TRANSPORTATION RESEARCH SYNTHESIS

Subject Area: Planning

Minnesota Department of Transportation
Office of Investment Management
Research Services Section
651-366-3780
www.research.dot.state.mn.us

August 13, 2008
TRS 0802

Methods of Estimating the Economic Impact of Transportation Improvements

Written by: Michael Iacono * & David Levinson †

1 Introduction

When confronted with the problem of evaluating proposals for projects involving new highway capacity, public decision makers face a bewildering array of options for anticipating and assessing project-related economic impacts. On one hand, the issue of geographic scale is highly relevant. Local or project-level impacts may be very di?erent from those estimated at regional and multi-regional levels. Another salient issue is that there are many metrics for assessing economic impacts, ranging from direct user benefits and changes in external costs of travel to more aggregate economic indicators, such as employment, income and productivity rates.

Several types of economic benefits arise from transportation improvements:

- reductions in travel costs, [1]
- more efficient supply chains,
- intra-firm scale economy effects (permitting individual firms to through larger scale operations at fewer locations),
- agglomeration (including inter-firm scale effects) whereby clusters of competing and complementary firms perform better than firms in isolation, and
- re-organizational benefits, where firms can reorganize the way they produce output, and improve quality or even the goods that can be produced thanks to new infrastructure, just-in-time production is an example.

* Research Fellow, University of Minnesota, Department of Civil Engineering iaco0009@umn.edu

† RP Braun-CTS Chair of Transportation Engineering; Director of Network, Economics, and Urban Systems Research Group; University of Minnesota, Department of Civil Engineering, 500 Pillsbury Drive SE, Minneapolis, MN 55455 USA, dlevinson@umn.edu http://nexus.umn.edu

[1] Some analysts consider reductions in travel costs a user benefit, not an economic benefit, but we find it hard to see how users are not part of the economy. We do believe that user costs should be quantified distinctly from other benefits and double counting of benefits should be avoided.

All of these benefits relate, and may be fully capitalized into the price of land, property and products. Project-level, disaggregate studies tend to focus on the first of these effects, while more aggregate methods are applied to the next two. Almost no studies consider the longer term agglomeration or reorganization benefits of improved infrastructure (20), and identifying the existence of positive externalities from infrastructure (i.e. gains that are not captured by users) is very difficult.

The economic impacts of transportation improvements have been measured alternatively at either a macro or a micro scale. The former contain much of the theoretical literature underlying the calculation of impacts and can be traced back to early works such as (42). The latter have become associated with more general studies of the overall impact of transportation or public capital spending on aggregate measures of output.

The development of methodological approaches to economic impact measurement has since evolved to fit more practical applications, and these have mostly been carried out at smaller scales, taking the form of benefit-cost analyses for particular projects (43), regional or corridor investment analyses (1; 18) , or studies of the impact of specific projects on local property values.

This synthesis reviews several strands of relevant literature that aim to assess the basic issue of the economic impact of highways. It begins with a discussion of traditional, project-based economic analysis methods, based on microeconomic foundations and benefit-cost analysis methods. Some attention is paid to the specific topic of induced demand, since this issue presents unique difficulties for microeconomic analysis methods. Then, the discussion turns to regional and macroeconomic methods, including input-output and econometric modeling. The final section summarizes the previous discussion and offers some prospective ideas about evaluating the impacts of transportation improvements.

2 Software Tools for Impact Analysis

The majority of economic impact studies for highway capacity projects are undertaken using conventional 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, somewhat intangible costs of travel (e.g., air pollution and crash injury) can usually be accommodated by using *shadow price* estimates, such as obtained from FHWA-suggested values, based on 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.

A number of economic analysis tools have been developed under the auspices of the Federal Highway Administration (FHWA) permitting different forms of benefit-cost analysis for different types of projects, at different levels of evaluation. Several of these tools are prevalent in past impact analyses, and are described here. However, none identifies the effects of infrastructure on the economy and development.

