NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 389

Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance

Transportation Research Board
National Research Council

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report 389

Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance

MICHAEL E. BELL
The Johns Hopkins University
Institute for Policy Studies
Baltimore, MD
and
THERESE J. McGUIRE
The University of Illinois
Institute of Government
and Public Affairs
Chicago, IL

Contributing Authors
John B. Crihfield
Douglas R. Dalenberg
Randall W. Eberts
Teresa Garcia-Mila
Joyce Z. Man

Subject Areas

Planning and Administration

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
Washington, D.C. 1997

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

Note: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP REPORT 389

Project 2-17(3) FY '93

ISSN 0077-5614

ISBN 0-309-06061-3

L. C. Catalog Card No. 97-60936

Price $25.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at:

http://www.nas.edu/trb/index.html

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

This report documents the findings of a project aimed at improving the understanding of the linkages between transportation investments and economic performance. The research evaluated data on the value of the public and private capital stock (structures, equipment, and land) in transportation over time. It developed an improved and updated dataset for capital stock to provide the basis for investigations into the linkages between public and private transportation investments and economic performance. The report will be useful to researchers interested in better understanding the linkages between transportation investments and economic performance. It should also be of interest to policy makers trying to estimate the impacts of transportation investment decisions.

This research was initiated in response to debate over the validity of estimates generated in the late 1980s by Aschauer, Munnell, McGuire, and others. Their analytical work indicated that there are positive relationships between public investments in infrastructure and economic productivity at the national and state levels, but their estimates varied considerably. A better understanding is needed of the linkages between transportation investments and economic performance, as measured in terms of macroeconomic factors such as employment, expenditures, income, production of goods and services, productivity, and competitiveness. Economists differ in their opinions about which factors are associated with productivity, but they do agree that productivity and national income are influenced by the amount of capital which labor has to work with, and that the amount of capital at any given time is a result of past levels of savings, investment, and depreciation. Therefore, it is important that the size and rate of growth of public and private transportation capital and its influence on productivity growth be determined. Accurate measures of the capital stock (e.g., the sum of past investments) are important to macroeconomic analysis as well as to the development of public policy relative to transportation. The 1974 U.S. DOT report, *Capital Stock Measures for Transportation,* was the most recent effort to estimate the value of the private and public capital stock in transportation. This study estimated the value of gross and net equipment and structures as well as the value of land in 1958 dollars, for the period 1950 to 1970. It also estimated the cost of capital services, the economic rate of depreciation, and capacity in the various transportation modes.

NCHRP Project 2-17(3) started with the objective of developing an improved estimate of the value of public and private capital stock (structures, equipment, and land) in transportation over time. The estimates generated in the 1970s were seen to represent a starting point for the project. It was felt that similar capital stock measures estimates, covering the period 1950–1990, would allow for determination of whether there had been a significant slowdown over time in the rate of net capital formation in different transportation modes, as well as allow for the determination of the impact of government actions (federal, state, and local) on net investments to public transportation capital. These estimates were noted to be critical in any efforts to validate the degree of economic impacts of transportation investments. It became apparent during evaluation of the capital stock measures that they needed to be restructured in order to effectively serve macroeconomic analysis needs and to address other research questions that arose.

A research team led by The Johns Hopkins University of Baltimore, Maryland, was selected to undertake the research, which began in late 1991. The research team arranged for cooperative support for this project from the Bureau of Economic Advisors of the U.S. Department of Commerce. In order to accomplish the objective, the research team critically reviewed recent and ongoing macroeconomic studies on the contribution of transportation and infrastructure investment to productivity. This review identified the types of data, the sources of transportation capital stock, and other data needed to conduct further research in this area. They assessed the dataset created in the 1974 U.S. DOT study for use in macroeconomic research and summarized its strengths and weaknesses. The team determined the modifications and updates needed to be responsive to anticipated research demands, identified feasible sources of information for a revised dataset, and described the mechanisms for routine updating of depreciation and the discounted value of capital. The recommended approach to updating was documented in an interim report, which was approved by the project panel in July 1992 after discussion of alternatives for developing the enhanced dataset. The contractor built and documented a dataset of transportation infrastructure investment and capital stock (gross and net) for the period 1950 to 1992, by mode and by state in accordance with the plan approved by the panel.

The dataset was initially used to generate measures of economic performance using the production functions (models) described in recent literature to validate the linkages between transportation investment and economic productivity. These efforts showed that the conclusion of a positive relationship was valid, but that the magnitude of impact could not be ascertained. Subsequently, the contractor demonstrated the usefulness of the dataset by addressing the following questions:

- Is there a differential benefit to various industries from transportation investment?
- Is the demand for transportation investments influenced by demographic factors?
- Is the impact of transportation investments the same at the regional level?

The research team was subdivided into two-person teams to simultaneously address these questions. The results from these independent efforts are presented in Chapters 4 through 6 of this report. They are believed to offer useful insights to transportation policy analysts and to suggest the nature of further investigations that are possible using the new dataset.

Possible refinements to macroeconomic models that would be possible with an updated and expanded dataset were identified (i.e., the use of surrogate variables to account for the productivity effects of nontransportation investments). The success of these initial efforts to use the dataset, and the prospects for an even more useful dataset, led the panel to approve a plan to further update and enhance it. Efforts began in 1995 to develop a second version of the dataset under NCHRP Project 2-17(3)A, "Update and Enhancement of Database for Macroeconomic Analysis of Transportation Investments and Economic Performance." In this effort, the data are being updated, data items refined, and new variables added. Work is nearly complete under a continuation effort with the original contractor. This revised version of the database will allow for further extension of macroeconomic analyses in this area. The contractor has outlined a methodology for maintaining and updating the dataset in the current effort and has also identified further opportunities for useful macroeconomic research.

The panel is awaiting the completion of the update and enhancement effort before determining whether additional analyses should be recommended under this study. The revised database will be made available in Fall 1997. It is hoped that other researchers will find the revised dataset useful in investigating the linkages between transportation investments and economic performance.

CONTENTS

ACKNOWLEDGMENTS

A project of this size and scope cannot be conducted by two individuals alone. We are indebted to a team of experienced and talented researchers who produced materials for this report, and reviewed and commented on various interim products. We would like to thank them for their time and patience in responding to all the demands for their insights on the issues explored here. Special thanks goes to team members John Crihfield, Randall Eberts, William Fox, Teresa Garcia-Mila, Charles Hulten, and Robert Schwab. In addition, we would like to thank John Marchelya, Susan McKusker, Regina Ostergaard, and Martin Panggabean for providing outstanding research assistance for this project. We also want to thank Theresa Smith and Doug Dalenberg for their contributions to this project.

Authorship of the following chapters is gratefully acknowledged. Chapter 3: Douglas R. Dalenberg, Department of Economics, University of Montana, Missoula, MN; and Randall W. Eberts, W.E. Upjohn Institute for Employment Research, Kalamazoo, MI. Chapter 4: Teresa Garcia-Mila, Department of Economics, Universitat Pompeu Fabra, Barcelona, Spain; and Therese J. McGuire, Institute of Government and Public Affairs, University of Illinois, Chicago, IL. Chapter 5: Joyce Z. Man, School of Public and Environmental Affairs, Indiana University, Indianapolis, IN; and Michael E. Bell, Institute for Policy Studies, The Johns Hopkins University, Baltimore, MD. Chapter 6: John B. Crihfield, Institute of Government and Public Affairs, Department of Agricultural Economics, University of Illinois, Urbana-Champaign, IL.

In addition, this report could not have been produced without the assistance of outstanding professionals working in federal agencies. While too numerous to list individually, we would like to thank all the individuals we worked with from the Bureau of the Census, the Federal Aviation Administration, the Federal Highway Administration, the Federal Transit Authority, the Transportation Research Board, and the Transportation Systems Center in Cambridge. It was a pleasure working with such dedicated professionals. We would especially like to thank our colleagues at the Bureau of Economic Analysis in the U.S. Department of Commerce—Hugh Knox, Ted Trott, Ann Dunbar, John Musgrave, Vernon Renshaw, and John Corte—for their support throughout this entire project.

Finally, we benefited greatly from the input we received from the NCHRP Panel overseeing this project. We would like to thank Deb Miller for her leadership and guidance as Chair of the Panel as well as the various members who participated in Panel meetings and read and commented on early versions of both the draft and final reports. Specifically, we would like to thank Philip Anderson, Stewart Butler, Ralph Erickson, Terry Gotts, Kenneth Simonson, Wayne Talley, and Susan Binder for generously giving of their time and talents. We would also like to thank Ken Cook and Ken Opiela from the TRB staff for shepherding this project through all its various phases.

MACROECONOMIC ANALYSIS OF THE LINKAGES BETWEEN TRANSPORTATION INVESTMENTS AND ECONOMIC PERFORMANCE

SUMMARY

The purpose of research project NCHRP 2-17(3) is to improve our understanding of the linkages between transportation investments and economic performance in light of the complex policy choices facing state and local transportation officials in the 1990s. This final report is divided into four major sections, and the findings are summarized below.

Chapter 1, Introduction, critically reviews the current literature examining the linkage between infrastructure investment and economic performance. Infrastructure can affect economic output directly as an input in the production process or by enhancing the productivity of private capital and labor. In addition, infrastructure can indirectly affect economic activity if a high-quality or low-cost infrastructure attracts labor and capital from other places. Thus, the literature reviewed differs in terms of the questions asked, the methodological approaches used, and the types of data employed.

This report concludes that infrastructure investments have a modest positive effect on the nation's private economic activity. Though there are examples of research cited where no significant effect of infrastructure is observed, most of the apparent inconsistencies in the findings are explained. The conclusion simply acknowledges what many believe—that roads, airports, water, and other core infrastructure services are important ingredients in a modern, productive economy.

Another conclusion is that the aggregate level of much of the research reviewed in this section fails to consider many dimensions that may be important for understanding more fully the linkage between transportation investment and economic activity. The level of analysis is too general to help government decision makers establish priorities for allocating scarce transportation resources. For example, state and local transportation officials need better information about

- How the relationship between transportation investment and economic activity varies across industries;
- How the productivity of different types of pubic capital, including individual transportation modes, varies;

- How investment flow data, rather than capital stock data, can be employed to understand the impact of transportation investment on economic growth;
- How various demographic and economic factors beyond the control of state and local officials influence the derived demand for transportation services and how the relative importance of those factors varies across transportation modes;
- How physical and performance characteristics of transportation networks influence private economic activity; and
- What types of relationships exist between transportation modes and other types of infrastructure and how they affect productivity.

To provide state and local transportation decision makers with the relevant information, it is necessary to develop a dataset disaggregated by state, industry, and transportation mode.

Chapter 2, Database Development, covers the review of a public capital stock series produced for the Federal Highway Administration (FHWA) in the mid-1970s to determine its usefulness for analyzing issues not addressed by current research. The dataset has limitations that make it inappropriate for investigating the linkage between transportation investment and economic performance on the level most useful for state and local transportation decision makers.

To improve understanding of the linkage between transportation investment and private economic activity, a disaggregate dataset was developed that includes information on

- Different types of infrastructure including different transportation modes;
- Private economic activity by different industries; and
- National data by region or state.

This new dataset is described and documented.

Chapters 3 through 6, Research Results, report the findings from four different empirical studies that used the database described in chapter two. Specifically, this dataset was used to contrast this report's capital stock estimates and to test empirically the linkage between transportation investment and economic performance in the context of (1) industry-specific production functions, (2) a traditional public goods demand model and (3) a neoclassical growth model. While the analytic approaches differ, the results show consistently that the link between transportation investment and private economic performance varies by transportation mode, by industry, and by state and that these differences are obscured in more aggregate analysis. The results also confirm that demographic and economic trends beyond the control of state and local transportation officials have important implications for transportation investments and these implications vary by transportation mode and industry. Finally, these studies demonstrate the value of additional information about the link between transportation investment and economic performance obtained from the more disaggregate approach proposed.

Chapter 7, Future Research Directions, suggests several extensions and refinements of the empirical studies contained in chapters three through six. Such extensions and refinements are necessary to test the robustness of the initial empirical findings contained in this report.

CHAPTER 1

INTRODUCTION

BACKGROUND

A review of the literature on the relationship between infrastructure investments and economic growth shows that research studies have reached widely different conclusions. The much discussed results of Aschauer (1989a) and Munnell (1990a) suggest that infrastructure is highly productive, to the point that new investments in infrastructure may even be more productive than increases in labor or private capital. On the other hand, Hulten and Schwab (1992) and Holtz-Eakin (1992) conclude that infrastructure plays no role in differential regional growth rates. The literature differs in terms of the questions asked, the methodological approaches used, and the types of data employed, and as a result, it is not surprising that different conclusions are reached. The first purpose of this chapter is to examine the literature and draw general conclusions about the importance of transportation investments for economic performance. The second purpose is to examine the limitations of current research for informing transportation investment policies.

Infrastructure affects economic output through a variety of mechanisms. First, the availability of infrastructure services can increase production. Economists normally envision infrastructure being important for expanding output either because the services are a direct input in production (as when firms use water as part of their technology) or because infrastructure creates an environment that makes other inputs (labor and private capital) more productive. Transportation has the potential to contribute in both ways. The specific benefits associated with transportation infrastructure may include time savings and vehicle cost reductions (Lewis, 1991).

Changes in the price or availability of transportation may allow firms to change to more productive technologies. For example, retailers can hold lower inventories when good transportation is available, since suppliers can, in effect, hold inventories for them. Just-in-time production processes also are intended to permit suppliers to hold inventories of intermediate goods for manufacturers. In these cases, better transportation can permit reductions in the overall level of inventories held in the economy.

Second, an indirect effect of infrastructure on production can occur if a high-quality or very low-cost infrastructure attracts labor and private capital from other places. The attraction may be amenities that entrepreneurs and workers seek from the infrastructure for their own consumption, or it may be the potential that businesses see for earning greater profits by using the infrastructure in production. The migration of resources may be a desirable advantage from the perspective of a given region, but the overall national economy may gain only under special circumstances, such as when there are increasing returns to scale in production or agglomeration economies in the receiving area.[1] The reason is that the shifting of resources usually enhances economic growth in gaining areas at the expense of losing areas. No new resources are available within the country unless the migration occurs from outside the United States. This chapter discusses each of these economic growth effects, but the emphasis is on the direct linkage between infrastructure and production.

This chapter is divided into three sections. The first two sections, Direct Effects and Attraction Effects, review recent research on the linkage between infrastructure and economic growth. Results of the literature are summarized and methodological problems are outlined. The final section, Issues Unresolved, examines limitations of the current research for helping develop better infrastructure policy and presents a set of unresolved issues.

The conclusion of this review is that infrastructure investments have a modest positive effect on the nation's private economic activity.[2] Though examples are cited here of research where no significant effect of infrastructure is observed, most of the apparent inconsistencies in the findings can be explained. The conclusion that infrastructure is a productive input simply acknowledges what many believe—roads, airports, water, and other core infrastructure services are important ingredients in a modern, productive economy. The conclusion that infrastructure is productive, however, does not mean that further investments in infrastructure, including transportation, are necessarily the best means of increasing the nation's output. The opportunity costs of public infrastructure investments must be considered in such

[1] Empirical literature on the new growth theory identifies factors, including public capital, which are important for creating an environment conducive to endogenous growth (Levine and Renelt, 1990).

[2] The literature reviewed herein examines narrow productivity implications of infrastructure investment. Consumption benefits of infrastructure are not considered. Therefore, conclusions about the value of transportation systems to the nation based on these narrowly focused studies may represent a lower bound estimate of the economic impact of transportation investments.

decisions. Other alternatives such as greater investments in human capital or in private capital must be considered to determine the best means for expanding the economy.

Direct Effects of Infrastructure Investments

There are two aspects affecting the theoretical basis of the research reviewed in this chapter. One aspect bases research on an understanding of how individual firms make decisions, which is then extrapolated to the economy as a whole (Elhance and Lakshmanan, 1988). The other bases research on understanding of national-level economic relations (Aschauer, 1989a, b). No effort is undertaken here to distinguish between these microeconomic and macroeconomic perspectives, since both approaches tend to lead researchers to estimate either cost or production functions.

Studies of the direct effect of infrastructure on economic activity can be separated into four groups: time-series production function studies, cross-section or panel-data production function studies, cost and profit function analyses, and sources-of-growth studies. Time-series evidence is needed to explore issues where variations over time are important while cross-section evidence is better suited to exploring issues where variations across space are important. For example, time-series data might be used to better understand the impact of technological change on production processes. Alternatively, cross-section data might be used to evaluate the impact of income on traffic volumes. Panel data, which combine time-series and cross-section data, enable the researcher to supplement variation over time with variation across space. Research of each type is discussed separately below.

Time-Series Production Function Studies

Aschauer (1989a) examines the role of infrastructure using the concept of an aggregate production function, where a production function is a technical relationship between inputs employed (e.g., capital and labor) and the maximum output that can be produced with those inputs. Production function studies are based on the assumption that there is a stable relationship between a set of inputs and the resulting output. Aschauer analyzes the relationship between private sector output and three inputs: private capital, labor, and public capital. Aschauer includes a time trend and a capacity utilization measure in the equation, and he uses U.S. time-series data for 1949 through 1985 to estimate his equations. Munnell (1990a) adopts similar methodology and data.

Both of these studies find public capital to be a very important determinant of output, with output elasticities between 0.31 and 0.39. Aschauer reaches the unexpected result that infrastructure has a higher output elasticity than labor. In other words, an extra dollar invested in public infrastructure will increase national output more than an extra dollar invested in labor. Further, the core infrastructure, including transportation, energy, and water and sewers, is found to have a greater effect than other public capital such as buildings and hospitals. These findings lead both Aschauer and Munnell to conclude that low investment in public capital was a major cause of the U.S. productivity growth slowdown in the 1970s and 1980s.

Several researchers have expressed strong concern over Aschauer's and Munnell's results. One line of argument states that their results may arise from a reverse causality that reflects an increased demand for infrastructure services as income grows. Aschauer (1989a) makes a limited attempt to examine this issue. Duffy-Deno and Eberts (1991) address the question of causality and determine that the causality does, indeed, run in both directions, with infrastructure causing growth and growth causing the demand for more infrastructure.

Another line of criticism argues that the role attributed to public infrastructure is too large to be credible and is based on results of questionable statistical validity. Schultze (1990) notes that Aschauer's results imply a 50 to 60 percent annual return to public investment, which he finds unreasonable. Aaron (1990) makes the same observation and argues that time-series data are not very useful for examining effects of public capital because there is insufficient variation in the value of the capital stock from one year to the next. In addition, he argues that conclusions based on aggregate time-series analysis are likely to reflect spurious correlation, meaning that the findings represent unrelated trends in the data over time. Thus, the role attributed to infrastructure may be exaggerated by an unrelated correlation between the time trends of infrastructure investment and productivity decline. Tatom (1991) provides further evidence in support of this argument.

Cross-Section and Panel-Data Production Function Studies

Production functions also have been estimated using cross-section data or panel data for states or cities in the United States or, in some cases, for a number of countries to evaluate the economic impact of infrastructure investments. Most of this research confirms the time-series findings that public infrastructure is an important input in the production process. However, infrastructure's effect is found to be much smaller. One possible explanation for a lesser effect is that the panel data used in these studies adjust for unrelated trends in the data over time and result in improved estimates of the relationship between infrastructure and economic activity. Alternatively, the coefficients found in panel-data studies may be lower than those found in the aggregate analysis, at least in part, because some of the payoff from infrastructure spills beyond the boundaries of the state or city where the investment occurs. Thus, studies using state- or city-level data may fail to account for all network benefits that may be captured in aggregate national data.

Using panel data, Munnell (1990b) finds that the output elasticity of public capital is less than one-half as large as her time-series results. Duffy-Deno and Eberts (1991) and Costa et al. (1987) obtain results similar in magnitude to Munnell's panel-data findings. These two studies also find evidence of diminishing returns to infrastructure, with a number of regions exhibiting negative returns from additional infrastructure investment.

Two studies permit specific analysis of the role of transportation in economic performance: Antle (1983), and Garcia-Mila and McGuire (1992). Antle (1983) estimates agricultural production functions using data from 66 countries, two-thirds of which are lesser-developed countries and one-third developed countries. Various inputs such as land and population in agriculture use are included in the production function. Infrastructure is measured as the gross domestic product in each country's combined transportation and communications sectors per square kilometer of land area. Education is used as a proxy for human capital and a count of agriculture research publications is used to account for the effect of new technology. Antle finds the size of the combined transportation and communications sectors to be a significant determinant of agricultural production and to be more important for the lesser-developed countries than agriculture research. Employing a dataset for the United States from 1969 to 1983, Garcia-Mila and McGuire (1992) find that highway capital per square mile of area has a positive, relatively small, statistically significant, influence on Gross State Product (GSP).

Holtz-Eakin (1992) argues that cross-section or panel-data studies are flawed when they fail to account for differences across states in factors such as weather, availability of raw materials, location, and land area. When he estimates a model similar to models specified by other researchers, he finds public capital to have a strong effect on GSP. When he reestimates the model using various means of accounting for differences in the characteristics of states (including both fixed effects and random effects), he obtains results that indicate that public capital is not a significant determinant of GSP. His overall conclusion is that infrastructure has no effect on growth at the margin. His interpretation is that some critical minimum level of infrastructure is essential to economic performance, but expansions in infrastructure beyond this level do not increase output. Eisner's (1991) results are consistent with these findings.

McGuire's (1992) research suggests that Holtz-Eakin's findings may arise because of an inability to disaggregate infrastructure. She examines numerous possible production function specifications and, like Holtz-Eakin, finds total infrastructure has no effect on GSP when state effects are taken into account. However, when she reestimates the equations with infrastructure separated into highways, water and sewer, and other, she finds that highways, and to a lesser extent water and sewer, have a statistically significant effect on GSP, though the effect is much smaller than without consideration of state-specific effects, as in Antle (1983).

Using the same dataset as McGuire (1992), Garcia-Mila, McGuire, and Porter (1994) estimate several specifications of a production function. Applying various econometric tests, they find that the preferred specification controls for nonstationarity and state-fixed effects. Using this preferred specification, they find that the effect on private output of public capital, both in aggregate and separated by type, is insignificant.

Overall, the production function literature does not definitively dispense with the question of how public capital affects private economic activity. Different studies, using different datasets covering different periods of time and using different methodologies, reach different conclusions. The extent to which public infrastructure contributes to private sector productivity remains an open question.

Cost and Profit Functions

A problem in estimating production function equations arises from concerns about the endogeneity of the input variables. Friedlaender (1990) argues that input prices are likely to affect factor choices. Input prices vary across the sample and the level of input usage is determined simultaneously with decisions on production. Thus, estimation of a production function may result in biased estimates, and it may be more appropriate to estimate a cost function rather than a production function. Deno (1988) argues that the most general approach is estimation of a profit function since all private factors (inputs and outputs) are adjustable in response to changes in the public capital stock.

A production function relates physical units of output to physical units of inputs. Alternatively, a cost or profit function relates output to prices of inputs for those inputs that the firm can control and consequently adjust over time. Since individual firms have little control over the amount of public capital stock put in place for an entire metropolitan area, public capital stock is incorporated in the cost or profit function at a fixed level.

Another basic shortcoming of production function estimates is that without input price data, it is difficult to say much about whether efficient choices have been made concerning the various inputs, particularly public capital. In the production function analysis, Garcia-Mila and McGuire (1992) use state and local government wages as a measure of the cost per unit of education capital to argue that the level of education may be inefficient. With input price data, researchers can explore questions like this concerning the optimal allocation of resources across private and public inputs. However, obtaining reliable data is difficult. Unlike production function estimates, cost and profit function estimates require input price data. Thus, they are subject to an additional source of measurement problem, as the price data for public inputs are difficult to conceptualize and obtain.

Deno (1988) uses a profit function to estimate the effect of infrastructure on production within metropolitan areas. The analysis is disaggregated by infrastructure type and leads to the conclusion that each type is important, with highways more productive than sewers or water.

Lynde and Richmond (1993) also estimate a profit function by employing national time-series data. Public capital is measured with a single variable rather than the disaggregated form used by Deno. Their methodology involves more sophisticated econometric techniques than those employed by Aschauer (1989a) in order to account for the nonstationarity of the time-series data. Also, they employ data on intermediate goods used in production. They find that infrastructure makes a positive, statistically significant contribution to output with the average elasticity being about one-half as great as estimated by Aschauer.

Infrastructure is found to be significant in reducing the cost of production for 12 U.S. manufacturing industries for the years 1956 through 1986 in Nadiri and Mamuneas (1991). The elasticities for individual industries are in line with the results of the panel data studies described above. However, the statistical conclusion that costs are lower only results when the infrastructure stock is reduced for differences in capacity utilization.[3] Otherwise, infrastructure has no impact or has a perverse effect on costs. The authors find that the social rate of return for infrastructure investments for use in these 12 industries ranges between 4.6 and 6.8 percent, although they observe the rate would most likely be greater if all industries were included in the analysis.

Dalenberg (1987) estimates a cost function for manufacturing firms using metropolitan public capital stock data. He finds that in many instances, the actual level of public capital exceeds the optimal level, which suggests an oversupply of public capital from the perspective of manufacturing firms.

Crihfield (1989, 1990) uses profit and cost functions to study economic change in U.S. metropolitan areas. Among many variables included in these disaggregated studies, the variables describing local and state public capital expenditures and variables for transportation costs are particularly relevant. The transportation cost measures, which vary by mode (truck, rail), sector (20 Standard Industrial Classification [SIC] industries), and region (8 Interstate Commerce Commission [ICC] regions), reflect the relative costs in shipping commodities across regions of the United States and incorporate the interregional and intermodal effects of transportation infrastructure. Crihfield finds that interregional and intermodal variations in the prices shippers face in hauling their products have, at most, only small effects on growth differentials across metropolitan economies. These findings are noteworthy because they are based on transportation price incentives faced by shippers, as opposed to a physical infrastructure measure, which at best is a poor proxy for price incentives.

Crihfield's studies indicate that local public capital expenditures have small, positive, significant effects on the supply of metropolitan manufacturing output and on the derived demand for metropolitan labor. However, state public capital expenditures do not have a significant effect.

Estimates of cost functions for Mexico (Shah, 1988) and Sweden (Berndt and Hansson, 1991) provide other examples for the cost function literature. Both studies are interesting because the authors specifically seek to determine if the stock of infrastructure is efficient, though the efficiency of infrastructure is measured relative to its use in production only, without consideration of its use in consumption. The existing stock in each country was determined to be near the optimum or above the desired level.

Berndt and Hansson (1991) examine the contribution of public capital to production in Sweden from 1960 through 1988. Sweden provides a useful parallel to the United States because both countries experienced similar growth in infrastructure investments over the last several decades. The authors estimate an Aschauer-and-Munnell-type production function equation and obtain results that they regard as implausible. They proceed by estimating both a variable and a total cost function. They find that the public capital stock is greater than can be justified given the marginal benefits that result for the private business sector. The stock is about 10 percent higher than the optimum appropriate for the private Swedish business sector and about 25 percent higher than the optimum appropriate for Swedish manufacturing.

Shah (1988) estimates a cost function using data for 34 Mexican industries from 1970 through 1983. Public capital is a productive factor in his equations, but is much less productive than private capital. He concludes that public capital is approximately at the level desired by Mexican industry.

Finally, Morrison and Schwartz (1991) conduct an analysis based on cost-side productivity growth measures, which are designed to capture the reduction in inputs used (and thus costs) to produce a given output level when technical changes occur. They find that shadow prices for both private and public capital are positive, in an appropriate range, and significantly different from zero. The shadow value for public capital is smaller than that for private capital, and the pattern of the indexes suggests complementarity of the two types of capital. Most important, they find that investment in highways, water, and sewers has contributed significantly to productivity growth across the United States, albeit the impact varies regionally and has declined since the early 1970s.

Sources of Growth

Hulten and Schwab (1991) decompose regional manufacturing growth (measured by value added and gross output) from 1951 through 1986 into that proportion resulting from growth in private capital, labor, private intermediate inputs, and multifactor productivity (MFP), which may reflect influ-

[3] The infrastructure stock is multiplied by the capacity utilization rate for manufacturing, under the assumption that the share of infrastructure being used at a point in time is proportional to the capacity utilization rate in manufacturing.

ences such as technological changes and changes in public infrastructure. In other words, MFP is calculated to account for all influences on growth except for increases in market inputs.[4] They compute the sources of growth separately for the nine census regions and for the sunbelt versus the snowbelt states. Value added and output are observed to increase more than twice as fast in the sunbelt, but the difference in growth between the two regions can be explained by more rapid increases in capital and labor in the sunbelt. MFP, on the other hand, grows faster in the snowbelt. The authors point out that more infrastructure investment occurred in the sunbelt, particularly since 1978, and if infrastructure were having a significant effect on growth it should show up in higher MFP growth in the south. Further, using a regression analysis, they are unable to find any evidence that infrastructure investment is a determinant of MFP.

The conclusions of Nadiri and Mamuneas (1991) and Lynde and Richmond (1993) conflict with Hulten and Schwab's results. Nadiri and Mamuneas decompose MFP further than Hulten and Schwab to account for infrastructure and R&D, in addition to technical change. Infrastructure contributes positively to growth for each of their 12 industries, both during the total time period studied and during a series of subperiods. However, the contribution of infrastructure is small relative to private capital and labor.

Lynde and Richmond (1993) use their profit function estimates to decompose productivity growth (output per worker) into that arising from increases in capital per worker, increases in infrastructure per worker, and a residual. During the time period examined, 1959 through 1989, the contribution of infrastructure was very small but they suggest this may be the result of averaging. Separation of their data into the periods 1959–1973 and 1975–1989 leads to the finding that productivity growth is 1 percent higher in the earlier time period. They observe that 41 percent of the decline in productivity growth between the two time periods could be explained by the difference in infrastructure investment.

Hulten and Schwab's conclusion that infrastructure does not matter is difficult to reconcile with the conclusions arrived at by many other researchers in the field. Still, it is not surprising that some differences in results occur given the widely different approaches used. On the whole, the conclusion that infrastructure has a modest effect on productivity appears valid. Nadiri and Mamuneas (1991) and Lynde and Richmond (1993) support this finding with their sources-of-growth analyses.

Sources-of-growth studies have several limitations that should be noted. First, no attempt is made to explain why private capital and labor increase in some regions and decrease in others. As a result, any role of infrastructure in attracting other inputs is attributed to growth in the other inputs without acknowledging the role of infrastructure. Second, Hulten and Schwab (1991) presume that the effects of infrastructure occur through MFP rather than arising separately as an input of production (see McGuire, 1992). The same conclusion might not have been reached if public capital were presumed to enter directly as an input, as is assumed in most production function studies. Third, the sources-of-growth studies include no tests of the statistical importance of various factors.

Limitations of Direct-Effect Literature

This section outlines several characteristic problems in much of the research on the direct effect of infrastructure on private economic activity. First, problems in data measurement exist in most of the literature. The research generally is based on examining the relationship between the dollar value of outputs and the dollar value of the infrastructure stock/investments, rather than a specific measure of the infrastructure services that are consumed.[5] This is acceptable if the per-unit purchase price of the facilities equals the per-unit discounted value of present and future marginal products; that is, if infrastructure returns its opportunity cost. Such an assumption may be valid for highly competitive markets, but is much less likely to be valid for public capital.

Several examples of this problem can be noted. Pagano (1989) asserts that the U.S. infrastructure problem is maintenance of the existing stock rather than new investment. Small and Winston (1988) argue that better technology decisions (using thicker surfaces) would have led in the long run to less rather than more physical capital investments to deliver improved highway services. Both of these studies suggest that a constant relationship between investment expenditures and service delivery does not exist.

Another dimension of the measurement problem involves the methodology used for valuing public capital stock. Most empirical estimates of the value of public capital stock employ some variation of the perpetual inventory method of determining asset value. There are two fundamental problems with this technique. First, a perpetual inventory technique only estimates the historical replacement cost of capital assets, not their economic value, which is what decision makers need to know for setting spending priorities.

Second, there is a difference between private and public capital that should be taken into account when measuring the latter. In valuing private investments there is an assumption that investments are independent (strongly separable) and, therefore, investments from past vintages can be summed up to form a total capital stock estimate. However, public transportation capital stock most often comes in the form of networks. A network is a spatially connected system of interlocking investments, and the separability assumption applied to private investments is not appropriate for such transportation networks. For example, the benefits of a road segment

[4] MFP includes the effects of omitted variables and errors in measuring capital, labor, and output as well as the effect of nonmarket inputs such as infrastructure.

[5] Crihfield (1989, 1990) are exceptions. These studies employ prices rather than a dollar value of infrastructure to represent transportation.

between points A and B and between B and C depend in part on the amount of investment in roads between A and C. Thus, the perpetual inventory technique, when applied to valuing public capital stock, may not produce an accurate estimate of the value of transportation services (Hulten and Schwab, 1992).

Other infrastructure measurement problems arise as well. For example, infrastructure normally is quantified only as that portion that is provided by the public sector. To the extent that differences exist nationwide regarding the public versus private responsibility for infrastructure, the share of infrastructure captured in the data series will differ. These differences could bias the results of empirical studies, particularly cross-section studies.

A final measurement problem involves quantifying the contribution of infrastructure to final output. Gross product (either national or state) or value added are normally used as output measures. However, some benefits of transportation are not included in such gross product statistics. For example, time savings (because of lower congestion) and health care cost savings (because of improved air quality) are likely not to be included in these statistics (Lewis, 1991).

A second limitation of much of the current literature is selection of specific functional forms for estimating equations. Each functional form implies a specific technology and a particular means through which infrastructure affects output. One example of the problem is that the Cobb-Douglas and translog forms of a production function, which are used frequently in the literature, assume continuous substitutability between factors, though it may not be possible to substitute infrastructure for private investments, or vice versa.[6] Also, functional forms usually are unable to address discrete effects, such as bottlenecks in production that could arise from an infrastructure shortage (Bell and Feitelson, 1989).

Attraction Effects of Infrastructure

The economic vitality of a regional economy is dependent on its resources and the productivity of those resources. The attraction of additional inputs permits an economic stimulus from infrastructure separate from the direct productive effect of infrastructure. However, the attraction of inputs to one region probably adds little or no productivity to the national economy unless the resources are drawn from another country, the resources represent entrepreneurial effort that would not have occurred without the infrastructure being in place, there are economies of scale, or there are agglomeration economies. Thus, analysis of the response of other inputs to availability of infrastructure probably is of more importance at the state or city level than at the national level.

[6] Berndt and Hansson (1991) observe that more flexible functional forms normally are used in state-of-the-art production and cost function literature rather than the restrictive Cobb-Douglas functional form, which has been commonly used in the infrastructure literature.

The research described in the previous section is generally based on the assumption that the supply of labor and private capital is determined exogenously, and thus it does not seek to analyze whether infrastructure is effective in attracting other inputs. There have been numerous studies attempting to identify determinants of the regional location of business investment and the migration of people (labor). Business location research has focused on the public sector's influence on siting decisions, but only limited attention has been paid to infrastructure, at least partly because of difficulties in obtaining data. However, the roles of taxes and of certain noninfrastructure government services have been studied extensively.

Research results provide mixed evidence that infrastructure attracts private capital. Fox and Murray (1990) study the startup and relocation of business establishments within county areas of a single state. They investigate the influence on siting decisions of different factors that enter the profit function, including a number of infrastructure proxies. They conclude that the presence of interstate highways is a significant determinant of where firms locate. Unfortunately, county areas are relatively small and the research is unable to separate whether new capital is attracted to the broader region, as highways allow industrialization that otherwise would not have occurred, or whether infrastructure merely shifts the location of firms from an area without interstate highways to one where they exist.

Bartik (1985), using a national sample, finds that the number of new industry plants is higher within states with more miles of roads. Eberts (1990) offers evidence that public infrastructure positively affects the number of firm openings in metropolitan areas, and Eberts and Stone (1991) show that public infrastructure positively affects employment growth through business startups and expansions.

Rietveld (1989) provides a review of several studies investigating the effect of transportation on the location of employment demand. He concludes that studies in the United Kingdom generally indicate that transportation has had little effect; most U.S. studies tend to find a somewhat larger impact.

In addition, Fox, Herzog, and Schlottmann (1989) examine the effect of local government public policies on residential migration. They consider three metropolitan migration decisions: the decision to move, the decision to move from the current city (metropolitan statistical area or MSA) of residence, and the decision to enter a particular city. A series of demographic and economic factors are studied in addition to local policies, although no specific measures of infrastructure are analyzed. Several local policies that are found to influence migration decisions include taxes, which discourage location, and the availability of services, which draws migrants. Since a higher level and quality of services generally attract migrants it is plausible that a metropolitan region with a high level and quality of transportation services might attract migrants also.

