POLICY FORUM

Transportation Investment and New Insights in Economic Analysis

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Fax: (202) 879-4719
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Transportation Investment: New Insights from Economic Analysis

Policy Forum—February 23, 1999

Forum Chair
Curtis Wiley
Commissioner, Indiana Department of Transportation

Report Prepared by
Chad Shirley
University of California at Berkeley

Eno Transportation Foundation

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ENO TRANSPORTATION FOUNDATION

Transportation Investment: New Insights from Economic Analysis

Policy Forum—Convened February 23, 1999

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Eugene Conti, U.S. Department of Transportation
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Larry Magid, National Governors' Association
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Summary

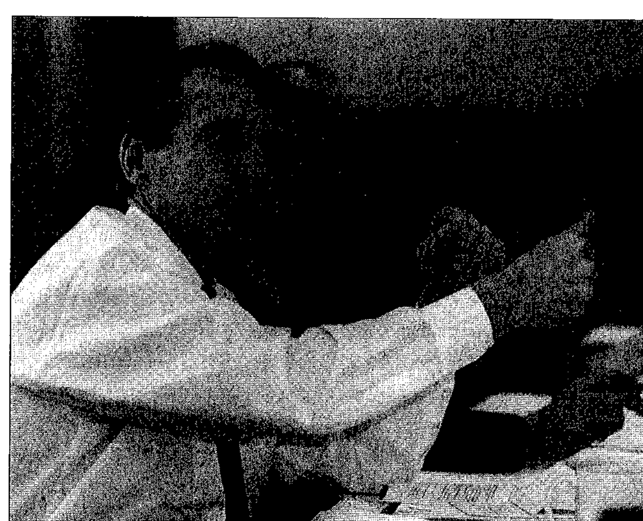
In the early 1990s, academic research proposing a vital connection between public infrastructure investment and "productivity growth rate" coincided with an economic recession, sparking great interest in the potential for investment in transportation as a way to spur economic growth. However, the strong claims of the initial research, put forward most notably by David Aschauer, now of Bates College, and later by Alicia Munnell of the Boston Federal Reserve Bank, came under attack in the research community. Plans to dramatically increase public infrastructure spending instead bowed to pressures to reduce the sizable federal budget deficit. With the decade drawing to a close, national fiscal pressures have been relieved, yet researchers still grapple to reach a consensus on the effects of transportation investment on the economy.

On February 23, 1999, 35 academic, government, and private-sector leaders met in Washington, DC, to discuss the importance of transportation investment for the future of the American economy. The one-day conference, sponsored by the Eno Transportation Foundation, focused on two issues:

- Improving the tools used in the economic analysis of the relationship between transportation investment and growth
- Improving ways to communicate findings to policy makers and the public

Ishaq Nadiri of New York University and the National Bureau of Economic Research presented the results of his most recent national study, *Contributions of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries*. This work offers solid support for the value of transportation investment. Analyzing the costs of 35 different industry groups over a 40-year period, Nadiri finds that greater investment in transportation infrastructure leads to lower business costs in almost all of the industries studied. The average rate of return for these transportation investments throughout the study period is at or above the average rate of return for private-sector investments. The corresponding implication is that the government's expenditure of tax money on transportation infrastructure has been an economically worthwhile activity. However, the most recent average returns have been the smallest of the past 40 years, indicating that the current highway system may have reached maturity.

Ishaq Nadiri and the forum participants identified several areas for future research. While Nadiri's study effectively captured the national effects of building the Interstate Highway System, the effect of such investment on a more local scale needs to be analyzed. One important area for future research is to incorporate the level of use of transportation infrastructure into studies. Trucking deregulation, enacted in the early 1980s, and increases in traffic congestion are believed to have profound effects on the use and value of roads and highways. But these effects have not been fully measured. Understanding the importance of capacity utilization will go a long way to clarifying the benefits of new policies such as the intelligent vehicle highway system ("smart highways") or research and development of other capacity-enhancing developments.