2.1 MicroBENCOST

MicroBENCOST (40) is a sketch planning tool for estimating basic benefits and costs of a range of highway improvement projects, including capacity addition projects. In each type of project, attention is focused on corridor traffic conditions and their resulting impact on motorist costs with and without a proposed improvement. This type of approach may be appropriate for situations where projects have relatively isolated impacts and do not require regional modeling.

2.2 SPASM

The Sketch Planning Analysis Spreadsheet Model (SPASM) is a benefit-cost tool designed for "screening" level analysis. It outputs estimates of project costs, cost-effectiveness, benefits, and energy and air quality impacts. SPASM is designed to allow for comparison among multiple modes and non-modal alternatives, such as travel demand management scenarios. The model is comprised of three modules (worksheets) relating to public agency costs, characteristics of facilities and trips, and a travel demand component. Induced traffic is dealt with through the use of elasticity-based methods, where an elasticity of vehicle-miles of travel (VMT) with respect to travel time is defined and applied. Vehicle emissions are estimated based on calcuations of VMT, trip length and speeds, and assumed shares of travel occuring in cold start, hot start, and hot stabilized conditions. Analysis is confined to a corridor level, with all trips having the same origin, destination and length. This feature is appropriate for analysis of linear transportation corridors, but also greatly limits the ability to deal with traffic drawn to or diverted from outside the corridor. (12) describe the model and its application to a freeway corridor in Salt Lake City, Utah.

2.3 STEAM

The Surface Transportation Efficiency Analysis Model (STEAM) is a planning-level extension of the SPASM model, designed for a fuller evaluation of cross-modal and demand management policies. STEAM was designed to overcome the most important limitations of its predecessor, namely the assumption of average trip lengths within a single corridor and the inability to analyze systemwide effects. The enhanced modeling capabilities of STEAM feature greater compatibility with existing four-step travel demand models, including a trip table module that is used to calculate user benefits and emissions estimates based on changes in network conditions and travel behavior. Also, the package features a risk analysis component to its evaluation summary module, which calculates the likelihood of various outcomes such as benefit-cost ratios. An overview of STEAM and a hypothetical application are given by (13).

2.4 SMITE

SMITE (Spreadsheet Model for Induced Travel Estimation) is a sketch planning application that was designed for inclusion with STEAM in order to account for the effects of induced travel in traffic forecasting. SMITE's design as a simple spreadsheet application allows it to be used in cases where a conventional, four-step travel demand model is unavailable or cannot account for induced travel effects in its structure (11). SMITE applies elasticity measures that describe the response in demand (VMT) to changes in travel time and the response in supply (travel time) to changes in demand levels.

2.5 SCRITS

As a practical matter, highway corridor improvements involving intelligent transportation systems (ITS) applications to smooth traffic flow can be considered capacity enhancements, at least in the short term. The FHWA's SCRITS (SCReening for ITS) is a sketch planning tool that offers rough estimates of ITS benefits, for screening-level analysis. SCRITS utilizes aggregate relationships between average weekday traffic levels and capacity to estimate travel speed impacts and vehicle-hours of travel (VHT). Like many other FHWA sketch planning tools, it is organized in spreadsheet format and can be used in situations where more sophisticated modeling systems are unavailable or insufficient.

2.6 HERS

In addition to helping states plan and manage their highway systems, the FHWA's Highway Economic Requirements System for states (HERS-ST) offers a model for economic impacts evaluation. In once case, (37) use HERS-ST to conclude that Texas is under-invested in highways particularly urban systems and lower-order functional classes by 50 percent. Combining economic priniciples with engineering criteria, HERS evaluates competing projects via benefit-cost ratios. Recognizing user benefits, emissions levels, and construction and maintenance costs, HERS operates within a GIS environment and will be evaluated under this project, for discussion in project deliverables. Well established software like HERS offer states and regions an oportunity to readily pursue standardized economic impact evaluations on all projects, a key advantage for many users, as well as the greater community.

