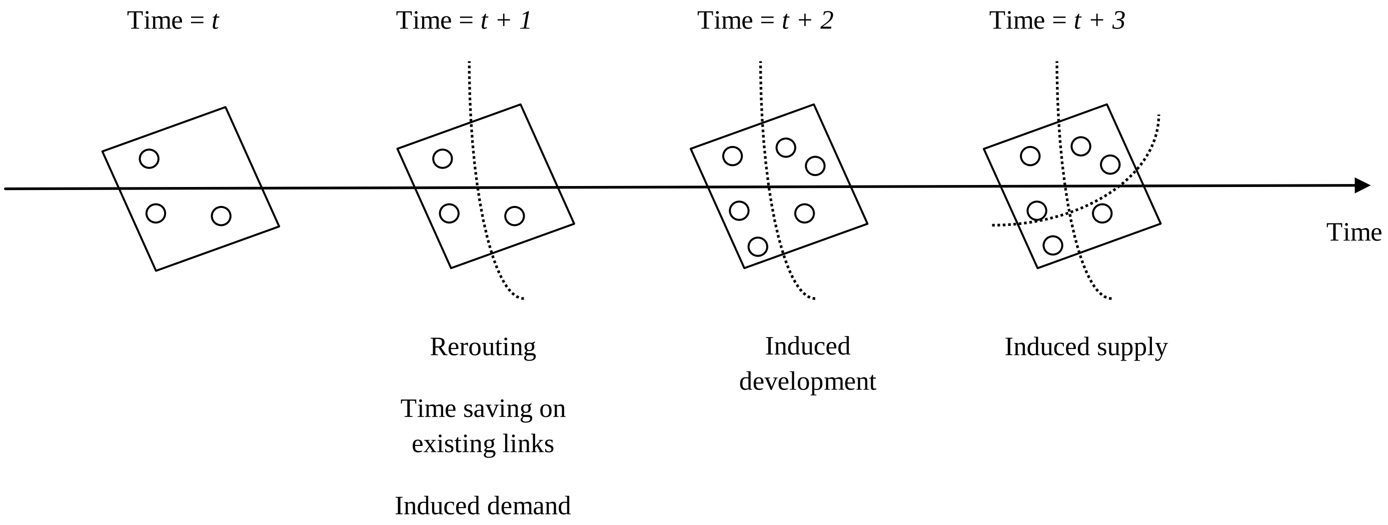

Figure 1 provides a conceptual sketch of the process of induced development by illustrating the process of interaction between transportation network development and land development through time. At time t there is some base amount of development at a given location. The introduction of a new road link at time $t+1$ leads to a set of short-term behavioral responses by travelers as a reaction to the improvement. In the short term, there is some travel time savings on existing links and rerouting, as travelers adjust their route choices to take advantage of lower travel costs. Some additional trips may also be made (induced demand) at previously congested times. At time $t+2$, the improved road link leads to a higher level of accessibility, and hence the location becomes more attractive to firms and households. Over time, this additional development increases the demand for travel, as more trips have origins or destinations in the given location. Thus, at time $t+3$, an additional link is built to serve the location and improve connections with neighboring locations. This process might be called "induced supply" (Levinson and Karamalaputi, 2003), as it is the counterpart to induced demand in the feedback process of transportation network growth and land development.

The recursive process of transportation network growth and land development suggests that efforts to evaluate the effects of larger projects will require model systems capable of replicating the dynamics of this process over time. Indeed, there are ongoing projects to develop integrated urban modeling systems which combine transportation models with models of urban land markets and, in some cases, economic production and exchange [1]. Of course, the additional complexity these more sophisticated model structures introduce also contribute additional sources of forecast error, and there continue to be investigations into the likely range of uncertainty associated with their predictions (Clay and Johnston, 2006; Sevcikova et al., 2007).