Curtis Wiley, Indiana Department of Transportation, Forum Chair (left), and Ishaq Nadiri, New York University

Participants also identified other ways to improve the tools of economic analysis. Several members of the group expressed a desire to measure benefits from transportation investment beyond the typical cost reductions for industry. The economy also benefits when transportation improvements increase the attractiveness of tourism and passenger safety. Arthur Jacoby of the Federal Highway Administration and Charlie Han of the Bureau of Transportation Statistics offered evidence that industries with higher proportional logistics costs derive greater benefit from transportation investments. Their work suggests that more attention needs to be paid to the specific mechanisms through which transportation investment benefits industry. Barbara Fraumeni from the Bureau of Economic Analysis offered recommendations for ways to more accurately measure the productive nature of highway capital.

Clyde Pyers of the Maryland Department of Transportation and Greg Bischak from the Appalachian Regional Commission presented state and regional case studies of highway investment programs. These studies showed reasonable rates of return to recent highway investments, relative to promoting short-term job creation, providing construction spending benefits, reducing longer-term industry costs, and affording net travel savings to the public. A few participants questioned whether these regional investments created benefits at the expense of economic activity in other areas. But the more widely held view was that these improvements do not constitute a zero-sum game. Further work could better identify the interrelations between localities and help to resolve the "net benefit" question.

While analytical improvements to better measure the relationship between transportation and growth is a vital activity, effectively communicating results to policymakers and the public is an equally important challenge. Miles Friedman of the National Association of State Development Agencies and Terrence Mulcahy from the Wisconsin Department of Transportation led the group to a number of insights. Rate of return measures of the kind generated by Nadiri's work provide justification for implementing transportation investment policies. At the same time, such returns alone may not be sufficiently compelling to the general public and legislators. Case studies and individual stories often provide much more effective calls to action. Effectively communicating results becomes a question of how to tie together local impacts, anecdotal evidence, and program-wide estimates.

One solution is to use stories and studies in tandem. National and state studies may reinforce and provide context for local anecdotes, and they can provide a starting point for local discussions of the pros and cons of specific projects. Conversely, stories of successful transportation projects can provide the edge needed to generate wider appeal for infrastructure investments.

Another solution is to make the results more closely address the questions that policymakers and the public want answered. People want to know about transportation's relationship not only with growth, but also with quality of life, community development, and local commerce. Because of its role as a facilitator of activity, states and regions should incorporate transportation analysis into their strategic planning and tie it into the area's economic development plan. Different regional development priorities will lead to different research needs—urban versus rural areas, manufacturing versus service sector businesses, retail versus wholesale trade, and tourism versus job access.

Overall, the conference offered several studies supporting the value of recent highway investment and identified a number of ways to improve future work in this field. By continuing to refine our tools to understand the mechanisms of growth and by using these tools to address a wider set of public concerns, we can more clearly illuminate the ways in which transportation investments change lives.

Background and Introduction

The United States at the close of the 20th century is enjoying a resurgence of economic growth and vitality that scarcely could have been imagined a decade ago. In the past few years, growth in the nation's productivity (i.e., growth that is not accounted for by increases in the amount of labor or capital in use in the economy) has reached levels not seen in 20 years, levels that many economists feared would never be seen again. Alan Greenspan, the Chairman of the Federal Reserve System, is widely hailed as a national hero and is gracing the covers of our news magazines. Have the laws of economic gravity changed? Or must what has gone up come down again? As the American economy continues to expand, the limits of the nation's transportation infrastructure are being tested, calling into question the need for further investment. How much gravity will our transportation systems' limits have?

Transportation improvements foster improvements in the business environment. Cheaper transportation increases the size of markets. With larger markets, firms can realize greater economies of scale in production. Inputs to the production process may become cheaper because of lower transport costs. The size of the labor pool expands. Inventory management becomes easier. New land and new resources can be put to productive use, and greater specialization can occur.