2.7 Summary of Software Tools

Many analytical tools, like those described above, are favored due to their relative ease of use and employment of readily available or easily acquired data. However, several characteristics limit their effectiveness in evaluating the effects of new highway capacity. First, they are almost always insufficient to describe the full range of impacts of new highway capacity. Such methods deliberately reduce economic analysis to the most important components, resorting to several simplifying assumptions. If a project adds capacity to a particularly important link in the transportation network, its effects on travel patterns may be felt outside the immediate area. Also, the effects of induced travel, in terms of either route switching or longer trips, may not be accounted for in travel models based on a static, equilibrum assignment of traffic. In the longer term, added highway capacity may lead to the spatial reorganization of activities as a result of changes in regional accessibility. These types of changes cannot typically be accounted for in analysis methods.

Second, there is the general criticism of methods based on benefit-cost analysis that they cannot account for all possible impacts of a project. Benefit-cost methods deliberately reduce economic analysis to the most important components and often must make simplifying assumptions. The project-based methods described here generally do not describe the economic effects of a project on different user or non-user groups. Winners and losers from a new capacity project cannot be effectively identified and differentiated.

Third, 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. 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, traveler wage, household income, and time of day. It is useful to test several plausible values.

Assessment procedures in the UK and other parts of Europe have moved towards a multi-criteria approach, where economic development is only one of several appraisal criteria. Environmental, equity, safety, and the overall integration with other policy sectors are examined in a transparent framework for decision makers. In the UK, the Guidance on the Methodologies for Multi-Modal Studies provides such a framework (14). These procedures require a clear definition of project goals and objectives, so that actual effects can be tied to project objectives, as part of the assessment procedure. This is critical for understanding induced travel effects. Noland (47)has argued that this implies that comprehensive economic assessment, including estimation of land valuation effects, is the only way to fully assess the potential beneficial impacts of projects.

3 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 (26) 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 (29; 31) 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 anlayses (21; 33; 44; 49) and addressing the reciprocal relationship between supply and demand (10; 32; 34).

The relationship between road capacity supply and demand is a dynamic process and is difficult to model with conventional models of travel demand. Since project-based microeconomic analysis techniques, including some developed by FHWA, use output from these models as inputs to benefit or cost calculations, their results may be somewhat skewed. Even the elasticity-based techniques provided in models like STEAM are likely to overestimate the response of travel demand to new capacity. The lack of a dynamic element in these analysis tools means that they are likely to overestimate user benefits due to a) an inability to capture short-term behavioral changes as the transportation network evolves toward a new equilibrium and b) an inability to capture the *co-development* process in the long run, whereby infrastrucutre and land use develop jointly over time in response to each other. While the benefits for individual users may drop in response to induced demand that diminishes the travel time savings, the fact that demand rises when capacity is added is indicative both of gains to users in general (more users take advantage of the facility), and of other economic benefits that this research aims to capture.

4 Aggregate Economic and Econometric Methods

An alternative method for exploring the economic impacts of transportation investment is to observe and measure, at a larger scale, the relationship between investment in transportation infrastructure and indices of economic performance. A range of different methods fall under this general category, including the use of regional economic models, aggregate productivity functions, as well as more disaggregate model specifications that allow for measurement at local and regional levels.

4.1 Regional Economic Models

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 (59).

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 (3) and regional estimates of commodity flows (58). (61) have noted a more recent shift in economic impact modeling toward the REMI (Regional Economic Models, Inc.) regional economic model (57). 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.

One may question though, the extent to which a single transportation project (such as the addition of capacity to a local highway) will register significant economic impacts, especially in larger urban areas. Since the changes to the transportation network and their associated cost savings are often modeled using static forecasting procedures, as described earlier, it is possible that any erosion of future benefits, due to unanticipated changes in network conditions, would also limit the economic impact forecasted by a regional economic model. Furthermore, the quality of the data on which regional economic forecasts are made can be considered suspect. It is inherently difficult to measure, with a high degree of precision, trade flows between counties or other relevant economic units. This problem is compounded at larger scales of analysis. A final note of caution is that regional economic models, like other types of complex, computer-based analysis tools, are vulnerable to misuse and abuse in order to justify new government projects. (41) identifies some of the more common errors, such as ignoring the need of state and local governments to raise money to finance capital projects and treating construction wages as benefits instead of costs.