Cummings et al. (1986) summarize literature that uses either hedonic price estimation or contingent valuation methods to measure the substitution of labor for infrastructure in rural U.S. regions. Hedonic price models use regression analysis and secondary data to quantify the relationship between availability of infrastructure and willingness to accept lower wages. Contingent valuation studies are based on surveys of how much people would pay for improved infrastructure. The authors estimate a hedonic price model using panel data for 26 rural towns and provide contingent value estimates based on surveys in 3 of the same 26 cities. They report an elasticity of approximately −0.04 using each approach, i.e., people will accept a 0.4 percent reduction in wages for a 10 percent increase in infrastructure services. The tradeoff between wages and infrastructure presumably arises as labor supply is attracted to a region by availability of infrastructure.

The findings of Mehta, Crihfield, and Giertz (1991) suggest different relationships between public infrastructure and private factors. Using two-stage least-squares estimation to model growth in per capita personal income, private sector investment, and population growth, they observe that private and public sector investment rates are inversely and significantly related, which could imply that public and private sector investments are substitutes in production. Their estimates indicate that a 1 percent increase in the rate of public investment leads to a 0.7 percent decline in the private investment rate. They also find that the rate of public investment is positively but insignificantly related to population growth.

Issues Unresolved by Current Research

The research to date has addressed the macroeconomic question of the relationship between public capital and economic growth and productivity. At the aggregate level characteristic of much of this research, the finding of a positive, statistically significant but small effect of public capital on output has been confirmed by many. Where the current research is lacking is in providing a deep understanding of why and how such a linkage exists between public capital and private economic activity.

Because of the startling implications of the early estimates of the productivity of public capital provided by Aschauer (1989a), research efforts have been narrowly focused on trying to document or validate this particular output elasticity estimate. Research has not paid much attention to the potential effects of public capital disaggregated by industry or by its different types. Nor has it examined the diverse ways of describing and measuring public infrastructure. The result is that current research has failed to explore the "micro foundations of the macro findings" sufficiently. It is important to do so to gain a fuller understanding of the linkage between public infrastructure and private economic activity.

Many of the studies in the literature were conducted at the state or metropolitan level. One clear lesson from them is that panel data, with both cross-section and time variation, are necessary to obtain credible estimates. However, most panel data studies have not employed rich enough datasets to be able to address important questions and policy issues relating to public infrastructure. As a result, there are at least six dimensions that have received insufficient attention in the literature.

First, while a few studies have attempted to incorporate some measure of the utilization of the public stock, they are crude and incomplete. It is likely that many attributes of public infrastructure, in addition to the value of the stock, are important for economic productivity. For example, congested highways are of much less use in transporting products than are congestion-free roads. Also, the quality of the service provided by a given amount of public capital stock will vary with the repair condition of the stock, the technology employed in producing the public service generated by the stock, and the location of the stock relative to the location of economic activity. Thus, many characteristics of a given type of public infrastructure are likely to contribute to the relationship between public capital and private economic growth.

Second, some industries are likely to receive more benefits from the various types of public infrastructure than others. For example, improvements in freight rail infrastructure may benefit manufacturing and wholesale trade industries; they have little impact on the services and retail trade industries. The literature has focused either on the total economy (in terms of output or labor or private capital) or on manufacturing. Analysis of industries other than manufacturing would seem to be increasingly important as manufacturing's share of employment continues to fall.

Third, while a few studies have examined annual investment flows rather than the total value of public capital stocks in place, much more remains to be done. One advantage of using annual investment flows of public capital investment rather than the value of capital stocks in place is that many of the data and measurement problems are associated with trying to generate stock data. It is possible to ask some of the same productivity questions as the production function literature by using investment flow data to estimate growth models. This is the approach taken by Mehta, Crihfield, and Giertz (1991). Further investigation along these lines would provide additional validation of the aggregate relationships obtained by estimating production, cost, and profit functions.

Investment data could also be used to examine the derived demand for public infrastructure by firms and individuals. The idea is that demand from firms for infrastructure services is likely to change as technological advances occur and as the structure of the economy changes. Econometrically, this approach defines public infrastructure investment as the dependent variable, and examines how private sector demand for public infrastructure changes as factors exogenous to the firms change. This type of analysis is complementary to typical production function analysis, providing a somewhat different perspective on the relationship between public capital and economic activity. (See Bell, 1990; Bell and Feitelson, 1991; and Musgrave, 1990.)

A fourth aspect of public infrastructure that has received too little attention is the relative productivity of different types of public capital, in particular, mass transit, highways, air transportation, ports, canals, locks, and other modes of transportation. The available evidence seems to support the idea that highways are relatively productive, but few credible comparisons with other modes of transportation have been made because of data limitations. Research on the question of the relative productivity of different types of public infrastructure will require data on the capital stock and other characteristics for each infrastructure type or mode.

Fifth, the research has not been very helpful for identifying the relationships between infrastructure types. Research on these relationships is necessary for understanding the appropriate dynamics for expanding the infrastructure stock. It seems probable that a minimum set and level of several types of infrastructure is necessary to allow an economy to be productive, and that an improved transportation network alone will offer little benefit. Also, the provision of one type of infrastructure may have implications on the need for other types. For example, more storm water drainage may be necessary when larger highways are built. Several infrastructure types must be studied simultaneously to provide insight on these issues.

A sixth aspect of public infrastructure virtually unexplored in the literature reviewed here is the productivity implications of improvements in networks. If the stock of public capital is increased in an area with little connection to economic activity, very little improvement in productivity would be expected. Networks are likely to be especially important for transportation and communication; thus future studies of transportation and communication infrastructure should consider the extent to which different areas of economic activity are linked by the infrastructure.

The six unresolved issues discussed above could be explored, at least tangentially, using a rich panel dataset for the 50 states. The data need to be rich in description of both the private economy and the public infrastructure of each state. Three other unresolved issues would require a different dataset or a very different focus.

One criticism of the conclusion that expansion of public infrastructure facilities may be justified based on the implications for productivity has been forcefully argued by Winston (1990). He argues that fewer public infrastructure services would be needed if externalities, such as congestion, were properly priced. Appropriate pricing would be expected to lead to relative shifts in the usage of infrastructure. For example, higher road tolls or congestion charges may cause people to shift to mass transit, resulting in a shift in demand from the former to the latter. Setting infrastructure prices too low may even cause firms to choose an inferior technology relative to the economically optimal strategy. Proper pricing and technology policies may result in decreased infrastructure spending, but more efficient use of infrastructure, thereby improving economic well-being.

Another difficulty with accepting the idea of public infrastructure as being a contributor to economic productivity is that very little is known about the precise ways in which firms use and possibly benefit from public infrastructure. There are no micro-based analyses of the precise linkages between measures of private economic activities (such as labor-intensity of production, profit margins, and choice of production technologies) and publicly provided infrastructure.

Finally, many issues surrounding investment in public infrastructure networks would seem to be best addressed by analysis of cities or metropolitan areas rather than of states or nations. For example, it would seem to make sense to investigate transportation networks by studying economic interaction between cities; or to investigate the effectiveness of different transportation policies in improving air quality by requiring analyses at the metropolitan level.

In conclusion, several important policy issues are left unresolved in the current literature because it does not disaggregate sufficiently across several dimensions. Many of the unresolved issues can be explored using techniques already available, but a rich, disaggregated state panel dataset needs to be compiled. Some of the important unresolved questions require micro-level analysis of firms or studies of cities, and the data requirements are severe. An important goal of future research is to improve our understanding of the linkage between public infrastructure and economic productivity so that public resources can be used most effectively to provide for the transportation services needed to support future economic growth.

PROJECT SCOPE

The overall objective of this report is to improve the understanding of the linkages between transportation investments and economic performance and to develop an improved estimate of the value of the public and private capital stock (structures, equipment, and land) in transportation over time.

Economists differ in their opinions concerning the factors associated with productivity; they do agree that productivity and national income are influenced by the amount of capital that labor has to work with, and that the amount of capital at any given time is a result of past levels of savings, investment, and depreciation. Therefore, it is important that the size and rate of growth of public and private transportation capital and its influence on productivity growth be determined.

In this report, the following efforts were undertaken: (1) macroeconomic studies of the contribution of transportation and infrastructure investment to productivity were critically reviewed and the types of data on transportation capital stock needed to conduct further research in this area were identified; (2) the dataset created in the 1974 U.S. DOT study was assessed to identify its strengths and weaknesses and feasible sources of information for a revised dataset were identified and mechanisms for routine updates to account for depreciation and the discounted value of capital were described; (3) an interim report was prepared that describes in detail a plan for modifying, updating, and applying a transportation capital stock database; (4) a database of transportation infrastructure investment and capital stock by mode and state was created and documented; (5) the derived measures of transportation capital stock were used in the production functions described in recent literature to validate the linkages between transportation investment and economic productivity; (6) other possible macroeconomic model refinements were identified; and (7) a final report documenting the findings was prepared.

SELECTED BIBLIOGRAPHY

Aaron, Henry J., "Discussion of 'Why is Infrastructure Important?'" *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Federal Reserve Bank of Boston (1990).

Antle, John M., "Infrastructure and Aggregate Agricultural Productivity: International Evidence." *Economic Development and Cultural Change*, Vol. 31 (1983) pp. 287–298.

Aschauer, David A., "Is Public Expenditure Productive?" *Journal of Monetary Economics*, Vol. 23 (1989a) pp. 177–200.

Aschauer, David A., "Does Public Capital Crowd Out Private Capital?" *Journal of Monetary Economics*, Vol. 24 (1989b) pp. 171–188.

Bartik, Timothy J., "Business Location Decisions in the United States: Estimates of the Effects of Unionization, Taxes, and Other Characteristics of States." *Journal of Business and Economic Statistics*, Vol. 3, No. 1 (January 1985) p. 14-2.

Bell, Michael, "Discussion of 'How Efficient Is Current Infrastructure Spending and Pricing?'" *Is There a Shortfall in Public Capital Investment?*, Alicia Munnell, ed. Federal Reserve Bank of Boston (1990) pp. 214–222.

Bell, Michael and Eran Feitelson, "Bottlenecks and Flexibility: Key Concepts for Identifying Economic Development Impacts of Transportation Services." *Transportation Research Record 1274*, Transportation Research Board, National Research Council, Washington, D.C. (October 1990) pp. 53–59.

Bell, Michael and Eran Feitelson, "U.S. Economic Restructuring and Demand for Transportation Services." *Transportation Quarterly*, Vol. 45, No. 4 (October 1991).

Berndt, Ernst R. and Bengt Hansson, "Measuring the Contribution of Public Infrastructure Capital in Sweden." Working Paper No. 3842, National Bureau of Economic Research, Inc. (September 1991).

Costa, Jose da Silva, Richard W. Ellson, and Randolph C. Martin, "Public Capital, Regional Output, and Development: Some Empirical Evidence." *Journal of Regional Science*, Vol. 27 (1987) pp. 419–437.

Crihfield, John B., "A Structural Empirical Analysis of Metropolitan Labor Demand." *Journal of Regional Science*, Vol. 29 (August 1989) pp. 347–371.

Crihfield, John B., "Manufacturing Supply: A Long-Run Metropolitan View." *Regional Science and Urban Economics*, Vol. 20 (November 1990) pp. 327–349.

Cummings, R., W. Schulze, S. Gerking, and D. Brookshire, "Measuring the Elasticity of Substitution of Wages for Municipal Infrastructure: A Comparison of the Survey and Hedonic Approaches." *Journal of Environmental Economics and Management*, Vol. 13 (1986) pp. 269–276.

Dalenberg, Douglas, "Estimates of Elasticities of Substitution Between Public and Private Inputs in the Manufacturing Sector of Metropolitan Areas." Ph.D. dissertation, University of Oregon (1987).

Deno, Kevin T., "The Effect of Public Capital on U.S. Manufacturing Activity: 1970 to 1978." *Southern Economic Journal*, Vol. 55 (1988) pp. 400–411.

Duffy-Deno, Kevin T. and Randall W. Eberts, "Public Infrastructure and Regional Economic Development: A Simultaneous Equations Approach." *Journal of Urban Economics*, Vol. 30, No. 3 (November 1991) pp. 329–343.

Eberts, Randall W., "Estimating the Contribution of Urban Public Capital Stock to Regional Growth." Working Paper 8610, Revised, Federal Reserve Bank of Cleveland (June 1988).

Eberts, Randall W., "Regional Differences in the Effect of Public Capital Stock on Manufacturing Outputs." Research Department, Federal Reserve Bank of Cleveland, Mimeo (July 1990).

Eberts, Randall W. and Joe A. Stone, *Wage and Employment Responses to Shocks in Local Labor Markets*, Upjohn Institute for Employment Research (1991).

Eisner, Robert, "Infrastructure and Regional Economic Performance," *New England Economic Review* (September/October 199) pp. 47–58.

Elhance, Arun and T. R. Lakshmanan, "Infrastructure-Production System Dynamics in National and Regional Systems: An Econometric Study of the India Economy." *Regional Science and Urban Economics*, Vol. 18 (1988) pp. 511–532.

Fox, William F., "The Contribution of Infrastructure Investments to Growth: A Review of the Literature." Paper prepared for the Urban Development Division, Infrastructure and Urban Development Department, The World Bank, Washington, D.C. (October 15, 1990).

Fox, William F., Henry Herzog, and Alan Schlottmann, "Metropolitan Fiscal Structure and Migration." *Journal of Regional Science*, Vol. 29 (1989) pp. 523–536.

Fox, William F. and Matthew N. Murray, "Local Public Policies and Interregional Business Development." *Southern Economic Journal*, Vol. 57 (1990).

Friedlaender, Ann F., "Discussion of 'How Does Public Infrastructure Affect Regional Economic Performance'." *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Federal Reserve Bank of Boston (1990).

Garcia-Mila, Teresa and Therese J. McGuire, "The Contribution of Publicly Provided Inputs to State's Economies." *Regional Science and Urban Economics*, Vol. 22, No. 2 (June 1992).

Garcia-Mila, Teresa, Therese J McGuire, and Robert H. Porter, "The Effect of Public Capital in State-Level Production Functions Reconsidered," IGPA Working Paper (March 1993, revised Feb. 1994).

Holtz-Eakin, Douglas, "Public-Sector Capital and the Productivity Puzzle," National Bureau of Economic Research, Working Paper No. 4122 (July 1992).

Hulten, Charles R. and Robert M. Schwab, "Is There Too Little Public Capital In The U.S.?" Revised, Presented at the Conference on Infrastructure Needs and Policy Options for the 1990s, American Enterprise Institute, Washington D.C. (January 1992).

Hulten, Charles R. and Robert M. Schwab. "Public Capital Formation and the Growth of Regional Manufacturing Industries." *National Tax Journal*, Vol. 43 (December 1991) pp. 121–134.

Levine, Ross and David Renelt, "A Sensitivity Analysis of Cross-Country Growth Regressions." The World Bank, Washington D.C. (1990).

Lewis, David, *NCHRP Report 342: Primer on Transportation Productivity and Economic Development,* Transportation Research Board, National Research Council, Washington, D.C. (1991).

Looney, Robert and Peter Frederiksen, "The Regional Impact of Infrastructure in Mexico." *Regional Studies*, Vol. 15 (1981) pp. 285–296.

Lynde, Catherine and J. Richmond, "Public Capital and Total Factor Productivity." *International Economic Review,* Vol. 34, No. 2 (May 1993) pp. 401-414.

McDowell, Bruce D., "Reinventing Surface Transportation: New Intergovernmental Challenges." Advisory Commission on Intergovernmental Relations," *Intergovernmental Perspective*, Vol. 18, No. 1 (Winter 1992).

McGuire, Therese J., "Highways and Macroeconomic Productivity: Phase II." Contract completion report for the Federal Highway Administration and Volpe National Transportation Systems Center, U.S. Department of Transportation (March 31, 1992).

Mehta, Shekhar, John B. Crihfield, and J. Fred Giertz, "Economic Growth in the American States: The End of Convergence?" University of Illinois IGPA working paper (November 1991).

Morrison, Catherine J., "Unraveling the Productivity Growth Slowdown in the United States, Canada and Japan: The Effects of Subequilibrium, Scale Economies and Markups." Working Paper #2993, National Bureau of Economic Research (June 1989).

Morrison, Catherine J. and Amy Ellen Schwartz, "State Infrastructure and Productive Performance." Tufts University, Mimeo (July 1991).

Munnell, Alicia H., "Why Has Productivity Growth Declined? Productivity and Public Investment." *New England Economic Review* (1990a) pp. 3–22.

Munnell, Alicia H., "How Does Public Infrastructure Affect Regional Economic Performance?" *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Federal Reserve Bank of Boston (1990b).

Musgrave, Richard, "Discussion of 'Why Is Infrastructure Important?'" *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Federal Reserve Bank of Boston (1990).

Nadiri, M. Ishaq and Theofanis P. Mamuneas, "The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries." Working Paper No. 3887, National Bureau of Economic Research (October 1991).

Nadiri, M. Ishaq and Theofanis P. Mamuneas, "The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries." *Review of Economics and Statistics*, Vol. 76, No. 1 (Feb. 1994) pp. 22-37.

National Council on Public Works Improvement, *Fragile Foundations: A Report on America's Public Works*, U.S. Government Printing Office, Washington, D.C. (1988).

Pagano, Michael A., "Maintenance Is the Key to Local Public Works." *The Public's Capital*, Vol. 1 (1989).

Rietveld, P., "Infrastructure and Regional Development: A Survey of Multiregional Economic Models." *The Annals of Regional Science*, Vol. 23 (1989) pp. 255–274.

Schultze, Charles L., "The Federal Budget and the Nation's Health." *Setting National Priorities: Policy for the Nineties*. The Brookings Institution, Washington, D.C. (1990).

Shah, Anwar, "Public Infrastructure and Private Sector Profitability and Productivity in Mexico." Working Paper No. 100, Country Economics Department, The World Bank, Washington, D.C. (September 1988).

Small, Kenneth A. and Clifford Winston, "Optimal Highway Durability." *American Economic Review* Vol. 78 (1988) pp. 560–569.

Tatom, John A., "Public Capital and Private Sector Performance." *St. Louis Federal Reserve Bank Review* (May/June, 1991).

U.S. Congress, 100th 1st SESS. Senate Committee on Environment and Public Works, *Infrastructure, Productivity, and Economic Growth: Hearing before the Subcommittee on Water Resources, Transportation and Infrastructure*, February 5, 1991. Washington, D.C.

Winston, Clifford, "How Efficient Is Current Infrastructure Spending and Pricing?" *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Federal Reserve Bank of Boston (1990).

Winston, Clifford and Barry Bosworth, "Public Infrastructure." *Setting Domestic Priorities*, Henry Aaron and Charles Schultze, eds. The Brookings Institution, Washington, D.C. (1992) pp. 267–293.

CHAPTER 2
DATABASE DEVELOPMENT

EXISTING CAPITAL STOCK DATA

In December 1974, the U.S. DOT published a five-volume study of transportation capital stock, investment needs, and capacity measures. The study, conducted by Jack Faucett Associates, Inc., examined 21 transportation modes over the period 1950–1970, and projected investment needs through 1980.* Under the current NCHRP 2-17(3) project, the investigators were asked to assess whether the data and findings contained in the Faucett study should be updated or replicated for use in research on the transportation issues identified in our literature review. Based on our evaluation, we conclude that the data presented in the Faucett study were most useful for filling perceived data needs that existed in the early 1970s. However, current issues in transportation policy research, and the data needed to address those issues, now differ from those of 20 years ago. Consequently, we conclude that it is not appropriate to simply extend the Faucett dataset to the most recent years. In this section we briefly describe the methods and products of each of the study's five volumes and how they relate to the data needs discussed in Chapter 1 of this report. The next section, "Description of Improved Disaggregate Dataset," describes the dataset generated to address the transportation policy issues of the 1990s identified in Chapter 1. A third section, "Application of Datasets," presents findings from preliminary empirical studies employing the new dataset.

The primary purpose of the Faucett study was to estimate capital stocks for 21 transportation modes in the United States for the period 1950–1970. Volume I describes the study's methodology and indicates the essential data sources. Data series calculated for all modes and years are presented in Volume II. Volume III forecasts investment "needs" for the years 1971–1980. Volume IV discusses the concept of "economic depreciation," and presents additional tables (to complement Volume II) showing data series for investment and capital stocks utilizing economic depreciation. Volume V focuses on the concept of "capacity" as applied to various transportation modes.

For the purposes of this NCHRP project, the most relevant Volumes are I, II, and IV. They address problems of measuring investment series, estimating capital stocks, and calculating costs of capital.

This chapter provides detailed discussion of the five Faucett volumes and assesses the usefulness of these volumes in the context of the NCHRP 2-17(3) project. The data presented in the Faucett study are now of limited use in addressing the policy issues identified in Chapter 1, and their findings provide little guidance in dealing with the issues identified. Therefore, efforts to extend this study or replicate these data for more recent years may not make the best use of limited time and resources.

* *Capital Stock Measures for Transportation, A Study in Five Volumes*, by Jack G. Faucett and Raymond C. Scheppach, Jack Faucett Associates, Inc., commissioned and published by the U.S. DOT, Assistant Secretary for Policy, Office of Transportation Planning Analysis, Washington, D.C. (December 1974).

SUMMARY OF AND COMMENTS ON VOLUMES I–V OF THE FAUCETT STUDY

Volume I: Capital Stock Measures for Transportation

This volume is the most important of the five volumes, and is considered the most detailed in this summary. Volume I is organized into seven chapters.

Chapter 1—Introduction

This chapter discusses the objectives of Volume I, improvements on previous work in the field, and policy uses of the constructed transportation capital stock series. The major objectives are to calculate transportation capital stocks and costs of capital services. The study lists the following advantages over previous studies: (1) it is more disaggregated than earlier work with its examination of 21 transportation modes; (2) it presents estimates for commercial modes and their *noncommercial* counterparts; (3) it calculates estimates for *public* transportation capital stocks; and (4) it calculates values for *nonreproducible* capital, i.e., land. The following is a list of the 21 modes considered in the study:

1. Automobiles
2. Noncommercial aircraft
3. Recreational boats
4. Not-for-hire trucks
5. Airports
6. Airways
7. Waterways
8. Highways (interstate highways, state systems, local county and township roads, local city streets, and other roads)
9. Railroads
10. For-hire trucks
11. Intercity buses

12. Oil pipelines
13. Domestic air carriers
14. Domestic water carriers
15. Freight forwarders
16. International air carriers
17. International water carriers
18. Local buses
19. Taxicabs
20. Rail transit
21. School buses

The authors also mention possible policy uses for their estimates: (1) to compare unit costs across transportation modes; (2) to help assess future investment demands; (3) to help set rates and determine profitability in regulated transportation modes; and (4) to measure total factor productivity. Of these, the authors address only future investment needs (in Volume III). Otherwise, the Faucett study does not address policy questions, in part because that was not the primary focus of its task.

Chapter 2—Methodology for Developing Capital Stocks

The major task of this chapter is to find gross and net values for capital stocks of structures and equipment ("reproducible" capital) and land ("nonreproducible" capital). The procedure appears to be as follows. First, the authors use reported data for gross investments. These data are based on reported government and industry measures, which usually omit "repairs and maintenance." The second step is to deflate these values. Next, each asset is given a "service life." In most cases, the evidence for these "lives" is not well documented. The service life is defined as the mean of a "retirement function" which is assumed to be truncated normal (based on work by Winfrey). This "vintage distribution" defines a distribution of percentages. The real investment series (above) is multiplied by these percentages to get the *gross capital stock.* This gross capital is assumed to be fully productive, that is, productivity occurs up to the service life, at which point the equipment completely breaks down, like a burned-out light bulb.

Over time, a given year's amount of gross investment becomes less productive due to depreciation. Therefore, one must depreciate each year of existing investment by the "efficiency loss" function (or by some accounting definition of depreciation). Those discussed in the text are straight line, double declining balance, and sum-of-the-digits. Faucett provides gross investment values in Volume II for those who prefer to use other depreciation methods. The sum of these net investments at any time, which is the essence of the perpetual inventory method of structuring a capital stock series, equals the *net capital stock.*

Several additional points are worth noting:

1. Changes in technology from improved vintages of capital are not explicitly considered in the estimates.
2. "Efficiency loss" depreciation is plausible, but the report could provide more supporting evidence for it. The key parameter is β ($\beta = 1$ represents no productivity loss until the end of the service life, and $\beta = 0$ is straight-line depreciation). In Volume IV the authors assume this equals 0.9, but the reason for this particular value is not made clear.
3. The distinction between "efficiency depreciation" and "economic depreciation" needs to be explained more clearly. As the authors explain later, "economic depreciation" incorporates three components: efficiency loss, a discount rate, and capital gain, but this explanation does not come until Volume IV.
4. "Nonreproducible" capital is defined as land, and it is assumed to be important only for four modes. Their measure for it is a "market value," and not an "efficiency" concept.

Chapter 3—Methodology and Sources for Capital Stock Input Data

This chapter explains in detail how capital stock data are constructed for reproducible capital (structures and equipment) and nonreproducible capital (land) for the 21 modes of transportation. The section on reproducible capital has 3 parts: (1) derivation of the investment series, (2) deflators, and (3) service lives.

Derivation of the investment series. Investment series data for reproducible capital are transformed into stock values using the perpetual inventory method. Companies and government agencies typically view short-term periodic repairs as "maintenance," which falls into the category "current operating cost." Consequently, these are not included in "investment" by those who report data, although in principle such repairs are investment. Faucett uses the definition of "investment" adopted by the reporting companies and government agencies, arguing that the differences between these definitions are probably minor.

Specific data series and sources used to construct investment series for each mode are given. Data from 62 sources are used (and listed at the end of Volume I). According to officials at the U.S. Department of Commerce, Bureau of Economic Analysis (BEA), most of these data series have been maintained since the 1974 Faucett study was completed; thus the investment data series could be replicated, if so desired.

Price deflators. Deflators come from two sources—the Business Defense Service Administration (BDSA) and the Office of Business Economics (OBE). For composite indices, deflator components are weighted by relative value shares. When series for equipment and structures are available separately, these are first deflated and then summed.

Service lives. Faucett states that assumptions about "service life" are very important, but that insufficient data exist to measure service lives accurately.

For nonreproducible capital, Faucett uses annual acreage data (urban and rural) for the relevant modes (railroads, pipelines, airports, and highways). Land values for 1958 (urban and rural, but not by mode) are used for all years. Thus, all rural land is assumed to be equally productive as measured by 1958 prices. Similarly, all urban land is assumed to be equally productive at the 1958 benchmark.

Chapter 4—Public Capital and Its Allocation

This chapter explains in detail how public capital is allocated across the various modes. In most cases, capital used by several modes is allocated on the basis of use, not in terms of the marginal cost of providing capital for an additional mode. For example, public investment in "channels and harbors" included in waterways is allocated between domestic and overseas carriers according to traffic volume. The methodology for deriving public capital is the same as for private capital. Once allocated, private and public capital are added for each mode.

Chapter 5—Cost of Capital Services

This chapter considers the cost of capital. It is not clear why the authors use the parameter 1.5 in the declining balance depreciation function. Nor is it clear why they apparently divide a nominal value by a real value to get the cost per unit of capital in Table 5.1. In many sections of these volumes, the explanation is cryptic and the discussion is frequently unclear. As a result, it would be very difficult for other researchers to replicate these data series based solely on the descriptions in the text.

Chapter 6—Capital in Transportation

This chapter describes capital-to-output ratios for transportation modes using capital-stock data constructed in the study. Capital-to-output measures for nontransportation sectors are also shown. The authors do not define "output." It appears that they use value added for nontransportation sectors. Comparisons are made across modes, with nontransportation industries, and over time. The chapter also reports net stocks of capital by mode and by year.

Chapter 7—Conclusions and Recommendations

This chapter reiterates potential uses of the capital stock data. It also mentions limitations due to lack of investment data, data on service lives, data on land prices, and difficulties in allocating public capital across modes (except for highways).

Volume II: Statistical Supplement

This volume consists of the data series constructed from the methodology described in Volume I. Although this supplement is very long, there is a basic structure that is repeated for each transportation mode. For each mode there are separate tables for structures, equipment, and vintages. Data series are constructed back to the 1920s for gross and net investment, discards, efficiency loss, gross and net capital stocks, and deflators. Other tables present data for nonreproducible capital, inventories, and average age of "revenue" capital (e.g., cars and trucks).

Volume III: Projections of Investment Needs

This volume projects investment "needs" for each mode for the period 1971–1980. Forecast reliability is tested using the data series constructed for 1950–1970.

The projections assume that service quality does not change, that investment can be funded, and that technology changes at historical rates. Investment forecasts are derived from forecasts of capital-to-output ratios and of output. The methodology allows for substitutions of labor for capital and for changes in the utilization rate of capital. Estimates are made for replacements and expansions. It is not clear how the reliability tests, which use historical data, are independent of the forecasts, which also are based on historical data. In their concluding remarks, the authors indicate possible uses of the forecasts (e.g., for national transportation policy planning, for determining user fees for public capital expansions, and for determining rates for regulated modes). Unfortunately, they do not apply their results to such purposes.

Volume IV: Economic or Market Values

The main purpose of this volume is to generate tables (presented in the appendix) resembling those in Volume II. The difference is that the tables in Volume IV reflect "economic depreciation" and not just "efficiency depreciation." In other words, the tables in this volume also include the effects of interest rates and capital gains. The appendix tables are broken down by equipment and structures for each mode, and time-series data are shown for gross investment, economic depreciation, net investment, and the market value of capital stocks.

Volume V: Transportation Capacity

The last volume considers theoretical and empirical aspects of transportation "capacity." The first chapter defines capacity and discusses how the concept is used. One such use is in forecasting short-run and long-run business investment, which may be related to transportation capacity. The other chapters consider the concept of capacity, how to measure capacity, how capacity in transportation may differ from other industries, and how capacity can be measured for the period, 1950–1970, for four transportation modes—water, rail, air, and motor freight.

EVALUATION OF THE FAUCETT STUDY

The most important volumes of the Faucett study for the purposes here are Volumes I, II, and IV. They address in detail the task of measuring transportation capital stocks. To do this, important concepts of investment, capital stocks, maintenance and repairs, efficiency loss, economic depreciation, accounting depreciation, book values, and deflators are applied to many transportation modes. The end products include net and gross capital stock measures and measures for the cost of capital. These data are also used in forecasting and capacity studies in Volumes III and V.

It is clear that considerable effort went into the Faucett study. The essential question we face is, to what extent can the Faucett work be updated to address the policy questions which are most critical in the next decade. In our view, the limitation of this work is that its findings have apparently had little or no impact in the formulation and assessment of transportation policy issues, in part, because that was not a primary focus of its task.

One reason other researchers have made limited use of this work is that the five volumes do not contain a description of how the data were generated. Moreover, the authors do not systematically assess the reliability of their estimates. There is no sensitivity analysis that might indicate how the stock estimates might change with the depreciation parameter (β), urban and rural land prices, service lives, price deflators, or alternative public capital allocation schemes. Researchers who use these data must accept many underlying assumptions that affect the reliability of the data, but are not fully explained in the report.

The literature review in Chapter 1 identifies issues that are at the forefront of transportation policy research in the 1990s: determining the positive externalities of infrastructure investment; developing more plausible models of economic growth that incorporate transportation capital; clarifying the importance of transportation networks in economic development; and the implications that economic restructuring has for transportation services demand. Replicating the Faucett study would not produce a dataset that could be used to address these and related questions because the data are not disaggregated to a subnational (city, state, or region) level, and do not contain alternative measures and characteristics of the transportation infrastructure. Also, some of the transportation variables are of limited use, and the capital stock data are not combined with a rich complementary dataset describing the private economy.

For the purposes here, a more appropriate strategy for gathering data would be to construct subnational measures for the major stocks of public transportation infrastructure such as highways, transit, airports, and waterways. To these measures it would be useful to add subnational data describing infrastructure quality (e.g., pavement quality), congestion, and networks. Data sources would include BEA and U.S. DOT, in addition to some of the sources used in the Faucett study. BEA could provide assistance with technical questions of depreciation, costs of capital, service lives, and vintage distributions. The result would be a dataset with measures of public transportation infrastructure by subnational region for several years, for the major modes (highways, railroads, airports, and waterways), along with measures of networks, quality, and congestion by mode. These data would be appropriate for addressing many of the transportation policy research questions proposed in Chapter 1.

This summary of the five-volume Faucett study shows it to be a long and sometimes unclear work that does not focus on the important policy issues identified in Chapter 1. Its data are aggregated to the national level, and focus exclusively on capital stock measures, with no data on other characteristics of transportation infrastructure. These concerns suggest that an update of the Faucett data and findings would be of limited value in addressing the policy issues discussed here.

The goal of the current NCHRP project is to provide a dataset that will assist policy research and inform the policy debate of the 1990s. The dataset used here (see Chapter 3) was developed in a different way from the Faucett study dataset. Spatially disaggregated data were collected for the major components of public transportation infrastructure including measures for both capital stock and other descriptors. These data were supplemented with equally rich descriptors of the private economy. Subsequently, this dataset was used for several research projects to illustrate the usefulness of the data for policy makers.

DESCRIPTION OF IMPROVED DISAGGREGATE DATASET

INTRODUCTION

The literature review in Chapter 1 revealed that

- Publicly provided infrastructure has a small, positive effect on private economic output;
- This empirical finding is not particularly robust, but the preponderance of available evidence supports the first conclusion; and
- The precise nature of the linkage between public infrastructure investment and private economic output is not well understood.

The current literature leaves many unanswered and important policy questions regarding the linkage between investment in public infrastructure and private economic performance because

- The high level of aggregation of much of the analysis does not support specific policy recommendations; and

- It is difficult to find comprehensive, consistent, and timely disaggregated data needed to perform more detailed and informative analysis.

The primary goal of the current project is to develop a dataset that can be used to verify, explore, and extend the results found in the current literature in order to inform the decision-making process.

To improve understanding of the linkage between public infrastructure investment and private economic activity, a disaggregate dataset is developed that includes information on

- Different types of public infrastructure;
- Private economic activity by different industries; and
- National data by region or state.

This approach represents an evolutionary step in efforts to create a base of empirical knowledge to better understand how public infrastructure, and specifically transportation infrastructure, affects private economic activity. This approach to the subject is important because current analyses do not provide adequate information to enable policy makers to set priorities. For example, even refined estimates of the coefficients produced by aggregate economic analysis will not provide information useful for policy makers in setting expenditure priorities; and a credible cost/benefit analysis is not possible until there is a complete understanding of the breadth of benefits and costs associated with infrastructure investments, plus a way to quantify those benefits and costs.

This chapter describes how the dataset was constructed and developed using published information from a variety of federal agencies. With the dataset, it was possible to calculate public capital stock estimates and, when necessary, to allocate national figures to the 50 states.

The most difficult part of this process was allocating national figures to the 50 states in an appropriate manner. There were difficult choices to make regarding which data to include, how to make the allocations, and how to ensure the database could be used to test particular hypotheses. Two fundamental decision rules were followed: (1) to develop a consistent and comprehensive dataset that disaggregated data by industry, by state, and by infrastructure category and (2) to provide some value-added relative to currently available information and analysis.

The dataset has two major categories of data to explore the linkage between public infrastructure and economic performance—one set describes private sector economic activity and the other describes public sector infrastructure investment trends, capital stock, and level and quality of service provided. These datasets are described below.

PRIVATE SECTOR DATA

In order to examine the linkages between public infrastructure and private economic activity, measures of private economic activity and private factor inputs are developed. Two measures of private economic activity are included in the dataset—Gross State Product and Personal Income. Two measures of private factor inputs—employment, which measures labor inputs, and private capital stocks, which is a measure of capital inputs—are also included. For the empirical analyses proposed, each dataset was disaggregated by state and by industry (one-digit SIC code). Thus, the dataset includes by state and by industry:

- Gross state product;
- Personal income;
- Employment; and
- Private capital stock estimates.

Each of these data files is discussed in more detail below.

Gross State Product

Gross State Product (GSP) is the market value of the goods and services produced annually in a specific state. It is essentially the state counterpart of the nation's Gross Domestic Product (GDP) from the National Income and Product Accounts (NIPA).[1]

The source of the GSP data is the U.S. Department of Commerce, Bureau of Economic Analysis (BEA), Regional Economic Analysis Division. A detailed description of the data, sources, and methodology used in the estimation of GSP is available in BEA Staff Paper 42, "Experimental Estimates of Gross State Product by Industry" (Washington, D.C.: U.S. Government Printing Office, 1985).[2]

BEA prepares GSP estimates for 61 industries and the data series contains information on four components of GSP:

- Compensation of employees;
- Proprietors' income with inventory valuation adjustment and capital consumption allowances;
- Indirect business tax and non-tax liability (IBT); and
- Capital-related charges.

The compensation and proprietors' income components of GSP are primarily based on BEA's estimates of earnings by place of work. The IBT component reflects liabilities charged to business expense, most of which are sales and property taxes levied by state and local governments. The capital charges component of GSP reflects capital stocks and profits by state.