With the building of the Interstate Highway System, the nation made a huge investment in transportation infrastructure during the 1950s and 1960s. As the Interstate Highway System neared completion in the early 1970s, transportation investment dropped, and it remained relatively smaller through the 1980s and 1990s. Since then, the nation's highway system has suffered increasingly from lower maintenance and increased traffic congestion, to which front-page stories in newspapers regularly attest.

The public clearly understands how much longer it takes to get to work today than it did 20 years ago. Is the public aware of the larger changes in economic activity spurred by the improvement of transportation systems? The slowdown in economic productivity that started in the 1970s (and that may or may not now be over) has been a puzzle for economists and the country for the past two decades. Once upon a time, economic historians considered the effect of canals and railroads on the economy. But it took until 1990 for research by David Aschauer, now of Bates College, and then work from Alicia Munnell of the Boston Federal Reserve Bank, to bring widespread attention to the potential for transportation systems, and public infrastructure more generally, to play a major role in promoting economic growth in the present.

Aschauer found huge benefits to the economy from public infrastructure investment and blamed the anemic performance of the economy in the 1970s and 1980s on the severe shortfall of such spending. His study and its clear call to action then came under intense scrutiny. Once put under a microscope, these claims lost a measure of their credibility; but the questions the study had provoked—why productivity growth had fallen and what effect public infrastructure investment, particularly transportation investment, had on the economy—did not go away.

Three years ago, the Eno Foundation held its first forum to address this second question. The Federal Highway Administration and the American Association of State Highway and Transportation Officials, through the National Cooperative Highway Research Program, asked the Eno Foundation to host a conference discussing the importance of transportation investment for the American economy. Transportation experts and policymakers from the private sector, public sector, and academia converged on Washington, DC, for a forum called Economic Returns from Transportation Investment.

The participants heard quantitative evidence of the importance of transportation investment from several parties. Ishaq Nadiri presented the results of a nationwide study spanning four decades that showed solid rates of return for the Interstate Highway System. Randall Eberts of the Upjohn Institute provided corroboration with studies of the rates of return on highway investment for localities. Colin Gannon of the World Bank offered estimates that World Bank transportation investments also had high social value and generated substantial rates of return. Industry examples such as developments in logistics management at General Motors were cited to illustrate some of the changes brought about by infrastructure improvement. The group advocated bringing these kinds of findings to the attention of policymakers and the public.

Three years later, the completion of a new study by Ishaq Nadiri presented an opportunity to conduct a second forum in which to revisit this important topic. The following report draws forth the most salient conclusions and intriguing speculations from that day.

In the first session of the forum, Nadiri presented the results of his most recent study of the contribution of highway capital to economic growth and productivity. In the second session, Arthur Jacoby and Charlie Han discussed their research exploring the connections between Ishaq Nadiri's cost elasticity results and other transportation-related industry characteristics. Barbara Fraumeni described her recommendations for improving the quality of the highway capital stock data used by much of the empirical research. The third session featured analyses of state and regional highway investment programs including input and output methodologies and employment analysis. The final session of the forum tackled the nettlesome problem of communicating the results of research to the public and policymakers, particularly the issues of who to target and in what form the messages are best conveyed. The bulk of the report is divided into four parts, paralleling the events of the forum. After a brief conclusion, the appendices contain the text of selected papers discussed during the forum.