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[1] For recent reviews of operational model systems, see (Wegener, 2004; Hunt et al., 2005; Chang, 2006; Iacono et al., 2008)

3 Accessibility as a Performance Measure

As the previous discussion suggested, estimating user benefits from transportation projects (especially larger ones) is a difficult task. Apart from the inherent sources of uncertainty in travel forecasting and economic analysis, user benefits depend on network flows over time, which may change in response to shifts in travel patterns. Longer term locational shifts may also contribute to the degradation of network performance and user benefit.

Complicating matters, it is not clear that network improvements which lower the generalized cost of travel necessarily translate into real time savings in the sense that they result in people spending less time on travel as opposed to other activities. The literature on travel time budgets (Zahavi and Talvitie, 1980; Mokhtarian and Chen, 2004) lends some support to the proposition that individuals spend a more or less fixed amount of time traveling during a given day.

In light of these issues, it may be sensible to consider an alternative method of estimating user benefits from a transportation improvement. As discussed in the preceding section, over longer periods of time changes to transportation networks result in altered patterns of accessibility [2]. These patterns of accessibility strongly influence the location of new development, with land markets serving an intermediary function by conveying information about prices. Thus, the price of land in a given location is a function of (among other things) the relative accessibility of that location to various types of opportunities such as employment and shopping. To the extent that there is a consistent relationship observed between these variables, changes to land prices may serve as a substitute for the direct estimation of user benefits from a given project. The empirical implementation of these methods generally makes use of one of two types of techniques: hedonic price functions and repeat sales methods.

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[2] For a more thorough discussion of the concept of accessibility and various types of accessibility measures, see Liu and Zhu (2004) or the collection of papers in Levinson and Krizek (2005)

3.1 Hedonic Price Functions

Models that use hedonic pricing methods are widely adopted for studying the effect of transportation improvements on the value of real property. Regardless of whether prices for raw land or improved properties are available, hedonic pricing models allow the user to decompose the determinants of prices into a set of attributes, each of which has an implicit price associated with it. The theoretical foundations of hedonic analysis of housing markets are widely attributed to the work of Lancaster (1966) that linked consumer utility to the *characteristics* of goods, rather than the goods themselves, and also to a paper by Rosen (1974) which demonstrated how consumers and producers interact in implicit markets for goods, such as housing characteristics. This approach turns out to be quite useful for analysis of the effects of transportation improvements, since data are more often available for developed properties than for the value of undeveloped land. Hedonic pricing methods allow the user to introduce statistical controls for characteristics of properties that influence the property's value.

The basic hedonic price function assumes that the price (or rent) of a property is a function of several sets of characteristics that collectively describe the quality (and quantity) of building features, the neighborhood in which the property is situated, and the property's location within the relevant real estate market. Malpezzi (2003) writes the basic hedonic function using the expression:

$$R = f(S, N, L, C, T) \tag{1}$$

where R represents the rental price of a property (value can be substituted for owner-occupied properties), S is a set of structural characteristics of the property, N is a set of characteristics describing the neighborhood where the property is located, L describes of the location of the property within the market (e.g., distance to CBD, distance to nearest highway, regional accessibility, etc.), C is a set of contract characteristics or conditions (for rental properties), and T is a variable or variables representing the time when the rent or sale was observed, such as a month or year-specific variable.

Together, these variables provide a more or less complete description of a given property. The associated parameters for each variable can then be estimated to give an approximation of their implicit value, as revealed by the consumption decisions of buyers or renters of houses or commercial property. The theoretical literature on hedonic price functions does not specify a particular functional form for the hedonic model, although many empirical studies adopt specifications that are nonlinear in prices but can be transformed to more easily estimable forms (Halvorsen and Pollakowski, 1981). Data on home sales tend to be more readily available than for other types of property, and this is where much of the evidence from hedonic price models has been accumulated. The effects of transportation improvements are usually specified in terms of the distance or travel time to some transportation facility, such as a highway link or public transit station. Where distance or travel time cannot be specified as a continuous variable, researchers sometimes adopt an approach of defining an "impact zone" within which property values are assumed to be influenced by a transportation improvement (Mohring, 1961).