For farming, mining, construction, and manufacturing industries, BEA estimates total GSP and three of its four components—compensation, proprietors' income, and IBT—and then subtracts the three components from total GSP to get capital charges (which is basically a residual). For the other industries, BEA estimates each of the four components and then sums the components to get total GSP.

The dataset used here includes two GSP series—a revised and unrevised series. The revised series was released in

November 1991 and includes annual estimates by state for the years 1977 through 1989. Estimates are presented in millions of dollars and are presented in both current and constant (1982) dollars. The estimates are consistent with estimates of gross state product by industry for the nation as revised in 1991.[3]

The unrevised series was released in May 1988 and includes annual estimates for the years 1963 through 1986. Estimates are presented in millions of dollars and are presented in both current and constant (1982) dollars. This series has not been benchmarked to be consistent with estimates of gross state product by industry for the nation as revised in 1991.

The dataset used here includes these data as provided by BEA. State codes and names for both series are presented in the Appendix A, as are industry codes and titles for both series.

Personal Income

Personal income by state is defined as the total income received by, or on behalf of, all residents in a state from all sources. It is measured as the sum of all wage and salary disbursements, other labor income, proprietors' income, rental income of persons, personal dividend income, personal interest income, and transfer payments, less personal contributions for social insurance.[4]

At the industry level, the data cover earnings only. Earnings, as defined by BEA, consist of

- Wage and salary disbursements;
- Other labor income, such as
  - Employer contribution to private pension and welfare funds,
  - Directors' fees,
  - Judicial fees,
  - Compensation of prisoners, and
  - Benefits paid from social insurance funds; and
- Proprietors' income.

These data are supplied by the U.S. Department of Commerce, Economics and Statistics Administration, BEA, Regional Economic Information System. The data come from the SA5 series and cover the years 1969 to 1990. These data were released in September 1991 and are reported in thousands of current dollars by state and two-digit SIC code industries.

The dataset used here includes these data as provided by BEA. State codes and names are presented in the Appendix A, as are industry codes and titles.

Employment

The employment series we include in the dataset (SA25) contain annual data on the total number of full-time and part-time employees (including proprietors) by two-digit SIC code industries and by state for the years 1969 through 1991. The data are prepared by the U.S. Department of Commerce, BEA, Regional Economic Measurement Division.

The dataset includes these data as provided by BEA in September 1992. State codes and names are presented in the Appendix A as are industry codes and titles.

Private Capital Stock Estimates

The preceding measures of private economic activity are reported exactly as received from BEA since the data are presented by industry and by state. BEA does not provide an equivalent dataset for private capital stock estimates. BEA calculates and publishes national capital stock estimates by industry (in millions of dollars), but they are not available by state. In order to carry out specific types of disaggregate analysis, e.g. state-level production functions, annual estimates of capital stock were needed by state. Thus, a project task was to allocate national capital stock estimates by industry to each of the 50 states.

Two existing datasets were identified from the literature review that had private capital stock estimates by state. For the purposes here, however, neither capital stock series was satisfactory.

First, Garcia-Mila and McGuire generated a state-level, total, private capital stock series for their analysis. Their dataset, based on data collected annually by BEA on total investment in private structures and equipment by state, provides annual private capital stock estimates for 48 states from 1969 to 1983. These state-level annual investment data were used in conjunction with initial national capital stock values for both structures and equipment to generate total capital stock estimates by state. For the base year, the initial national capital stock values were allocated to the states using each state's share of the appropriately discounted and depreciated investment streams; then the state-specific investment amounts were added to the initial capital stock estimates using the perpetual inventory method.[5]

This general approach has conceptual appeal because it uses actual private sector investment data by state to estimate the total private capital stock series.[6] However, it has two major limitations. First, for budgetary reasons, BEA stopped collecting the investment flow data in 1983 so the analysis could not be extended beyond 1983. Second, the data are not broken down by industry—a primary goal of this project.

The second available dataset that provides private capital stock estimates by state is the Munnell and Cook dataset, which has been used in a number of studies. Munnell and Cook started with the same BEA national totals by industry reported here, but allocated them to the states in a different manner. Basically, they used allocators from various economic censuses that occur every five years. The five-year benchmark is used to allocate the five years closest to that census year. For example, the 1977 data are used to allocate industry totals across states for 1975–1979.

For mining, construction, and all manufacturing industries, Munnell and Cook used gross book value of depreciable assets as their allocators. For service industries they used sales as an allocator. For transportation services they used various measures of physical assets (e.g. track miles for railroads, or number of civil aircraft for air transportation) and usage (the estimated value of commerce in ports for water transportation).[7]

This general approach has several limitations. For example, unlike the Garcia-Mila and McGuire approach, Munnell and Cook do not use actual state-level investment series, which they point out do not exist for nonmanufacturing sectors. In addition, the use of gross book value as an allocator for manufacturing industries and sales for service industries raises important methodological issues. For example, it is not clear what the relationship is between the gross book value of depreciable assets and their actual market value, or how that relationship varies over time or across industries.

Finally, not all sectors were included in the Munnell and Cook estimates. In fact, the correlations between the Munnell and Cook and the Garcia-Mila and McGuire total private capital stock series are relatively high (0.906), indicating that the two series move together over time and across states, but the difference in the means is very large, suggesting that the coverage of the private capital stock data in Munnell and Cook is about one-third less than Garcia-Mila and McGuire.[8]

Thus, the conclusion was that no existing private capital stock data series is sufficiently comprehensive or timely for the purposes here. Consequently, it was necessary to generate another private capital stock series by industry and state. This series started, like Munnell and Cook, with BEA national capital stock estimates by industry because they are comprehensive, consistent, and well documented and are generally considered to be the best available estimates.

The allocation of BEA's national industry private capital stock estimates across states provided a challenging opportunity. Hulten sums up the challenge as follows.

> The measurement of economic variables almost always involves significant problems, but Sir John Hicks is certainly correct in his appraisal of the special difficulties encountered in the area of capital measurement. The theoretical problems are indeed "nasty," and the practical problems are even nastier.[9]

In one sense, this task provided a great opportunity for significant value-added in developing a disaggregated database. On the other hand, however, these were second- or third-best solutions since the preferred measures based on actual investment flows by industry, by state are not available.

The task was to identify ways to allocate the national BEA estimates across states that improved upon the Munnell and Cook approach. In addressing this issue, the primary concern was developing a consistently allocated, comprehensive data series incorporating the most recent data available. Working with BEA, a number of alternatives were explored.

The ideal industrial capital stock series for each state would be constructed using the perpetual inventory method (PIM) and actual annual capital investment flows by industry (per Garcia-Mila and McGuire). In this approach, BEA's national estimates would serve as control totals. The Annual Survey of Manufactures series on new capital investment is available, by state, electronically through 1980, from the research department at the Cleveland Federal Reserve Bank and could be updated for this purpose. Unfortunately, these data are only available for total manufacturing, so the industry detail available in the BEA private capital stock series would be lost. More importantly, for the nonmanufacturing sector, an annual series on new capital investment is unavailable electronically over time. Therefore, a perpetual inventory approach is not feasible.

Alternatively, industry depreciation data could provide an indication of the relative size of the capital stock across states. However, the Internal Revenue Service (IRS) reports these data at the national level only. Even if available, state-level depreciation data, as reported to the IRS, would be a relatively meaningless indicator of the physical distribution of capital assets because the data are distorted by the distribution of corporate tax returns. Since tax returns are filed according to the state in which a company incorporates, not by the location of its operations, the depreciation data would attribute an unreasonably large weight to states with relatively favorable corporate tax status, such as Delaware and New York. For these reasons, this approach did not seem promising, except for the farm sector.

For the farm sector, state-level depreciation data are available from the Department of Agriculture's Economic Research Service (ERS). ERS analysts provided the data electronically for the period covered in the present analysis. These data do not have the same location problems contained in the IRS data.

As discussed above, Munnell and Cook used data published by the Census on the gross book value of depreciable assets, by state, to allocate national capital stocks to the states, but only for mining, construction, and total manufacturing. For the purposes here, these data have two limitations. First, they are not available on a comparable basis for all industries. Second, the relation between gross book value and actual economic value of capital assets is unclear.

An alternative approach was to use state-level industrial capital charges (published electronically by BEA as a component of GSP) to distribute the nonfarm national capital stock estimates to the states. To the extent capital charges reflect the value of capital services consumed, it would be an ideal measure. However, the capital charges component of GSP includes profits and net interest payments also. These two elements lead to negative observations in many cases. After examining these data, BEA concluded that for many industries these problems were significant and irreconcilable, even when taking five-year averages. These problems were exacerbated when data for two-digit SIC industries were examined.

BEA recommended the use of Bureau of Labor Statistics (BLS) state-level industry occupation matrices as a means of allocating some of the 39 classes of capital assets across states. This methodology would assume, for example, that the capital asset class "trucks" would be distributed among states based on the number of truck drivers in each industry.

Investigations at the BLS indicated that the agency terminated support of state efforts to estimate the matrices in the early- to mid-1980s. Without a central clearinghouse from which to collect the data electronically over time, the resources required to gather the data from the 40 states that continue to produce the matrices would exceed those provided for this project. Furthermore, representatives from the National Occupational Industrial Coordinating Committee (NOICC) indicated that even if readily available, the level of detail desired (two-digit SIC) would most likely lead to significant disclosure problems at the state level. The Census Bureau collects a similar matrix for each of the 50 states. This matrix, however, is only available for decennial census years, e.g., 1970, 1980, and 1990.

Based on what was learned during these investigations, and consultation with BEA representatives afterward, and given the specific time and resource constraints, it was decided that the most feasible statewide allocators available were gross state product minus indirect business taxes (GSP-IBT),[10] and employment.

There are several advantages and potential disadvantages to using GSP-IBT. First, this approach accurately reflects the relative level of industrial activity across states. In fact, it was actually used by BEA to apportion nonmanufacturing new capital investment estimates for the 1963–1978 period. Second, this approach represents a uniform methodology that is easily accessible and consistent across states, industries and time.

However, this approach implicitly assumes a fixed capital-output ratio across states, within an industry. This is a somewhat restrictive assumption. Second, this approach could lead to statistical problems when used with GSP to estimate production functions since a component of the dependent variable (GSP) is used to allocate values of one independent variable (private capital) across states. In order to minimize potential statistical problems, it was decided to generate a second private capital stock series by industry and state by allocating BEA's private capital stock estimates using employment as well.

Using employment shares as an allocator also has limitations. For example, like GSP-IBT, using employment shares to allocate national capital stock estimates by industry across states implicitly assumes a constant capital/labor ratio across states within an industry. This is a restrictive assumption. Also, for production-function analyses this means that the private capital stock estimates may be highly correlated with the labor variable creating the possibility for econometric problems, albeit they would be less serious than those discussed above with the GSP-IBT based estimates. Nevertheless, the presentation of both statewide capital stock estimates provides researchers and practitioners with a rich dataset with which to explore the relationship between public and private capital investments and economic activity.

Thus, the dataset includes two private capital stock series disaggregated by state and by industry. Both series start with the BEA national net nonresidential constant price capital stock estimates by industry for the period 1970–1989.[11] The estimates are in millions of 1987 dollars. The actual construction of each individual series is described in Appendix A.

Given the objectives in developing this private capital stock database, the resulting improvements are significant (although in the historical research they are only evolutionary). They reflect the benefits of an approach that is

- Conceptually appealing since it is based on indicators of relative economic activity across states;
- More comprehensive in its coverage of industries;
- More consistent over time since the vast majority of the data is based on actual annual observations and not dependent on observations that are five years apart;
- Based on the most recent public information, that is well documented, easily accessible, and reproducible; and
- Based on two different allocators so that potential econometric problems can be minimized.

Private Sector Variables

DATASET	STATES	INDUSTRIES	TIME PERIOD
Gross State Product			
Revised	50+D.C.	2-digit SIC	1977-1989
Unrevised	50+D.C.	2-digit SIC	1963-1986
Earnings	50+D.C.	2-digit SIC	1969-1990
Employment	50+D.C.	2-digit SIC	1969-1991
Private Capital Stock			
National BEA	National	2-digit SIC	1947-1991
State-level	50+D.C.	1-digit SIC	1970-1989

PUBLIC SECTOR DATA

To explore the linkage between public infrastructure investment and private economic activity, measures of public capital were needed. The dataset that was constructed includes investment flows by infrastructure categories, capital stock estimates by infrastructure categories, and, where available, information describing transportation network characteristics, including capacity measures as well as the level and quality of service actually provided. Specifically, these datasets include information on

- State and local government total and capital spending on six categories of infrastructure provided by the U.S. Census Bureau, which were used to generate state-level capital stock estimates for each infrastructure category;
- Total all-government highway capital and maintenance outlays by state provided by the FHWA, which were used to generate two highway capital stock estimates by state;
- The level and quality of service provided by the nation's highway network obtained from the FHWA;
- The level and quality of service provided by the nation's mass transit systems obtained from the FTA; and
- The level and quality of service provided by the nation's airports and airways obtained from the FAA.

These data series are briefly described below.

Census Data

Two sets of data were received from the Governments Division of the Bureau of Census, U.S. Department of Commerce. The first set reports state and local spending by individual infrastructure category by state from 1977 through 1990. Specifically, it includes annual information on total spending and on capital outlays by state and local governments for six different categories of infrastructure: highways, mass transit, air transportation, water transportation, water supply, and sewerage. The data represent a comprehensive measure of spending because they include total spending by state and local governments on each category, after intergovernmental transfers and regardless of the source of funds. These data include more categories of infrastructure, especially transportation infrastructure, than any existing dataset.

The second data series provided by the Governments Division contains total U.S. state and local annual spending and capital outlays for the same six categories of infrastructure from 1902 to 1990, but the data are not broken down by state. The dataset includes annual observations from 1952 to 1990, observations every two years from 1932 to 1952, and only five observations between 1902 and 1932. For the period 1977 to 1990, the annual totals from this aggregate national series correspond to the annual U.S. totals from the series disaggregated by states so the datasets are consistent.

These series are included in the dataset as provided by BEA. However, these data series were used to construct an estimated capital stock series by state for each of the six categories of infrastructure from 1977 to 1990.

First we used the national capital outlay series to construct an estimated national capital stock series for each of the six infrastructure categories based on actual investment data dating back to 1932, using the perpetual inventory method.

After that series was constructed, the 1976 capital stock estimate for each infrastructure category was allocated to individual states. The allocation to individual states was based on each state's average share of total expenditures on that category from 1977 to 1990. Then, using actual state-level capital outlay data from 1977 to 1990, the perpetual inventory approach was used to estimate a capital stock series by state for each of the infrastructure categories. The product is a state-by-state capital stock estimate for each of the six categories of infrastructure including the transportation categories highways, mass transit, air transportation, and water transportation for the years 1977–1990. No other existing dataset contains this level of detail for public capital stock estimates. A more detailed discussion of this process is contained in Appendix A.

Census Data

DATASET	STATE	INFRASTRUCTURE CATEGORIES	TIME PERIOD
Infrastructure spending by state+local governments	50+D.C.	6	1977-1990
Infrastructure spending by state+local governments	National	6	1902-1990
Infrastructure capital stock estimates	50+D.C.	6	1977-1990
Infrastructure capital stock estimates	National	6	1952-1990

This dataset has significant value-added compared to other public sector capital stock estimates because

- It is based on a consistent series of actual investment that goes back to 1932;
- It is disaggregated into six categories of infrastructure, including four different transportation modes; and
- It uses actual capital outlay data disaggregated by state to estimate each state capital stock series.

Federal Highway Administration

The FHWA publishes annual data on all public expenditures on streets and highways. These data include annual observations of both capital and maintenance outlays on all roads including expenditures for acquisition of rights-of-way by all levels of government, by state, from 1957 to 1989. These data were used to construct an alternative series of highway capital stock estimates by state.

Unfortunately, the capital and maintenance outlay series published annually by the FHWA only go back to 1957. In order to generate capital stock estimates for the 1970–1989 period, the series had to be extended back beyond 1957 by using data from other sources. Data were collected from annual reports on financing of highways by counties and rural local governments, and financing of municipal highways.

These data were used to construct a comparable series from 1931 to 1956 by adding together the component parts from each individual data series.[12] The figures in the individual series were simply added together. Because of incomplete reporting, the data before 1945 are not comprehensive in the coverage of all 48 states for some variables. This is not a major problem since investments in the 1940s (especially maintenance expenditures) will be fully depreciated by the 1970s, and the data accurately reflect the period from the 1950s on, when spending on the nation's transportation network began to increase substantially.

The capital outlays for 1957 generated for the constructed series were then compared with the 1957 outlay data from the all-government series published annually by the FHWA. Differences in the two datasets are primarily due to missing direct federal expenditures on public access roads in parks and forests which are important for only four states. We were told by the FHWA that these data do not exist in any form before 1956 at Federal Highway, and they are expected to be relatively minor. To compensate for these missing data, the 1956 constructed data were inflated by half of the percent difference in the 1957 data, and all previous years were left unadjusted. Differences between the two series were generally less than 5 percent.

A similar process was employed to estimate an all-government maintenance series going back to the early 1930s. Again, the differences in the 1957 values between the constructed series and the actual series were minor with only two states having differences of 5 percent or more in 1957.

These series of actual capital and maintenance outlays were then used to construct two highway capital stock estimates by state, one based solely on capital outlay data and the other combining capital and maintenance expenditures. Three important features of these series enhance their credibility compared with other estimates of highway capital stock. First, different average asset lives were assumed for different components of the roadway (e.g., pavement was assumed to account for 52 percent of total expenditures and was assumed to have an average life of 14 years; grading was assumed to represent 26.5 percent of total expenditures and was assumed to have an average life of 80 years; and structures was assumed to account for 21.5 percent of expenditures with an assumed average life of 50 years).[13] Second, current expenditures were converted to constant dollars using the FHWA's composite price index rather than some general GNP deflator. Third, maintenance expenditures were added to capital outlays as another component of highways and they were assumed to have an average life of 4 years.[14]

Federal Highway Data

DATASET	STATES	TYPE OF EXPENDITURE	TIME PERIOD
Total receipts all highways, all units of government	50+D.C.	Annual capital and maintenance outlays	1957-1989
Constructed total receipts all highways, all government	48+D.C.	Annual capital and maintenance outlays	1931-1956
Capital stock estimates capital outlays, maintenance outlays	48+D.C.	Annual capital stock estimates	1931-1989

NETWORK CHARACTERISTICS

All current public capital stock estimates employ the perpetual inventory method of aggregating past investments. The measures of public capital stock developed apply this same technique, but go beyond other available estimates in several respects as follows:

- The estimates disaggregate public capital into six categories, including four separate categories of transportation modes;
- Public highway capital stock estimates are adjusted using FHWA data to reflect actual maintenance expenditures;
- The capital outlay series are divided into different types of capital investments that have different assumed average lives; and
- The investment data are adjusted to reflect price changes by using a transportation-related composite price index provided by the FHWA.

In this report, however, questions were raised about whether the perpetual inventory method of valuing private capital stock was an adequate means of estimating the value of public capital. While private investment flows are a good proxy for the estimated current value of future benefits from private capital goods, public sector investment flows may not be a good proxy for the estimated current value of future benefits from public capital facilities. Therefore, the dataset here includes, to the extent possible, measures of various characteristics of the nation's transportation networks, including network capacity as well as the level and quality of infrastructure services provided by highways, mass transit, and airports.[15] These characteristics data, used in conjunction with traditional public capital stock estimates, give a more complete picture of the benefits from the nation's transportation networks.

Highways

In this category, data were gathered describing various characteristics of the nation's highway network and the level and quality of service provided. The data come from information published annually by the FHWA in *Highway Statistics*. Individual states provide the data to the FHWA through the Highway Performance Monitoring System (HPMS). HPMS includes data on road mileage, physical dimensions, usage, condition, performance, operating characteristics, and fatal and injury accidents. The HPMS data reported annually by each state consist of areawide data reports, 23 data items that identify the nation's total public road network, and sample section data for approximately 110,000 sample sections of the nation's highway system. Information on the level and quality of service provided is only available from the 110,000-sample section survey.

In addition, the information gathered could be used to evaluate the level and quality of service provided by the nation's highway network, which are contained in the following tables:

- DL-FR provides information potentially related both to actual *usage* of the nation's highway network as well as the *quality* of service provided;
- VEHREG provides information potentially related to actual *usage* of the nation's highway network;
- LANEMLS provides information on the *capacity* of the nation's highway network;
- VEHMLS provides information on the *level of usage* provided by the nation's highway network; and
- INSTMLS provides information related to the *quality* of service provided.

The information contained in these tables and their sources are discussed more fully in the Appendix.

Transit

In this category, data were gathered describing characteristics of the nation's transit network and the level and quality of service provided. Specifically, the data fall into five major categories:

- Maintenance data,
- Mileage data,
- Accident and fatality rates,
- Measures of service supplied and consumed, and
- Performance indicators.

The data used to describe the characteristics of the nation's transit network and the level and quality of service provided by our nation's transit authorities were compiled from the FTA's Section 15 Data Tables.[16] These data provide detailed summaries of financial and operating data submitted to the FTA by the nation's transit agencies. The FTA has gathered the data yearly since 1979; however, significant inconsistencies exist for the years prior to 1984.

Under subcontract to FTA, the Transportation Systems Center maintains this database and electronically readable copies of the annual data can be obtained from a private vendor, again operating under contract to FTA. The Transportation Systems Center conducts a detailed examination of each transit system's report, and identifies errors or questionable entries. A transit system's report can be rejected if it is not in full compliance with reporting requirements or the data may not be entered if any data items are of questionable reliability. FTA or the Transportation Systems Center cannot change any reported data; all changes must be made by the reporting transit system.

In the 1984 through 1987 annual reports, data whose validity and reliability were questionable were not entered into the

Section 15 database. In the 1988 through 1990 reports, the values of uncertain data were included in the database followed by a "Q" for "questionable" data. The data affected are those where the transit system failed to respond satisfactorily to questions raised during the validation process and/or did not collect the data in accordance with required FTA definitions and requirements.

For the variables we use in our dataset, questionable data were a significant problem in two areas. First, a number of variables have significant amounts of questionable data for the year 1987. For example, questionable data were reported for the following variables: annual scheduled vehicle revenue miles, annual vehicle miles, annual actual vehicle revenue miles, annual vehicle revenue capacity miles, annual vehicle hours, annual vehicle revenue hours, annual unlinked passenger trips, and annual passenger miles.

In order to compensate for these questionable data, other existing data were used to estimate the missing values. Specifically, missing values were estimated by trending other available information for the states and variables in question.

Second, all of the performance indicator variables have significant questionable data for most of the years reported. Thus, trending was not a viable option since more reliable data were not available. Since these are the only performance data available, all available data were merely summed. Given the extensive presence of questionable data, however, the results of any analysis using these data should be interpreted with caution. This is clearly one area where further work needs to be done in the future to develop more consistent, comprehensive, and meaningful data.

The FTA data are broken down by transit mode and by transit system. FTA recognizes 13 different modes and some 500 different transit systems.[17] Data for all transit systems within a state were summed to get state totals (and Washington, D.C.). These data were reported for the five most common transit modes:

- CR – Commuter Rail (using existing railroad rights-of-way);
- RR – Rapid Rail (e.g., Bay Area Rapid Transit System);
- SC – Streetcar or Light Rail;
- MB – Motorbus; and
- DR – Demand Response (e.g., dial-a-bus).

The resulting dataset contains state totals of transit system data for each of the 50 states and Washington, D.C., for five different modes of transit from 1984 to 1990. The complete dataset is described in Appendix A.

Airports and Airways

In this category, the data collected described the level of service provided by the nation's airports and airways. The dataset includes information on domestic and international annual operations by state from 1972 to 1989.[18] The data come from Table 2 of the Annual Airport Activity Statistics Report from the Research and Special Programs Administration of the FAA. In order to gauge the level of service provided, data were collected on the following variables for both domestic and international service:

- The total number of scheduled departures made at an airport as set forth in the air carriers published schedule;
- The total number of scheduled departures actually performed or completed pursuant to published schedules at each airport;
- The total number of departures performed, which includes both scheduled and unscheduled (e.g., charters) aircraft takeoffs;
- The total number of revenue passengers boarding aircraft (i.e., enplanements); and
- The total number of revenue tons of freight (excluding mail, express, and passenger baggage).

Dividing item two by item one gives the percent of scheduled flights actually completed; this reflects the quality of service provided to some extent.

Network Characteristics

DATASET	STATES	VARIABLES	TIME PERIOD
Federal Highway Statistics and Highway Performance Monitoring System	50+D.C.	Lane-miles, vehicle miles traveled, capacity-flow ratios	1984-1989 1970-1980 1981-1990
Federal Transit Authority - Section 15	50+D.C.	Various measures of service and finances	1984-1988
Federal Aviation Administration	50	Enplanement, freight, departures performed and scheduled	1972-1989

CONCLUSIONS

The dataset compiled here contains the following 14 different data files:

1. Gross State Product (Revised: 1977–1989, Unrevised: 1963–1986)
2. Earnings by Industry (1969–1990)
3. Employment by Industry (1969–1991)
4. Private Capital Stock Estimates by Industry—National Totals (1947–1991)
5. State-Level Private Capital Stock Estimates by Industry Using Employment Shares as Allocators (1970–1989)
6. State-Level Private Capital Stock Estimates by Industry Using GSP-IBT Shares as Allocators (1970–1989)
7. State-Level Infrastructure Spending on Six Categories of Infrastructure (1977–1990)
8. National Infrastructure Spending on Six Categories of Infrastructure (1902–1990)
9. State-Level Public Capital Stock Estimates for Six Categories of Infrastructure (1977–1990)
10. Highway Capital and Maintenance Outlays by State Constructed from FHWA Data (1931–1989)
11. Highway Capital Stock Estimates by State Using FHWA Data (1931–1989)
12. Highway Characteristics by State (Various time series)
13. Transit Characteristics by State (1984–1988)
14. Airport and Airways Characteristics by State (1972–1989).

Not surprisingly, we were not always able to obtain or generate all of the data in the form or for the time periods we would have liked. The dataset described here, however, has significant value-added compared to other datasets used to examine the link between transportation investment and economic performance. Specifically, this dataset contains

- Private capital stock estimates by state and by industry that are conceptually appealing, comprehensive in the coverage across industries, consistent over time, and based on easily accessible and reproducible data;
- Public capital stock estimates, available by state, that disaggregate public capital into six categories (including four transportation categories), adjust state highway capital stock estimates for actual maintenance, and are based on actual capital outlays by state and local governments; and
- Network characteristics that reflect, to some extent, the level and quality of service provided by each of the transportation modes examined.

Chapter 3 presents initial empirical findings of three studies that employ these data to investigate, on a disaggregate level, the relationship between transportation investment and economic performance.

ENDNOTES

1. Trott, Edward A., Jr., Ann E. Dunbar, and Howard L. Friedenberg, "Gross State Product by Industry, 1977–89." *Survey of Current Business* (December 1991) pp. 43–59.
2. This paper is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (order number PB-85-240-885). The information is also presented in Trott, Edward, A., Jr. et al., "Gross State Product by Industry, 1963–86," *Survey of Current Business* (May 1988) and Trott, Edward A., Jr. et al., "Gross State Product by Industry, 1977–89," *Survey of Current Business* (December 1991).
3. De Leeuw, Frank, Michael F. Mohr, and Robert P. Parker, "Gross Product by Industry, 1977–88: Progress Report on Improving the Estimates." *Survey of Current Business* (January 1991) pp. 23–37.
4. U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Measurement Division, "State Per Capita Personal Income, 1985–90, and State Personal Income, 1988–90: Revised Estimates." *Survey of Current Business* (August 1991) pp. 29–42.
5. Garcia-Mila, Teresa and Therese J. McGuire, "The Contribution of Publicly Provided Inputs to States' Economies." *Regional Science and Urban Economics*, Vol. 22, No. 2 (June 1992).
6. According to BEA, even in this dataset annual investment flows for nonmanufacturing sectors are allocated to individual states based on GSP shares.
7. Munnell, Alicia H., "How Does Public Infrastructure Affect Regional Economic Performance?" *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell (ed.), Federal Reserve Bank of Boston (1990) pp. 69–103.
8. McGuire, Therese J., *Highways and Macroeconomic Productivity: Phase II.* Report prepared for the Federal Highway Administration and the Volpe National Transportation Systems Center (March 31, 1992).
9. Hulten, Charles R., "The Measurement of Capital," *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth.* Ernst R. Berndt and Jack E. Triplett (eds.), University of Chicago Press (1990) p. 144.
10. We want to use a measure of economic activity as the state allocator. Since indirect business taxes vary across states and are unrelated to the productive activity of a business, they are excluded from gross state product.
11. For a discussion of how BEA estimates are generated, see U.S. Department of Commerce, Bureau of Economic Analysis, *Fixed Reproducible Tangible Wealth in the United States, 1925–89.* U.S. Government Printing Office, Washington, D.C. (January 1993).
12. Data before 1957 were obtained from U.S. Department of Commerce, Bureau of Public Roads, *Financing Highways by Counties and Local Rural Governments, 1931–42.* Tables 23–33 (LF-D-2), U.S. Government Printing Office, Washington, D.C. (1949); U.S. Department of Commerce, Bureau of

Public Roads, *The Financing of Highways by Counties and Local Rural Governments, 1942 to 1951*, Tables 25–34, U.S. Government Printing Office, Washington, D.C. (with annual updates from Federal Highway Administration); *Highway Statistics* (annually from 1950 to 1957), Table LF-D-2 (LF-21 in 1956 and 1957); and U.S. Department of Commerce, Bureau of Public Roads, *A Quarter Century of Financing Municipal Highways, 1937–61*, Tables 50–70 (UF-21), U.S. Government Printing Office, Washington, D.C. (1964).
13. These assumptions follow U.S. Department of Transportation, *Capital Stock Measures for Transportation: A Study in Five Volumes*. U.S. Government Printing Office, Washington, D.C. (1971).
14. For more detailed discussion of the methodology and assumptions used to generate these capital stock series, see Eberts, Randall, Chul Soo Park, and Douglas Dalenberg, *Public Infrastructure Data Development*. National Science Foundation (May 6, 1986).
15. We also talked with the Corps of Engineers about data for the nation's waterways. The data collected by the Corps, however, are organized by specific project and are not easily presented by state. For example, most of the projects are river- or watershed-specific and difficult to allocate to individual states. We do have a series from the Census Bureau that is total state and local spending on water transportation. To the extent that these data reflect spending on ports, which are really the critical factors that determine access to the nation's waterways, they more accurately reflect the economic benefits accruing to individual states from the nation's waterways.
16. Data Tables for the 1990s Section 15 Report Year. Federal Transit Administration, U.S. Department of Transportation, Washington D.C. (December 1991).
17. The number and size of transit systems within a state are positively correlated to the state's population and its number of urban centers.
18. The international component of the data is not reported separately after 1989.

APPLICATION OF DATASETS

INTRODUCTION

State and local transportation officials face important resource allocation problems daily. Citizens demand an improved level and quality of service, while the funds available to finance the maintenance and expansion of transportation networks are limited. In an environment of constrained resources, there will never be sufficient funds to satisfy all demands put on the nation's transportation networks. The critical issue faced regularly by state and local transportation officials, therefore, is how to allocate limited resources in a way that best meets household demand for transportation services, promotes economic activity, and enhances economic efficiency. This challenge is particularly important in the post-ISTEA environment where the focus has shifted to improving mobility and considering air quality issues, not simply building more highways.

In order to address these challenges, decision makers need better information about the linkage between transportation investment and economic performance on a level that allows policy differentiation by transportation mode and that recognizes differences across states. Much of the literature reviewed in Chapter 1 has very little bearing on the day-to-day challenges facing state and local transportation officials. This conclusion is based on the aggregate nature of most studies and the methodological approaches taken. This literature is critically important, however, because it does establish the intrinsic value of transportation services and confirms that such expenditures should be considered along with health care, education, and other government spending priorities rather than seen simply as a countercyclical tool. More certainly needs to be done in this area to verify, refine, and extend these findings. In addition, more needs to be done to understand the manner in which transportation investments and economic performance are linked so that state and local transportation officials can allocate scarce resources in the most effective manner.

In Chapter 2 a new dataset disaggregated by state, industry, and transportation mode was developed that includes information on

- Different types of transportation infrastructure;
- The characteristics and performance of different modes of transportation; and
- Private economic activity by different industries and states.

The purpose of this section is to present findings from preliminary empirical studies employing this new dataset. These studies complement and extend the literature reviewed in Chapter 1 through analysis disaggregated by state, industry, and transportation mode. The findings of these preliminary studies improve our understanding of the general benefits of transportation investments in a manner useful to state and local transportation officials. They demonstrate the value of disaggregate analysis, and suggest future directions for research that will generate information relevant to the decisions being made by state and local transportation officials. These studies are briefly summarized below.

THE COMPARISON OF HIGHWAY CAPITAL STOCK ESTIMATES

The relationship between public infrastructure and economic performance has generated considerable controversy in recent years. According to Dalenberg and Eberts (DE), the controversy is in part a result of the different data and methodologies used in various studies. Because the statistical relationship between infrastructure and economic activity rests on the accuracy of the measure of public capital stock, it is important to explore and compare estimates based on different data sources and methodologies. The DE paper compares new highway capital stock estimates generated as part of NCHRP 2-17(3) from FHWA and Census data with other estimates of highway capital stock.

After discussing the various methodologies used to generate capital stock estimates and analyzing the relations between different data series, DE conclude that

- The highway capital stock series generated using Census data as part of NCHRP 2-17(3) is an improvement over that of both Munnell and Holtz-Eakin because we use Census data for both the national capital estimates and for the states, rather than mixing different datasets;
- The highway capital stock series generated as part of NCHRP 2-17(3) using data from the FHWA is an improvement over all other capital stock estimates because it is based on a consistent data series that extends for a long enough time period to use the perpetual inventory methodology of accumulated past investments, without having to resort to any type of apportionment scheme;
- Assumptions about the appropriate average life and depreciation rates for highway investments seem to be critical in affecting national-level and state-level highway capital stock estimates; and
- Despite improvements in capital stock estimates, aggregate production function estimates using these new capital stock series do not differ appreciably from those based on previously constructed capital stock series, suggesting that while it is important to continue to improve estimates of public capital stock, such advancements do not appear to compensate for problems associated with modelling the relationship between public infrastructure and economic activity.

The next three studies investigate the linkage between transportation investment and economic performance from three different perspectives.

INDUSTRY PRODUCTION FUNCTIONS WITH HIGHWAY CAPITAL AS AN INPUT

Garcia-Mila and McGuire (GM) extend traditional production function analysis to investigate whether highway capital has differential effects on the output and productivity of different industries. This study represents an advancement over previous estimates of state-level production functions, which use aggregate measures of output, in that GM explores the possible impact of highway capital on productivity on an industry-by-industry basis. This paper sheds light on three related questions important to state and local transportation officials:

- Do certain industries benefit differentially from investment in highway capital?
- Does the restructuring of the U.S. economy away from goods production to services affect the productivity of highways?
- Should investment in highway capital be directed toward certain regions of the country because these regions have high concentrations of industries that are strongly, positively affected by highway infrastructure?

The GM study involves estimation of industry-specific production functions using a panel dataset consisting of annual observations of private economic and public capital variables for the 48 contiguous states extracted from the dataset generated for NCHRP 2-17(3). The preliminary results of this analysis suggest two important findings:

- Highway capital stock has no statistically significant impact on output in four industries, but does have a significant effect on three industries, including retail trade and services, indicating that highways will become increasingly important in the productivity of our service-based economy; and
- State-level, industry-specific analysis provides more useful information to state and local transportation officials because the findings for the analysis of aggregate output show no effect of highway capital on output, essentially neutralizing the statistically important differential effects of highway capital on different industries that constitute aggregate output.

TRANSPORTATION INVESTMENT AND ECONOMIC ACTIVITY: EVIDENCE FROM PUBLIC SECTOR DEMAND ANALYSIS

Man and Bell (MB) investigate the linkage between transportation investment and economic performance by starting with the premise that transportation services are an intermediate good in private consumption and production processes. In other words, to understand the linkage between transportation investment and economic performance, we need to identify demographic and economic factors, typically beyond the control of state and local transportation officials, that influence the derived demand for transportation services. Specifically, MB propose and empirically test a demand equation for transportation services in an effort to address two critical questions important to state and local transportation officials:

- Is the demand for transportation services responsive to changes in demographic variables like per capita income, urbanization, age distribution of the population, and poverty rates and, if so, does the response vary by transportation mode?
- Is the demand for transportation services responsive to economic restructuring and the changing sectoral composition of the economy, and, if so, does the response vary by transportation mode?