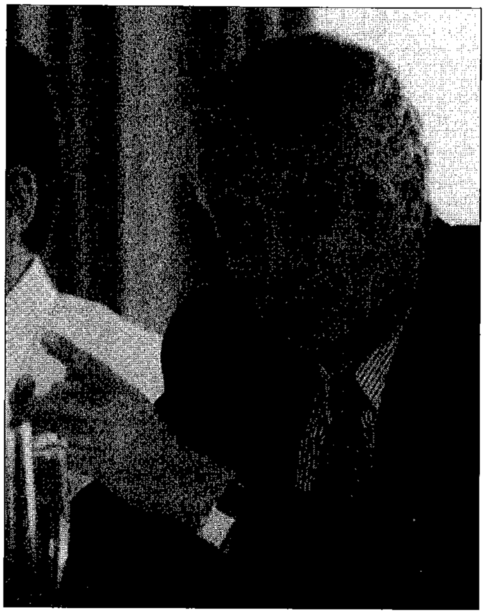
The Need for this Forum

The growth of economic prosperity in America should not be taken for granted. For more than 100 years, from the end of the Civil War to the early 1970s, the American economy grew at a rate of nearly 3.5 % per year. In the 20 years that followed, through the end of the 1980s, the economy's rate of growth slowed by more than a percentage point to 2.4 % annually. Economic growth can be adjusted to account for changes in the use of labor in the economy to better measure the change in a nation's standard of living over a long period of time. This measure is called labor productivity, and it describes how much workers can produce in a given amount of time. When workers can produce more goods in the same amount of time, the savings in cost can be shared between the workers and the owners of capital. As a result, the standard of living rises. Unfortunately, while labor productivity grew at more than 2 % per year over that same 100-year period, labor productivity grew at only half that rate during the 1970s and 1980s.

The construction of the Interstate Highway System in the 1950s and 1960s coincided with a period of strong growth in the American economy. The nation's highway capital stock is a dollar value measure of the infrastructure in the national road and highway system. From 1952 to 1959, the nation's highway capital stock grew at an annual rate of 6.2 %. During the past 20 years of slower economic growth, the rate of addition to the nation's highway system has dropped markedly. Since 1982, the rate of growth has fallen to 1.2 % a year. Is this relationship between economic growth and the highway system merely coincidental? The increase in demand for transportation has continued unabated over the past 20 years. Congestion continues to increase, fewer large-scale transportation projects are started, and more funding for those projects that do start comes from state and local governments.

Recent research shows that investment in the national highway system has provided demonstrable benefits to the U.S. economy over the last several decades. However, public awareness of this benefit may be lacking. Part of the need for this forum is to communicate these promising research results in clear terms to the public. Ultimately, the country needs a vision of transportation investment for the postinterstate era. Two questions need to be successfully addressed in this forum:

- How do we improve the tools we use to guide this vision?
- How do we successfully present this vision within the policy arena?



Ishaq Nadiri, New York University

The Contributions of Highway Capital

New Research on the Economic Returns from Transportation Investment

Ishaq Nadiri, the Jay Gould Professor of Economics at New York University and a member of the National Bureau of Economic Research, explores the relationship between infrastructure investment and economic output. Nadiri presented the results of his most recent study of this complex relationship, *Contributions of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries.*

Nadiri explained that to understand research in this area, it is important to recognize the special characteristic of highway capital that sets it apart from private capital: Its influence is shared across firms in the economy. This special characteristic is called an externality. An externality is any kind of shared or additional effect of an activity on entities other than those who are direct parties to the activity. By capturing the externalities of highway capital—its effect on firms throughout the economy—studies measure the social rate of return from highway capital investment, that is, the value that the investment provides to society as a whole (rather than any private individual part of society). Calculating a social rate of return for such investments provides policymakers and the public with some ability to compare the relative value of government investment in different activities. Investments with higher social rates of return will provide more economic growth for a given amount of expenditure and benefit the nation most.

Nadiri's study represents a significant advance in the field of applied econometric analysis. It is an important piece of evidence supporting the proposition that infrastructure investment matters economically. For years, economists have been struggling to achieve a consensus view about this relationship. Several well-known studies in the late 1980s concluded that infrastructure investment was crucial to the rate of productivity growth. The influential works of David Aschauer and Alicia Munnell attributed most of the slowdown in economic productivity growth in the 1970s and 1980s to the lower rate of national infrastructure investment during this period. Before these studies appeared, few economists had empirically explored how public investment affected the nation's performance. However, when a flurry of new research followed the provocative Aschauer and Munnell findings in subsequent years, the new research showed that public infrastructure investment has an incredibly large effect on productive capacity. A number of methodological issues were raised about the modeling that underpinned the Aschauer and Munnell studies, and their strong conclusions were later cast into doubt by the academic community.