4.2 Aggregate 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 (2) and (45). 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. 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 (23). 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 (19; 30).

(46) 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 (22) 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.

4.3 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 (17) 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 (16). 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.

5 Disaggregate Economic and Econometric Methods

5.1 Disaggregate Econometric Models

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 (7). A related finding was that there were spillover effects from the provision of new highway infrastructure (8; 27; 62). These findings were not necessarily new – previous research had examined spatially-differentiated effects of highway capital spending (53; 54; 55), 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 infrastruture 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 (4; 8; 15). Finally, new conceptualizations of the link between transportation investment and economic performance have been suggested, such as relationships between improved accessibility and employment outcomes (5; 48), firm inventory behavior as a way to measure the returns from highway infrastructure (50), and hybrid economic evaluation approaches that attempt to bridge the project-specific and macroeconomic approaches described herein (60).

It should also be noted that there have been significant advances in methodologies for disaggregate spatial econometric models, including generalized method of moments, maximum likelihood estimation, Prais-Winsten regression, and other techniques for dealing with spatially distributed panel data. These methods are becoming increasingly popular in current empirical research on infrastructure investment.

5.2 Hedonic Models for Property Valuation

Hedonic methods to capture the element of property value that is associated with infrastructure accessibility are arguably the most prevalent in the literature. These types of studies have been carried out mostly at local scales and attempt to capture the capitalization of transportation-related benefits (and costs) on nearby properties. The analytical framework that is typically employed is that of least-squares regression, where the value of property can be decomposed into individual attributes of a structure and land value, based on neighborhood attributes that property buyers implicitly value. Recent examples include (6; 24; 28; 52; 56) and (9), which emphasize access to a particular freeway corridor. The application of hedonic modeling has been paralleled by attempts to probe the underlying causal relationship between transportation and land use (35) and specify the relationship within existing models. This line of research has asserted the importance of accessibility as the mechanism linking transportation and land use (38), (39) by lowering the cost of interaction between individuals and various types of opportunities (e.g. work, shopping).

5.3 Other Methodologies for Consideration

Of course, not all impacts can be quantified with available data sets. (36) survey employers near Dallas' new high-five interchange (the largest project of its kind in the State of Texas) reveal a wide variety of fundamental information, including employers' valuations of employee commute time and anticipated, as well as, ultimately, perceived, effects of project construction (on employee and customer access, for example). (25) survey of residents in bypassed Texas towns illuminate a range of meaningful, perceived benefits (including diminished downtown congestion and noise), even in the wake of reduced sales in these same communities (51). Such details can serve as a priceless supplement to more numeric studies, emphasizing modeled travel time savings, hedonic values, employment levels, and the like.

6 Conclusion

This paper has reviewed a variety of approaches that might be employed to analyze the economic impacts of a highway network improvement. Several types of project-specific and more aggregate econometric methods have been described, each with important limitations for modeling the effects of upgraded facilities. The project-based methods reviewed here share the common limitation of being insufficiently dynamic to model accurately the short-term (much less longer-term) impacts of changes to the service level provided by highways. The issue of induced demand and its effect on both travel behavior and location choice cause estimates of user benefits to be unreliable, particularly in the long run. On the other hand, the econometric modeling approaches to the evaluation of highway improvements may provide plausible estimates of the economic effects of highway investment at an aggregate level, though they perform less well at specifying this relationship at the level of an individual project. This is particularly true of aggregate production function approaches, which have emphasized macroeconomic modeling at the expense of actual *transportation* economics (50). Hence, they lack the policy sensitivity to accurately reflect the economic impacts of small-scale changes to transportation networks.