3.2 Repeat Sales Methods

Some of the early studies of the effects of transportation improvements on property values used fairly simple test-control methods that looked at changes in land or property prices near a new transportation link before and after an improvement, and compared these changes to those observed for a control site not near the improved link. (Ryan, 1999). One weakness of this approach is that the composition of the sample may change over time if new development takes place near the improved link, especially if this new development is quantitatively or qualitatively different from existing properties. Also, this method does not account for any improvements made to the observed properties during the period of study.

A refinement on this method, and an alternative to the hedonic pricing method, is to use repeat sales of properties to estimate annualized changes in price for a given study period. Historically, a more common use for repeat sales methods has been the creation of constant-quality house price indices for entire urban areas (Bailey et al., 1963; Case and Shiller, 1989). However, some more recent applications of the repeat sales approach have generalized the basic equation to allow for the testing of differences in appreciation between different submarkets. This method was used by Archer et al. (1996) to study locational differences in house price appreciation between various segments of the Miami housing market between 1971 and 1992, and by Smersh and Smith (2000) to study differences in rates of appreciation associated with accessibility increases brought about by the opening of a new bridge in Jacksonville, Florida (USA).

Where rich data sets containing extensive attribute information on structure and neighborhood characteristics are not available, repeat sales methods present an appealing alternative for measuring location effects on changes in property prices. In principle, measuring the sale of the same unit at different points in time alleviates the problem of attempting to construct a model that accounts for all sources of variation in prices. However, the usefulness of the repeat sales method relies on the assumption that no significant changes are made to the properties under observation during the period between sales. Also, unless a fairly long time series of observations on sales are available, finding properties that sold multiple times may prove difficult. This may be especially true if a submarket under consideration contains only properties near an improved transportation link or node. A further issue with using this method is that by using only properties that sell more than once during a given study period, much of the information provided in data sets of property sales is lost. More recently, researchers studying house price index construction have begun to establish "hybrid" methods that combine data on repeat sales of unchanged properties with repeat sales of improved properties *and* with single sales, all in one joint estimation procedure (Case and Quigley, 1991).

4 Regional Economic Models

Up to this point, the emphasis has been placed on the evaluation of individual projects and the degree to which they can be effectively assessed using conventional methods such as benefit-cost analysis. Many such projects are deployed at an intraurban or at least intraregional scale. However, some projects are large enough in scale (for example, the Channel Tunnel across the English Channel) that they may generate impacts beyond their immediate area and hence require tools of analysis which are broader in scope.

One approach to measuring the effects of transportation investment at a regional level is to apply macroeconomic simulation modeling methods to represent the effects of cost savings and productivity enhancements due to transportation infrastructure investment. Economic impacts from such a model are measured in terms of employment, income and value added. A basic method for estimating the impacts of investment in a transportation project would involve estimating user benefits from the project, translating these benefits into economic consequences, allocating benefits to specific economic sectors, and finally estimating the additional impact due to changes in logistics and product markets (Weisbrod and Grovak, 1998).

Regional input-output models, such as IMPLAN and RIMS II, have seen extensive application in the transportation sector to issues such as the economic impact of highway and bridge construction (Babcock and Bratsberg, 1998) and regional estimates of commodity flows (Vilain et al., 1999). Weiss and Figura (2003) have noted a more recent shift in economic impact modeling toward the REMI (Regional Economic Models, Inc.) regional economic model (Treyz et al., 1992). This has been attributed to the fact that while IMPLAN and RIMS II are largely expenditure-driven (implying that, from a local perspective, a larger project is invariably a better project), the REMI model is able to translate the results of an analysis of the transportation impacts of a project into regional economic performance via its effects on business costs and productivity. For example, since trucking costs are an important input to most economic sectors, any cost savings attributable to a project can be traced through the local economy.