The Aschauer and Munnell approach to estimating the relationship between public investment and economic growth focused on using a production function as the basic model of behavior. In a production function, firms in the economy use labor and capital with a certain level of technological sophistication to produce specific amounts of output. Aschauer's insight was to recognize that firms use both private capital and public capital (highways, airports, power generation and transmission facilities, sewers and water treatment plants, and other such public infrastructure) in production. Looking at production aggregated across firms throughout the country in this way showed an extremely significant relationship between the amount of output the economy could produce and the level of public infrastructure available to the economy.

The main problem with the approach is that the results are hard to interpret. Does investment in public infrastructure lead to economic growth, or does growth give the public sector more ability to invest in infrastructure? The nature of the correlation is unclear. In growing economies, many of the underlying variables grow together at similar rates. The nature of the production-function approach and the aggregate nature of the data used in the Aschauer and Munnell studies did not address the issue of causation very well. Economic growth and infrastructure expansion may have occurred contemporaneously without any direct causal relationship or in response to some unexamined variables.

After taking into account the possible simultaneities and self-correlations in this model, several academic researchers concluded that infrastructure investment had a much smaller effect on the economy than Aschauer and Munnell concluded. Most of these subsequent studies focused on economic output in smaller geographic areas, usually states or regions but sometimes counties or metropolitan areas. More output in a small part of the country is less likely to lead to increased local infrastructure, because the Interstate Highway System program was a nationwide initiative. Indeed, studies conducted at smaller geographic levels found a much smaller economic influence for infrastructure investment. Unfortunately, studies performed on a smaller geographic scale leave open the possibility that the benefits of infrastructure in any given locality may spill over into neighboring regions. If such spillovers exist, then the benefits measured in these studies are too small. That is, the externality aspect of infrastructure investment is not fully captured.

Nadiri navigated through the problems associated with production functions by focusing on the cost of production rather than the level of productive output. Costs of production are clearer to interpret as being driven by changes in infrastructure rather than the other way around. Nadiri also focused on modeling specific industries rather than all economic activity in a specific geographic location to reinforce the interpretation of a causal relationship between public infrastructure and productivity. By encompassing industrial production throughout the nation, though, Nadiri made sure to capture all of the network spillover effects that might exist.

Nadiri's industry focus accounted for different industries using the highway capital they share very differently. Differences in highway capital use among industries have important implications for the way in which highway capital investment is financed. According to economic theory, those who receive most of the benefits of an investment should pay proportionally more of the costs. Nadiri's study explored these differences in the effect of highway capital on individual industries. Just as different industries use highway capital differently, their use of capital may have different implications for their patterns of employment, capital utilization, and materials use. These effects are important to the economy.

Nadiri's study started by separately estimating a cost function and a demand function for each industry. A cost function, like a production function, is a model of firm or industry behavior. A demand function is a model of consumer behavior with respect to different goods. In the cost functions used in this study, the cost for an industry depended on relative factor prices of labor, materials, and capital; quantity of output; disembodied technical change; and public capital services. Price increases for labor, materials, or capital increase industry costs, as do increases in industry output. Increases in public capital or technical change may lead to lower industry costs. In this study, Nadiri used a different functional form for the cost function than in his prior work, allowing for more complicated and expanded modeling. In the demand functions used for these industries, changes in demand varied with changes in the price of output relative to prices in the rest of the economy. Demand also varied with changes in aggregate income and population. As population and incomes grow, demand grows as well. When the price level for an industry increases, though, demand for the output of that industry falls.