MB estimate a traditional public goods demand equation for total transportation investment and for three individual modes of transportation: highways, mass transit, and airports. The results are encouraging, albeit preliminary. Specifically, they find that

- The demand for transportation investments is much more sensitive to personal income than traditionally thought;
- Demographic trends beyond the control of state and local officials impact the demand for investment in individual modes of transportation in different but important ways;
- As suggested by GM, industry mix is an important element in determining the demand for transportation investment and it has different implications for individual transportation modes; and
- Considering the level and the quality of service *provided* (not just the level of spending on each mode) is important.

TRANSPORTATION AND OTHER PUBLIC INFRASTRUCTURE IN A NEOCLASSICAL GROWTH MODEL

Crihfield and Panggabean (CP) adopt yet another approach to understanding the linkage between transportation investment and economic performance. Specifically, CP estimate a neoclassical growth model using the disaggregated dataset generated for NCHRP 2-17(3), to investigate the productivity of public capital. In this model, growth in per capita income in a region is determined by the endowment of various factors including private capital, labor, technology, and public capital.

CP conclude that public infrastructure's impact on metropolitan economies appears to be weak, at least at the margin. This is particularly true for growth in per capita income. These results are consistent regardless of which measure of highway capital stock they use, adding support to the DE conclusion that model specification is as important in understanding the link between transportation investment and economic performance as obtaining good estimates of the value of highway capital stock.

CONCLUSIONS

The empirical studies included in this section extend the analysis of the link between transportation investment and economic activity to consider many different dimensions and manifestations of that relationship. While the analytic approaches vary, the findings are surprisingly consistent and demonstrate the improved level and quality of information made available to state and local transportation decision makers from analysis disaggregated by state, industry, and transportation mode.

CHAPTER 3

COMPARATIVE ANALYSIS OF CAPITAL STOCK ESTIMATES*

The relationship between public infrastructure and economic activity has generated considerable controversy in recent years. Research by Aschauer (1989) and Munnell (1990) suggested that investment in public infrastructure, such as roads and highways, can bring about sizable returns in the form of increased economic activity. The most optimistic estimates based on Aschauer's work indicate that a dollar of public investment adds as much output as $3.30 invested in private capital.

However, the estimates and the underlying methodology used to generate these results have come under close scrutiny by the profession. A host of studies have emerged that have shown that Aschauer's results are not supportable. Holtz-Eakin (1992), Hulten and Schwab (1991), and Tatom (1991), for example, show that public infrastructure has little or no statistically significant effect on economic activity, and in some cases the effect is even negative.

Because the statistical relationship between infrastructure and economic activity rests on the accuracy of the measure of public capital stock, it is important to explore and compare different estimates. The purpose of this paper is to compare several estimates of state-level highway public capital, which are derived from different data sources, using different methodologies. Although an additional dollar of public investment may not yield the large returns indicated by previous studies, the importance of public infrastructure in the U.S. economy cannot be denied. Therefore, the issue of the measurement of public capital stock is still paramount in critically assessing the supply, and ultimately the effect, of public infrastructure in the U.S. economy.

One of the realizations in the recent investigation of the linkage between infrastructure and economic activity is that national level analysis, based on the correlation of time series, produces spurious results. Attention has therefore been given to subnational analyses, which are better able to control for such effects. This level of analysis depends upon measures of public and private capital stock, which unfortunately are not readily available, leaving researchers to construct their own series.

Two basic approaches have been suggested for measuring public infrastructure at any level of aggregation. One method measures capital by summing the value of past capital purchases adjusted for depreciation and discard value, referred to as the perpetual inventory method (PIM). An alternative approach is to use physical measures by taking inventory of the quantity and quality of all pertinent structures and facilities.

While each approach has its advantages and disadvantages, most researchers have adopted some variant of a PIM. Consequently, this paper focuses only on estimates based on a PIM-type methodology. The advantage of the PIM is twofold. The Bureau of Economic Analysis (BEA) uses this technique to estimate public capital and private capital at the national level. This established methodology offers benchmarks and other depreciation and discard schedules that can be used to construct state-level estimates. In addition, since most analyses of the effect of public infrastructure on economic activity are based on a neoclassical production function, current input capital should be measured as the maximum potential flow of services available from the measured stock. The PIM yields such a measure by using a depreciation function that reflects the decline in the asset's ability to produce as much output as when it was originally purchased.

Of course, the ability to accurately measure the maximum flow of capital services using the PIM depends upon the accuracy of the depreciation and discard functions and the price deflators. For subnational estimates, these components should vary by the unit of analysis in order to reflect differences in construction costs, usage, and differences in maintenance.

Only a few subnational measures of public capital stock are available, and most are hybrids of the PIM. For instance, instead of accumulating state-level government capital outlays, several studies apportion national public capital stock estimates to states using a variety of state allocators. In addition to the major drawback of finding the appropriate allocators, this approach does not embody the accumulation of state-level investments but adopts national-level depreciation and discard functions for each state, and it does not take into account state differences in construction costs per unit of capital.

This paper offers two new estimates of highway public capital stock, which are different from previous estimates and improve upon previous methodologies. Our benchmark

* Contributing authors: Douglas R. Dalenberg, Department of Economics, University of Montana, Missoula, MN; and Randall W. Eberts, W.E. Upjohn Institute of Employment Research, Kalamazoo, MI.

estimate for purposes of comparison is the series constructed by Munnell. Other estimates, including those derived by Garcia-Mila and McGuire (1992) and Holtz-Eakin (1993), have been constructed and used in a production function framework. We selected Munnell's data, however, because they have been widely used and because they offer a convenient opportunity to compare estimates. Comparisons are made in two ways. First, the relationships between the different estimates are examined in various ways, including a regression analysis following Holtz-Eakin (1993). Second, the estimates are entered into several specifications of a Cobb-Douglas production function, in order to discern whether or not the different series yield different results.

PERPETUAL INVENTORY METHOD

The measure of capital under the PIM is the sum of the value of past capital purchases adjusted for depreciation and discard. Two assumptions are necessary when applying this technique. First, that the purchase price of a unit of capital (which is used to weight each unit of capital put in place) reflects the discounted value of its present and future marginal products. Second, a constant proportion of investment in each period is used to replace old capital (depreciation). The first assumption is met if a perfectly competitive capital market exists. The second assumption is fulfilled if accurate estimates of the asset's average service life, discard rate, and depreciation function are used.

A frequent criticism of the PIM for public capital stock is that the government is not subject to competitive markets, and public goods are not allocated through a price mechanism. Arguments can be made that governments, particularly state and local governments that construct most of the nonmilitary public capital stock, are subject to market forces (see Eberts and Gronberg, 1990).

The major problem in constructing state and local estimates of public capital stock is the availability of data. Since public capital stock is quite durable, with an average life approaching 50 years in some cases, annual times series exceeding 50 years are required to sufficiently accumulate data that account for all current capital stock. Eberts, Fogarty, and Garofalo pursued such an approach for 40 metropolitan areas, collecting public outlays for each city since 1904 in order to construct a capital stock series from 1958 to 1985.

However, public outlays by both state and local governments, within each state, are not available for this length of time. A consistent annual series of state *and* local government outlays does not begin until 1958, which is too short a period for a meaningful estimate of public capital stock.

MUNNELL'S METHODOLOGY

To circumvent the data problem, Munnell (1990) apportioned the BEA national estimate of state and local public capital stock to each state for each year. She used a truncated capital stock estimate, following the BEA method, as the allocator for each state. The capital stock is truncated in that data were not available before 1958, so investments before that time were not recorded. Munnell suggests that using this pseudo-capital stock estimate only to allocate national capital stock, which incorporates an adequate history of investment, reduces the bias.

The first step in her approach was to deflate annual data on nominal dollar investment in each state into constant dollar investment with the same deflators used by the BEA in its calculations of national public capital stocks. Next, BEA's assumptions regarding discard functions (modified Winfrey S-3) and average service lives (60 years for highways) were used to obtain the value of discards, which were subtracted from the annual real investments. Third, a depreciation function was constructed, using BEA's assumption of straight-line depreciation over the service life of the asset. Subtracting depreciation from the original annual investments left the net value in the end year of each period's investment. These values were summed to obtain the net value of the capital stock in that year. Finally, the capital stock for each state was used to allocate BEA's national capital stock to each state in that year.

This approach introduces some biases as Munnell and later, Holtz-Eakin (1993), point out. First, Munnell offers that her method will underestimate capital stock in older regions that have put in place a sizable portion of their capital stock before 1958, and overestimate capital stock in newer regions. She reports that the sum of estimates across states equaled approximately 75 percent of the BEA total state and local net stock measure in 1970, and that by 1980 it equaled 97 percent. Second, Holtz-Eakin suggests that the capital stock that was estimated using Munnell's technique will be biased upward for states that have accumulated capital faster than the national average, and vice versa. Third, Munnell's approach mixes data sources which also leads to some bias. BEA's national-level capital stock data are based on data obtained from the National Income and Product Accounts, while the state-level estimates come from Census data. Munnell reports that the sum of state estimates in 1986 was 108 percent of the BEA total.

STATE-LEVEL HIGHWAY ESTIMATES USING FHWA DATA

Although Munnell encountered data problems when constructing a comprehensive measure of public capital stock, sufficient data are available to construct state-level highway capital stock using the PIM. The FHWA has collected data on outlays and maintenance on state-administered highways, county and local rural roads, and municipal highways at all levels of government from 1931 to 1989. Appendix 3-1 lists the data sources and assumptions for constructing the capital and maintenance series.

TABLE 3–1 Asset life assumptions for highway capital, version 1

Percent	Average Life	Justification
52	14 years	Paving
26.5	80 years	Grading
21.5	50 years	Structures
100	4 years	Maintenance

TABLE 3–2 Asset life assumptions for highway capital, version 2

Percent	Average Life	Justification
32.8	14 years	Paving
16.7	80 years	Grading
13.6	50 years	Structures
37	4 years	Maintenance

The capital stock estimates were constructed using the PIM. The assumption made was that discards followed a truncated normal distribution, with the truncation occurring at one half the average life and at one and one-half times the average life. An efficiency depreciation schedule was used with a depreciation parameter of 0.9, which is relatively close to the depreciation schedule with a parameter value of 1. The straight-line depreciation schedule would take a value of 0 (see U.S. DOT, 1971). The FHWA composite price index was used to deflate outlays to 1982 dollars (see *Statistical Abstract of the United States*).

Two versions of highway capital stocks were estimated. The first version treated maintenance as a separate stock. Table 3–1 contains the assumptions regarding average life for the various components of highways, which follow U.S. Department of Transportation (1971). Maintenance was calculated as a separate addition to the stock and was assumed to have an average life of four years. The second version considers maintenance to be another component of highways and is assumed to account for 37 percent of content of highway capital, as shown in Table 3–2. This assumption was based on the average of the ratio of maintenance to capital outlay plus maintenance for the entire time series. Although including maintenance improves the accuracy of the highway stock estimates, the decision was to concentrate only on capital stock estimates without maintenance in the rest of the paper in order to keep the comparisons as similar as possible. In this case, the distribution of the three highway components are the same as in Table 3–1, excluding maintenance.

Even though construction of these highway series based on FHWA data follow the BEA's version of the PIM methodology, further improvements could be made. Price deflators, average lives, depreciation, and discard functions are the same for each state. As mentioned earlier, construction costs due to local market conditions and variations in climate and terrain, wear and tear, and obsolescence vary by state and are not reflected in these measures.

STATE-LEVEL HIGHWAY ESTIMATES USING CENSUS DATA

State-level public capital stock estimates were also constructed for several categories of infrastructure, following Munnell. The Governments Division of the Census Bureau provides total annual state and local capital outlays by state from 1977 through 1990. The categories of infrastructure were: Total, Air Transportation, Water Transportation, Sewer, Water Utilities, Mass Transit, and Highways. Since 14 years is too short a series to apply the PIM to, estimates of capital stocks for individual states were made by apportioning U.S. capital stock in 1976 and 1990 and then applying the Holtz-Eakin method (1993) to estimate state capital stocks for 1977 through 1990.

Construction of the U.S. highway capital stock, which is apportioned to states, is described below. The advantage of this approach over Munnell is that the national level estimates used are computed from the same Census data that we use to construct state-level estimates. Furthermore, according to Holtz-Eakin (1993), the apportionment technique does not introduce as much bias as the Munnell allocator. Since the focus here is on highway capital stock, the description of this approach will mention only the highway component, even though the other components were calculated in a similar manner.

The first step in generating a highway capital stock measure was to construct a capital stock series at the national level, which would then be apportioned to states following the procedure suggested by Holtz-Eakin. The national-level series was estimated using Census investment data from 1932 to 1990 and follows the BEA's assumptions of average lives, and so forth.[1] Therefore, these estimates differ from Munnell's, who used NIPA-based investment, and from the national aggregate of the FHWA-based highway capital stock. For example, Munnell reports the 1990 national highway stock to

[1]Actually, an unbroken annual investment series is available only from 1952 to 1990, which is a rather short investment series for the PIM. The data series was extended to 1932 by interpolating capital outlay data for the odd years from 1933 through 1955.

be $722 billion, whereas the estimate here is $807 billion. The FHWA-based estimate (minus maintenance) is $711 billion in 1989, which is the latest year available.

The national capital stock was apportioned to states on the basis of the average of the ratio of state expenditure to U.S. expenditure for the period 1977 through 1990. Using two capital stock benchmarks, 1976 and 1990, an imputed depreciation rate was calculated using the U.S. capital outlay data. State capital stocks were calculated following Holtz-Eakin (1993), where capital is the 1976 state capital estimate plus the sum of investment adjusted for depreciation. The FHWA composite price index was used to deflate highway outlays to 1982 dollars (see *Statistical Abstract of the United States*).

COMPARISONS OF HIGHWAY CAPITAL STOCK MEASURES

Each of the various methods of constructing highway capital stock yields state-level estimates for several years. Munnell estimated public capital stock for the period 1969 through 1986.[2] The estimates here of highway capital stock using FHWA data extended from 1970 through 1989, and estimates using Census data went from 1977 through 1990. Therefore, the comparisons here will be based on the intersection of the three data series, 1978 through 1986. All capital stock estimates were converted to 1982 dollars for comparison purposes.

Table 3–3 displays per capita highway capital stock for 1986 for each of the three series. The FHWA series generated the highest level of capital stock, even without including maintenance, which is not included in the other two series. The average per capita highway stock under the FHWA method was $2,801. This estimate is 5.3 percent higher than the Munnell estimate of $2,659 but only 0.5 percent higher than the Census-based estimate of $2,789.

Sensitivity to Depreciation and Average Life Assumptions

Several factors contribute to the difference in capital stock estimates, including differences in gross outlays and in assumptions regarding average life and depreciation rates. To illustrate the sensitivity of estimates to the depreciation and average life assumptions, national highway capital stock was computed using two different depreciation rates and measures of average lives. A comparison was made between the straight line method adopted by Munnell and the efficiency method used in this report's estimates. Munnell's 60-year average life, adopted from the BEA, was also compared with this report's 40-year average life, following the FHWA. Gross outlays were kept the same in each estimate.

[2]Munnell updated the capital stock series through 1988, but we had access only to data up to 1986.

As shown in Figure 3–1, the two depreciation rates yield significantly different amounts of public capital stock. U.S. highway capital stock was $169 billion (or 45%) higher in 1989 when the efficiency depreciation rate was used than when the straight line method was adopted. This difference follows from the fact that the straight line method depreciates a greater percentage of the capital during the first several years of an asset's life than does the efficiency method. For example, after 10 years, 94 percent of the capital stock remains under the efficiency assumption, while only 54 percent remains using the straight line assumption. Therefore, during periods in which new investment is high and consequently a higher proportion of the asset is relatively new, the difference in the capital stock estimates under the two depreciation rate assumptions would be larger.

However, Munnell's estimates are much closer to this report's estimates than the simulation would suggest. The different average life assumptions narrow the gap. According to simulations made here using the same national-level gross outlays as before and an efficiency depreciation rate, the additional 20 years of average life raises 1989 highway capital stock by $322 billion or 56 percent. Applying the 40-year average life to the straight line method yields a capital stock estimate that is higher than the estimate derived from the efficiency depreciation rate with a 40-year average life assumption. In short, the average life assumption has a larger effect on capital stock estimates than does the depreciation assumption. Furthermore, the older the capital stock is, the larger the effect will be.

Comparing State-Level Estimates

Obviously, adopting different depreciation and average life assumptions will have a significant impact on state-level estimates, as states invest in public capital at different rates. Furthermore, this example illustrates the importance of using state-specific depreciation rates and average lives, which reflect the effect of weather and usage on highway capital stock. Using a single depreciation rate and average life for all highways can lead to gross overestimates and underestimates of highway capital stock for individual states.

As a result of different depreciation and average life assumptions, as well as other factors, the various state-level estimates of highway capital stock vary widely. The FHWA-based estimates exhibit the widest range of values, with Wyoming having the largest amount of highway capital stock per person ($7,007) and South Carolina having the least amount ($1,447). The ranges for the other two estimates are of similar magnitudes with the same states possessing the most and least highway infrastructure per capita.

However, the estimates for each state vary widely in several instances. As shown in Table 3–3 and displayed graphically in Figure 3–2, the Census estimate for Arizona is 47 percent higher than Munnell's estimate and the FHWA estimate is 28 percent higher than Munnell's. Munnell suggested

TABLE 3–3 Per capita highway capital stock, 1986 (in 1982 dollars)

				Percentage Difference	
State	Munnell	Census	FHWA	Census/Munnell	FHWA/Munnel
WY	6708	6855	7007	2.19%	4.46%
NV	5527	5770	5796	4.40%	4.87%
MT	5000	4498	5639	-10.04%	12.78%
ND	4603	4339	5169	-5.74%	12.30%
SD	4564	4251	5102	-6.86%	11.79%
WV	3936	3531	4196	-10.29%	6.61%
IA	3648	3773	3781	3.43%	3.65%
VT	3383	3277	3565	-3.13%	5.38%
NE	3344	3492	3508	4.43%	4.90%
KY	3258	2966	3068	-8.96%	-5.83%
DE	3242	2884	3212	-11.04%	-0.93%
MN	3026	3478	3416	14.94%	12.89%
KS	2973	3358	3220	12.95%	8.31%
LA	2949	2883	3051	-2.24%	3.46%
ID	2880	2994	3244	3.96%	12.64%
NM	2769	3331	2897	20.30%	4.62%
WA	2360	2803	2772	18.77%	17.46%
MS	2535	2658	2785	4.85%	9.86%
UT	2493	2640	2556	5.90%	2.53%
OR	2485	2537	3167	2.09%	27.44%
MD	2462	2725	2466	10.68%	0.16%
VA	2459	2649	2370	7.73%	-3.62%
IL	2432	2445	2335	0.53%	-3.99%
NH	2288	2815	2058	23.03%	-10.05%
WI	2268	2780	2340	22.57%	3.17%
TN	2238	2229	2268	-0.40%	1.34%
MO	2216	2148	2110	-3.07%	-4.78%
OH	2210	1929	1992	-12.71%	-9.86%
ME	2163	2747	2319	27.00%	7.21%
CT	2154	2320	2084	7.71%	-3.25%
MI	2099	1924	1922	-8.34%	-8.43%
NY	2038	2211	2112	8.49%	3.63%
PA	2005	2007	2207	0.10%	10.07%
TX	2004	2299	1990	14.72%	-0.70%
AZ	1998	2934	2556	46.85%	27.93%
AR	1962	2283	2240	16.36%	14.17%
AL	1956	2030	2100	3.78%	7.36%
OK	1937	2306	2130	19.05%	9.96%
RI	1932	1788	1871	-7.45%	-3.16%
IN	1920	1890	1871	-1.56%	-2.55%
GA	1895	2208	2217	16.52%	16.99%
CO	1865	2526	2118	35.44%	13.57%
NJ	1799	2142	1716	19.07%	-4.61%
CA	1605	1414	1630	-11.90%	1.56%
NC	1602	1781	1642	11.17%	2.50%
FL	1564	1848	1555	18.16%	-0.58%
MA	1540	1731	1658	12.40%	7.66%
SC	1328	1396	1447	5.12%	8.96%
Average	2659	2788	2802		

that her methodology would overestimate the capital stock of newer regions compared to older regions. While it is not possible to directly test this hypothesis, since the FHWA (the only series of the three that incorporates the "true" PIM for each state) is based on a different data source than Munnell's, it is still instructive to point out that Munnell's estimates appear to understate highway capital stock in states with more recent growth.

Figure 3–3 plots the percentage difference in the FHWA and Munnell estimates in 1986 (taken from Table 3–3) against percentage population change from 1977 through 1986. There appears to be a positive correlation between these two series, with a simple correlation coefficient of 0.25. Furthermore, several states stand out. Arizona, which experienced a population increase of 42 percent during the 10-year period, exhibited the largest percentage difference between the FHWA and Munnell estimates. The difference in the FHWA and Munnell estimates of Oregon's highway capital stock is of similar magnitude, and the state's population growth is above average. There are exceptions. Nevada

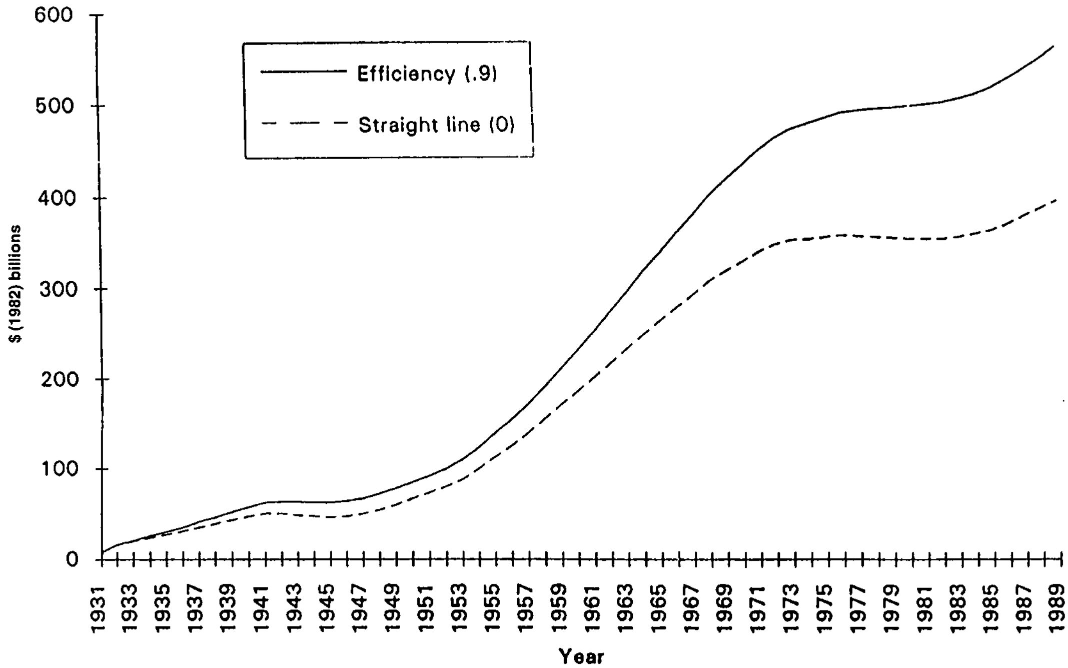

Figure 3–1. Highway capital stock under different depreciation assumptions.

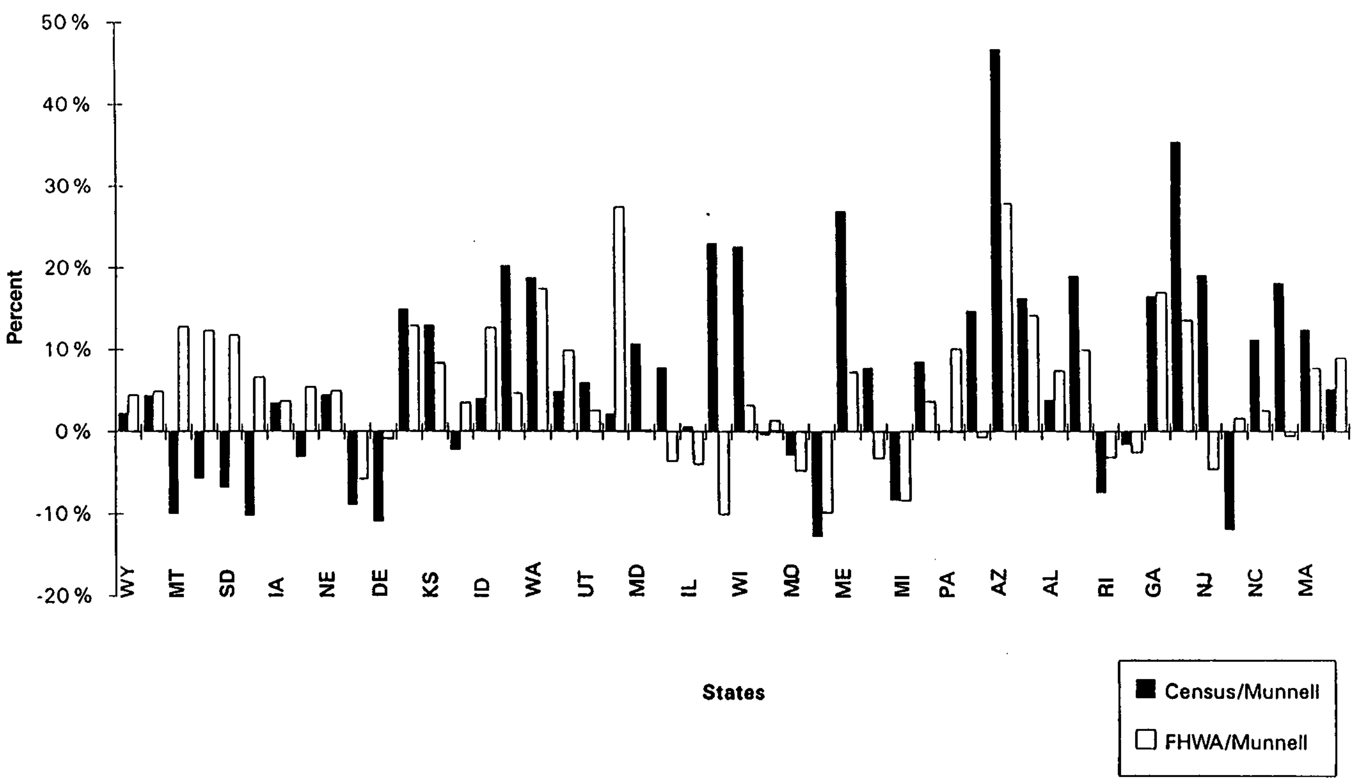

Figure 3–2. Percentage difference between per capita capital stock estimates, 1986.

Figure 3–3. Relationship between population growth and estimate differences.

registered the largest increase in population, but the FHWA estimate was only 5 percent higher than Munnell's. There was virtually no difference in the two estimates of Florida's highway capital stock, even though that state experienced the third highest population growth rate. While this positive relationship may not be conclusive, there is definitely no negative relationship, as hypothesized.

A stronger positive relationship existed between the difference in the Census-based estimates and Munnell's estimates and population growth. The simple correlation coefficient was 0.42, which is reflected in the upward trend exhibited in Figure 3–4. As with the FHWA estimate, the large difference in the estimates for Arizona's highway stock influences the upward trend. This relationship runs counter to the relationship between Holtz-Eakin's estimate and Munnell's. Holtz-Eakin's findings support his suggestion that the Munnell methodology should understate capital stock in recently growing areas. He shows that Munnell's estimates are higher than his for states with higher growth rates in GSP, but over a longer time period than used here. Nevertheless, since the Census estimates here use Holtz-Eakin's methodology (though the report's national estimates are based on Census, not NIPA data) a similar relationship would be expected.

In addition to cross-sectional differences in the various estimates, there are also differences in the rates of growth over time. Table 3–4 displays the percentage change in the various capital stock measures from 1977 through 1986. Population growth rates are included as a point of reference. Growth rates of Munnell's estimates average about 3 percentage points less than the growth rates of the FHWA and Census estimates. These differences are statistically significant. Growth rates of the FHWA and Census estimates, on the other hand, are not statistically different. For the FHWA estimates, Arizona, Arkansas, and South Carolina exhibit the largest differences, with the FHWA stock growing faster

Figure 3–4. Relationship between population growth and estimate differences.

TABLE 3–4 Growth rates by state, 1977–1986

State	Munnell	FHWA	Census	Population Growth
AL	5.35	11.45	7.62	22.09
AR	7.79	20.37	6.77	10.59
AZ	22.3	32.86	12.03	42.82
CA	-8.04	-4.3	7.35	23.31
CO	12.54	19.29	7.76	25.85
CT	-8.31	-0.867	8.96	2.74
DE	-4.95	5.34	9.85	8.76
FL	15.83	23.91	11.01	38.36
GA	20.16	21.64	11.35	20.84
IA	4.52	1.11	8.07	-1.01
ID	10.72	5.52	9.29	16.92
IL	4.72	9.41	8	2.72
IN	1.52	3.32	7.16	3.25
KS	8.25	10.13	9.32	5.72
KY	13.43	10.17	8.51	7.75
LA	14.08	18.86	10.34	14.74
MA	-1.24	-1.96	6.06	0.9
MD	14.28	19.8	9.73	7.78
ME	0.54	2.64	5.87	8.02
MI	-3.11	-2.79	4.56	0.11
MN	8.55	15.14	9.31	5.99
MO	1.8	1.12	8.48	5.48
MS	10.36	11.43	7.37	9.84
MT	5.11	8.05	9.61	7.36
NC	4.04	5.86	4.12	14.59
ND	6.19	10.63	8.32	3.98
NE	10.63	9.76	8.7	2.37
NH	4.11	6.33	4.93	20.97
NJ	-1.69	-0.96	12.12	4.04
NM	16.98	14.16	12.32	24.29
NV	18.39	22.44	11.92	52.77
NY	-0.59	2.76	9.54	-0.72
OH	-4.69	-3.095	8.65	0.44
OK	7.91	4.08	9.53	17.61
OR	4.81	10.07	10.42	13.72
PA	-9.44	-4.28	5.62	0.93
RI	-8.22	-4.97	11.84	4.28
SC	-5.77	6	9.04	17.56
SD	-1.82	3.65	9.29	2.76
TN	4.71	7.27	9.58	11.65
TX	13.68	20.81	12.22	30.08
UT	13.08	14.82	13.52	31.23
VA	4.32	5.36	6.08	12.85
VT	-8.4	-6.15	5.87	12.01
WA	14.19	17.48	10.5	22.01
WI	2.79	8.8	6.59	2.84
WV	9.76	3.08	8.24	3.12
WY	17.35	24.2	15.77	24.88

than the Munnell stock. For the Census estimates, Arizona also displays a large difference, but this time Munnell's estimate grows faster. The FHWA and Census estimates of Connecticut's and California's capital stock also grow faster than Munnell's estimates. The relationships between these various measures are displayed in Figures 3–5 through 3–7. The FHWA estimates and Munnell's estimates exhibit a positive correlation, as one would expect if the two series closely track one another. However, the Census estimates and Munnell's estimates show little positive correlation. The same is true for the Census and FHWA estimates.

These relationships can be examined more precisely by following Holtz-Eakin's (1993) approach of regressing one series on another, while controlling for time and state effects using dummy variables. In this way, it is possible to discern the differences over time and across states of the various estimates, in addition to recording the simple pairwise correlation. Table 3–5 displays the estimates of various combinations under different model specifications. The relatively tight relationship between the FHWA estimates and Munnell's estimates is seen in the first set of estimates. In this model, the FHWA capital stock estimates are regressed against Munnell's estimates, with either time dummies or state dummies or both included in the regression.[3] Even though there are statistically significant differences across states and over time, the correlation between the FHWA and Munnell estimates is high and not appreciably affected by including the state and time dummies. Even so, there is a systematic difference over time between the two sets of estimates, as shown in Figure 3–8, in which the FHWA estimates are increasingly larger on average than Munnell's from 1982 through 1986.

On the other hand, differences across states have a notable effect on the relationship between the Census estimates and Munnell's estimates. When state dummy variables are included to account for state differences, the correlation is quite low, as indicated by the coefficient of 0.14. However, when the state differences are not accounted for, the correlation between the two series is 0.94. The same relationship holds for Census versus FHWA estimates, except that state differences do not affect the correlation as much as in the previous case.

COMPARING HIGHWAY PUBLIC CAPITAL STOCK WITHIN A PRODUCTION FUNCTION

Since the creation of additional capital stock estimates was motivated by the current interest in its effect on economic activity, as analyzed in a production function framework, the next logical step would be to enter the various estimates in a standard production function. A Cobb-Douglas framework was used, which was the form adopted by Munnell. State and time dummies were included, following the work by Holtz-Eakin (1992), which demonstrated the econometric problems associated with not controlling for fixed effects. To estimate the production function, Munnell's private capital stock estimates, employment, GSP, and unemployment rates were used. All variables, except the unemployment rate, are entered as logs. The time period from 1977 through 1986 is used once again, because this is the common time period for the three capital stock estimates.

The estimates of the production functions are shown in Table 3–6. As demonstrated by Holtz-Eakin (1992) and oth-

[3] In all cases the R-squares are high and the coefficients on the time and state dummy variables are, in statistical terms, significantly different from zero.

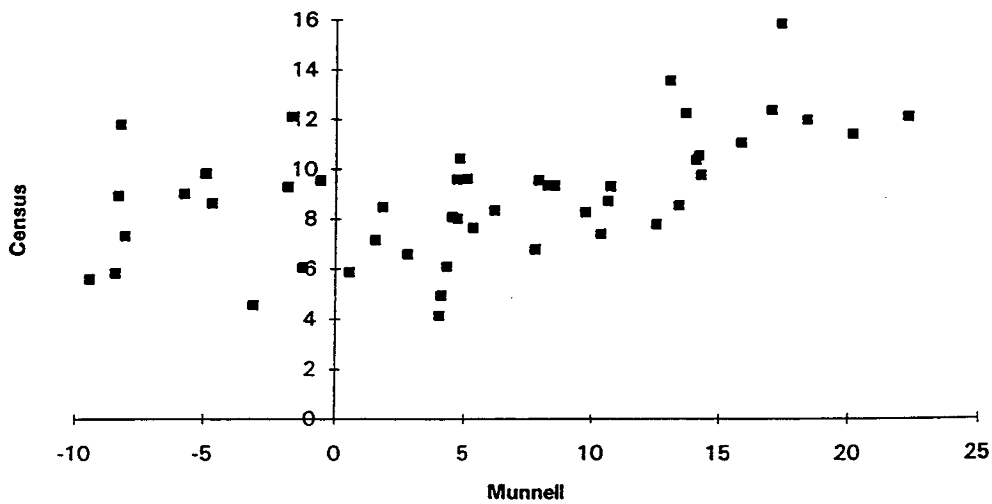

Figure 3–5. Percentage change from 1977 to 1986, Census versus Munnell.

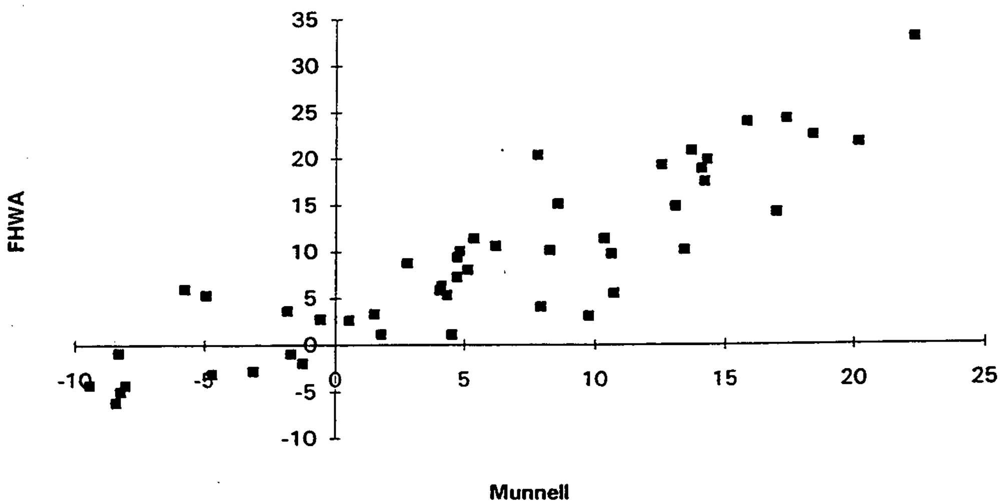

Figure 3–6. Percentage change from 1977 to 1986, FHWA versus Munnell.