Regional and inter-regional input-output models are closely related to another type of regional economic model, computable general equilibrium (CGE) models, which can be used to simulate the wider effects of large projects or packages of transportation improvements (Bröcker, 2004). CGE models simulate the behavior of supply, demand and prices in interacting markets within the economy. As applied to transportation, CGE models are given an explicitly spatial component, where changes to transportation networks are transmitted in the form of changes in spatially-differentiated prices among locations, which affect production and household welfare. Accordingly, this type of model is typically referred to as a *spatial* computable general equilibrium (SCGE) model. Bröcker et al. (2010) notes that SCGE models offer improvements over other types of analysis techniques in that they allow for simulations involving market imperfections, such as monopolistic competition, which underpin many New Economy Geography models. They also allow for the estimation of distributional consequences across locations, which Bröcker et al. (2010) illustrates with a simulation of the effects of a package of improvements that are part of the Trans-European Transport network (TEN-T) initiative.

Regional economic models are gaining in popularity due not only to their ability to simulate the effects of large intra- or inter-regional transportation improvements, but also due to their ability to be adapted to emerging theories and concepts in urban and regional economies, as well as transportation. The preceding discussion of SCGE models noted their adaptability to regimes of monopolistic competition, which help explain patterns of specialization and trade (Krugman, 1991). Transportation costs, especially where they are falling, are also considered to be an important factor in the emergence of agglomeration economies and associated productivity gains. Venables (2007) provides a theoretical framework for incorporating productivity improvements due to agglomeration into the evaluation of transportation improvements. Recent empirical work on this topic has suggested that transportation costs may figure prominently into the realization of agglomeration benefits at both the urban and regional levels (Rice et al., 2006; Graham and Kim, 2008), though the gains may not be evenly distributed across industries. Agglomeration effects may be prove to be an important consideration in the evaluation of projects designed to enhance integration within the European Community.

A related concept that is relevant to regional modeling is that of *network effects*. Laird et al. (2005) distinguishes between two types of network effects: those relating to the network itself and its associated set of flows, and effects in the economic sectors linked by transportation networks. The former type of network effect relates more to the physical flows on the network, and so may be captured mostly within a transportation network model that is coupled with a regional economic model, while the latter relates more closely to patterns of production and exchange enabled by the transportation network. This latter type of network effect, the ability of transportation network changes to alter patterns of trade and production, may be more important in the long run and at the regional level. Thus, they may become a priority for the development of extensions to input-output and SCGE modeling systems (Vickerman, 2007).

5 Aggregate Analysis Methods

At larger scales of analysis, there are several types of empirical methods available for estimating the contribution of transportation infrastructure to economic growth. The regional economic models discussed in the previous section can be extended to national levels, though this often adds considerably to the computational and data requirements of the effort. In this section, we will explore a few examples of simpler econometric approaches to estimating the relationship between transportation and economic growth at more aggregate levels. These studies tend to move away from the analysis of individual projects and instead evaluate the cumulative effects of transportation network growth over time. Many of the examples presented here are drawn from the United States, since these approaches have tended to be more popular there.

5.1 Production Functions

During the early 1990s, there was a resurgence of interest in research attempting to measure the contribution of public capital to economic productivity, following the publication of work by Aschauer (1989) and Munnell (1990). Both of these researchers estimated econometric production functions for national productivity using time series data and treating public capital stocks as a separate input. Both studies found enormous returns to public capital and suggested that declines in spending on infrastructure as a share of GDP during the 1970s and 1980s might have been a cause for the decline in productivity observed during that period. This immediately prompted national debate over whether there was an "infrastructure shortfall", a debate recently re-ignited by the collapse of the I-35W Mississippi River Bridge in Minneapolis, Minnesota (USA). Subsequent research largely dispelled these claims. For example, federal spending on public nonmilitary capital was shown to be roughly constant from 1950 to 1990, while state and local capital stocks (which tend to be much larger), grew considerably (Gramlich, 1994). Also, research that focused on industry-specific and state-level production functions, while controlling for unobservable differences in state-specific conditions, found much lower (and in some cases, statistically indistinguishable) rates of return (Holtz-Eakin, 1994; Garcia-Mila et al., 1996).