Highway infrastructure enters this system of equations by affecting each industry's cost of supply. An investment in highway infrastructure may have several different effects on the cost of supply. First, it may directly allow firms to realize lower costs of production—called the "productivity effect." Second, firms may change their use of inputs (labor, materials, and physical capital) in production if highway infrastructure is either a substitute for or complement to labor, intermediate inputs, or physical capital. This is called the "factor-demand effect." Third, cost reductions may lead to price reductions for consumers, and these price reductions may lead to an increase in the demand for output. In cost studies of the effect of infrastructure, levels of output are typically held constant. In this work, prices were allowed to fall when firms lowered their costs of production as a result of productivity improvements. This change shifted the cost curve downward, and industry output expanded to meet the increased demand at the lower price. This

Ishaq Nadiri, New York University (left), and Curtis Wiley, Indiana Department of Transportation

"output-expansion effect" is an additional benefit to the economy not captured in previous research. The net effect of highway investment will be the combination of the productivity, factor demand, and output expansion effects. To ensure that the results attributed to highway capital investment were accurate, other kinds of public infrastructure (e.g., ports, airports, water treatment plants, and sewers) were included separately in the model. In this way, significant findings for the effects of highway capital on costs were not influenced by the effects of other public capital expenditures on costs.

Nadiri used data aggregated into 35 different industry groupings. Data were consolidated from data on more than 80 sectors of economic activity and spanned the late 1940s to 1991. Combining such an expansive data set with the cost function model provided a level of comprehensiveness and detail unmatched by previous studies.

Nadiri econometrically estimated all of the industry cost and demand functions through a series of stages to generate output and cost elasticities with respect to highway infrastructure. Elasticities are measures of responsiveness between two variables: changes of a measured variable associated with a single percentage change in a base variable. These output and cost elasticities measure how output and cost would change when the highway capital stock is increased by 1%. With output levels held constant, almost all (32 of 35) of the industries saw positive benefits (cost reductions) from highway capital investment. In addition to this productivity improvement, industries also realized the output expansion effect of highway investment. When output was allowed to vary, the drop in costs allowed industries to lower the prices of their products. This price reduction prompted an expansion of output. The net effect of highway capital on total costs for the industries then became negligible because the increased production costs from the expansion in output offset the decrease in costs from the productivity improvement. Consumers (rather than firms) effectively captured the benefit of the highway capital effect as prices fell and industry output expanded.

In the course of his econometric estimation, Nadiri also examined the relationship between highway investment and the use of capital, labor, and materials by industries. Looking at the interaction of highway investment with these inputs to production, in all of the industries studied, highway capital investment was found to be a substitute for labor and materials and a complement for private capital. Increases in the highway capital stock reduced the need for labor and materials while apparently spurring the demand for capital to create and expand additional business. When output was allowed to expand to the decline in prices in the model, the substitution effect of highway capital investment diminished for labor and materials, and the complementary effect of capital increased. The complementary relationship between capital and highway investment is important to note—investment in one benefits from investment in the other. The slight substitutability with labor and materials indicates that highway expansion leads to greater efficiency in the use of these inputs. This relationship may offer clues to the underlying responses by firms to changes in transportation infrastructure.

When the results of the model were inspected by industry, some of the industries benefited from highway investment more than others. Service and transportation industries were the chief beneficiaries of more highway capital stock, while manufacturing industries also gained, but to a lesser degree. The result suggested that an expanding service sector in the economy might make future highway investment more important, although further work needs to be done before coming to firm conclusions in this regard. The distributional results can have important implications for the form of finance chosen for future highway capital investment. Because the benefits fall in certain patterns, it may be advisable for payments for taxes or other methods of finance to be more closely aligned with the gain of benefits.