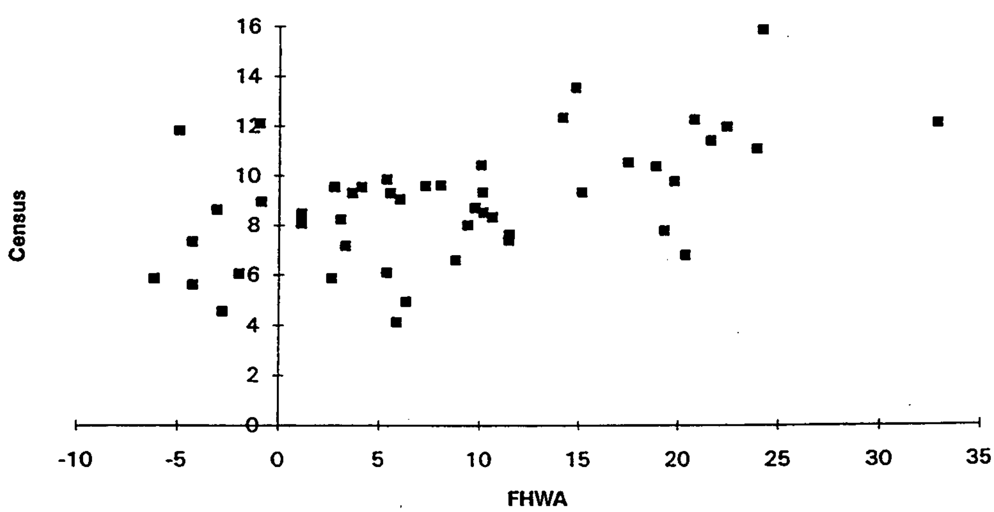

Figure 3–7. Percentage change from 1977 to 1986, Census versus FHWA.

TABLE 3–5 Regression estimates of pairwise comparisons of highway capital stock

Dependent Variable	FHWA			Census			FHWA		
Explanatory Capital Stock Variable	Munnell			Munnell			Census		
Coefficient Estimate	0.91	0.98	0.96	0.14	0.30	0.94	0.62	0.66	0.98
Time Dummies	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes
State Dummies	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No

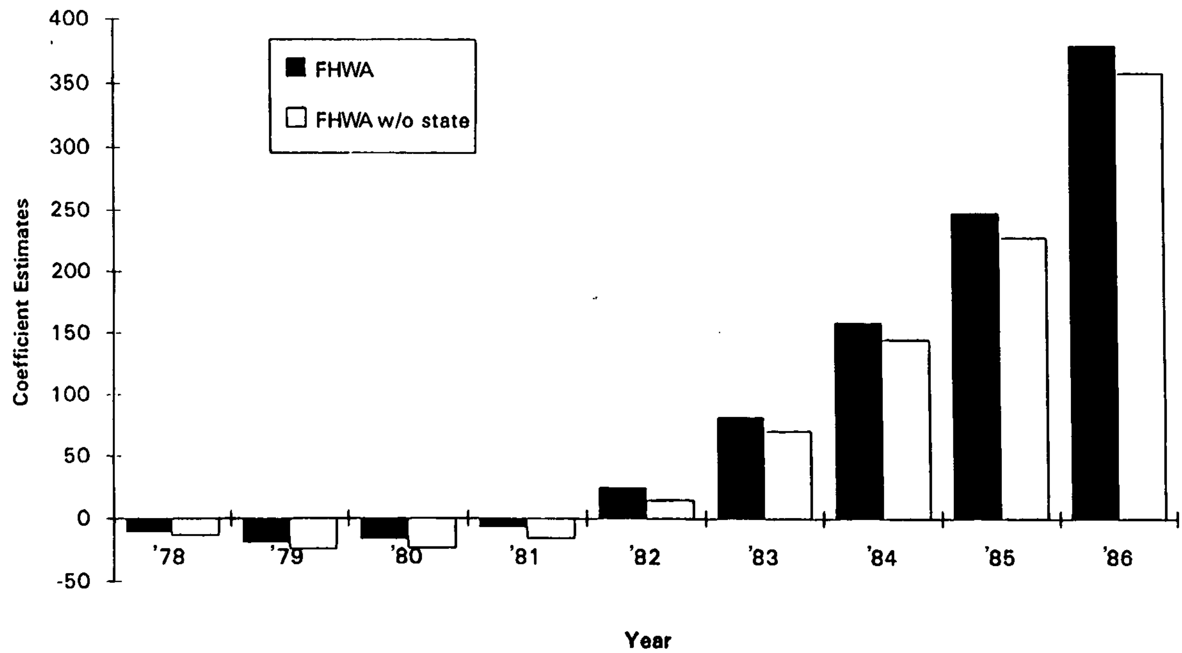

Figure 3–8. Coefficients of time dummies when FHWA estimates are regressed against Munnell estimates.

ers, public capital stock (in this case, highway capital) has a positive and statistically significant effect on output when fixed effects are not included. However, when state dummy variables are included, public capital stock is either statistically insignificant or negatively significant. More importantly, the properties of a production function break down, as the coefficient on labor exceeds 1 and the coefficient on private capital turns negative.[4]

Obviously, different capital stock series cannot compensate for problems with the specification of the model. In all cases, the coefficient on labor is 1 or greater, and the coefficient on the highway capital stock is negative when state dummy variables are included. When they are omitted, the Munnell capital stock and the Census capital stock yield similar results, with highway capital registering a modest but positive and statistically significant coefficient. The FHWA estimate is smaller by a magnitude of 10 and not statistically significant, while the other coefficients are very similar to those obtained when the Census and Munnell stocks were included. One would expect that the coefficient on highway capital would be smaller the larger the amount of capital available, holding everything else constant. While the FHWA stock yielded the highest estimates, the difference in magnitude between the two capital stock series, on average, is much smaller than inferred by the much smaller capital stock coefficient. This is somewhat puzzling since the FHWA and Munnell estimates tracked much more closely than did Munnell's and the Census estimates, according to several measures.

[4]Although not reported here, a first-difference model generates similar results.

TABLE 3–6 Estimates of a Cobb-Douglas production function with highway capital stock

Highway Capital Stock	Munnell		FHWA		Census	
Explanatory Variables						
Private Capital	0.31	0.18	0.33	-0.006	0.30	0.009
	(21.35)	(5.17)	(21.58)	(-0.18)	(20.10)	(0.26)
Employment	0.71	1.09	0.72	1.09	0.70	0.99
	(58.59)	(20.0)	(63.68)	(22.7)	(56.70)	(22.71)
Highway Capital Stock	0.05	-0.19	0.005	-0.31	0.06	-0.67
	(2.28)	(-3.06)	(0.25)	(-6.01)	(2.88)	(-5.04)
Unemployment rate	-0.01	-0.002	-0.009	-0.003	-0.009	-0.006
	(-5.56)	(-1.31)	(-5.35)	(-2.37)	(-5.20)	(-5.04)
Time Dummies	No	Yes	No	Yes	No	Yes
State Dummies	No	Yes	No	Yes	No	Yes

CONCLUSIONS

This section describes two additional estimates of highway capital stock, which are considered to be an incremental improvement over existing capital stock estimates. The differences in the various methodologies are outlined and differences in the estimates are documented. Put simply, the Census estimate methodology employed is an improvement over that of Munnell (and Holtz-Eakin), because Census data are used for both the national capital estimates and for the states, while Munnell mixes data sources. The FHWA estimate is an improvement over both of these methods, because it is based on data that cover a long enough time period to apply the PIM of accumulated past investments, without the need to resort to an apportionment scheme. (It is also superior, because it includes maintenance measures, although this dimension has not been explored here.[5])

Despite these improvements, at least conceptually, production function estimates using these new capital stock series do not differ appreciably from those based on previously constructed capital stock. Therefore, while it is important to continue to improve estimates of public capital, such advancements do not appear to compensate for problems associated with poor modeling of the relationship between public infrastructure and economic activity. However, based on simulations, what appears to be critical are the appropriate assumptions of average life and depreciation for national-level and state-level estimates. Further refinements using state-specific assumptions should be considered and explored.

[5]Garcia-Mila and McGuire (1992) also construct highway capital stock with features superior to Munnell, including operating expenses as a proxy for highway maintenance expenses.

SELECTED BIBLIOGRAPHY

Aschauer, David A., "Is Public Expenditure Productive?" *Journal of Monetary Economics*, Vol. 23 (1989) pp. 177–200.

Eberts, Randall W., and Timothy J. Gronberg, "Structure, Conduct, and Performance in the Local Public Sector," *National Tax Journal*, Vol. 43(2) (June 1990) pp. 165–174.

Garcia-Mila, Teresa, and Therese McGuire, "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*, Vol. 22 (1992) pp. 229–241.

Holtz-Eakin, Douglas, "Public-Sector Capital and the Productivity Puzzle," National Bureau of Economic Research, Working Paper, No. 4122 (July 1992).

Holtz-Eakin, Douglas, "State-Specific Estimates of State and Local Government Capital," *Regional Science and Urban Economics,* Vol. 23, No. 2 (April 1993) pp. 185–209.

Hulten, Charles R., and Robert M. Schwab, "Public Capital Formation and the Growth of Regional Manufacturing Industries," *National Tax Journal*, Vol. 43 (December 1991) pp. 121–134.

Munnell, Alicia H., "How Does Public Infrastructure Affect Regional Economic Performance?" *New England Economic Review* (September/October 1990) pp. 11–32.

Tatom, John A., "Public Capital and Private Sector Performance," *St. Louis Federal Reserve Bank Review* (May/June 1991).

U.S. Bureau of Economic Analysis, *Fixed and Reproducible Tangible Wealth in the United States*, 1925–1985, Washington D.C.: USGPO (June 1987).

U.S. Bureau of Labor, "Capital Stock Estimates for Input-Output Industries, Methods and Data," *Bureau of Labor Statistics Bulletin 2034*, Washington D.C.: USGPO (1969).

U.S. Department of Commerce, *Statistical Abstract of the United States*, Washington D.C.: USGPO (various years).

U.S. Department of Transportation, *Capital Stock Measures for Transportation, A Study in Five Volumes*, Washington D.C.: USGPO (1971).

APPENDIX 3-1

STATE-LEVEL HIGHWAY AND ROAD DATA

Source 1: Annual observations of Capital Outlays for Highways disaggregated by levels of government, by state from 1957 to 1989 come from Table HF-201 in *Highway Statistics, Summary to 1985* and Table HF-2 in the annual *Highway Statistics* reports from 1986 to 1990. This is an inclusive measure of capital expenditures on all roads, by all levels of government and includes expenditures for acquisition of right-of-way.

Source 2: This source contains annual observations of Maintenance Outlays for Highways disaggregated by all levels of government, by state from 1957 to 1989. Data come from Table HF-202 in *Highway Statistics, Summary to 1985* and Table HF-2 in the annual *Highway Statistics* reports from 1986 to 1990.

Source 3: Annual observations of Expenditures for Capital Outlays on State-Administered Highways disaggregated by state from 1921 to 1985 come from Table SE-201 in *Highway Statistics, Summary to 1985*. Again, these capital outlay data include expenditures on right-of-way.

Source 4: Annual observations of Expenditures for Maintenance Outlays on State-Administered Highways disaggregated by state from 1921 to 1985 come from Table SE-202 in *Highway Statistics, Summary to 1985*.

Source 5: This source contains annual observations of Capital Outlays by Counties and Local Rural Governments on all roads disaggregated by state from 1931 to 1957. The data come from Tables LF-D-2 in *Financing Highways by Counties and Local Rural Government*, 1931–1942 and 1942–1951, and from Tables LF-D-2 and LF-21 from annual reports between 1951 and 1957. These data include expenditures on right-of-way. This source also contains annual observations of Maintenance Outlays by Counties and Local Rural Governments on all roads disaggregated by state from 1931 to 1957.

Source 6: This source contains annual observations on Capital Outlays on Highways and Roads by Municipal Governments disaggregated by state from 1937 to 1958. These data come from Table UF-21 in *A Quarter Century of Financing Municipal Highways, 1937–1961*. These data include expenditures on right-of-way. This source also contains annual observations on Maintenance Outlays on Highways and Roads by Municipal Governments disaggregated by state from 1937 to 1958.

Source 7: This source contains annual observations on Capital Outlays by State Agencies on County, Rural and Municipal Roads and Streets disaggregated by state from 1945 to 1957, the only years for which data are available. The data come from Table SF-6 in the annual *Highway Statistics* reports.

The final capital outlay series from 1931 to 1989 was constructed by taking the all-government capital outlay data from 1957 to 1989 and constructing an equivalent series from 1931 to 1956 by adding the component parts contained in Sources 3, 5, 6, and 7. The numbers in those individual tables were simply added together so the data before 1945 may not be comprehensive in their coverage of all 48 states for some variables. For example, not all tables cover the same dates and some tables only have some states reporting for early years. The capital outlays for 1957 from this constructed series was then compared with the 1957 outlay data from the all government series. The differences that exist are primarily due to missing direct federal expenditures on public access roads in parks, forests, etc. Since these data do not exist in any form before 1956 at FHWA, but are expected to be relatively minor, the 1956 constructed data were inflated by half of the percent difference in the 1957 data and all previous years are left unadjusted.

The final maintenance outlay series from 1931 to 1989 was constructed by taking the all-government maintenance outlay data from 1957 to 1989 and constructing an equivalent series from 1931 to 1956 by adding the component parts contained in Sources 4, 5, and 6. The numbers in those individual tables were simply added together so the data before 1945 may not be comprehensive in their coverage of all 48 states for some variables. For example, not all tables cover the same dates and some tables only have some states reporting for early years. The maintenance outlays for 1957 from this constructed series was then compared with the 1957 outlay data from the all government series. The differences were minor with only two states having errors of 5 percent or more. No adjustments to the data were made.

CHAPTER 4

INDUSTRY PRODUCTION FUNCTIONS WITH HIGHWAY CAPITAL AS AN INPUT*

INTRODUCTION

The basic premise of NCHRP Project 2-17(3) is that in order to gain a better understanding of the linkage between transportation investment and economic performance, the connection among many disaggregated dimensions must be examined. In this chapter the dimension under scrutiny is industry-specific productivity. Within the production function framework, the question is whether highway capital has differential effects on the output and thus the productivity of different industries.

This study, because it explores the possible impact of highway capital on productivity on an industry-by-industry basis, represents an advancement over available state-level production function estimates, which use aggregate measures of output. If highways have a differential impact on various industries, then studies of aggregate output will not uncover these differential effects. The present analysis is an attempt to shed light on three related questions. Do certain industries benefit differentially from investment in highway capital? Does the restructuring of the U.S. economy away from goods production toward services affect the productivity of highways? Finally, should investment in highway capital be directed toward certain regions of the country because these regions have high concentrations of industries that are strongly, positively affected by highway infrastructure?

STUDY DESIGN

The study design involves estimation of industry-specific production functions using a panel dataset consisting of annual observations for the 48 contiguous U.S. states. This requires the gathering of annual data by state and by industry for the private variables (output, labor, and private capital), and by state for the public variable, highway capital. Highway capital *by industry* is not needed because highway capital is assumed to be a public good available to all industries. The coefficients on the highway capital variable in the industry regressions will reflect both the impact of highways on productivity and the differential usage of highways by the different industries. It is possible that the differential effects across industries may be countervailing and there may therefore be no observable effect of highways on aggregate output.

The stumbling block in this disaggregate approach is private capital data *by state* by industry. Private capital data by industry are readily available for the nation, but the data are not disaggregated by state. As described in Chapter 2 of this report, state-level, industry-specific measures of private capital were generated by allocating industry-specific national private capital to the states using two different allocators, employment and GSP-IBT (Gross State Product minus Indirect Business Taxes). The method was to determine annually a given state's private capital in a given industry by multiplying the national private capital stock in the industry by the state's share of employment, or GSP-IBT, in each industry relative to the nation. Two different measures of private capital by state and by industry were generated.

Let K represent the true (and unavailable) measure of private capital, KG the measure of private capital generated using GSP-IBT as the allocation, and KL the measure of private capital generated using employment (or labor) as the allocation. The goal is to estimate the following equation, a Cobb-Douglas production function, for each industry:

$$GSP_{st} = constant_{st} + aL_{st} + bK_{st} + cH_{st} + e_{st} \qquad (1)$$

where each variable is in logarithms, GSP is gross state product or output, L is labor, H is highway capital, s denotes state, t denotes time (year), and $constant_{st}$ is shorthand for a full set of state and time dummies. However, since there is no K, KG or KL must be used.

The variable KG assumes a constant K to GSP ratio, which is unlikely to be the case, and if it is the case, it prevents the estimation of a production function. This is so because KG and GSP are perfectly correlated so that estimation of Equation 1 with KG in place of K would yield an estimate of b equal to 1.0 and estimated coefficients on the other inputs of zero. The assumption of a constant K to GSP ratio also restricts the type of productivity differences allowed over time and across states. For these reasons, KG is rejected as the measure of K.

---

* Contributing authors: Teresa Garcia-Mila, Department of Economics, Universitat Pompeu Fabra, Barcelona, Spain; and Therese J. McGuire, Institute of Government and Public Affairs, University of Illinois, Chicago, IL.

The other approximation of K is KL, a variable that due to its construction has systematic measurement error built into it, and thus the use of KL in Equation 1 would be likely to result in biased estimates. KL is predicated on the assumption of a constant K to L ratio, which is a strong assumption, but not unreasonable. This assumption does allow for productivity differences across states and over time with respect to private inputs and to highways.

If KL is accepted as a reasonable measure of K, the problem becomes one of perfect multicolinearity. In essence, KL and L only differ over time and only as the ratio of K to L for the United States differs over time. Once there is a control for time, which is done with time dummy variables in each specification, KL gives no additional information over L. Thus, it becomes impossible to estimate separate coefficients for KL and L. In other words, the sum of a and b can be estimated but not each coefficient separately. Fortunately, under certain assumptions, this lack of a good measure of K does not prevent estimation of the highway capital coefficient, c.

The equation is respecified as

$$GSP_{st} = constant_{st} + dL_{st} + cH_{st} + e_{st} \quad (2)$$

where the coefficient, d, captures the joint effect of labor and private capital. Under the strong assumption of a constant capital to labor ratio, the estimate of c will be unbiased. Otherwise, the omission of K, true private capital, from Equation 2 will result in a biased estimate of c to the extent that K and H are correlated. Equation 2 represents the best model of an industry-specific production function that is estimable given currently available data.

Thus, state-level, industry-specific production functions with highway capital as an input can be estimated, but the separate effects (the elasticity coefficients) of labor and private capital cannot be recovered. For each industry there is an estimate of various specifications of Equation 2. The coefficient of interest is c for each of the industries examined, which indicates the effect of highway capital on industry output.

The data available under the NCHRP project helped to estimate Equation 2 for the period, 1970–1989, for eight industries: total private nonfarm, durable manufacturing, nondurable manufacturing, TCPU (transportation, communications and public utilities), wholesale trade, retail trade, FIRE (finance, insurance and real estate), and services.

The GSP data employed are provided by the BEA, as are the employment data. The highway capital stock data series is constructed from the FHWA data on government highway capital expenditures.

For each industry-specific production function, three specifications are estimated, each drawn from the literature. The first specification includes annual time dummies, but no controls for state effects. This is Equation 2 with a constant that varies only with time, ($constant_t$). This specification is similar to those employed in Munnell (1990) and Garcia-Mila and McGuire (1992).

The second specification includes both annual time dummies and state dummies (or state fixed effects). In this case the constant varies both with time and across states ($constant_{st}$). This specification is stressed in McGuire (1992).

The third specification includes both state and time dummies, and the variables are transformed into first differences. In other words, the third specification is estimated as the following:

$$GSP_{st} - GSP_{st-1} = constant_{st} + d(L_{st} - L_{st-1}) + c(H_{st} - H_{st-1}) + e_{st} \quad (3)$$

This specification occurs in Holtz-Eakin (1992), and it is the preferred specification in Garcia-Mila, McGuire, and Porter (1994), where the authors arrive at the specification in first differences with state and time fixed effects after testing for state effects, nonstationarity, measurement error, and endogeneity.

Of these four econometric difficulties, the most important for the public infrastructure debate is nonstationarity, or the time-series nature of the data. Nonstationarity occurs when the variables in the estimating equation grow over time for reasons other than their relationship. In this situation, if the relationship is estimated *without* controlling for nonstationarity, then the results indicate an erroneous positive correlation. Once one controls for the common growth over time (usually by taking first differences), the true relationship between the variables can be uncovered.

RESULTS

Table 4-1 presents the results of estimating the three specifications for each of the eight industries. It is important to stress that an unbiased estimate of the effect of highway capital on industry output (the coefficient c) depends on the assumption of a constant capital to labor ratio across the states for each industry, or that highway capital and private capital are uncorrelated. It is not clear whether or not these assumptions are valid for these data.

The results for total private nonfarm are displayed in the first panel. These results are qualitatively similar to the results obtained in Garcia-Mila, McGuire, and Porter (1994). With comparable specifications they find a range for the combined effect of labor and private capital to be 0.65 to 1.33, and a range for the effect of highway capital to be zero to 0.37.

While tests for nonstationarity were not performed for each industry, the time-series nature of the data employed here is similar to the data employed in Garcia-Mila, McGuire, and Porter (1993). Therefore, nonstationarity—when the highway and output variables grow together over time independent of their true relationship—is likely to be the case in these regressions as well. Emphasis is thus placed

TABLE 4–1 Estimates of industry-specific production functions, annual observations 1970–1989, for 48 contiguous states *(continued on next page)*

	Total Private Nonfarm		
	Specification (1)	Specification (2)	Specification (3)
Labor	0.732 (55.80)	0.974 (42.68)	1.106 (28.87)
Highway Capital	0.357 (21.16)	-0.038 (1.30)	0.028 (0.77)
# Observations	960	960	912
R^2	0.98	0.70	0.50

	Durable Manufacturing		
	Specification (1)	Specification (2)	Specification (3)
Labor	1.038 (154.46)	1.077 (48.54)	0.966 (32.91)
Highway Capital	0.031 (2.77)	-0.079 (1.56)	0.045 (0.72)
# Observations	960	960	912
R^2	0.99	0.73	0.56

	Nondurable Manufacturing		
	Specification (1)	Specification (2)	Specification (3)
Labor	0.847 (91.32)	0.812 (24.69)	0.676 (10.74)
Highway Capital	0.300 (20.04)	0.153 (3.07)	-0.057 (0.78)
# Observations	960	960	912
R^2	0.97	0.47	0.12

	TCPU		
	Specification (1)	Specification (2)	Specification (3)
Labor	0.917 (71.73)	0.918 (40.88)	0.833 (19.42)
Highway Capital	0.113 (6.96)	0.197 (6.68)	0.076 (1.68)
# Observations	960	960	912
R^2	0.99	0.74	0.31

	Wholesale Trade		
	Specification (1)	Specification (2)	Specification (3)
Labor	1.030 (118.33)	1.119 (73.06)	0.951 (41.85)
Highway Capital	0.026 (2.16)	-0.048 (2.07)	-0.039 (0.92)
# Observations	960	960	912
R^2	0.99	0.86	0.68

TABLE 4–1 *(continued)*

Retail Trade			
	Specification (1)	Specification (2)	Specification (3)
Labor	1.047 (113.08)	1.217 (61.57)	1.225 (35.70)
Highway Capital	-0.007 (0.57)	-0.066 (2.75)	0.064 (2.04)
# Observations	960	960	912
R^2	0.99	0.83	0.60

FIRE			
	Specification (1)	Specification (2)	Specification (3)
Labor	0.789 (64.71)	0.760 (22.70)	0.514 (10.11)
Highway Capital	0.248 (14.84)	0.102 (2.09)	0.049 (0.60)
# Observations	960	960	912
R^2	0.98	0.40	0.11

Services			
	Specification (1)	Specification (2)	Specification (3)
Labor	1.188 (120.18)	0.914 (40.45)	1.074 (28.69)
Highway Capital	-0.147 (11.71)	0.169 (6.99)	0.063 (2.30)
# Observations	960	960	912
R^2	0.99	0.69	0.49

Notes to Table 4-1:

All regressions include a complete set of annual time dummies, although the estimated coefficients are not reported. The dependent variable is the log of GSP. Similarly, the reported explanatory variables are all in logarithms. The figures in parentheses are t-statistics.

Specification (1) includes time dummy variables (fixed effects).
Specification (2) includes time and state fixed effects.
Specification (3) includes time and state fixed effects, and the dependent variable and reported explanatory variables are all first differences of logarithms.

on the third specification where highway capital is found to be insignificantly related to total GSP.

Total private nonfarm, or total output, is the larger category that encompasses the other seven industries.

What does an examination of the seven industries that constitute total output reveal? Focus goes on the third specification for each industry, the specification that controls for nonstationarity. Of course, nonstationarity may not be a problem for each industry. But in order to understand the zero coefficient used to estimate for the highway variable in the third specification for total output, focus must be placed on the same specification for each of the industries.

In fact, quite different results are found for each of the seven industries examined. Focusing on the third specification in each case, highway capital is statistically insignificant for durable manufacturing, nondurable manufacturing, wholesale trade, and FIRE. The highway capital variable is significant at the 10 percent level for TCPU, and at the 5 percent level for retail trade and services. For these three industries the effect of highway capital on GSP is positive.

The finding of a variable effect of highway capital across the seven industries may be one explanation for the insignificant effect of highway capital in the regression with total GSP as the dependent variable. There is no explanation for the different results obtained for the different industries. The results do seem to indicate that industry-specific analysis of the productivity of public infrastructure might be fruitful.

CONCLUSIONS

Within the production function framework, the question is asked whether highway capital has a differential effect on the productivity of different industries. The results obtained must be viewed as highly preliminary nevertheless, they point in clear directions. Highway capital has no effect on output for four of the seven industries examined. Highway capital has a significant, positive effect on output in three industries: TCPU (at the 10 percent level of significance), retail trade and services (both at the 5 percent level). Retail trade and especially services are fast-growing industries, representing increasingly large portions of the U.S. economy. Thus, these results point to an increasing role for highways in the productivity of our service-based economy.

Our attempt to investigate the role of highway capital in industry productivity has been somewhat frustrated by the inability to generate state-level, industry-specific private capital stock variables free of measurement error. For future research attempting to verify the results contained herein, it would be very useful to have better measures of private capital by industry, by state. It would also be useful to have a longer time series of data, as the power of nonstationarity tests with 20 years of data is not strong.

While definitive results using the production function approach have not been produced, it would seem that the direction pursued, analysis of the linkage between transportation infrastructure and industry-level measures of economic activity, is the right one. The results obtained here indicate that state-level, industry-specific analysis is likely to be the most informative. The industry-specific focus is particularly important, because the findings for aggregate output show no effect of highway capital, reflecting the differential effects of highway capital on the different industries comprising aggregate output.

SELECTED BIBLIOGRAPHY

Garcia-Mila, Teresa and Therese J. McGuire, "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*, Vol. 22, No. 2 (June 1992).

Garcia-Mila, Teresa, Therese J. McGuire, and Robert H. Porter, "The Effect of Public Capital in State-Level Production Functions Reconsidered," IGPA Working Paper (March 1993, revised February 1994).

Holtz-Eakin, Douglas, "Public-Sector Capital and the Productivity Puzzle," NBER Working Paper No. 4122 (July 1992).

McGuire, Therese J., "Highways and Macroeconomic Productivity: Phase Two," Federal Highway Administration, Washington, D.C. (March 1992).

Munnell, Alicia H. "How Does Public Infrastructure Affect Regional Economic Performance?," Alicia H. Munnell, ed. *Is There a Shortfall in Public Capital Investment?*, Federal Reserve Bank of Boston (1990).

CHAPTER 5

TRANSPORTATION INVESTMENT AND ECONOMIC ACTIVITY: EVIDENCE FROM PUBLIC SECTOR DEMAND ANALYSIS*

INTRODUCTION

A review of the recent literature examining the link between infrastructure investment and economic performance concludes that at the aggregate level the weight of available evidence supports a positive, statistically significant, albeit small, effect of public capital on output.[1] One area where the current research is lacking is in providing an understanding of why and how such a linkage exists between public capital and private economic activity.

The purpose of this paper is to provide government decision makers with better information in order to allocate limited resources most effectively. However, the approach here differs from that which is in the current literature, for it starts from the perspective that transportation services are an intermediate good in private consumption and production processes.[2] In other words, to understand the linkage between transportation investment and economic performance, demographic and economic factors that influence the derived demand for transportation services must be identified at a disaggregate level. The empirical testing of a demand equation for transportation services is proposed as the means to analyze the impact of trends beyond the control of state and local officials on the demand for transportation services.

This approach permits development of information on the link between transportation investment and economic performance that can be used by state and local decision makers to allocate limited resources most effectively. Specifically, three questions are addressed:

- Is the demand for transportation services responsive to changes in demographic variables like per capita income, urbanization, age distribution, and poverty rates?
- Is the demand for transportation services responsive to economic restructuring and the changing sectoral composition of the economy?
- If dollar investment flows for individual modes of transportation are not good proxies for the level of benefits provided, do measures of the level and quality of service provided generate different empirical results in the demand model used?

*Contributing authors: Joyce Z. Man, School of Public and Environmental Affairs, Indiana University, Indianapolis, IN; and Michael E. Bell, Institute for Policy Studies, The Johns Hopkins University, Baltimore, MD.

We investigate these issues for transportation investments in general, and for three individual transportation modes—highways, mass transit, and airports.

THE MODEL

Most previous studies of the linkage between transportation investment and economic performance involve estimation of aggregate production or cost functions as a means for understanding the impact of transportation infrastructure on economic productivity. These studies evaluate the productivity implications of existing transportation capital on private output and input. Investment in transportation networks, however, impacts the nation's economic performance in a number of ways beyond these productivity impacts. There is, therefore, reason to identify the factors that influence the derived demand for transportation services. We estimate a public goods demand equation for transportation services.

The starting point is the standard median-voter model for estimating the demand for public goods. This approach assumes that the outcome in a jurisdiction coincides with the preferences of the median voter. The median voter is assumed to maximize the individual utility function $u_i = u_i(x_i, q_i)$ subject to the budget constraint $Y_i = px_i + t_iqG$, where Y_i is the median voter's income; p is the price of the private good, x_i, which is assumed to be the numeraire (the base value to which everything else is related, usually defined to be 1); G is the total quantity of public goods and services; t_i is the tax liability per unit of G; and q is the unit cost of the public good.

If there is a congestion problem associated with the publicly provided good, or impure public good, population size has a direct effect on the individual's consumption of the public good. The amount of public good captured by the individual voter depends on the divisibility of the service flow of G in consumption. Only when G is a purely public good does the quantity of the public good consumed by individual citizen, g_i, equal G. If the amount of public output enjoyed by the median voter, q_i, differs from the amount supplied, G [Borcherding and Deacon (1972), and Bergstrom and Goodman (1973) argued that it depends upon the number of persons sharing the services], then $g_i = N^{-\alpha}G$, where N is the number of people sharing the public good, α is the "publicness" or congestion parameter. If $\alpha = 0$, the public good is a pure public good in the Samuelsonian sense without congestion occurring at all. If $\alpha = 1$, G may be taken as corresponding to a private good. Other values of α allow for intermediate cases. As the value of α increases, the public good becomes more and more crowded. The budget constraint of the decisive voter can then be rewritten as $Y_i = x_i + t_i q N^{\alpha} g_i$.

Utility maximization and simple substitution yields the standard demand function for desired public goods and services, g_i, assuming a multiplicative form, as follows:

$$g_i = c[t_i q N^{\alpha}]^{\delta} Y_i^{\gamma} \qquad (1)$$

where c is the scalar parameter. Since the total quantity of public good demanded is N^{α} times the quantity of g_i demanded, the demand for G is

$$G = c q^{\delta} t_i^{\delta} N^{\alpha(1+\delta)} Y_i^{\gamma} \qquad (2)$$

where $(t_i q)^{\delta} N^{\alpha(1+\delta)}$ is the effective cost per unit of G. δ is the price elasticity of demand for the public good and γ is the income elasticity. Since the per capita expenditure is defined as, $E = qG/N$, then

$$E_j = c q_j^{1+\delta} t_j^{\delta} N^{(\alpha(1+\delta)-1)} Y_j^{\gamma} \qquad (3)$$

Taking logarithms, we generate two alternative specifications of the basic public goods demand equation

$$\begin{aligned} \ln E_j = {} & \beta_0 + (1+\delta)\ln q_j + \delta \ln t_j + \gamma \ln Y_j \\ & + (\alpha(1+\delta) - 1)\ln N_j + \textstyle\sum_k \beta_{jk} \ln Z_{jk} + u_j \end{aligned} \qquad (4)$$

$$\begin{aligned} \ln G_j = {} & b_0 + \delta \ln q_j + \delta \ln t_j + \gamma \ln Y_j + \alpha(1+\delta)\ln N_j \\ & + \textstyle\sum_k \beta_{jk} \ln Z_{jk} + v_j \end{aligned} \qquad (5)$$

where E_j is the desired level of per capita expenditures on transportation in each state and G is the level and quality of service provided. The cost variable, q_j, is the jurisdiction-specific cost of providing public goods and services in employing labor and land. Z_{jk} denotes a vector of jurisdiction demographic and economic characteristics that affects public expenditure on transportation. Finally, u_j and v_j denote the error terms. By estimating the equations above, one can identify not only the income elasticity of demand, the price elasticity, and the crowding parameter, but also coefficients of cost variables, tax variables, and other demographic and economic variables representing jurisdiction-specific characteristics which influence the derived demand for transportation services.

Demand Equations 4 and 5 are estimated for total transportation capital outlays and three separate transportation modes: highways, mass transit, and airports. The dependent variable in Equation 4 in each case is state-level observations of real per capita annual capital outlays by state and local governments for the years 1977 through 1988. The dependent variable in the estimation of Equation 5 reflects the level of services provided by each of the three different transportation modes.

Duffy-Deno and Eberts show that the relationship between public infrastructure investment and regional growth goes in both directions. That is, public infrastructure affects personal income and personal income affects the level of investment in public infrastructure. Their findings highlight the potential single-equation estimation bias if public investment is considered exogenous, as is the case with other studies.[3] Therefore, both OLS and 2SLS estimates are reported for the demand equations.

ESTIMATION

In order to obtain a robust estimation of the public expenditure demand function, there must be control for the simultaneous relationship between E_j and Y_j as suggested by Duffy-Deno and Eberts. Without controlling for the simultaneous equation problem, estimates of the income elasticity coefficient are biased. Estimated income elasticities will be too low, suggesting that the demand for public goods and services is relatively income inelastic. This simultaneous equation bias exists in the results of most demand analysis of public sector expenditures (e.g., Borcherding and Deacon, 1972; Bergstrom and Goodman, 1973; Gramlich and Rubinfeld, 1982). Both a personal income equation and a demand equation for transportation services is estimated as a means of correcting for this simultaneous equations bias.

Personal Income Equation

The dependent variable in the personal income equation is real per capita personal income deflated by the national Consumer Price Index (CPI). Transportation capital stock is defined as per capita real dollar value of the total transportation capital stock including highways, mass transit, and air transportation as calculated for NCHRP Project 2-17(3).[4] The capital stock variables are estimated using the PIM from an annual capital outlay series obtained from the Government Finance Division of the Census Bureau. The remaining independent variables include (1) tax liability variables; (2) demographic and labor force characteristics; (3) other core infrastructure investments (sewerage, water supply, and other government expenditures including education); and (4) regional and time dummy variables to control for time shocks and regional fixed effects which are not observable and/or measurable. A pooled time-series, cross-section dataset is used that includes observations for each of the 50 states and the District of Columbia for the years 1977 to 1988.