Nadiri and Mamuneas (1998) estimated the benefits of highway investment at the national level between the 1950s and the 1980s and concluded that in the early years returns were as high as 35 percent per year, but that by late in the years of the construction of the Interstate system that contribution had dropped to roughly the same as the return from private capital, about 11 percent.

One of the benefits that has been associated with transportation improvements is the impact that increased accessibility has on agglomeration of urban areas. *Agglomeration economies* are an external benefit that arise from the interaction and co-location of productive factors within an economy, such as infrastructure, suppliers and customers, as well as a pool of labor with the needed skills. This can provide added economic value to an economy. Agglomeration economies are mitigated by various diseconomies, such as congestion, that may also occur. Recent research by

Graham (2007) has examined these impacts which may effect different industry sectors in different ways.

The flurry of economic research into the role of public capital and, in particular, highway infrastructure capital, shed light on an important way to measure the economic returns from transportation infrastructure investment, albeit at a highly aggregate level. With the aid of time series data, public infrastructure capital can be specified as a factor of production, and its contribution to productivity tracked over time. This information is critically important at a time when the U.S. National Highway System is essentially complete, and marginal improvements to the network must be evaluated. Care needs to be taken, though, in the specification and interpretation of the results from aggregate production function research. Definitions of public capital and other factors of production need to be rigorous (e.g. separating public highway capital from schools, airports, water systems, etc.). Also, the geographic scale of the research (local, state, national) needs to be clearly defined.

5.2 Other Econometric Methods

An alternative to using aggregate production functions is to specify econometric models relating levels of highway capital spending to economic indices such as employment, income, or various forms of output. Some of the later production function studies noted that, at smaller geographic scales, the effect of highway capital spending was to redistribute, rather than generate, economic activity (Boarnet, 1997). A related finding was that there were spillover effects from the provision of new highway infrastructure (Boarnet, 1998; Haughwout, 1998; Williams and Mullen, 1998). These findings were not necessarily new – previous research had examined spatially-differentiated effects of highway capital spending (Stephanedes and Eagle, 1986, 1987; Stephanedes, 1990), but they did signal a new direction for econometric research into the economic effects of highway capital.

The contribution of much of the recent research into the relationships between transportation infrastructure provision and economic performance has been to refine methods of analysis. New methodologies aim to correct for potential temporal and/or spatial autocorrelation in datasets (Duffy-Deno and Eberts, 1991; Boarnet, 1998; Berechman et al., 2006). Finally, new conceptualizations of the link between transportation investment and economic performance have been suggested, such as relationships between improved accessibility and employment outcomes (Berechman and Paaswell, 2001; Ozbay et al., 2006), firm inventory behavior as a way to measure the returns from highway infrastructure (Shirley and Winston, 2004), and hybrid economic evaluation approaches that attempt to bridge the project-specific and macroeconomic approaches described herein (Weisbrod and Treyz, 1998).

5.3 Cliometric Methods

Economic historians, utilizing so-called Cliometric methods (after Clio, the muse of history), have assessed the long-term retrospective impacts of major infrastructure investments. Among the more noted of these is the assessment by Fogel (1964) of railroads and economic growth in the nineteenth century, which sought to estimate the incremental economic contribution of railroads compared with its precursor system of canals. Fogel concluded that railroads contributed an increment of only 0.4 percent per year of growth in economic output, compared with competing estimates as high as 4 percent per year (Fishlow, 1965). Fogel later won a Nobel Prize in Economics for his work.

What is noteworthy about the economic history assessments of infrastructure assessments is that they underscore the profound difficulty of a deep assessment of the impact of major infrastructure system implementations even a century after the fact. Of course, investments at a smaller scale pose less daunting challenges for analysis.

The larger point is that the scale of investment is in many respects inversely proportionate to the difficulty of measuring impacts. Thus, assessing the effects of a Washington Beltway is an order of magnitude more difficult that assessing the impact of adding a single link to an already deployed network.

6 Conclusion

This review has documented a variety of approaches that might be employed to analyze the economic impacts of transportation improvements. As should be clear by now, the matter of geographic scale is critical to selecting the appropriate type of analysis (Banister and Berechman, 2001). Matters of geographic context and resource distribution also figure prominently.