Noting these limitations, the best way to proceed with an evaluation of the impact of a new or upgraded transportation link might be to combine one or more of the above approaches, perhaps across spatial scales, and compare the results. For example, in the case of an upgraded highway in a small urban or rural area, one might choose to evaluate the impact of this new link by estimating the increment in land values near the highway, then comparing this result to results obtained by modeling city or county-wide employment and income with and without the upgraded facility. Both of these results could be compared with the benefits estimated from standard engineering economic models of highway performance. If the results of the different approaches largely agree with another, then this is a sign that the different approaches are essentially measuring the same thing and can be used to bound the true value of the economic impacts. If they differ greatly, then some effort should be devoted to uncovering the different assumptions and methodological concepts that underlie each approach. A good evaluation approach should both provide consistent estimates of project impacts and provide insight into the process that generated those impacts, so that the results can be applied in a policy-relevant context.

References

[1] B.J. Allen, C.P. Baumel, and D.J. Forkenbrock. Expanding the set of efficiency gains of a highway investment: conceptual, methodological, and practical issues. *Transportation journal*, 34(1):39–47, 1994.

[2] D.A. Aschauer. Is public expenditure productive? *Journal of Monetary Economics*, 23:177–200, 1989.

[3] Michael W. Babcock and Bernt Bratsberg. Measurement of economic impact of highway and bridge construction. *Journal of the Transportation Research Forum*, 37(2):52–66, 1998.

[4] Joseph Berechman, Dilruba Ozmen, and Kaan Ozbay. Empirical analysis of transportation investment and economic development at state, county and municipality levels. *Transportation*, 33(6):537–551, November 2006.

[5] Joseph Berechman and Robert E. Paaswell. Accessibility improvements and local employment: an empirical analysis. *Journal of Transportation and Statistics*, 4(2/3):49–66, Sept./Dec. 2001 2001.

[6] M Bina and K. Kockelman. Location choice vis-á-vis transportation: the case of recent home buyers. In *Proceedings of the 85th Annual Meeting of the Transportation Research Board.*, 2006.

[7] M.G. Boarnet. Infrastructure services and the productivity of public capital: the case of streets and highways. *National Tax Journal*, 50(1):39–57, March 1997.

[8] M.G. Boarnet. Spillovers and the locational effects of public infrastructure. *Journal of Regional Science*, 38:381–400, 1998.

[9] J. Carey and J. Semmens. Impact of highways on property values: case study of the superstition freeway corridor. *Transportation Research Record*, pages 128–135, 2003.

[10] R. Cervero and M. Hansen. Induced travel demand and induced road investment: a simulataneous equation analysis. *Journal of Transport Economics and Policy*, 36(3):469–490, 2002.

[11] P. DeCorla-Souza and H. Cohen. Accounting for induced travel in evaluation of urban highway expansion. Online resource, U.S. Department of Transportation, Federal Highway Administration, 1998.

[12] P. DeCorla-Souza, H. Cohen, and K. Bhatt. Using benefit-cost analysis to evaluate across modes and demand management strategies. In *Compendium of Technical Papers, 66th Annual Meeting of the Institute of Transportation Engineers*, pages 439–445. Institute of Transportation Engineers, ITE, 1996.

[13] P. DeCorla-Souza, H. Cohen, D. Haling, and J. Hunt. Using steam for benefit-cost analysis of transportation alternatives. *Transportation Research Record*, 1649:63–71, 1998.

[14] Department of Transport and the Environment. Guidance on the Methodologies for Multi-Modal Studies. Technical report, Department of Transport and the Environment, 2000.

[15] Kevin T. Duffy-Deno and Randall W. Eberts. Public infrastructure and regional economic development: a simultaneous equations approach. *Journal of Urban Economics*, 30:329–343, 1991.

[16] A. Fishlow. *American Railroads and the Transformation of the Ante-bellum Economy*. Harvard University Press Cambridge, 1965.

[17] R.W. Fogel. *Railroads and American Economic Growth: Essays in Econometric History*. Johns Hopkins Press, 1964.