Nadiri next combined the estimated cost elasticities with calculations of the opportunity cost of providing highway capital to generate rates of return for each industry. These results were summed across industries to derive the social rate of return for the highway infrastructure investment. The effects of highway capital investment were found to be very substantial. A 1 % increase in highway capital stock reduced costs by 0.08 % (producing a cost elasticity of -0.08). The average social rate of return over the study period was a healthy 29 %. As table 1 shows, this rate of return is clearly larger than the private rate of return over the same period, providing strong evidence for the value of this investment.

However, when broken down into shorter periods of time, the rates of return varied. Benefits were highest during the earlier development of the Interstate Highway system, when the nation was underinvested in highway capital. After the 1960s, as the system matured and more investment was made, the rate of returned declined. The results for the most recent years, the 1980–1991 period, show that the rate of return was roughly comparable with that of the private sector.

Table 1
Annual Rate of Return by Type of Investment

	1960–1969	1970–1979	1980–1991	Average 1960–1991
Highway Capital	54%	27%	16%	32%
Private Capital	16%	18%	17%	17%
Interest Rate	5%	8%	10%	8%

Nadiri also analyzed the different contributions of changes in exogenous demand, prices, and highway capital to the nation's productivity growth. Total factor productivity measures how output in the economy changes when the amount of labor and capital used in production stays constant. Total factor productivity is typically affected by determinants such as exogenous demand for goods and services, which depends on the size of the population and the level of income (as opposed to endogenous demand, which depends on the price of the product). Other determinants include the relative prices for the different goods used as inputs into the production process. The remainder of the change not explained by these two factors is usually attributed to autonomous technological change. Autonomous technological change represents the myriad improvements in products and processes that increase production as they accumulate over time. In this model, the highway capital stock is added as an additional factor affecting productivity.

In table 2, the main source of total factor productivity growth is change in exogenous demand. Over the sample period, exogenous demand accounts for roughly half of the total factor productivity change. Highway capital makes a sizable contribution to total factor productivity growth as well, roughly a quarter of the total. Relative price changes offer the least contribution, working slightly against growth in the study sample.

Interpretation

Nadiri's study presents a clear case for the historical value of infrastructure investment to the country's economic growth. The average social rate of return exceeds the average rate of return for private-sector investment. The study also finds a sufficiently large rate of return in the later years of highway investment to justify continued investment in the system, although the decline of the rate of return in the most recent period does raise some questions about the extent of the future benefits of highway capital.

One participant wondered if the smaller marginal benefits of more recent highway capital investment could be the byproduct of smaller proportional increases in investment spending in recent years. If so, larger levels of investment might generate higher returns. What remains unclear is whether appreciably larger investments could be made in the current U.S. highway system. Most believe that the system is mature enough that further large expansions would lead to smaller and smaller returns. The first highways in an area usually provide a much greater benefit than later ones, which tend to compete with the older highways.

Participants also speculated what the relationship should be between the rate of return on highway investment and the rate of return on private capital. If the rate of return on highway investment falls below the private rate of return, should that end most highway investment? Conversely, realizing an average rate of return lower than the private rate of return calls into question the advisability of investing tax dollars that could possibly be kept in private hands. One rejoinder is that the private rate of return is also an average and that private rates of return are also influenced by the risk inherent in the investment. At the same time, public capital and private capital are complements, not substitutes for each other. Highway

Table 2
Contributions of Highway Capital and Other Factors to Productivity

	1951–1960	1961–1970	1971–1980	1981–1991	Average 1951–1991
Total Factor Productivity	0.64%	0.88%	0.10%	0.30%	0.48%
Exogenous Demand	0.40%	0.63%	0.18%	-0.06%	0.29%
Price Changes	-0.01%	0.01%	-0.04%	0.01%	-0.01%
Highway Capital	0.35%	0.30%	0.07%	0.04%	0.19%

investment may be justified in its complementary role even at lower calculated rates of return.