We reviewed project-based evaluation methods, where benefit-cost analysis is the predominant technique of analysis in most developed countries. This approach may be appropriate for many urban and even regional-scale projects. We also suggested that, given the difficulty of measuring direct user benefits and the dynamic nature of the relationship between transportation networks and patterns of development, analysts might consider using changes in land prices as an alternative measure of benefit. Other researchers have suggested using this method in order to capture the local, micro-scale effects of a transportation improvement (Banister and Thurstain-Goodwin, 2011). However, its consistent application may require the resolution of some remaining issues.

First, there is the nature of land values as a measure of benefits. As Mohring (1993) points out, the spillover effects of transportation projects are, in a sense, transfers of benefits initially received by users to those who provide services complementary to the use of the network. Thus, land price changes cannot be counted in addition to direct user benefits, as this would result in double-counting. Second, many of the spillover benefits arise due to mispricing of transportation facilities. Prices set closer to marginal cost would reduce the incidence of such spillovers. Third, if land values are to be used for the analysis of a project at a local level, there may be some underestimation of benefits if some users of the improved link have neither an origin nor a destination in the local area (i.e pass-through traffic). These benefits will likely not be capitalized into local land values. Fourth, if an *ex ante* analysis of a project seeks to use accessibility changes as the primary driver of user benefit (through the medium of land value changes), the estimation of accessibility change may encounter some of the same issues associated with uncertainty in the estimation of user benefits in congested networks, since travel time estimates play an important role in all types of accessibility measures. As a related matter, such calculations may also need to take into account the effect of emerging technological trends, such as the availability of smart phones and small computing devices, on users' perception and valuation of their travel time. While this is already an area of active research for those studying the habits of public transport users, it may eventually also apply to private automobile users with the advent of autonomous vehicle technologies. These issues may represent fruitful areas for future research.

The aggregate-scale analyses discussed in this chapter seem to have a different purpose than the other project-level techniques discussed earlier. The literature on production functions and the growth effects of public infrastructure initially became popular due to the intense interest in the hypothesis of public capital shortfalls as a possible explanation for the slowdown in productivity growth during the 1970s and 1980s in the United States (and to a lesser extent, Europe). While the many papers produced on this topic since then have gradually refined the methodology for conducting such analysis, the reality is that the results of these studies are often not policy sensitive enough to be terribly useful in terms of policy analysis. The geographic scale of analysis and the treatment of transportation are too aggregate to provide much direction as to which types of investment to pursue, where, and how much. Nonetheless, these studies have helped to provide some rough evidence of the scale of returns from additional infrastructure investment in countries with already mature, well-developed networks (Vickerman, 2000; Banister and Berechman, 2001).

Similarly, cliometric methods represent a fascinating line of research, especially where the historical development of transportation networks is concerned, but is often not relevant to much current analysis. They do, however, often provide fodder for rich debates about the role of certain historical developments, as in the works cited here on the economic contribution of the railroads in the United States, in addition to offering useful frameworks for the analysis of such topics.

Regional analysis of transportation improvements and the economy will likely remain the target of much research in transportation economics and planning in the coming years. Opportunities remain for developing regional economic models in such ways that they can incorporate some of the key developments in urban and regional economics from recent decades. Probing network effects on production and supply chains, as well as interactions with agglomerative forces, will prove to be considerable challenges.

Perhaps as important though is the need to develop tools which are practical, as well as theoretically consistent. Modeling transportation flows accurately has historically been a challenging enough endeavor. Coupling these models with large-scale economic models introduces additional layers of complexity and uncertainty. One other important criticism of these models is that they lack transparency, that is, that they retain a certain "black box" character. This presents an inherent limitation to their usefulness in terms of policy analysis. Thus, the designers and users of such tools must be mindful that they are developing tools which not only give meaningful answers, but also understandable ones.

Acknowledgements

The authors would like to acknowledge the helpful comments of an anonymous reviewer which contributed to the improvement of this chapter.

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