The results reported here are for two alternative specifications of the personal income equation—Specification (1) includes total transportation capital outlays and stock data, and Specification (2) includes transportation capital outlays and stock data for three separate modes of transportation (highway, mass transit, and air). The results are reported in Table 5–1. Both specifications show that public transporta-

TABLE 5-1 OLS and 2SLS estimates of the personal income equation

		Specification (1)		Specification (2)	
Variable	Definition	OLS	2SLS	OLS	2SLS
LTREXP	log(public transportation	0.064***	0.087***	—	—
	investment per capita)	(0.01)	(0.01)	—	—
LTRLAG	log(lagged transportation	-0.003	-0.004	—	—
	capital stock per capita)	(0.007)	(0.007)	—	—
LHIGHEXP	log(public expenditure on	—	—	0.034***	0.050***
	highway per capita)	—	—	(0.009)	(0.01)
LMASSEXP	log(public expenditure on	—	—	0.010***	0.023***
	mass transit per capita)	—	—	(0.001)	(0.002)
LAIREXP	log(public expenditure on	—	—	0.001	0.002
	air transp. per capita)	—	—	(0.003)	(0.003)
LHIGHLAG	log(lagged highway	—	—	0.026***	0.03***
	capital stock per capita)	—	—	((0.01)	(0.01)
LMASSLAG	log(lagged mass transit	—	—	0.004	0.0001
	capital stock per capita)	—	—	(0.001)	(0.001)
LAIRLAG	log(lagged air transp.	—	—	-0.004*	-0.001
	capital stock per capita)	—	—	(0.002)	(0.003)
LREVINC	log(state tax liability)	-0.333***	-0.337***	-0.326***	-0.336***
		(0.03)	(0.016)	(0.016)	(0.018)
DENSITY	population density	-0.112***	-0.121***	-0.049**	0.018
		(0.02)	(0.02)	(0.02)	(0.02)
EMPLMPC	ratio of manufacturing	0.005***	0.006***	0.002***	0.002***
	employment to total	(0.0007)	(0.0008)	(0.0007)	(0.0008)
UNION	percentage of workers	0.003***	0.004***	0.003***	0.004***
	unionized	(0.0005)	(0.0005)	(0.0005)	(0.0006)
COLLEGE	percentage of residents	0.019***	0.019***	0.021***	0.018***
	with college education	(0.001)	(0.001)	(0.001)	(0.002)
LINFRA	log(per capita spending in	0.082***	0.077***	0.070***	0.051***
	sewerage, water supply)	(0.01)	(0.01)	(0.01)	(0.01)
LOEXP	log(other per capita	0.022***	0.022***	0.015***	0.008***
	public expenditure)	(0.003)	(0.003)	(0.003)	(0.004)
MIDWEST	=1 if the state is in	-0.033***	-0.033***	-0.029**	-0.023*
	Midwest	(0.01)	(0.01)	(0.01)	(0.01)
SOUTH	=1 if the state is in South	-0.118***	-0.119***	-0.113***	-0.105***
		(0.01)	(0.01)	(0.01)	(0.01)
WEST	=1 if the state is in West	-0.107***	-0.102***	-0.106***	-0.084***
		(0.01)	(0.01)	(0.01)	(0.01)
Y77	=1 if year is 1977	0.071***	0.071***	0.093***	0.121***
		(0.019)	(0.019)	(0.02)	(0.02)
Y78	=1 if year is 1978	0.092***	0.092***	0.115***	0.147***
		(0.018)	(0.018)	(0.02)	(0.02)
Y79	=1 if year is 1979	0.056***	0.056***	0.077***	0.102***
		(0.017)	(0.017)	(0.02)	(0.02)
Y80	=1 if year is 1980	-0.011	-0.011	0.004	0.018
		(0.017)	(0.016)	(0.02)	(0.02)
Y81	=1 if year is 1981	-0.023	-0.021	-0.01	0.006
		(0.016)	(0.016)	(0.01)	(0.01)
Y82	=1 if year is 1982	-0.029*	-0.024	-0.025	-0.014
		(0.016)	(0.016)	(0.016)	(0.017)
Y83	=1 if year is 1983	-0.023	-0.017	-0.019	-0.008
		(0.016)	(0.016)	(0.016)	(0.017)
Y84	=1 if year is 1984	0.015	0.018	0.012	0.007
		(0.015)	(0.015)	(0.015)	(0.016)
Y85	=1 if year is 1985	0.008	0.010	0.009	0.001
		(0.01)	(0.014)	(0.01)	(0.01)
Y86	=1 if year is 1986	0.016	0.017	0.016	0.011
		(0.015)	(0.015)	(0.014)	(0.016)
Y87	=1 if year is 1987	0.010	0.011	0.006	0.002
		(0.01)	(0.014)	(0.01)	(0.01)
Intercept		7.473***	7.472***	7.58***	7.67***
		(0.09)	(0.09)	(0.09)	(0.1)
Adjusted R^2		0.79	0.80	0.801	0.774

NOTE: Dependent variable is the log of real per capita income, deflated by CPI. Standard errors appear in parentheses below the estimated coefficients. Asterisks (***, **, and *) indicate that the estimate is significantly different from zero at 1 percent, 5 percent, and 10 percent levels, respectively. The omitted regional dummy variable is the Northeast, and the omitted time variable is 1988.

tion investment has a positive and statistically significant effect on real per capita personal income. A 10 percent increase in public transportation investment increases per capita personal income by 0.64 percent using OLS estimates and 0.87 percent using 2SLS estimates.

Focusing on investment on specific transportation modes, the results under Specification 2 show that capital outlays on highway and mass transit have a positive and statistically significant impact on real per capita income, although the effects are relatively small. A 10 percent increase in state-local capital outlays on highway and mass transit will raise real per capita personal income by 0.34 percent and 0.1 percent, respectively, using OLS estimates, and by 0.5 percent and 0.23 percent, respectively, using 2SLS estimates. The coefficient on airport and airway investment is insignificant, possibly because such investments are generally irregular and relatively small in comparison with other types of investment.

The coefficients of lagged highway capital stock variable also indicate a statistically significant and positive relationship with personal income. Specifically, a 10 percent difference in lagged highway capital stock among states produces a 0.3 percent difference in per capita personal income.

Since this report focuses only on transportation infrastructure, the absolute levels of the coefficients are somewhat different from those reported by Duffy-Deno and Eberts. However, the findings for the personal income equation here are consistent with their finding that causality goes in both directions.

The tax liability variable, measured as the ratio of tax revenue to total personal income, is statistically significant and has the expected negative sign. These results indicate that a 10 percent increase in state tax liability will reduce personal income by over 3 percent. These coefficients are very stable across all specifications of the personal income equation and are consistent with the general level of coefficients reported by Duffy-Deno and Eberts.

The variables measuring business climate associated with labor market, such as EMPLMPC (which is the ratio of manufacturing to total employment) and UNION (which measures the percentage of work force that is unionized), have statistically significant positive coefficients, suggesting that the wage component of personal income is higher in the manufacturing industry and in highly unionized states. The variable measuring labor quality, COLLEGE (which is defined as the percentage of residents with college education), has a statistically significant and positive coefficient indicating that a more educated work force generally has higher per capita income. The core infrastructure investment variables, INFRA (sewerage and water supply) and OEXP (other government expenditure including education), have positive and statistically significant effects on personal income. The statistically significant and negative coefficient of the DENSITY variable suggests that high population density is associated with relatively lower levels of per capita income. These statistical results are generally consistent across all specifications of the personal income equation—testimony to the general robustness of these findings.

Transportation Expenditure Demand Equations

Based on the theoretical model discussed above, annual capital outlays for each transportation mode (and total transportation capital outlays) are a function of the cost of producing the public service, the tax price facing the median voter, income, population, and a vector of demographic and economic variables measuring characteristics of each jurisdiction relevant to the derived demand for transportation services. In this study, independent variables measuring per capita income, population, state tax burdens and property tax shares, federal aid, the extent of urbanization, and industry mix variables are included in the demand equation.

The most difficult variable to calculate is the tax-price variable. Since the focus is total state and local spending on transportation, and on each transportation mode, information on own-source revenues is needed. Therefore, two variables measuring tax price are included. First, the ratio of total state tax revenues to personal income, REVINC, is computed. This measures the overall tax burden in the state. Second, the property tax share of median voter, TSHARE, is calculated as the ratio of median property value to the market value of total property tax base in the state which is, in essence, a tax-price variable.

The demand equations are estimated with both OLS and 2SLS techniques and all variables are in logs. Table 5–2 presents the results for the equation using per capita total transportation capital outlays by state and local governments as the dependent variable. Table 5–3 reports the results from three equations using per capita total state and local capital outlays on highways, mass transit, and airports as the dependent variables. The results are based on pooled times-series and cross-section data for 50 states and the District of Columbia from 1977 to 1988. A fixed-effects model was estimated that uses dummy variables to capture the variation across time and region that is not observable and/or measurable.

Table 5–2 presents the results for the equation using total real per capita state and local transportation capital outlays as the dependent variable. The income elasticity coefficient is positive and statistically significant. The estimate of income elasticity using OLS technique is 1.34, which increases to 2.05 in the 2SLS model. These results are almost identical to the magnitude of the income elasticity estimates in the Duffy-Deno and Eberts public expenditure equation. Thus, simultaneous equation bias is important and, after adjusting for the bias, the results suggest that the demand for transportation capital outlays are more sensitive to changes in income than traditionally thought.

These findings also are consistent with Oates' concern that traditional public goods demand estimates systematically underestimate income elasticity, albeit his concern is with omitted community characteristics which are captured by our

TABLE 5–2 OLS and 2SLS estimates of the transportation investment equation

Variable	Definition	OLS	2SLS
LPINC	log(real per capita personal income)	1.31*** (0.16)	2.05*** (0.23)
LPOP	log(population)	-0.573*** (0.059)	-0.552*** (0.06)
LREVINC	log(state tax liability)	0.021 (0.07)	0.248*** (0.09)
TSHARE	property tax share	-0.105*** (0.027)	-0.093*** (0.027)
LFAID	log(federal aid for transportation)	0.503*** (0.034)	0.503*** (0.035)
DENSITY	population density	-0.166* (0.086)	-0.073 (0.089)
METROPC	percentage of residents living in metro area	-0.008*** (0.001)	-0.10*** (0.001)
POVERTY	percentage below poverty	-0.032** (0.016)	-0.038*** (0.016)
OWNOH	percentage owner-occupied housing	-0.036*** (0.004)	-0.034*** (0.004)
POP65PC	percentage over 65 years old	0.045*** (0.008)	0.056*** (0.008)
POPCH	population change from 1980 to 1988	0.0004 (0.001)	0.0008 (0.002)
CPBASEPC	share of commercial & industrial property base	0.011*** (0.003)	0.012*** (0.003)
EMPLSPC	ratio of services to total employment	-0.0013 (0.002)	0.002 (0.002)
EMPLTPC	ratio of retail-wholesale to total employment	0.004*** (0.001)	0.004*** (0.001)
LTRLAG	log(lagged public transp. capital stock per capita)	0.198*** (0.027)	0.215*** (0.03)
MIDWEST	= 1 if state is in Midwest	0.051 (0.04)	0.09** (0.04)
SOUTH	= 1 if state is in South	0.156*** (0.05)	0.271*** (0.05)
WEST	= 1 if state is in West	-0.006 (0.06)	0.045 (0.06)
AK	= 1 if state is Alaska	-0.10 (0.16)	-0.55*** (0.19)
DC	= 1 if region is District of Columbia	0.934*** (0.15)	0.573*** (0.16)
HI	= 1 if state is Hawaii	0.03 (0.1)	-0.03 (0.1)
Intercept		-6.4*** (1.6)	-13.1*** (2.2)
Adjusted R^2		0.793	0.790

NOTE: Dependent variable is the log of real per capita state and local public transportation capital outlays, deflated by CPI. Standard errors appear in parentheses below the estimated coefficients. Asterisks (***, **, and *) indicate that the estimate is significantly different from zero at 1 percent, 5 percent, and 10 percent levels, respectively. The omitted regional dummy variable is the Northeast, and the omitted time variable is 1988. The year dummy variables are computed, but are not reported here.

fixed effect variables, not the simultaneity between income and expenditures.[5]

Results in Table 5–3 use real per capita state and local capital outlays for highways, mass transit, and airports in both an OLS and 2SLS model. These results also suggest the presence of a simultaneous equations bias. In the highway equation, the income elasticity estimates are statistically significant and positive in both equations and the coefficient increases from 1.23 in the OLS model to 1.31 in the 2SLS model. When the stimulus effect of highway investment on economic activity is taken into account, the demand for highway investment is more sensitive to changes in income than

TABLE 5–3 OLS and 2SLS estimates of demand for investment on different transportation modes

	HIGHWAY		MASS TRANSIT		AIRPORT	
Variable	OLS	2SLS	OLS	2SLS	OLS	2SLS
LPINC	1.23***	1.313***	1.456	3.433*	-0.811	0.756
	(0.15)	(0.21)	(1.4)	(2.0)	(0.55)	(0.77)
LPOP	-0.55***	-0.54***	0.905*	1.005*	-0.226	-0.159
	(0.06)	(0.06)	(0.5)	(0.5)	(0.2)	(0.2)
LREVINC	0.021	0.045	2.33***	2.82***	-0.334	0.107
	(0.07)	(0.08)	(0.65)	(0.77)	(0.25)	(0.29)
TSHARE	-0.043*	-0.038	-0.007	0.017	-0.025	-0.004
	(0.02)	(0.02)	(0.24)	(0.24)	(0.09)	(0.09)
LFAID	0.511***	0.521***	0.393	0.328	0.45***	0.44***
	(0.03)	(0.03)	(0.3)	(0.30)	(0.11)	(0.11)
DENSITY	-0.17**	-0.161**	-2.27***	-2.05***	1.02***	1.212***
	(0.08)	(0.08)	(0.77)	(0.79)	(0.29)	(0.30)
METROPC	-0.008***	-0.008***	0.049***	0.043***	-0.005	-0.01**
	(0.001)	(0.001)	(0.01)	(0.01)	(0.004)	(0.004)
POVERTY	-0.019	-0.021	-0.311**	-0.327**	-0.052	-0.069
	(0.014)	(0.014)	(0.14)	(0.14)	(0.055)	(0.056)
OWNOH	-0.004	-0.002	0.009	0.012	-0.101***	-0.097***
	(0.004)	(0.004)	(0.036)	(0.04)	(0.02)	(0.015)
POP65PC	0.045***	0.048***	-0.108*	-0.081	0.033	0.058**
	(0.007)	(0.007)	(0.065)	(0.068)	(0.026)	(0.027)
POPCH	0.001	0.001	-0.005	-0.003	0.021***	0.023***
	(0.001)	(0.001)	(0.014)	(0.014)	(0.005)	(0.005)
CPBASEPC	0.005*	0.006*	-0.001	-0.001	0.019*	0.023**
	(0.003)	(0.003)	(0.196)	(0.02)	(0.01)	(0.01)
EMPLSPC	0.009***	0.012***	-0.079***	-0.076***	0.021***	0.028***
	(0.002)	(0.002)	(0.02)	(0.02)	(0.008)	(0.008)
EMPLTPC	0.004***	0.0045***	0.098***	0.097***	0.0008	0.0006
	(0.001)	(0.001)	(0.01)	(0.01)	(0.004)	(0.004)
LHIGHLAG	0.169***	0.171***	—	—	—	—
	(0.03)	(0.03)	—	—	—	—
LMASSLAG	—	—	0.149***	0.149***	—	—
	—	—	(0.03)	(0.03)	—	—
LAIRLAG	—	—	—	—	-0.101***	-0.105***
	—	—	—	—	(0.026)	(0.026)
MIDWEST	0.169***	0.171***	-0.369	-0.266	1.419***	1.493***
	(0.04)	(0.04)	(0.37)	(0.38)	(0.15)	(0.15)
SOUTH	0.29***	0.307***	-0.15	0.14	0.923***	1.16***
	(0.04)	(0.05)	(0.42)	(0.47)	(0.16)	(0.18)
WEST	0.126**	0.13**	0.589	0.74	1.448***	1.556***
	(0.05)	(0.05)	(0.49)	(0.5)	(0.19)	(0.19)
AK	0.051	0.013	4.902***	3.76**	-0.328	-1.28*
	(0.16)	(0.18)	(1.48)	(1.7)	(0.61)	(0.7)
DC	-0.778***	-0.942***	10.71***	10.17***	-10.8***	-11.49***
	(0.14)	(0.15)	(1.32)	(1.4)	(0.52)	(0.56)
HI	-0.143	-0.142	0.942	0.798	1.155***	1.05***
	(0.09)	(0.09)	(0.88)	(0.89)	(0.34)	(0.34)
Intercept	-8.64***	-9.75***	-26.3*	-44.8**	5.27	-9.37
	(1.58)	(2.0)	(14.8)	(19.5)	(5.79)	(7.5)
Adjusted R^2	0.799	0.8003	0.59	0.587	0.763	0.753

NOTE: Dependent variable is the log of real per capita state and local capital outlays on highway (LHIGHEXP), mass transit (LMASSEXP), and air transportation (LAIREXP), respectively. Standard errors appear in parentheses below the estimated coefficients. Asterisks (***, **, and *) indicate that the estimate is significantly different from zero at 1 percent, 5 percent, and 10 percent levels, respectively. The omitted regional dummy variable is the Northeast, and the omitted time variable is 1988. The year dummy variables are computed, but are not reported here.

what was previously found in the literature, i.e., between 0.2 and 1.0. The coefficients are not significant in the mass transit or airport equations, which supports the notion that it is important to disaggregate the analysis by mode whenever possible.

Several other demographic variables are of interest as well. For example, the percentage of the population over 65 is statistically significant with a positive coefficient in the total transportation and highway equations. This suggests that as the population ages and older retired people have more leisure time, they travel more and demand more investments in transportation and highway networks. This shows up, to a somewhat lesser extent, in the airport equation as well. The coefficients for this variable are generally not significant for mass transit.

Also of interest are the coefficients for the variable measuring the percentage of a state's population living in metropolitan areas. In the total transportation and highway equations, the coefficients are statistically significant and negative and the values of the coefficients are almost identical in all four equations suggesting some robustness to this finding. The interpretation might be that as the population shifts to the exurbs and rural areas, there is a greater demand for increased investment in the state's highway network. This view is also consistent with the statistically significant and positive coefficients for the same variable in the mass transit equations. These results suggest that as the population becomes more concentrated in metropolitan areas, people demand increased investments in mass transit rather than highways. This is consistent with the argument that increased population concentrations are necessary to make investments in mass transit economically viable.

In addition to these demographic variables, a number of other economic variables are also of interest. Specifically, the coefficients for the federal aid variable are consistently positive and significant in the total transportation, highway, and airport equations. The positive coefficients on the federal aid variable indicate that federal aid stimulates spending on highways and airports, but by an amount less than the amount of aid. For example, both OLS and 2SLS estimates reveal that a 10 percent increase in per capita real federal aid for transportation increases highway investment at the state and local level by about 5 percent. The coefficients are consistent across both specifications of the model and hold up in the highway and airport models reported in Table 5–3. This finding is consistent with other empirical research suggesting that highway grants substitute for state and local own-source financing of highway investments.[6]

Potentially more troubling are the results for the tax-price variables. Generally, coefficients for both the state tax burden variable and the property tax share variable are statistically insignificant in virtually all equations and across all modes. The interpretation of this finding is that price does not affect the demand for investment in total transportation or for individual modes. While these results are consistent with those found by Borcherding and Deacon (1972), that does not explain the counterintuitive finding that price does not affect demand. However, upon reflection, our measures of the tax-price variables may be too aggregate to capture the effect of price on the demand of transportation investment. For example, each of the individual modes of transportation examined have dedicated revenue sources to finance investment, e.g., gasoline taxes for highways, gas taxes and farebox revenues for mass transit, and specific user fees for airports. Therefore, using property tax shares of total tax burdens may not be good proxies for the tax-prices of individual transportation modes. More work needs to be done to refine the measures of the tax-price variable.

Three variables are included to try and capture the differential impact of industrial mix on the demand for transportation investments. Variables are calculated that measure the share of the state's property tax base in commercial and industrial property (CPBASEPC), the ratio of employment in services to total employment (EMPLSPC), and the ratio of employment in retail and wholesale trade to total employment (EMPLTPC).

The commercial/industrial tax base and retail/wholesale employment variables are statistically significant and positive in the total transportation and highway equations, suggesting that as these activities become more important in a state's economy, the demand for investment in transportation generally, and highways specifically, increases. Similarly, the coefficients for the variable measuring the share of employment in services are positive and statistically significant for highways and airports, possibly reflecting the increased need for face-to-face meetings associated with a service-oriented economy.[7] It is also important to note that this variable is not significant in the total transportation equation, and that the coefficient for this variable in the airport equation is more than twice as large as it is in the highway equation. This suggests that airports may become a more important mode for travel in a service-oriented economy. The statistically significant and negative coefficient for the service variable in the mass transit equation is more difficult to explain. However, if service jobs are more dispersed throughout a metropolitan area and if the face-to-face contacts are time sensitive, a negative coefficient might be anticipated, a priori, for this variable in the mass transit equation.

Finally, in each equation the lagged value of the capital stock for each mode, and for total transportation is included. In all equations the lagged value of capital stock is statistically significant and positive, except in the airport equation, where it is significant but negative. This means that, in part, the demand for transportation investments is influenced by the extent of the existing capital stock.

Alternative Specification of Transportation Demand Equations

Expenditures have most commonly been used as a measure of subnational government output for comparisons over time and among different jurisdictions. But expenditures are really a measure of the inputs used by the government in the production process. Expenditures equal costs, and costs depend both on the amount of inputs used and the prices of those inputs. Changes or differences in production technology, input prices, and community environmental characteristics all cause disparity between expenditures and the results of government production enjoyed by consumers. Directly produced output on a service may fall even though expenditures are constant or even increasing. It is also possible that two different subnational jurisdictions, with equal per capita expenditures on a particular function, will provide different levels of the same service.

Oates argues that using expenditures on an activity as the dependent variable is really using an imperfect proxy for the desired measure of service outputs. A better measure of public output would focus on the level of government services actually provided to citizens. The level of services consumed, which results from a given amount of directly produced output, depends on the population and the environmental characteristics of the community. Therefore, the demand functions for public transportation, in this section, are estimated with both measures of expenditure (taken from the previous section) and of the levels of service actually provided.

Naturally, the problem in estimating demand equations with some measure of output as the dependent variable is that such measures are difficult to define and generally do not exist. However, the dataset developed for NCHRP Project 2-17(3) includes some measures of the level of service consumed for each of the three modes of transportation examined in this paper. Specifically, the dependent variables used for measuring highway output include total vehicle miles travelled (LMILE), and total vehicle miles travelled on urban highways (LUMILE), weighted by the area of each state. The dependent variables used to measure mass transit output include the number of passenger trips (LPTRIP), passenger miles travelled (LPMILE), and vehicle miles travelled (LVMILE). Finally, the dependent variables used for the airport equation includes enplanements (LAIRENP) and the number of scheduled flights actually completed (LAIRCOM).

The results for these equations are reported in Tables 5–4 and 5–5. The specification of the models tested is similar to the model used in the previous section. Since this is a first effort to employ measures of the level of service provided as the dependent variable, these results should be considered preliminary in nature.

Overall, the results reported in Tables 5–4 and 5–5 are not dramatically different from those reported for the traditional specification of the demand model, although there are some inconsistencies and variations that suggest more work is necessary to refine these estimates.

For the highway equations, the income elasticity measure is positive and statistically significant but it is three times higher for the equation using urban vehicle miles travelled than it is for the equation using total vehicle miles travelled. The coefficient for this variable is insignificant for all the mass transit equations. Both of these results are similar to the results obtained in the traditional demand model described in the previous section. The major difference between the two approaches is that the income elasticity measure for both airport equations is statistically significant and negative when using measures of the level of service provided, while it was insignificant in the traditional specification of the demand model.

The over-65, federal aid, and tax-price variables are not as well behaved in the equations using level of service as a dependent variable as they are in the traditional specification of the model. The variable measuring the percentage of the population living in metropolitan areas, however, behaves in the level of service equations much as it does in the traditional specification of the model. Specifically, the results suggest that the higher the percentage of the population living in metropolitan areas is, the fewer are the number of vehicle miles travelled, and the more mass transit is used for transportation.

Finally, the results for the industry mix variables continue to suggest that this is an important dimension of the demand for transportation investments, and that these effects vary across modes of transportation. Like the traditional specification of the demand model, the industry mix variables suggest that the more an economy relies on commercial and industrial activity, and the more it relies on wholesale and retail trade, the more vehicle miles will be provided. Similarly, the more an economy relies on services, the higher the demand for airport services. Finally, the results for mass transit equations are mixed, with no clear conclusions.

CONCLUSIONS

The purpose of this report is to establish a means for understanding why economic and demographic trends beyond the control of state and local officials affect the demand for transportation investments. This approach focuses on the aspect of transportation services that is an intermediate good and uncovers demographic and economic factors that influence the derived demand for transportation services. The three questions addressed are

- Is the demand for transportation services responsive to changes in demographic variables like per capita

TABLE 5–4 Estimates of the highway and air transportation demand equation with measures of level and quality of service as dependent variables

	Highway Output		Airport & Airway Output	
Variable	LMILE	LUMILE	LAIRCOM	LAIRENP
LPINC	0.182**	0.464***	-3.83***	-5.35***
	(0.08)	(0.08)	(0.48)	(0.65)
LPOP	0.008	0.225***	2.06***	3.03***
	(0.03)	(0.03)	(0.18)	(0.24)
LREVINC	-0.045	0.035	-1.27***	-1.63***
	(0.04)	(0.04)	(0.22)	(0.3)
TSHARE	0.053***	0.102	0.21***	0.378***
	(0.01)	(0.01)	(0.08)	(0.1)
LFAID	0.022	-0.058***	0.677***	0.914***
	(0.017)	(0.017)	(0.11)	(0.14)
DENSITY	-1.77***	-1.59***	0.195	0.64*
	(0.04)	(0.04)	(0.27)	(0.34)
METROPC	-0.01***	-0.0014**	-0.0019***	-0.024
	(0.0005)	(0.0005)	(0.003)	(0.004)
POVERTY	0.019**	-0.021**	-0.414***	-0.69***
	(0.008)	(0.009)	(0.04)	(0.06)
OWNOH	0.005**	-0.0025	-0.117***	-0.18***
	(0.002)	(0.002)	(0.012)	(0.016)
POP65PC	-0.02***	-0.011***	-0.052**	0.096***
	(0.004)	(0.004)	(0.02)	(0.03)
POPCH	-0.0003	-0.0004	0.013***	0.02***
	(0.0007)	(0.0007)	(0.005)	(0.006)
CPBASEPC	0.0005*	0.0057***	-0.007	-0.009
	(0.002)	(0.001)	(0.009)	(0.01)
EMPLSPC	-0.0042***	-0.005***	0.027***	0.036***
	(0.001)	(0.001)	(0.007)	(0.009)
EMPLTPC	0.0013**	0.003***	0.017***	0.021***
	(0.0006)	(0.0006)	(0.004)	(0.005)
MIDWEST	0.002	-0.008	0.048	-0.327*
	(0.02)	(0.02)	(0.13)	(0.17)
SOUTH	0.046*	0.102***	-0.665***	-1.15***
	(0.04)	(0.02)	(0.14)	(0.19)
WEST	0.067**	0.164***	0.43***	0.242
	(0.028)	(0.028)	(0.17)	(0.22)
AK	-0.027	-0.0106	2.15***	1.56**
	(0.08)	(0.08)	(0.52)	(0.68)
DC	0.781***	1.03***	2.53***	2.88***
	(0.07)	(0.07)	(0.47)	(0.6)
HI	-0.219***	-0.163	0.95***	1.46***
	(0.05)	(0.05)	(0.3)	(0.4)
Intercept	-2.85***	-3.95***	-13.2***	17.5**
	(0.85)	(0.86)	(5.1)	(6.9)
Adjusted R^2	0.897	0.935	0.786	0.776

NOTE: Standard errors appear in parentheses below the estimated coefficients. Time effects, though computed, are not reported here. Asterisks (***, **, and *) indicate that the estimate is significant at 1 percent, 5 percent and 10 percent levels, respectively.

income, urbanization, age distribution, and poverty rates?

- Is the demand for transportation services responsive to economic restructuring and the changing sectoral composition of the economy?
- If dollar investment flows for individual modes of transportation are not good proxies for the level of benefits provided, do measures of the level and quality of service provided generate different empirical results in our demand model?

The results obtained are very encouraging. The demand for transportation investments proves to be much more sensitive to personal income than traditionally thought, once adjustments are made for simultaneous equations bias and missing variables. There are also encouraging implications for urbanization trends and the aging of the nation's population. The results also suggest that these demographic trends, which are generally beyond the control of state and local officials, will impact the demand for investment in individual modes of transportation in different but important ways.

TABLE 5–5 Estimates of mass transit output demand equation

Variable	LPTRIP	LPMILE	LVMILE
LPINC	-0.532	0.566	-0.95
	(1.2)	(1.1)	(1.0)
LPOP	2.38***	2.386***	1.653***
	(0.42)	(0.39)	(0.36)
LREVINC	0.946*	1.56***	0.445
	(0.56)	(0.51)	(0.48)
TSHARE	0.407**	0.35**	0.179
	(0.18)	(0.16)	(0.15)
LFAID	0.129	0.124	0.156
	(0.29)	(0.26)	(0.24)
DENSITY	-1.007*	-1.36***	-1.04**
	(0.58)	(0.53)	(0.49)
METROPC	0.014*	0.012	0.02***
	(0.008)	(0.007)	(0.007)
POVERTY	-0.33***	-0.29***	-0.19**
	(0.11)	(0.1)	(0.09)
OWNOH	-0.052*	-0.026	-0.025
	(0.03)	(0.03)	(0.024)
POP65PC	-0.017	0.023	-0.021
	(0.05)	(0.04)	(0.04)
POPCH	0.022**	0.0273***	0.022**
	(0.01)	(0.009)	(0.009)
CPBASEPC	0.038*	0.039*	0.028
	(0.02)	(0.02)	(0.02)
EMPLSPC	-0.043*	0.044**	0.006
	(0.02)	(0.02)	(0.02)
EMPLTPC	0.005	0.003	0.007**
	(0.004)	(0.004)	(0.004)
MIDWEST	-0.25	-0.648	-0.19
	(0.28)	(0.25)	(0.24)
SOUTH	-0.32	-0.66**	-0.47*
	(0.3)	(0.29)	(0.27)
WEST	-0.10	-0.15	0.086
	(0.35)	(0.32)	(0.3)
AK	0.32	0.48	0.888
	(1.2)	(1.1)	(0.9)
DC	-0.61	0.067	1.6
	(1.3)	(1.2)	(1.1)
HI	0.93	1.53**	0.56
	(0.72)	(0.65)	(0.6)
Intercept	-16.2	-24.1**	-5.9
	(12.3)	(11.2)	(10.4)
Adjusted R^2	0.828	0.863	0.828

NOTE: Standard errors appear in parentheses below the estimated coefficients. Time effects, though computed, are not reported here. Asterisks (***, **, and *) indicate that the estimate is significant at 1 percent, 5 percent and 10 percent levels, respectively.

The results are also very encouraging in economic terms. Estimates of the tax-price variable need to be refined, but results for federal aid are consistent with other studies concerning the substitutability of federal aid for state and local own-source expenditures. What is both new and important is the impact that industry mix has on the derived demand for transportation investment. Not only is there evidence that industry mix is an important element in determining the demand for transportation investment, but the findings also suggest that industry mix has different implications for individual modes of transportation. This further reinforces the notion that such analysis must be conducted on a disaggregate level.

Finally, the findings suggest that there are important implications for looking at the level of service provided, and not just at the level of spending on each mode. Since this analysis is preliminary, much work still needs to be done to refine the measures of the level and quality of service provided, to refine the specification of that model, and to develop improved measures of other independent variables—especially the tax-price variable.

The important conclusions generated by this initial empirical study should be considered as state and local decision makers allocate scarce resources. Specifically,

- The empirical results indicate that different factors influence the demand for different transportation modes so that future analysis needs to disaggregate the public capital variable into individual transportation modes;
- Using 2SLS techniques did result in substantially higher estimates of income elasticity so care must be taken to account for simultaneous equation bias;
- The use of the fixed-effect model with pooled time-series, cross-section data captures variations over time and space that are typically omitted from other demand analysis, resulting in relatively high R-squares and better estimates of individual coefficients; and
- Investment flows are not always good proxies for the level of service being provided so more effort needs to go into developing measures of the level and quality of service actually consumed.

The approach taken in this paper goes beyond the current literature as a start to understanding the mechanisms by which transportation investments and economic activity interact. However, these results are highly preliminary. Much more analysis needs to be conducted with this dataset to verify and extend the robustness of these findings. The findings, however, do suggest that this is a promising avenue for future research.

ENDNOTES

1. Bell, Michael E. and Therese McGuire, *Transportation Investment and Economic Performance: Final Report.* NCHRP Project No. 2-17(3), Section I, Transportation Research Board, National Research Council, Washington, D.C. (August 1994).
2. Musgrave, Richard A., "A Discussion of 'Why Is Infrastructure Important?' by David Alan Aschauer." *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell (ed.), Conference Series No. 34, Federal Reserve Bank of Boston (June 1990) pp. 64–68.
3. Duffy-Deno, Kevin T. and Randall W. Eberts, "Public Infrastructure and Regional Economic Development: A Simultaneous Equations Approach." *Journal of Urban Economics*, Vol. 30, No. 3 (November 1991) pp. 329–343.

4. Bell and McGuire, *op. cit.* (Chapter Two).
5. Wallace E. Oates, *The Estimation of Demand Functions for Local Public Goods: Issues in Specification and Interpretation.* Mimeograph, University of Maryland (October 1986).
6. See Miller, Edward, "The Economics of Matching Grants: The ABC Highway Program." *National Tax Journal*, Vol. 27, No. 2 (1974) and Meyers, Harry G., "Displacement Effects of Federal Highway Grants." *National Tax Journal*, Vol. 40, No. 2 (1987).
7. See Bell, Michael and Eran Feitelson, "U.S. Economic Restructuring and Demand for Transportation Services." *Transportation Quarterly*, Vol. 45, No. 4 (October 1991) pp. 517–538.

CHAPTER 6

TRANSPORTATION AND OTHER PUBLIC INFRASTRUCTURE IN A NEOCLASSICAL GROWTH MODEL*

INTRODUCTION

There is no single way to show how transportation and other forms of public infrastructure affect the economy. The most direct approach defines infrastructure as an input in production and then proceeds to estimate the production function. Aschauer (1989) does this using national aggregates while Munnell (1990) uses national and broad regional aggregates for private sector and public sector capital stocks, labor, and output. Garcia-Mila and McGuire (1992) adopt a similar strategy, but estimate production functions using state data. Each of these studies adopts Cobb-Douglas technology, but obtains different estimates for the productivity of public capital.[1]

There are methodological problems associated with direct estimation of production functions. One is from omitted variables, since a firm's optimal level of output depends on many inputs, some of which are not observed by the econometrician but which may be known to producers. These omitted variables bias the direct estimation of output as a function of known inputs (Varian, 1984). Another problem is simultaneity bias, which arises when the explanatory variables are determined, in part, by the endogenous (left-hand side) variable. This problem can be especially pronounced when using highly aggregated data (e.g., for states or the nation) since these data represent the simultaneous reduced-form outcomes of many firms and not the independent choices of separate firms. Even relatively disaggregated data (e.g., for cities) can lead to bias, although presumably less so, since these data are also aggregates. One vexing source of simultaneity bias when using national (and state) aggregates arises from Say's Law: increases in aggregate output lead to a comparable rise in income, and consequently, to higher demands for labor and capital.

There are alternative procedures that avoid these problems. One is to use disaggregated metropolitan data whenever possible. Another is to use the dual production function, i.e., cost and profit functions.[2] This approach is not biased by omitted variables since in this procedure such variables are not correlated with the equation's error term. Another procedure is to derive a neoclassical growth function, and to model the endogenous components of growth separately so that these are uncorrelated with omitted variables or with the left-hand side variable.[3] The neoclassical growth model is used here in conjunction with a disaggregated dataset.

The question addressed is whether different measures of public capital alter the estimation of model parameters in general, and productivity measures for public capital in particular. The Aschauer-Munnell productivity estimates for public capital seem inordinantly high, and these findings have been criticized on methodological grounds, in addition to the ones mentioned above.[4] These findings have also not held up to estimations based on state data.[5] The purpose here is to push the analysis further. What happens if one uses local data? What if, in addition to local data, one uses several new measures of public capital infrastructure, including measures based on data used by Munnell? These questions are analyzed in depth below. The estimations are confined to the period 1960 to 1977. In other work (Crihfield and Panggabean, 1993) the growth model fits the data for these years very well. Public and private sector infrastructure data obtained from several sources, including Holtz-Eakin, Munnell, and NCHRP, are combined with these data.