[18] D.J. Forkenbrock and N.S.J. Foster. Economic benefits of a corridor highway investment. *Transportation Research*, 24(4):303–312, 1990.

[19] Teresa Garcia-Mila, Therese J. McGuire, and Robert H. Porter. The effect of public capital in state-level production functions reconsidered. *Review of Economics and Statistics*, 78(1):177–180, February 1996.

[20] W.L. Garrison and D. Levinson. *The Transportation Experience: Policy, Planning, and Deployment*. Oxford University Press, 2006.

[21] P.B. Goodwin, Carmen Hass-Klau, and Sally Cairns. Evidence on the effects of road capacity reduction on traffic levels. *Traffic Engineering and Control*, 39(6):348–354, 1998.

[22] D.J. Graham. Variable returns to agglomeration and the effect of road traffic congestion. *Journal of Urban Economics*, 62(1):102–120, 2007.

[23] Edward Gramlich. Infrastructure investment: a review essay. *Journal of Economic Literature*, 32:1176–1196, September 1994.

[24] M. Haider and E. Miller. Effects of transportation infrastructure and locational elements on residential real estate values: application of spatial autoregressive techniques. *Transportation Research Record*, 1722:1–8, 2000.

[25] S. Handy, K.M. Kockelman, S. Kubly, S. Srinivasan, J. Jarrett, M. Oden, and H. Mahmassani. Economic effects of highway relief routes on small and medium-size communities. project report 1843-2. Technical report, Texas DOT. Center for Transportation Research, The University of Texas at Austin., 2001.

[26] Mark Hansen and Yuanlin Huang. Road supply and traffic in Californina urban areas. *Transportation Research, Part A*, 31A(3):205–218, May 1997.

[27] Andrew F. Haughwout. Aggregate production functions, interregional equilibrium, and the measurement of infrastructure productivity. *Journal of Urban Economics*, 44:216–227, 1998.

[28] J. Heiner and K.M. Kockelman. The costs of right of way acquisition: methods and models for estimation. *Journal of Transportation Engineering*, 131(3):193–204, 2005.

[29] Peter J. Hills. What is induced traffic? *Transportation*, 23(1):5–16, February 1996.

[30] D. Holtz-Eakin. Public sector capital and the productivity puzzle. *Review of Economics and Statistics*, 76:12–21, 1994.

[31] Douglass B. Lee, Lisa A. Klein, and Gregorio Camus. Induced traffic and induced demand. *Transportation Research Record*, 1659:68–75, 1999.

[32] D. Levinson and Wei Chen. *Access to Destinations*, chapter Paving new ground: a Markov chain model of the change in transportation networks and land use, pages 243–266. Elsevier, 2005.

[33] D. Levinson and S. Kanchi. Road capacity and the allocation of time. *Journal of Transportation and Statistics*, 5(1):25–46, 2002.

[34] D. Levinson and Ramachandra Karamalaputi. Induced supply: a model of highway network expansion at the microscopic level. *Journal of Transport Economics and Policy*, 37(3):297–318, 2003.

[35] David Levinson and Kevin Krizek, editors. *Access to destinations*. Elsevier, 2006.

[36] D. Luskin and A. Chandrasekaran. Employer valuations of employee commuting time: case study of office tenants in North Dallas, Texas. *Transportation Research Record*, 1902:10–17, 2005.

[37] D. Luskin and Erin Mallard. Potential gains from more efficient spending on Texas highways. In *Proceedings of the 84th Annual Meeting of the Transportation Research Board, January, Washington D.C.*, 2005.

[38] F.J. Martínez. Access: the transport-land use economic link. *Transportation Research*, 29:457–470, 1995.

[39] F.J. Martínez. *Handbook of transport modelling*, chapter Towards a land-use and transport interaction framework, pages 145–164. Elsevier, 2000.

[40] McTrans. Microbencost. Web page, 2007.

[41] Edwin Sadler Mills. The misuse of regional economic models. *Cato Journal*, 13(1):29–39, Spring-Summer 1993.

[42] H. Mohring and M. Harwitz. *Highway Benefits: An Analytical Framework*. Published for the Transportation Center at Northwestern University by Northwestern University Press, 1962.

[43] Herbert. Mohring. Maximizing, measuring, and not double counting transportation-improvement benefits: a primer on closed- and open-economy cost-benefit analysis. *Transportation research. Part B: methodological*, 27(6):413–424, 1993.

[44] P.L. Mokhtarian, F.J. Samaniego, R.H. Shumway, and N.H. Willits. Revisiting the notion of induced traffic through a matched-pairs study. *Transportation*, 29(2):193–220, 2002.

[45] A.H. Munnell. Why has productivity growth declined? productivity and public investment. *New England Economic Review*, pages 3–22, January/February 1990. Reported infrastructure returns in excess of 100

[46] M.I. Nadiri and T.P. Mamuneas. Highway capital and productivity growth. In *Economic Returns from Transportation Investment*. Eno Transportation Foundation, Inc., Landsdowne, VA, 1996.

[47] R.B. Noland. Transport planning and environmental assessment: implications of induced travel effects. *International Journal of Sustainable Transportation*, 1(1):1–28, 2007.

[48] Kaan Ozbay, Dilruba Ozmen, and Joseph Berechman. Modeling and analysis of the link between accessibility and employment growth. *Journal of Transportation Engineering*, 132(5):385–393, May 2006.

[49] P. Parthasarathi, D. Levinson, and R. Karamalaputi. Induced demand: a microscopic perspective. *Urban Studies*, 40(7):1335–1351, 2003.

[50] Chad Shirley and Clifford Winston. Firm inventory behavior and the returns from highway infrastructure investments. *Journal of Urban Economics*, 55:398–415, 2004.

[51] S. Srinivasan and K.M. Kockelman. The impacts of bypasses on small-and medium-sized communities: an econometric analysis. *The Journal of Transportation and Statistics*, 5(2):57–69, 2002.

[52] I.M. Srour, K.M. Kockelman, and T.P. Dunn. Accessibility indices: a connection to residential land prices and location choices. *Transportation Research Record*, 1805:25–34, 2002.

[53] Yorgos J. Stephanedes. Distributional effects of state highway investment on local and regional development. *Transportation Research Record*, 1274:156–164, 1990.

[54] Yorgos J. Stephanedes and David M. Eagle. Highway expenditures and non-metropolitan employment. *Journal of Advanced Transportation*, 20(1):43–61, 1986.

[55] Yorgos J. Stephanedes and David M. Eagle. Highway impacts on regional employment. *Journal of Advanced Transportation*, 21(1):67–79, 1987.

[56] B. Ten Siethoff and Kara Kockelman. Property values and highway expansion: timing, size, location, and use effects. *Transportation Research Record*, 1812(1812):191–200, 2002.

[57] George I. Treyz, D.S. Rickman, and G. Shao. The REMI economic-demographic forecasting and simulation model. *International Regional Science Review*, 14:221–253, 1992.

[58] Pierre Vilain, Louie Nan Liu, and David Aimen. Estimate of commodity inflows to a substate region: an input-output based approach. *Transportation Research Record*, 1653:17–26, 1999.

[59] Glen E. Weisbrod and Michael Grovak. Comparing approaches for valuing economic development benefits of transportation projects. *Transportation Research Record*, 1649:86–94, 1998.

[60] Glen E. Weisbrod and Frederick Treyz. Productivity and accessibility: bridging project-specific and macroeconomic analyses of transportation investment. *Journal of Transportation and Statistics*, 1(3):65–79, October 1998.

[61] Martin Weiss and Roger Figura. Provisional typology of highway economic development projects. *Transportation Research Record*, 1839:115–119, 2003. Review of weaknesses of REMI models.

[62] Martin Williams and J.K. Mullen. Highway capacity spillover and interstate manufacturing activity. *International Journal of Transport Economics*, 25(3):287–295, October 1998.