THE MODEL

The growth model is developed elsewhere and only the main points are sketched here.[6] It starts with production at time t, which is given by

$$Q(t) = A(t)K^{a}(t)Z^{b}(t)H^{c}(t)L^{R-a-b-c}(t) \quad (1)$$

where Q is net-of-depreciation (δ) output, K is net private sector capital, Z is net public sector capital, H is net human capital, L is labor, A represents a technological shift factor, and R is returns to scale. Labor and technology grow according to the relationships

$$L(t) = L(0)e^{gt} \quad (2)$$

$$A(t) = A(0)e^{\lambda t} \quad (3)$$

The population growth rate g is a function of relative factor prices and other characteristics of state and local areas, and

* Contributing author: John B. Crihfield, Institute of Government and Public Affairs, Department of Agricultural Economics, University of Illinois, Urbana-Champaign, IL.

the growth rate in technology, λ, is exogenous. Fractions of output, s_i, are saved and invested in private sector capital, public sector capital, and human capital. The model is solved for steady-state levels in per capita output and per capita levels of the capital stocks. Steady-state per capita output, q^*, is given by

$$\log q^*(t) = \log A(0) + \lambda t + \frac{a}{1-a-b-c}\log s_k + \frac{b}{1-a-b-c}\log s_z + \frac{c}{1-a-b-c}\log s_h - \frac{a+b+c}{1-a-b-c}\log(\delta+g) + \frac{R-1}{1-a-b-c}\log L(t) \quad (4)$$

Metropolitan area economies need not be at their steady states at any given time, so that per capita output at time t relative to initial-year output equals a fraction of the difference between steady-state per capita output and initial-year per capita output, or

$$\log q(t) - \log q(0) = (1-\pi)[\log q^*(t) - \log q(0)] \quad (5)$$

When $\pi = 1$, there is no adjustment toward steady state during the period 0 to t; when $\pi = 0$, there is full adjustment. Substituting for $\log q^*$ and solving for growth in per capita income gives

$$\log q(t) - \log q(0) = (1-\pi)\log A(0) + (1-\pi)\lambda t + \frac{(1-\pi)a}{1-a-b-c}\log s_k + \frac{(1-\pi)b}{1-a-b-c}\log s_z + \frac{(1-\pi)c}{1-a-b-c}\log s_h - \frac{(1-\pi)(a+b+c)}{1-a-b-c}\log(\delta+g) - (1-\pi)\log q(0) + \frac{(1-\pi)(R-1)}{1-a-b-c}\log L(t) \quad (6)$$

Many fundamental relationships can be tested on the basis of this equation. The convergence hypothesis can be tested, which asserts that poorer regions catch up with wealthier ones, and the speed of convergence from the coefficient of log q(0) can be measured. The coefficients of Equation 6 can also be solved for the production parameters. In particular, the productivity of public investment is a function of the coefficient of log s_z. The coefficient of log L tests returns-to-scale in production, and the sum of coefficients for $\log(s_k)$, $\log(s_h)$, $\log(s_z)$, and $\log(\delta+g)$ tests the Cobb-Douglas hypothesis embodied in the production function in Equation 1.[7]

Endogeneity of factor flows is considered through modeling separately the population growth rate g and private sector investment rate s_k. Identifying determinants of these is important because it is unlikely that these are exogenous in an open economy consisting of many cities where labor and capital are free to move to places of highest net returns. Differences in labor growth and in investment rates affect relative factor returns, and therefore factor flows and per capita outputs.

ESTIMATION

Equation 6 is estimated in two ways. One way is directly with ordinary least squares, which assumes that all variables on the right-hand side of Equation 6 are exogenous in the growth process. It is unlikely, however, that the population growth rate and investment rates on the right-hand side of Equation 6 are exogenous across metropolitan areas for relatively long time periods. This is because factor flows for a small area in an open economy are influenced by relative returns in competing areas, and are functions of relative factor flows across areas. Consequently, a second approach estimates reduced-form population growth and investment equations separately.[8] Predicted values from these estimations are entered into Equation 6 as the second stage of a two-stage least squares estimation strategy.

The models for population growth (POP) and investment (K) are important for two reasons. Statistically they control for simultaneous equations bias. But these equations are also interesting on their own, since they correspond to reduced-form, short-run factor market equilibria. Results from these estimations add to a growing literature on the determinants of interregional and intermetropolitan growth in factor markets.[9] These reduced-form equations include all exogenous variables in Equation 6 plus other variables which shift factor demand and supply functions. These other variables are also referred to as omitted exogenous variables which make it possible to identify POP and K. Variables LPOP60 (log of metropolitan area population in 1960), LY60 (log of real metropolitan area per capita income in 1960), ED (a proxy for investment in human capital), LOC (log of local governments investment rate), and STATE (log of state government investment rate) appear in first-stage regressions for POP and K since they also appear in Equation 6. Shifters serving to identify POP and K include STAX (log of state tax rate), TAX (log of local tax rate), PELEC (log of electricity price), PGAS (log of natural gas price), UNION (log of unionization rate), and eight regional dummies (the Pacific region is the excluded dummy). In regressions for K, SPT (log of state property tax) replaces STAX and TAX. This is because the property tax rate enters directly into the cost of capital whereas average tax rates do not.[10]

Output data are unavailable for metropolitan areas. However, income is a close proxy which is used in measuring per capita growth (left-hand side of Equation 6) and as the denominators in measuring investment rates. Expected signs from estimating the growth model are clear from Equation 6. The factor market estimations represent reduced-form, short-run equilibria for labor and capital. Tax variables STAX, TAX, and SPT shift factor demands to the left (or, equivalently, shift factor supplies to the left), thereby reducing POP or K.[11] Effects of PELEC and PGAS are indeterminate a priori. Higher energy prices have negative scale effects, which reduce demands for labor and capital. However, if energy is a substitute for these factors, then outward shifts in factor demands could offset negative scale effects. UNION shifts the demand for labor leftward thereby lowering POP, but has an indeterminate effect on K due to a substitution effect between labor and capital.

If public investment (LOC, STATE) complements private factors, then expected signs for LOC and STATE are positive. This is more likely for labor than for private capital, if public and private capital are, on average, substitutes. Expected signs for other variables (ED, LPOP60, LY60) are ambiguous since they can affect supply and demand in offsetting ways. For example, education increases labor productivity and shifts out the demand for labor, but this could be offset by higher costs of better-trained workers. It is also not clear whether wealthier areas (high LY60) invest and save more than poorer areas. A positive relationship between savings and wealth is a possible source of income divergence. Nine regional dummies are also defined for Census regions. These serve as proxies for variables (such as wages, rents, and climate) that exhibit strong regional correlations.

Population and Labor

The starting point here is the first-stage estimations for population and labor growth (POP). The standard, or benchmark, models reported in Tables 6–1 through 6–3 (POP-1,

TABLE 6–1 Population growth

Model:	POP-1	POP-2	POP-3
Description:	Basic Model	BEA total private capital	BEA mfg capital (same as POP-2)
Dependent Variable			
D1	-.022 (.004; -6.07)*	-.018 (.007; -2.68)	-.018 (.007; -2.68)
D2	-.015 (.003; -5.63)	-.013 (.004; -3.34)	-.013 (.004; -3.34)
D3	-.017 (.002; -7.20)	-.016 (.003; -5.19)	-.016 (.003; -5.19)
D4	-.025 (.003; -7.75)	-.023 (.004; -6.26)	-.023 (.004; -6.26)
D5	-.006 (.004; -1.53)	-.003 (.005; -.71)	-.003 (.005; -.71)
D6	-.006 (.003; -1.85)	-.004 (.004; -1.05)	-.004 (.004; -1.05)
D7	-.010 (.004; -2.34)	-.009 (.005; -1.71)	-.009 (.005; -1.71)
D8	-.006 (.005; -1.42)	-.004 (.006; -.75)	-.004 (.006; -.75)
LPOP60	-.006 (.001; -4.52)	-.006 (.001; -4.46)	-.006 (.001; -4.46)
LY60	-.0001 (.003; -.04)	-.001 (.003; -.39)	-.001 (.003; -.39)
ED	.028 (.005; 6.07)	.028 (.004; 6.17)	.028 (.004; 6.17)
STAX	-.004 (.001; -3.66)	-.004 (.001; -3.57)	-.004 (.001; -3.57)
TAX	.001 (.003; .19)	.001 (.003; .47)	.001 (.003; .47)
PELEC	.010 (.002; 5.85)	.008 (.003; 2.83)	.008 (.003; 2.83)
PGAS	-.005 (.003; -1.75)	-.007 (.006; -1.23)	-.007 (.006; -1.23)
UNION	-.002 (.003; -.83)	-.002 (.003; -.66)	-.002 (.003; -.66)
CONSTANT	.036 (.023; 1.58)	.032 (.028; 1.14)	.032 (.028; 1.14)
Public Capital:			
LOC	.005 (.002; 2.74)	.005 (.002; 2.66)	.005 (.002; 2.66)
STATE	-.012 (.004; -2.89)	-.015 (.005; -2.77)	-.015 (.005; -2.77)
$\bar{R}^2$	.504	.493	.493
Dummies	10.42 (8,255)	8.96 (8,252)	8.96 (8,252)

NOTES: The null hypothesis of no heteroskedasticity is rejected at the 5 percent level in all regressions reported in the table using the Breusch-Pagan-Godfrey (BPG) and Glejser tests. White's heteroskedastic-consistent covariance matrix estimation is used to correct estimates for an unknown form of heteroskedasticity. "Dummies" refer to F-tests of the joint hypotheses that D1=D2=......=D8=0 (D9 for the Pacific region is the omitted dummy). For comparison, F(8,120) = 2.66 at the 1 percent level of significance (numbers in parentheses refer to degrees of freedom in the numerator and denominator). All variables are defined in the appendix.

* The first number in parentheses is the standard error of the coefficient, and the second number is a two-tailed t-statistic for the hypothesis that the coefficient is zero.

TABLE 6–1 Population growth (continued)

Model:	POP-4			POP-5			POP-6		
Description:	Holtz-Eakin 5 types of capital			Holtz-Eakin total public capital			Holtz-Eakin (higher ed, other ed, streets & highways)		
Dependent Variable									
D1	-.033	(.008;	-4.01)	-.018	(.007;	-2.44)	-.034	(.008;	-4.34)
D2	-.021	(.005;	-4.56)	-.013	(.004;	-3.10)	-.022	(.005;	-4.95)
D3	-.015	(.004;	-4.09)	-.013	(.003;	-4.13)	-.018	(.003;	-5.39)
D4	-.028	(.004;	-6.31)	-.025	(.004;	-6.37)	-.025	(.004;	-6.30)
D5	-.010	(.005;	-2.18)	-.007	(.005;	-1.58)	-.011	(.004;	-2.40)
D6	-.011	(.005;	-2.26)	-.001	(.003;	-2.93)	-.010	(.004;	-2.49)
D7	-.018	(.006;	-2.98)	-.014	(.005;	-2.77)	-.017	(.005;	-3.61)
D8	-.009	(.006;	-1.57)	-.009	(.005;	-1.73)	-.009	(.005;	-1.70)
LPOP60	-.007	(.002;	-4.42)	-.004	(.001;	-3.27)	-.010	(.001;	-4.26)
LY60	.004	(.004;	.97)	.0003	(.004;	.09)	.006	(.004;	1.82)
ED	--			.029	(.005;	6.29)	--		
STAX	-.005	(.001;	-3.72)	-.002	(.001;	-2.11)	-.004	(.001;	-3.25)
TAX	.005	(.003;	1.94)	.005	(.003;	1.95)	.006	(.003;	2.14)
PELEC	.013	(.003;	4.77)	.012	(.003;	4.16)	.011	(.003;	4.07)
PGAS	-.011	(.008;	-1.39)	-.007	(.006;	-1.14)	-.008	(.006;	-1.24)
UNION	-.002	(.003;	-.88)	-.005	(.003;	-1.77)	-.004	(.003;	-1.66)
CONSTANT	.046	(.033;	1.39)	.086	(.022;	3.88)	.035	(.031;	1.14)
<u>Public Capital</u>:									
HE-HIED	-.007	(.003;	-2.32)	--			-.008	(.003;	-2.92)
HE-OED	.005	(.003;	1.51)	--			.008	(.003;	2.87)
HE-STR	-.005	(.002;	-2.04)	--			-.004	(.002;	-1.80)
HE-SEW	.003	(.001;	1.79)	--			--		
HE-UT	.001	(.001;	.77)	--			--		
HE-TOTPUB	--			.004	(.003;	1.02)	--		
$\bar{R}^2$	.411			.457			.399		
Dummies	9.52	(8,232)		7.44	(8,253)		8.64	(8,252)	

TABLE 6–1 Population growth (continued)

Model:	POP-7	POP-8	POP-9
Description:	Holtz-Eakin (higher ed, other ed, streets & highways) with ED	FHA with LOC, STATE	FHA without LOC, STATE
Dependent Variable			
D1	-.025 (.008; -3.00)	-.019 (.007; -2.81)	-.022 (.007; -2.98)
D2	-.017 (.004; -3.81)	-.014 (.004; -3.50)	-.016 (.004; -3.83)
D3	-.015 (.003; -4.65)	-.017 (.003; -5.27)	-.017 (.003; -5.23)
D4	-.024 (.004; -6.52)	-.023 (.004; -6.17)	-.023 (.004; -5.99)
D5	-.007 (.004; -1.71)	-.003 (.005; -.75)	-.004 (.004; -.93)
D6	-.006 (.004; -1.69)	-.005 (.004; -1.18)	-.006 (.003; -1.83)
D7	-.014 (.005; -2.84)	-.010 (.005; -1.82)	-.011 (.005; -2.13)
D8	-.008 (.005; -1.67)	-.005 (.006; -.89)	-.006 (.005; -1.23)
LPOP60	-.004 (.001; -3.52)	-.007 (.001; -4.40)	-.006 (.002; -4.21)
LY60	-.0001 (.004; -.02)	-.001 (.003; -.32)	-.002 (.003; -.48)
ED	.029 (.005; 6.00)	.027 (.001; 6.05)	.029 (.005; 6.36)
STAX	-.003 (.001; -2.41)	-.005 (.001; -3.59)	-.004 (.001; -3.44)
TAX	.006 (.003; 2.22)	.002 (.003; .52)	.005 (.003; 1.92)
PELEC	.011 (.003; 4.23)	.008 (.003; 2.87)	.009 (.003; 3.46)
PGAS	-.007 (.006; -1.16)	-.008 (.006; -1.41)	-.009 (.006; -1.49)
UNION	-.004 (.003; -1.68)	-.001 (.003; -.36)	-.001 (.003; -.43)
CONSTANT	.061 (.031; 1.93)	.072 (.043; 1.69)	.115 (.020; 5.66)
Public Capital:			
HE-HIED	-.007 (.003; -2.59)	--	--
HE-OED	.006 (.003; 2.39)	--	--
HE-STR	-.002 (.002; -.93)	--	--
FHA	--	-.006 (.005; -1.22)	-.012 (.004; -2.90)
LOC	--	.005 (.002; 2.74)	--
STATE	--	-.009 (.007; -1.33)	--
$\bar{R}^2$	.467	.493	.478
Dummies	7.30 (8,251)	9.00 (8,251)	8.62 (8,253)

TABLE 6–1 Population growth (continued)

Model:	POP-10			POP-11			POP-12		
Description:	Lane-miles			Lane-miles, Air			Lane-miles, Air, Network		
Dependent Variable									
D1	-.021	(.007;	-2.87)	-.029	(.007;	-4.22)	-.030	(.007;	-4.39)
D2	-.014	(.004;	-3.73)	-.019	(.004;	-5.15)	-.019	(.004;	-5.16)
D3	-.014	(.003;	-4.64)	-.017	(.003;	-5.83)	-.017	(.003;	-6.01)
D4	-.017	(.004;	-4.67)	-.023	(.004;	-6.05)	-.023	(.004;	-6.10)
D5	-.006	(.004;	-1.38)	-.014	(.004;	-3.21)	-.014	(.004;	-3.26)
D6	-.006	(.004;	-1.35)	-.010	(.004;	-2.80)	-.011	(.004;	-2.87)
D7	-.009	(.005;	-1.66)	-.012	(.005;	-2.55)	-.011	(.005;	-2.47)
D8	-.005	(.006;	-.73)	-.015	(.006;	-2.37)	-.015	(.007;	-2.24)
LPOP60	-.008	(.002;	-5.02)	-.010	(.002;	-6.34)	-.010	(.002;	-6.07)
LY60	-.003	(.003;	-1.06)	-.005	(.003;	-1.64)	-.005	(.003;	-1.60)
ED	.029	(.005;	6.31)	.028	(.005;	6.20)	.028	(.005;	6.06)
STAX	-.005	(.001;	-4.26)	-.008	(.001;	-5.84)	-.008	(.005;	-1.53)
TAX	.0004	(.003;	.14)	-.001	(.003;	-.43)	-.001	(.003;	-.27)
PELEC	.006	(.003;	2.28)	.011	(.003;	3.89)	.011	(.003;	3.86)
PGAS	-.008	(.006;	-1.23)	-.003	(.006;	-.53)	-.003	(.005;	-.47)
UNION	-.004	(.003;	-1.54)	-.005	(.002;	-2.40)	-.005	(.002;	-2.28)
CONSTANT	.079	(.031;	2.53)	.088	(.027;	3.24)	.078	(.032;	2.42)
<u>Public Capital</u>:									
LOC	.005	(.002;	2.76)	.005	(.002;	2.99)	.005	(.002;	2.95)
STATE	-.011	(.005;	-2.18)	-.007	(.004;	-1.57)	-.007	(.005;	-1.53)
LANE	-.006	(.003;	-2.25)	-.009	(.002;	-3.84)	-.004	(.007;	-.64)
I-57	.040	(.065;	.62)	.011	(.055;	.20)	.013	(.055;	.23)
AIR	--			.008	(.002;	4.53)	.012	(.006;	2.00)
NTWK	--			--			-.002	(.003;	-.64)
$\bar{R}^2$	.515			.554			.553		
Dummies	5.70	(8,250)		6.87	(8,249)		6.92	(8,248)	

TABLE 6–1 Population growth (continued)

Model:	POP-13			POP-14		
Description:	Munnell total private capital and total public capital			Munnell total private capital and 3 types of public capital		
Dependent Variable						
D1	-.017	(.008;	-2.26)	-.028	(.008;	-3.37)
D2	-.013	(.005;	-2.67)	-.021	(.005;	-4.15)
D3	-.014	(.003;	-4.18)	-.020	(.004;	-5.33)
D4	-.024	(.004;	-5.55)	-.029	(.004;	-7.55)
D5	-.005	(.005;	-1.02)	-.006	(.005;	-1.22)
D6	-.008	(.003;	-2.39)	-.010	(.003;	-3.33)
D7	-.013	(.005;	-2.46)	-.012	(.005;	-2.53)
D8	-.007	(.005;	-1.35)	-.009	(.005;	-1.91)
LPOP60	-.004	(.001;	-3.29)	-.006	(.002;	-3.52)
LY60	.0004	(.004;	.13)	-.002	(.003;	-.50)
ED	.030	(.005;	6.34)	.029	(.005;	6.21)
STAX	-.002	(.001;	-2.13)	-.004	(.001;	-2.51)
TAX	.005	(.003;	1.96)	.005	(.002;	1.97)
PELEC	.010	(.003;	3.06)	.017	(.003;	4.81)
PGAS	-.008	(.006;	-1.25)	-.004	(.006;	-.69)
UNION	-.004	(.003;	-1.64)	.002	(.003;	.51)
CONSTANT	.071	(.017;	4.20)	.067	(.018;	3.79)
Public Capital:						
MUN-TOTPUB	-.001	(.002;	-.41)	--		
MUN-HIWAY	--			-.001	(.001;	-.59)
MUN-WATSEW	--			-.0004	(.0006;	-.64)
MUN-OTH	--			.003	(.002;	2.22)
$\bar{R}^2$	.455			.494		
Dummies	7.54	(8,253)		10.14	(8,243)	

TABLE 6–2 Investment

Model:	K-1		K-2		K-3	
Description:	Basic Model		BEA total private capital		BEA mfg capital	
Dependent Variable						
D1	.793	(.272; 2.91)[a]	-.396	(.132; -2.99)	-1.530	(.322; -4.75)
D2	.456	(.188; 2.42)	-.568	(.079; -7.20)	-1.834	(.181; -10.15)
D3	.874	(.141; 6.21)	-.092	(.056; -1.62)	.355	(.122; 2.91)
D4	.355	(.207; 1.71)	-.052	(.064; -.81)	-.113	(.143; -.79)
D5	.271	(.273; .99)	.414	(.103; 4.03)	-.583	(.214; -2.72)
D6	.334	(.260; 1.29)	.427	(.115; 3.72)	-.054	(.224; -.24)
D7	-.001	(.297; -.005)	.467	(.132; 3.52)	-.042	(.287; -.15)
D8	-.018	(.242; -.07)	.387	(.102; 3.79)	-.706	(.279; -2.54)
LPOP60	.039	(.045; .87)	-.020	(.011; -1.75)	.052	(.033; 1.55)
LY60	-.729	(.246; -2.97)	-.066	(.059; -1.13)	-.941	(.201; -4.69)
ED	-.776	(.490; -1.58)	-.041	(.095; -.43)	-.379	(.274; -1.39)
SPT	-.026	(.230; -.11)	.420	(.069; 6.05)	.434	(.164; 2.66)
PELEC	-.343	(.167; -2.05)	-.077	(.073; -1.06)	.217	(.147; 1.48)
PGAS	.025	(.250; .10)	.027	(.155; .17)	.542	(.316; 1.72)
UNION	.052	(.184; .28)	-.121	(.058; -2.09)	-.711	(.144; -4.94)
CONSTANT	-2.442	(1.392; -1.76)	-2.514	(.653; -3.85)	.896	(1.663; .54)
Public Capital:						
LOC	.013	(.137; .10)	.018	(.030; .58)	-.095	(.088; -1.09)
STATE	.040	(.285; .14)	.075	(.121; .62)	.808	(.348; 2.32)
$\bar{R}^2$	.204		.798		.711	
Dummies	6.32	(8,256)	26.43	(8,253)	32.86	(8,253)

NOTES: The null hypothesis of no heteroskedasticity is rejected at the 5 percent level in all regressions reported in the table using the Breusch-Pagan-Godfrey (BPG) and Glejser tests. White's heteroskedastic-consistent covariance matrix estimation is used to correct estimates for an unknown form of heteroskedasticity. "Dummies" refer to F-tests of the joint hypotheses that D1=D2=......=D8=0 (D9 for the Pacific region is the omitted dummy). For comparison, F(8,120) = 2.66 at the 1 percent level of significance (numbers in parentheses refer to degrees of freedom in the numerator and denominator). All variables are defined in the appendix.

[a] The first number in parentheses is the standard error of the coefficient, and the second number is a two-tailed t-statistic for the hypothesis that the coefficient is zero.

TABLE 6–2 Investment (continued)

Model:	K-4	K-5	K-6
Description:	Holtz-Eakin 5 types of capital	Holtz-Eakin total state public capital	Holtz-Eakin (higher ed, other ed, streets & highways)
Dependent Variable			
D1	.510 (.456; 1.12)	-.135 (.330; -.41)	.459 (.422; 1.09)
D2	.352 (.228; 1.55)	-.023 (.186; -.12)	.297 (.207; 1.44)
D3	.802 (.195; 4.11)	.538 (.147; 3.66)	.705 (.163; 4.33)
D4	.441 (.218; 2.02)	.377 (.186; 2.03)	.291 (.172; 1.69)
D5	.267 (.274; .98)	.137 (.292; .47)	.185 (.273; .68)
D6	.476 (.278; 1.71)	.443 (.226; 1.66)	.332 (.257; 1.29)
D7	.577 (.307; 1.88)	.396 (.283; 1.40)	.430 (.266; 1.62)
D8	.013 (.276; .05)	.109 (.232; .47)	-.021 (.253; -.08)
LPOP60	.040 (.046; .87)	.032 (.044; .74)	.040 (.044; .90)
LY60	-.698 (.309; -2.26)	-.568 (.249; -2.28)	-.766 (.285; -2.69)
ED	--	-.648 (.460; -1.41)	--
SPT	-.088 (.272; -.33)	-.203 (.233; -.87)	-.136 (.250; -.54)
PELEC	-.009 (.272; -.33)	-.062 (.180; -.35)	.009 (.155; .06)
PGAS	1.063 (.399; 2.67)	.864 (.331; 2.61)	.829 (.323; 2.57)
UNION	.003 (.173; .02)	.055 (.176; .31)	.028 (.171; .16)
CONSTANT	-2.368 (1.928; -1.23)	-4.203 (1.351; -3.11)	-1.906 (1.871; -1.02)
<u>Public Capital</u>:			
HE-HIED	.282 (.192; 1.47)	--	.275 (.170; 1.62)
HE-OED	-.314 (.221; -1.42)	--	-.287 (.176; -1.63)
HE-STR	.294 (.154; 1.91)	--	.214 (.144; 1.48)
HE-SEW	-.124 (.095; -1.30)	--	--
HE-UT	.048 (.063; .77)	--	--
HE-TOTPUB	--	-.146 (.297; -.49)	--
$\bar{R}^2$	.188	.200	.195
Dummies	3.32 (8,233)	4.65 (8,254)	4.15 (8,253)

TABLE 6–2 Investment (continued)

Model:	K-7			K-8			K-9		
Description:	Holtz-Eakin (higher ed, other ed, streets & highways) with ED			FHA with LOC, STATE			FHA without LOC, STATE		
Dependent Variable									
D1	.269	(.406;	.66)	-.164	(.319;	-.52)	-.082	(.323;	-.25)
D2	.190	(.217;	.87)	-.078	(.185;	-.42)	.050	(.185;	.27)
D3	.648	(.164;	3.95)	.601	(.143;	4.20)	.614	(.145;	4.23)
D4	.311	(.171;	1.81)	.160	(.212;	.75)	.176	(.209;	.84)
D5	.104	(.275;	.38)	.002	(.264;	.01)	.010	(.266;	.04)
D6	.259	(.268;	.97)	.138	(.259;	.53)	.268	(.230;	1.17)
D7	.350	(.271;	1.29)	.092	(.303;	.30)	.251	(.275;	.91)
D8	.003	(.250;	.01)	-.342	(.281;	-1.22)	-.131	(.246;	-.53)
LPOP60	.036	(.043;	.83)	.036	(.043;	.85)	.041	(.043;	.95)
LY60	-.599	(.250;	-2.40)	-.500	(.247;	-2.02)	-.570	(.248;	-2.30)
ED	-.619	(.449;	-1.38)	-.748	(.462;	-1.62)	-.691	(.440;	-1.56)
SPT	-.166	(.249;	-.67)	.020	(.232;	.09)	-.136	(.226;	-.60)
PELEC	-.001	(.160;	-.01)	.146	(.183;	.80)	.068	(.173;	.39)
PGAS	.842	(.323;	2.61)	.623	(.345;	1.81)	.852	(.332;	2.57)
UNION	.010	(.169;	.06)	.059	(.180;	.33)	-.021	(.177;	-.12)
CONSTANT	-2.472	(1.845;	-1.34)	1.334	(3.325;	.40)	-4.587	(.892;	-5.14)
Public Capital:									
HE-HIED	.267	(.170;	1.57)	--			--		
HE-OED	-.260	(.181;	-1.44)	--			--		
HE-STR	.181	(.144;	1.26)	--			--		
FHA	--			-.391	(.440;	-.89)	.352	(.236;	1.49)
LOC	--			.004	(.134;	.03)	--		
STATE	--			1.083	(.573;	1.89)	--		
$\bar{R}^2$	.201			.211			.206		
Dummies	4.02	(8,252)		5.59	(8,252)		5.21	(8,254)	

TABLE 6–2 Investment (continued)

Model:	K-10			K-11			K-12		
Description:	Lane-miles			Lane-miles, Air			Lane-miles, Air, Network		
Dependent Variable									
D1	-.008	(.333;	-.02)	.151	(.326;	.47)	.126	(.328;	.38)
D2	-.068	(.177;	-.39)	.019	(.180;	.11)	.030	(.179;	.16)
D3	.567	(.172;	3.30)	.639	(.168;	3.79)	.632	(.169;	3.74)
D4	.034	(.256;	.13)	.158	(.254;	.62)	.181	(.252;	.72)
D5	-.064	(.260;	-.25)	.118	(.280;	.42)	.130	(.275;	.47)
D6	.067	(.249;	.27)	.174	(.262;	.66)	.176	(.258;	.68)
D7	.028	(.284;	.10)	.079	(.279;	.28)	.094	(.274;	.34)
D8	-.058	(.290;	-.20)	.137	(.288;	.48)	.191	(.278;	.69)
LPOP60	.045	(.043;	1.04)	.044	(.042;	1.03)	.041	(.043;	.96)
LY60	-.486	(.254;	-1.91)	-.500	(.250;	-2.00)	-.457	(.263;	-1.74)
ED	-.770	(.447;	-1.72)	-.762	(.448;	-1.70)	-.799	(.453;	-1.77)
SPT	-.041	(.226;	-.18)	.033	(.231;	.14)	.061	(.232;	.26)
PELEC	.142	(.191;	.74)	.015	(.202;	.07)	.007	(.199;	.04)
PGAS	.594	(.332;	1.79)	.410	(.326;	1.26)	.430	(.330;	1.31)
UNION	.032	(.164;	.19)	.078	(.161;	.48)	.080	(.157;	.51)
CONSTANT	-.294	(2.647;	-.11)	-.143	(2.599;	-.06)	-1.047	(2.777;	-.38)
Public Capital:									
LOC	-.023	(.129;	-.18)	-.017	(.127;	-.14)	-.014	(.127;	-.11)
STATE	.718	(.398;	1.80)	.599	(.407;	1.47)	.627	(.396;	1.58)
LANE	-.172	(.242;	-.71)	-.157	(.243;	-.65)	.235	(.458;	.51)
I-57	-7.279	(3.771;	-1.93)	-6.503	(3.824;	-1.70)	-6.210	(3.831;	-1.62)
AIR	--			-.203	(.102;	-1.98)	.109	(.307;	.35)
NTWK	--			--			-.133	(.130;	-1.02)
$\bar{R}^2$	.216			.221			.220		
Dummies	3.40	(8,251)		3.51	(8,250)		3.46	(8,249)	

TABLE 6–2 Investment (continued)

Model:	K-13			K-14		
Description:	Munnell total private capital and total public capital			Munnell total private capital and 3 types of public capital		
Dependent Variable						
D1	.250	(.174;	1.43)	.561	(.223;	2.51)
D2	.135	(.125;	-1.08)	.114	(.136;	.84)
D3	.168	(.063;	2.67)	.359	(.075;	4.79)
D4	.305	(.097;	3.16)	.331	(.086;	3.83)
D5	.678	(.159;	4.27)	.559	(.161;	3.48)
D6	.545	(.116;	4.70)	.515	(.114;	4.53)
D7	.282	(.109;	2.59)	.184	(.106;	1.73)
D8	.547	(.107;	5.11)	.500	(.130;	3.83)
LPOP60	-.033	(.013;	-2.62)	-.014	(.011;	-1.22)
LY60	-.107	(.081;	-1.32)	-.060	(.078;	-.76)
ED	.078	(.098;	.79)	.078	(.090;	.86)
SPT	.233	(.094;	2.50)	.256	(.111;	2.31)
PELEC	-.497	(.092;	-5.40)	-.638	(.107;	-5.95)
PGAS	-.764	(.160;	-4.79)	-.895	(.179;	-5.01)
UNION	.049	(.089;	.55)	-.180	(.068;	-2.65)
CONSTANT	-2.139	(.423;	-5.06)	-1.466	(.392;	-3.74)
Public Capital:						
MUN-TOTPUB	-.034	(.076;	-.45)	--		
MUN-HIWAY	--			.059	(.025;	2.36)
MUN-WATSEW	--			.021	(.020;	1.09)
MUN-OTH	--			-.151	(.047;	-3.24)
$\bar{R}^2$	.830			.869		
Dummies	13.45	(8,254)		20.03	(8,244)	

TABLE 6–3 Growth models in per capita income

Model:	GRO-1	GRO-2	GRO-3
Description:	(2SLS; restricted)	(2SLS; restricted; BEA total private capital)	(2SLS; restricted; BEA mfg capital)
Dependent Variable			
K	-.020 (.016; -1.21)[a]	.025 (.026; .98)	.005 (.010; .55)
ED	.181 (.053; 3.44)	.194 (.049; 3.97)	.178 (.050; 3.54)
LDP	-.125 (.043; -2.88)	-.123 (.045; -2.71)	-.096 (.041; -2.36)
LY60	-.676 (.331; -20.45)	-.689 (.031; -22.55)	-.690 (.036; -19.40)
LPOP60	.043 (.006; 7.10)	.044 (.006; 7.38)	.043 (.006; 7.33)
CONSTANT	1.148 (.129; 8.92)	1.086 (.123; 8.85)	1.127 (.121; 9.29)
Public Capital			
LOC	-.019 (.018; -1.06)	-.026 (.018; -1.46)	-.027 (.018; -1.53)
STATE	-.018 (.032; -.56)	-.070 (.025; -2.78)	-.060 (.021; -2.81)
$\bar{R}^2$	.760	.780	.780
Cobb-Douglas	1.32	.60	.73
λ	.066	.069	.069
a_k	-.024	.031	.007
a_b	.226	.239	.226
a_L	.898	.902	.932
a_{public}	a_{loc} -.024	a_{loc} -.032	a_{loc} -.034
	a_{st} -.022	a_{st} -.086	a_{st} -.076
RTS	1.054	1.054	1.055
Hausman[b]	4.19 (2,265)	2.89 (2,262)	2.68 (2,262)
LKR[c]	2.65	-.53	.30
LGR[c]	-1.47	-2.09	-2.20

NOTES: All models are corrected for heteroskedasticity (see Tables 1 and 2). In all cases either the BPG test, Glejser test, or both are rejected at the 10 percent level or less, although there is much less heteroskedasticity in th regressions (as reflected in the significance levels for BPG, Glejser, and other tests) than in the factor market mod of Tables 1 and 2. "Cobb-Douglas" refers to the t-statistic testing whether the sum of a set of coefficients equals zero (see text). If the null hypothesis is accepted, then this restriction is imposed in estimation. All Hausman and Nakamura test statistics are estimated from models corrected for heteroskedasticity. LKR and LGR are residuals from estimating K and POP (first-stage estimations) and are used to test endogeneity for K and POP separately (Godfrey, 1989).

[a] The first number in parentheses is the standard error, the second number is the t-statistic.
[b] F statistics, with degrees of freedom in parentheses.
[c] Values reported are t-statistics.

TABLE 6–3 Growth models in per capita income (continued)

Model:		GRO-4	GRO-5	GRO-6
Description:		(2SLS; restricted; Holtz-Eakin, 5 types of capital)	(2SLS; unrestricted; Holtz-Eakin, total public capital)	(2SLS; restricted; Holtz-Eakin higher ed, other ed, streets & highways)
Dependent Variable				
K		.031 (.021; 1.50)	.038 (.023; 1.63)	.037 (.014; 2.68)
ED		--	.193 (.059; 3.25)	--
LDP		-.020 (.030; -.67)	-.029 (.047; -.62)	-.016 (.025; -.62)
LY60		-.593 (.043; -13.85)	-.672 (.030; -22.37)	-.599 (.040; -15.13)
LPOP60		.039 (.006; 6.82)	.042 (.006; 7.41)	.040 (.006; 7.25)
CONSTANT		1.438 (.102; 14.12)	1.622 (.196; 8.27)	1.397 (.093; 15.01)
Public Capital				
	HE-HIED	.010 (.018; .56)	--	.006 (.017; .32)
	HE-OED	-.054 (.025; -2.18)	--	-.049 (.023; -2.15)
	HE-STR	.022 (.013; 1.69)	--	.022 (.011; 1.99)
	HE-SEW	.010 (.012; .80)	--	--
	HE-UT	.001 (.008; .11)	--	--
	HE-TOTPUB	--	-.028 (.025; -1.11)	--
$\bar{R}^2$		.778	.779	.774
Cobb-Douglas		.18	1.96	.29
λ		.053	.065	.054
a_k		.051	.043	.060
a_h		--	.221	--
a_L		1.031	.861	1.041
a_{public}	a_{HIED}	.017	--	.009
	a_{OED}	-.087	--	-.080
	a_{STR}	.035	--	.036
	a_{SEW}	.016	--	--
	a_{UT}	.001	--	--
	a_{TOTPUB}	--	-.032	--
RTS		1.064	1.048	1.066
Hausman		4.90 (2,242)	7.33 (2,262)	5.12 (2,262)
LKR		3.07	3.38	3.01
LGR		-.44	-1.77	-.70

TABLE 6–3 Growth models in per capita income (continued)

Model:	GRO-7		GRO-8		GRO-9	
Description:	(2SLS; unrestricted; Holtz-Eakin higher ed, other ed, streets and highways, with ED)		(2SLS; restricted; FHA with LOC, STATE).		(2SLS; restricted; FHA without LOC, STATE)	
Dependent Variable						
K	.051	(.023; 2.21)	-.003	(.015; -.20)	-.007	(.014; -.49)
ED	.183	(.059; 3.09)	.181	(.056; 3.21)	.170	(.054 3.16)
LDP	-.022	(.051; -.43)	-.095	(.044; -2.14)	-.111	(.042; -2.63)
LY60	-.640	(.036; -17.99)	-.702	(.029; -24.40)	-.693	(.029; -23.80)
LPOP60	.041	(.006; 7.31)	.043	(.006; 7.38)	.041	(.006; 7.26)
CONSTANT	1.543	(.250; 6.18)	1.206	(.315; 3.83)	1.542	(.131; 11.77)
Public Capital						
HE-HIED	-.014	(.017; -.80)	--		--	
HE-OED	-.034	(.024; -1.45)	--		--	
HE-STR	.016	(.012; 1.32)	--		--	
FHA	--		-.011	(.049; -.23)	-.052	(.021; -2.48)
LOC	--		-.026	(.018; -1.50)	--	
STATE	--		-.046	(.052; -.89)	--	
$\bar{R}^2$	.782		.778		.776	
Cobb-Douglas	1.90		1.05		1.36	
λ	.060		.071		.070	
a_k	.061		-.004		-.008	
a_h	.217		.228		.211	
a_L	.808		.935		.913	
a_{public} a_{HIED}	-.016		a_{FHA} -.014		a_{FHA} -.064	
a_{OED}	-.041		a_{loc} -.033		--	
a_{STR}	.019		a_{st} -.058		--	
RTS	1.048		1.054		1.051	
Hausman	10.24	(2,260)	7.52	(2,261)	7.87	(2,263)
LKR	3.73		3.62		3.46	
LGR	-1.93		-1.94		-2.33	

TABLE 6–3 Growth models in per capita income (continued)

Model:	GRO-10			GRO-11			GRO-12		
Description:	(2SLS; restricted; Lane-miles)			(2SLS; restricted; Lane-miles; Air)			(2SLS; restricted; Lane-miles, Air, Network)		
Dependent Variable									
K	.002	(.013;	.14)	.005	(.014;	.36)	.005	(.014;	.35)
ED	.168	(.051;	3.27)	.169	(.050;	3.37)	.169	(.050	3.40)
LDP	-.083	(.040;	-2.05)	-.087	(.037;	-2.32)	-.086	(.037;	-2.33)
LY60	-.699	(.028;	-25.13)	-.697	(.027;	-25.57)	-.697	(.027;	-25.64)
LPOP60	.043	(.006;	7.37)	.043	(.006;	7.42)	.043	(.006;	7.43)
CONSTANT	1.148	(.127;	9.05)	1.147	(.126;	9.13)	1.148	(.125;	9.21)
Public Capital									
LOC	-.028	(.018;	-1.60)	-.027	(.018;	-1.56)	-.028	(.018;	-1.56)
STATE	-.059	(.023;	-2.62)	-.060	(.022;	-2.67)	-.060	(.023;	-2.64)
$\bar{R}^2$	.779			.780			.780		
Cobb-Douglas	1.44			1.57			1.62		
λ	.071			.070			.070		
a_k	.002			.006			.006		
a_h	.215			.216			.215		
a_L	.949			.944			.944		
a_{public}									
a_{loc}	-.036			-.035			-.035		
a_{st}	-.075			-.076			-.076		
RTS	1.055			1.055			1.055		
Hausman	7.32	(2,262)		6.80	(2,262)		6.98	(2,262)	
LKR	3.47			3.39			3.43		
LGR	-2.15			-1.99			-1.96		

TABLE 6–3 Growth models in per capita income (continued)

Model:		GRO-13		GRO-14	
Description:		(OLS; restricted; Munnell total private capital, total public capital)		(2SLS; restricted; Munnell total private capital & 3 types of public capital)	
Dependent Variable					
K		-.006	(.015; -.44)	-.013	(.019; -.66)
ED		.136	(.039; 3.47)	.122	(.044; 2.79)
LDP		-.120	(.034; -3.51)	-.101	(.043; -2.37)
LY60		-.669	(.031; -21.39)	-.662	(.038; -17.51)
LPOP60		.042	(.006; 7.57)	.042	(.006; 7.22)
CONSTANT		1.278	(.090; 14.20)	1.295	(.087; 14.89)
Public Capital					
	MUN-TOTPUB	-.010	(.013; -.77)	--	
	MUN-HIWAY	--		.010	(.011; .93)
	MUN-WATSEW	--		.001	(.009; .13)
	MUN-OTH	--		-.019	(.010; -2.04)
$\bar{R}^2$		.778		.782	
Cobb-Douglas		1.29		1.76	
λ		.065		.064	
a_k		-.008		-.017	
a_b		.173		.160	
a_L		.901		.922	
a_{public}	a_{TOT}	-.012		--	
	a_{HIWAY}	--		.013	
	a_{WATSEW}	--		.002	
	a_{OTH}	--		-.025	
RTS		1.053		1.055	
Hausman		2.46	(2,263)	2.89	
LKR		-.49		-.31	
LGR		-2.21		-2.37	

K-1, GRO-1) are the same as in Crihfield and Panggabean (1993) for the years 1960 to 1977. The framework and time period are used because they provide a good fit to the data and allow focus on public and private sector infrastructure. However, the findings with respect to public capital are not much affected by the choice of period.

Findings from the standard model (POP-1) hold up in almost all model specifications. These are summarized as follows (see Table 6–1). During the period, population and labor grew fastest in smaller, less unionized metropolitan areas, especially in the South and West. Relatively high state tax rates, but not composite local tax rates, slowed population and labor growth. Relatively high rates of investment by local governments, but not by state governments, increased growth in population. Energy prices did not have a clear impact in these growth models.

Models POP-2 through POP-14 examine the consequences of introducing alternative measures of public investment. POP-2 (and POP-3, which is identical to POP-2) is virtually the same as POP-1. This is because the BEA total private investment data used in measuring the dependent variable in K-2 do not affect POP. There are minor differences between POP-2 and POP-1 because BEA capital stock data are unavailable for Alaska, Hawaii, and the District of Columbia, thereby reducing the number of observations in POP-2.

Models POP-4, POP-5, POP-6, and POP-7 use Holtz-Eakin data to measure investment rates. As in all models in this paper, investment rates s_k, s_h, and s_{public} are used as explanatory variables rather than capital stocks, which are used as explanatory variables in the production function studies. The s_i represent shares of income devoted to various types of investment.[12] The adjusted-R^2 fall in all four of these specifications compared to the benchmark. POP-4 omits LOC and STATE (local and state government investment rates) and ED (educational attainment) and adds five-specific-factor, public sector investments. POP-5 replaces local and state investment rates (LOC, STATE) with the Holtz-Eakin measure of total state and local public investment (HE-TOTPUB). POP-6 replaces LOC, STATE, and ED with three-specific-factor, Holtz-Eakin investments (higher education, other education, and water and sewers). POP-7 is the same as POP-6, except that it reintroduces educational attainment (ED).

Several anomalies arise in considering the Holtz-Eakin results (compared to the benchmark, POP-1), which may be caused by omitted variables. Initial-period per capita income (LY60) becomes positive when skill (ED) is omitted in POP-4, POP-5, and POP-6. Also, the composite local tax rate (TAX) becomes significant (and positive) in all four specifications. This may be because TAX is the only local fiscal variable in these variations, and therefore picks up local infrastructure effects otherwise measured by LOC. The UNION effect is also more pronounced in these models.

Public infrastructure plays a minor role in these four variations. State and local investment taken as a whole in POP-5 has a positive, but insignificant sign. When investment is disaggregated, higher education (HE-HIED), and streets and highways (HE-STR) have negative and often significant coefficients, whereas investments in public schools (HE-OED) and sewers and sanitation (HE-SEW) have positive, significant coefficients.[13] Theory does not provide unambiguous guidance on how public infrastructure should affect labor market outcomes, since these outcomes in part depend upon the strength of complementarity between labor and public capital. However, as a rule we expected positive signs. The mixed results suggest that the role of public capital is either very subtle or relatively weak. Results from practically all other models suggest the same, as will be shown.

Models POP-8 and POP-9 incorporate highway data compiled from the FHWA. POP-8 leaves in local and state investment (LOC, STATE), whereas POP-9 takes these out. Estimations of these models resemble the benchmark model (POP-1), with the following differences. PGAS is not significant in either model. Local tax (TAX) becomes significant when local public investment (LOC) is omitted in POP-9, which probably reflects the omitted variable problem discussed above. As when using Holtz-Eakin data, investment rates based on FHWA data do not behave as expected. FHWA is negative in both models, and is significant in POP-9.

Models POP-10, POP-11, and POP-12 add several measures of physical transportation infrastructure to the benchmark model (lane miles per capita, fraction of roads on interstates, air departures per capita, and a network index). POP-10 includes indices of quantity and quality of highway infrastructure, as measured by lane-miles per capita (a quantity index, LANE) and fraction of road system on interstate highways (a quality index, I-57). POP-11 adds air departures per capita (AIR), and POP-12 constructs a network index (NTWK), defined as lane-miles per capita times air departures per capita. The network variable investigates whether there is a positive impact on growth due to the interaction of road and air infrastructure.

Results from these estimations are similar to the benchmark, POP-1. For the new transportation infrastructure variables, growing areas are not correlated with indices of quantity and quality of highway (in fact, LANE has a significant negative coefficient). There is also no network effect as defined above. On the other hand, growing areas had relatively high levels of air departures per capita (AIR).

Estimations POP-13 and POP-14 replace the benchmark LOC and STATE with public investments based on Munnell's data. POP-13 and POP-5 are the same, except that POP-13 uses Munnell's data for total public capital and POP-5 uses Holtz-Eakin's data. The results are similar; there is no statistically significant effect from public infrastructure. POP-14, which uses three types of capital from Munnell, resembles POP-6, which uses three types of capital from Holtz-Eakin (not the same types of capital). Highways and water and sewers have statistically insignificant negative signs in POP-14, and only "other" capital has the expected positive and significant sign.

Overall, there are two noteworthy generalizations which emerge from studying variations in POP-1 through POP-14. First, results of the benchmark model, as explained above and considered in depth elsewhere (Crihfield and Panggabean, 1993) are not much changed when alternative specifications of public and private investment enter the model for POP. Second, there is no strong evidence that public capital affects population (and employment) growth. The best evidence comes from LOC, the original measure used here of the composite rate of local government investment. However, state measures of public investment typically perform poorly. These include the original measure (STATE), measures using Holtz-Eakin and Munnell data (HE-HIED, HE-STR, MUN-HIWAY, MUN-WATSEW), measures using FHWA data, and direct measures of physical transportation infrastructure (LANE, I-57). The exceptions are spending on primary and secondary public schools (HE-OED), sewers and sanitation (HE-SEW), "other" (MUN-OTH), and air departures (AIR), where a positive, significant relationship between public infrastructure and population growth is found.

Investment

There is more variation across the investment models than across the population growth models (see Table 6–2). This is not surprising since data from three sources are used to measure the dependent variable log s_k. The basic model (K-1) and most other models use investment in manufacturing in metropolitan areas to calculate the private sector investment rate s_k (from *Census of Manufactures* data). The exceptions are K-2, which uses BEA total investment, K-3, which uses BEA manufacturing investment, and K-13 and K-14, which use Munnell total private investment.

Models K-1 through K-14 correspond directly with models POP-1 through POP-14, so there is no need to repeat the descriptions of the model variations. Results are first examined across models in variables other than those pertaining to public capital. A consistent finding across all models is that LY60 is negative and usually significant. This is noteworthy because it suggests that savings and investment rates fall with higher per capita incomes, which means that the savings rate has apparently not been a source of diverging per capita incomes across cities.

The behavior of other terms varies widely across models. Educational attainment (ED) is negative and usually significant in models measuring private investment with manufacturing data, but not in models which use total private investment. This could be because there is greater substitutability between skilled labor and physical capital in manufacturing than between skilled labor and capital in nonmanufacturing industries. The state property tax rate (SPT) shows no clear pattern. It is negative (as expected) although not significant in most models, but is positive and highly significant in models using BEA and Munnell data. Energy prices (PELEC and PGAS) are significantly negative when using Munnell data, but not in most other models.[14] City size (LPOP60), for which there is no a priori sign, is significantly negative using total investment data (BEA and Munnell), but is otherwise positive though not significant. Similarly, UNION is significantly negative using BEA and Munnell data, but is otherwise positive and not significant.

It is especially difficult to discern consistent relationships between the various measures of public investment and private sector investment. In most cases measures of public sector investment are statistically insignificant. In a few cases a statistically significant sign (e.g., STATE in model K-3) is not confirmed in similar estimations (e.g., STATE is insignificant in K-1, which has a similar dependent variable as K-3). In particular, there is no clear relationship between investments in transportation infrastructure and overall private investment. Investment in streets and highways in model K-4 (HE-STR) is positive and significant, but the same term is not significant in other models (K-6, K-7). In addition, other transportation variables are insignificant (FHWA in K-8, K-9; LANE in K-10, K-11, K-12), and AIR and I-57 have significantly negative signs in K-10 and K-11. The only other positively significant transportation variable is MUN-HIWAY in K-14.

Public sector investing generally bears no clear relationship to private sector investing, whether measures are used for total private sector investment and state and local investment, or used for specific types of investment. The goal here was to see whether these estimations threw light on the substitutability between private and public investing. Due to the very mixed results, one cannot say much more than that the two types of investing are not clearly related.

The Neoclassical Growth Model

Estimations of the neoclassical growth model are presented in Table 6–3. Variations GRO-1 through GRO-14 are not described in detail since they correspond exactly to the POP and K models above. In all but one case (GRO-13) are rejected at approximately the 5 percent level or less. Consequently, all models given in the table, except for GRO-13, are two-stage least-squares (2SLS) estimations. GRO-13 is ordinary least squares (OLS). When the endogeneity of labor and capital is tested separately (LGR for labor and LKR for capital in Table 6–3), exogeneity is rejected for both factors in most models, except for those using BEA and Munnell data. For these models (GRO-2, GRO-3, GRO-13, GRO-14) only labor is endogenous.

In all but two cases (GRO-5, GRO-7), the Cobb-Douglas specification is accepted. In these estimations the Cobb-Douglas restriction is imposed regarding the sum of coefficients (see discussion of model). All models also test positively for heteroskedasticity at the 10 percent level or less, based on Breush-Pagan-Godfrey and Glejser tests, and estimations are corrected for this problem.

There are strong regularities across all models. During the study period there was strong convergence in real per capita incomes at the rate of 5 to 7 percent per year (see LY60 and λ in Table 6–3). Per capita income growth was also strongly influenced by skill accumulation (ED) and by population growth and capital depreciation (LDP). All models also indicate increasing returns to scale of about 1.05 (see LPOP60 and RTS). These fundamental parameters are not affected by the various measures of infrastructure.

Variables behaving poorly are investment rates in private and public capital. Private sector investment (K) is significantly positive in models GRO-4 through GRO-7 (models using Holtz-Eakin data). In all other estimations K is statistically insignificant. More disappointing are investments in public infrastructure. In only one instance (investments in streets and highways, HE-STR in GRO-6) is public investment significantly positive. In nine cases the public investments receive statistically negative signs, and in 22 others these coefficients are insignificant.

CONCLUSIONS

Public infrastructure's impact on metropolitan economies appears to be weak, at least on the margin. It appears to have a modest effect in labor markets, especially from local public infrastructure (LOC), but not on capital markets. However, public infrastructure has virtually no effect on the more fundamental question of growth in per capita income, either indirectly (through the labor and private capital terms in Equation 6), or directly through the public infrastructure variable.

The results for transportation infrastructure in particular are representative of other forms of public investments. Of 15 transportation-related coefficients in the population and labor market models, 8 were insignificant (at the 10 percent level), 5 were significantly negative, and 2 were significantly positive. For the investment models there were 10 insignificant coefficients, 3 were significantly negative, and 2 were significantly positive. In the fundamental growth models, 3 were insignificant, 1 was significantly negative, and 2 were significantly positive. The expected signs of public infrastructure are positive in the neoclassical growth model. In the other models, the expected signs are also positive, if one believes that public sector capital complements other factors or provides important public goods externalities. Findings here are the same for other specific types of public infrastructure, and for public infrastructure taken as a whole.

The findings pertaining to public infrastructure are noteworthy because they do not depend on whose capital stock data were used. The results are also similar to those in other work done here that consider other periods and alternative model specifications. The most productive factors, at least on the margin, appear to be labor, and especially skilled labor. Such low measurements for the implied production function parameters for private sector and public sector capital were not expected. It is possible that these estimates are too low. However, they are consistent across models and are estimated from disaggregated data with controls for simultaneity and other problems. At the very least, the findings here suggest that major efforts at increasing public infrastructure in local areas may not generate anything beyond normal rates of return or have anything but a modest effect on growth in per capita income.

ENDNOTES

1. The productivity parameter in question is "b" from a function such as $Q = AK^aZ^bL^{R-a-b}$, where Z is public capital. From "b" one can determine the marginal productivity and the rate of return to public investment. Aschauer (1989) estimates "b" to be about 0.39; Munnell (1990) about 0.15; Duffy-Deno and Eberts (1989) about 0.08, and Garcia-Mila and McGuire (1992) about 0.04 for highways and 0.07 for education.
2. Panggabean's dissertation (in progress) adopts this strategy using data employed in this study.
3. A third method would be to model separately L and K in the production function, and to use predicted values for L and K in the estimation of output. To our knowledge, none of the direct estimates of production uses this approach.
4. See Tatom (1991) for an analysis of bias due to misspecification of the time-series model.
5. In addition to Garcia-Mila and McGuire (1992), see Mehta, Crihfield, and Giertz (1992).
6. See Mehta et al. (1992) for details. Mankiw et al. (1992) develops a similar model. Both are based on the original Solow (1956) growth model.
7. In particular, we test for constant-returns-to-scale (R = 1), which implies that the coefficient of log L is zero. The Cobb-Douglas specification in Equation 1 implies that the sum of coefficients for $\log(s_k)$, $\log(s_h)$, $\log(s_z)$, and $\log(\delta + g)$ in Equation 6 is zero. This was tested against the alternative hypothesis that technology is not Cobb-Douglas.
8. Population growth was estimated since it appears in Equation 6. However, population and employment growth are closely correlated, so they are referred to interchangeably.
9. Numerous works examine interregional growth, such as Borts and Stein (1964) and Carlton (1979). Those focusing more specifically on factor markets include Hodge (1979), Crihfield (1989), and Mehta et al. (1992).
10. All variables are defined in Appendix A. In his dissertation (in progress), Panggabean includes cost of capital and broader commodity taxes in an investment model. However, in the models for the investment rate in this chapter, the single tax variable SPT is included.
11. POP and K are used because these are the variables appearing in Equation 6. POP (growth in population) increases when the short-run equilibrium level of employment rises. K (the investment rate) rises when the short-run level of investment rises (holding income constant).

12. In some cases, capital stock data (Holtz-Eakin, Munnell, and BEA manufacturing capital and total private capital) are converted to average investment flows. In other cases (Crihfield and Panggabean, FHWA), average investment flows are calculated over time.
13. The effect of sewers and sanitation is not confirmed by Munnell's similar measure in POP-14.
14. A negative sign means that the scale effect of higher energy prices outweighs a possible substitution toward capital. Similarly, a negative sign for UNION means that investors avoid unionized areas more than they may substitute toward capital and away from unionized labor.

SELECTED BIBLIOGRAPHY

Aschauer, David A. "Is Public Expenditure Productive?" *Journal of Monetary Economics*, Vol. 23 (1989) pp. 177–200.

Borts, George H. and Jerome L. Stein. *Economic Growth in a Free Market*. New York: Columbia University Press (1964).

Carlton, Dennis W. "Why New Firms Locate Where They Do: An Econometric Model," William C. Wheaton, ed. *Interregional Movements and Regional Growth.* The Urban Institute, Washington, D.C. (1979) pp. 13–50.

Crihfield, John B. "A Structural Empirical Analysis of Metropolitan Labor Demand," *Journal of Regional Science*, Vol. 29 (1989) pp. 347–71.

Crihfield, John B. and Martin P. H. Panggabean. "Growth and Convergence in U.S. Cities," University of Illinois IGPA Working Paper (April 1993).

Duffy-Deno, Kevin T. and Randall W. Eberts. "Public Infrastructure and Regional Economic Development: A Simultaneous Equations Approach." Federal Reserve Bank of Cleveland Working Papcr 8910 (August 1989).

Garcia-Mila, Teresa and Therese J. McGuire. "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics* (1992) p. 22.

Godfrey, L. G. *Misspecification Tests in Econometrics*. Cambridge University Press (1989).

Hodge, James H. "A Study of Regional Investment Decisions," J. Vernon Henderson, ed. *Research in Urban Economics*. Greenwich, CT: JAI Press, Inc. (1981) pp. 1–65.

Mankiw, N. Gregory, David Romer, and David N. Weil. "A Contribution to the Empirics of Economic Growth," *The Quarterly Journal of Economics*, Vol. 107 (1992) pp. 407–37.

Mehta, Shekhar, John B. Crihfield, and J. Fred Giertz. "Economic Growth in the American States: The End of Convergence?" Working paper, Institute of Government and Public Affairs, University of Illinois at Urbana-Champaign (1992).

Munnell, Alicia H. "How Does Public Infrastructure Affect Regional Economic Performance?" *New England Economic Review* (1990) pp. 11–32.

NCHRP Project 2-17(3). "Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance: An Interim Report" (September 1992).

Solow, Robert M. "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics* (February 1956) pp. 65–94.

Tatom, John A. "Public Capital and Private Sector Performance," *Federal Reserve Bank of St. Louis Review* (1991) pp. 3–15.

Varian, Hal R. *Microeconomic Analysis.* Fourth Edition. New York: W. W. Norton and Company (1984).

APPENDIX 6-1

DEFINITION OF VARIABLES

This appendix defines variables used in the text and tables. All dollar values are stated in 1982 dollars.

Variable	*Definition*
LYxxzz	Log(Yzz) – log(Yxx), where Yzz is per capita income in year 19zz. This is the dependent variable in the neoclassical growth model (see Eq. 6).
POP	Log(GPOP+1), dependent variable in first-stage regression.
K	Log(SK), where SK is the share of income invested by the private sector; dependent variable in first-stage regression.
LPOPxx	Log of metropolitan area population in year 19xx.
LYxx	Log of metropolitan area per capita income in year 19xx.
GPOP	Compound annual growth in metropolitan area population over the period.
ED	Log of the fraction of people 25 years old or older with at least 12 years of schooling.
STAX	Log(state tax rate), where the state tax rate is state taxes divided by state income.
TAX	Log(local tax rate), where the local tax rate is local taxes divided by local income.
SPT	Log(state property tax rate), where the state property tax rate is the average effective property tax rate by state on existing single family homes with FHWA insured mortgages.
PELEC	Log of electricity price
PGAS	Log of natural gas price
UNION	Log of the state unionization rate
LDP	Log(GPOP+δ), where δ is the depreciation rate
D1	New England states
D2	Middle Atlantic states
D3	East North Central states
D4	West North Central states
D5	South Atlantic states
D6	East South Central states
D7	West South Central states
D8	Mountain states
D9	Pacific states (omitted dummy)
λ	Annual rate of convergence (or divergence) in per capita income
a_k, a_h, a_l, a_i	Production function parameters for private capital, human capital, labor, and public capital i
RTS	Returns to scale
[Public capital]	
LOC	Log(SZL), where SZL is the share of local income invested in local public capital outlays
STATE	Log(SZS), where SZS is the share of state income invested in state public capital outlays
HE-HIED	Holtz-Eakin higher education (state and local, by state)
HE-OED	Holtz-Eakin other education (state and local, by state)
HE-STR	Holtz-Eakin streets and highways (state and local, by state)
HE-SEW	Holtz-Eakin sewerage and sanitation (state and local, by state)
HE-UT	Holtz-Eakin utilities (state and local, by state)
HE-TOTPUB	Holtz-Eakin total (state and local, by state)
FHWA	Federal Highway Administration (all governments, by state)
MUN-TOTPUB	Munnell total (state and local, by state)
MUN-HIWAY	Munnell highway (state and local, by state)
MUN-WATSEW	Munnell water and sewerage (state and local, by state)
MUN-OTH	Munnell other (state and local, by state)
LANE	Lane-miles per capita (all roads and highways, by state)
I-57	Interstate highway lane miles divided by total lane miles (rural and urban, by state)
AIR1	Air departures per capita (by state)
NTWK	LANE times I-57 (network effect of road and air systems, by state)

CHAPTER 7

CONCLUSIONS

SUMMARY

The purpose of research project NCHRP 2-17(3) is to improve our understanding of the linkages between transportation investments and economic performance so that policy makers are better informed when setting priorities in allocating scarce transportation resources. In Chapter 1 it was concluded that current aggregate research pays insufficient attention to several important questions including the following:

- How do physical and performance characteristics of transportation systems influence private economic activity?
- How does the relationship between transportation investment and economic activity vary across industries?
- How can investment flow data, rather than capital stock data, be employed to understand the impact of transportation investment on economic growth?
- How do various demographic and economic factors influence the derived demand for transportation investment and how does the importance of these factors vary across transportation modes?
- How does the productivity of different types of public capital vary across transportation modes and industries?
- What types of relationships exist between transportation modes and other types of infrastructure and how do they affect productivity?

Many of these questions can be explored using analytical techniques already available, but the argument was put forth that a disaggregated state panel dataset needed to be compiled. Such a dataset was developed as part of this project and is described and documented in Chapter 2 of this report.

The empirical studies presented in Chapters 3–6 employ the disaggregated dataset and represent an initial step toward addressing the first four of these unanswered questions. The results of these studies are very encouraging, and suggest that the disaggregated approaches pursued here are important for understanding the linkages between transportation investment and economic performance, and shed new light on our understanding of those linkages.

The empirical results obtained in the studies are sufficiently encouraging to merit pursuing these disaggregated approaches. The dataset constructed here can be used to further explore the link between infrastructure investment and economic performance on a disaggregated basis. This concluding section suggests several steps for building upon and extending the work completed to date. The new work will increase our understanding of how transportation investments affect economic activity.

CONCLUSIONS

Specific conclusions drawn from the analysis efforts of research team members using the new dataset provide some useful insights. Initially, the new dataset was used to test the validity of the relationships between public infrastructure and economic performance that have generated considerable controversy in recent years (e.g., the work of Aschuaer, Munnell). It was concluded by Dalenberg and Eberts that the controversy is, in part, a result of different data and methodologies used in the various studies. Using the updated estimates of highway capital stock, comparisons of the economic performance results were made. It was concluded that

- The capital stock data in the updated dataset is an improvement over those used in previous analysis because it was based on a single source,
- The use of a consistent data source that extends for a long enough period allows the use of a perpetual inventory accumulation methodology, without the need for apportionment schemes,
- Assumptions about appropriate average service lives and depreciation rates for highway estimates seem to be critical to capital stock estimates, and
- Despite the improvements in capital stock estimates, aggregate production function estimates do not differ appreciably suggesting that further improvements in the models are necessary.

This research effort utilized the newly compiled database to address several other basic questions about the linkages between transportation investments and economic performance. These included

- **Assessment of Industry Production Functions with Highway Capital as an Input.** Traditional production function analyses do not include highway capital as an input. Garcia-Mila and McGuire found that some industries, namely retail trade and services, indicate a statistically significant impact of highway capital. This suggests that it is important to provide highway capital to support a growing services-based economy. Further, the more detailed analyses made possible by the disaggregation of the dataset may allow state and local agencies to assess the impacts of highway investments.

- **Transportation Investment and Economic Activity: Evidence from Public Sector Demand Analysis.** Based upon the premise that transportation services are an intermediate good in private consumption and production processes, Man and Bell's preliminary analysis of the data indicates that: 1) demand for transportation investments is much more sensitive to personal income than previously thought, 2) demographic trends impact the demand for investment in individual modes in different but important ways, 3) industry mix is an important element in determining the demand for transportation investment and it has different implications for each mode, and 4) the level and quality of service provided, not just the level of investment, are important.
- **Transportation and Other Public Infrastructure in a Neoclassical Growth Model.** Using a neoclassical growth model, Crihfield and Panggabean investigated the productivity of public capital and concluded that the public's infrastructure impact on metropolitan economies appears to be weak, at least at the margin. These models estimate growth in per capita income in a region by the endowment of various factors including private capital, labor, technology, and public capital. This analysis found consistent results regardless of the measure of capital stock that was used, supporting the findings of other investigations that model specification is as important as obtaining good estimates on the value of highway capital stock.

These empirical studies extend the analysis of the linkages between transportation investment and economic activity to consider many different dimensions and manifestations of the relationship. While the analytic approaches vary, the findings are surprisingly consistent and demonstrate the improved level and quality of information made available to state and local transportation decision makers from analyses based on data disaggregated by state, industry, and transportation mode.

FUTURE EFFORTS AND RESEARCH

Several topics for future efforts and research were derived from the project. These are described below.

Maintain the Database

Since the database constructed in Chapter 2 relied on limited existing information, it cannot comprehensively measure the performance of individual transportation networks. The data-gathering efforts were frustrated by the fact that much of the data was either not available or was not in machine-readable form so that much of it had to be entered from hard copy (e.g., most of the highway data from the FHWA, and the airport data from the FAA). Moreover, changes in definitions, reporting formats, and agency data-gathering efforts made it difficult to find a historical series of consistent data needed to examine long-term trends between transportation investment and economic performance (e.g., the mass transit Section 15 data and some highway data).

These problems could be exacerbated by the future development of the National Highway System mandated by the ISTEA. As a prelude to defining the National Highway System, states are currently reclassifying their roads and streets to establish updated designations. Once this new system is defined, and statistics are compiled and reported in a manner consistent with this designation, it is not clear whether comparability with previously reported data will be maintained.[1]

For these reasons, this report endorses the development of a National Transportation Performance Monitoring System for gathering data to track key indicators of the nation's transportation system. Such an effort would gather data based on major physical and performance attributes of the transportation system including the supply of transportation services, the demand for transportation services, and the performance of individual transportation networks.[2] The major problem for such a dataset will be the initial lack of a consistent historical series. Therefore, to the extent possible, such a dataset should build on existing information.

Despite the many data difficulties, the database that was constructed in Chapter 2 has significant value-added (see section for details) relative to other databases used to explore the link between transportation investment and economic performance. In addition, it was demonstrated how the database could be used to provide additional knowledge about the link as reflected in the research done in Chapters 3–6. These studies should be regarded as a first step toward a better understanding of the interaction of transportation investment and economic activity.

The database constructed for this project included information that was readily accessible given certain time and resource constraints. The database should be updated and extended; all of the variables in the database have at least one more year of data that should be added. Some of the databases have undergone significant revisions as well and these should be reflected in an updated database. [BEA has already substantially revised their personal income series including the earnings by industry and state that were included in the database.]

Enrichment of the database could be furthered in some important areas. For example, time constraints made it impossible to acquire as broad a range of performance data as desired from individual agencies. It would have been helpful to have more of the HPMS performance data from the FHWA in machine-readable form. It is also desirable to reexamine, with BEA, the allocation of national private capital stock estimates by industry to the 50 states.

Industry-Specific Production Functions with Six Types of Public Capital

In the research for NCHRP Project 2-17(3), industry-specific production functions were estimated using a panel dataset for the states with annual observations from 1970 to 1989. Because of problems in data development, only one type of public infrastructure was incorporated into the equations, that of highway capital using the measures developed from FHWA sources. The effect of highway capital varied across the different industries examined. This finding indicates that industry-specific analysis is interesting and important. It also indicates that examination of the effects of other types of public capital on different industries might be productive.

For example, take a research project to estimate industry-specific production functions incorporating the six types of public capital for which new measures were generated. The period of analysis will be shorter as the data for the six types only exist for 1977–1990. However, the same set of regression specifications as contained in the present NCHRP research could be developed for other transportation modes as well. That is, three different specifications of the production function for each of seven industries plus total output could be generated, the only difference being that six types of public infrastructure could be used instead of just highways. All of the data necessary for the estimation of these industry-specific production functions with six types of public capital are contained in the current NCHRP dataset.

Explaining the Differences in State Employment Growth Rates Using Industrial Mix and Public Capital

In related research examining the economic growth of individual states and their industries, Garcia-Mila and McGuire have established some interesting facts.[3] First, there is significant variability across states in employment growth patterns. Some of the differences across states are persistent over time. Second, industries differ from one another in their employment growth patterns across states. Third, the industrial composition of a state seems to be related to the employment growth rates of the state's industries. Finally, the usual set of explanatory variables (wages, taxes, energy costs, etc.) has not been powerful in explaining the differences in employment growth rates across states.[4]

These findings, taken together with the industry-specific production function research reported herein, where public capital seems to matter for some industries, leads to a second general area of interest for future research. Specifically, taking the employment growth rates of industries as the variables to be explained, one could estimate a series of equations, one for each industry, with states as the unit of observation. The NCHRP research indicates that public capital variables might be important explanatory variables, and the research mentioned above indicates that measures of industrial mix also might be important explanatory variables. Neither of these sets of variables has been incorporated in previous business location studies, such as McGuire and Wasylenko (1987), which attempt to explain the differences in state employment growth rates.

The key policy question to address with this line of inquiry is, what role does public capital play in determining industry employment growth rates across states? The question should be asked for each of the major industries, because our previous research indicates that different factors are likely to be important for different industries. Therefore, equations with industry employment growth rates as the dependent variables are specified. Also, a typical set of factors often used in business location studies as explanatory variables is incorporated, and (as an innovation) public capital variables and variables measuring the industrial composition of the states are also included.

To estimate such equations, one would need to gather a traditional set of explanatory variables (wages, taxes, etc.), and these data are readily available. All other required data are available from the NCHRP dataset. Thus, the data requirements above and beyond the NCHRP dataset are minimal for such a project.

The Demand for Transportation Services

Part of NCHRP Project 2-17(3) was the estimation of demand equations for investment in individual transportation modes for their use in identifying demographic and economics factors that affect the derived demand for transportation services and in determining the differential impact of those factors on the demand for specific transportation modes. Traditional specifications of these demand equations, that use annual investment flows as the dependent variable, were estimated and the equations using measures of the level of service provided were reestimated. The empirical results suggest that different demographic and economic factors are important influences on the demand for investment in transportation modes, the effects of these factors do vary across transportation modes, and measures of the level and quality of service provided are important variables to include in the analysis.

In essence, these initial empirical results suggest that a number of demographic and economic trends directly affect the demand for transportation services, although these trends are generally beyond the control of transportation officials at all levels of government. The results are consistent with the concerns expressed in the *National Transportation Strategic Planning Study*[5]:

- The aging of America's population between 2010 and 2030 will impact travel demand by stimulating leisure travel, reducing the percentage of work-related trips, and affecting the trip distribution by time of day while increasing the importance of transportation convenience and accessibility;

- Continued growth of metropolitan areas with the accompanying shift of population and jobs to the suburbs will create multidirectional traffic flows between many destination nodes, traffic patterns that are not well served by existing transportation systems; and
- Economic restructuring will place greater emphasis on the speed and reliability of transportation services available.

These findings suggest that this type of demand analysis is interesting and important, and that further refinement of these findings would be productive.

A number of important research developments are possible. First, the traditional demand models reported in Chapters 3–6 are generally well behaved and provide important insights about the factors affecting transportation investment demand. This analysis can be extended to examine the linkages between different types of public infrastructure. One might reestimate these demand equations and include information on the availability of other infrastructure facilities. Currently, lagged capital stock estimates of the transportation mode being considered were included, and the results are statistically significant. One might include similar measures for other public capital facilities, both transportation and nontransportation related. This would allow the researcher to comment on the complementarity and substitutability among different types of public capital.

The empirical results reported in Chapters 3–6 also suggest that it is important to consider the level and quality of service provided, not just the annual dollar flow of investments, for each transportation mode. Since the study contained in these chapters is only an initial effort to address these concerns, several refinements and extensions of that effort are possible to test the robustness of the findings. Specifically, one might

- Use information in the NCHRP dataset to develop more refined measures of the level and quality of service provided by each transportation mode to use as dependent variables in these equations;
- Use information in the NCHRP dataset to develop and to test other measures of industry mix, both more disaggregated measures and alternative measures, to include in these demand equations;
- Refine the measures of our tax-price and federal aid variables to obtain a more precise estimate of the impact of price on the level and quality of service consumed; and
- Test alternative model specifications because the results suggest that using the level and quality of service as a dependent variable is substantively different from using annual investment flows as the dependent variable.

The results for NCHRP Project 2-17(3) suggest that further analysis and future research is important and that the benefits of such analysis are valuable for policy makers trying to set priorities in allocating scarce transportation resources.

ENDNOTES

1. See *The Status of the Nation's Highways, Bridges and Transit: Conditions and Performance,* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (January 1993) p. 38.
2. *Ibid.,* pp. 25–43.
3. Garcia-Mila, Teresa and Therese J. McGuire, "Industrial Mix as a Factor in the Growth and Variability of States' Economies." *Regional Science and Urban Economics,* Vol. 23, No. 6 (Dec. 1993) pp. 731-748.
4. McGuire, Therese J. and Michael Wasylenko, "Employment Growth and State Government Fiscal Behavior: A Report on Economic Development for States from 1973 to 1984." Prepared for the New Jersey State and Local Expenditure and Revenue Policy Commission (July 1987).
5. National Transportation Strategic Planning Study, U.S. Department of Transportation, Washington, D.C. (March 1990) pp. S-1 to S-8.

APPENDIX A

DATA DOCUMENTATION

Appendix A as submitted by the research agency is not published herein, but is available for loan on request to NCHRP.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 8970