One qualification to the results offered by Nadiri is that changes in consumer welfare are left unmeasured. Investing in public highway infrastructure may benefit consumers in a number of ways. Personal vehicle operating costs are likely to be lower as a result of more direct-trip routing and better-quality road surfaces. Similarly, drivers have faster commute times to work and better travel times to nonwork places. Highway users may enjoy an expansion in opportunities for recreational activities, a greater choice in the location of their residences and possibly even wider employment opportunity as improved highways offer greater spatial accessibility. Because these consumer benefits may well be large in and of themselves, the rate of return estimates in this study are likely to underestimate the true effect of these improvements on the entire economy. If this underestimate is small, then the average private rate of return and the social rate of return on highway investment are converging. This convergence is a warning that the need for further physical expansion of the highway network is waning. If the uncounted benefits to consumers are large, then the social rate of return from the commercial sector, even in the most recent period, is well above the private rate of return, making further highway investment highly desirable.

Areas for Improving Research

The group proposed several areas for improving research. One suggestion involved incorporating more geographic detail into the estimates. Since the Nadiri study identified the effect of infrastructure investment on individual industries, without regard to location, all of the spillover effects of location-specific construction were captured in the model. Individual states or regions also need tools to help them gauge how such consequences are related to transportation investment. But because states and regions compete for economic development, the gain to one area may come partly at the expense of a loss in some other area. Economic growth, as measured by Nadiri, is the national effect of this process, and in effect it nets out the gains and losses of individual areas. But the redistribution of economic activity within the nation may be an important consequence of transportation investment as seen by a state or region, and better tools for this purpose are also needed.

The ability to estimate rates of return for highway investment in different areas or places within the country, or even for different industries in different places, is desirable. Such estimates would be valuable for two reasons. First, public officials have an interest in how they would be affected by transportation changes. Second, a comparison of local benefits estimates with similarly computed national ones would shed light on the size of any spillover effects. While the spillover effects of highway infrastructure are generally thought to be positive, negative spillovers also may exist. Additions to one part of the highway system could spur growth in an area at the expense of growth somewhere else. The sizes and kinds of spillovers influence the way that any investment should be financed. If spillovers are very small, localities can capture all of the benefits of their investment in their area. In this situation, coordinating finance and construction with other localities is not important. If spillovers are large, then financial support needs to come from a larger geographic entity. Local construction may need to be subsidized nationally if the net effects of spillovers are positive, or taxed if the net effect of spillovers is negative. Extending the idea of negative spillovers internationally, highway infrastructure investment may affect the ability of the United States to attract economic activity that may have otherwise taken place outside the country.

Investment in transportation may improve international competitiveness by making transportation costs, logistics costs, or the costs of other inputs of production less expensive relative to these costs in other counties. The theoretical underpinning for studying U.S competitiveness needs further elaboration. An empirical exploration might best be grounded in a particular industry or region.

The changing nature and intensity of transportation infrastructure use also pose conceptual challenges for measuring the infrastructure's benefit. Highways that initially carry little traffic often fill over time as they are used more. Highways that face too much demand may see their use fall because traffic congestion diminishes their service. Trucking deregulation clearly altered the transportation environment and the use of infrastructure. Technological innovations, such as smart highways, could change highway use even more in the future. Simply measuring an annual flow of dollar investment fails to capture the effect of changes in infrastructure use patterns on the economy. Researchers need to develop new measures to better address the flow of transportation services provided by the highway capital stock. (This topic is discussed more in the next section of the report.) A participant suggested studying the benefits of research and development spending for highways. This aspect of investment has generally been left untapped and could prove to be a good topic for future research.

The participants made several other points during the discussion. Some noted that the benefits generated by highway capital investment have not come without additional costs to the environment. The costs of additional pollution, urban sprawl, loss of natural habitat and environment for plants and animals, and other environmental damage should be incorporated into future work. Other participants pointed out that policymakers and the public often desire more up-to-date results than the ones presented. In response, some of the data experts in the forum reminded the group that data of the sort used in Nadiri's study take at least three years to collect, process, and disseminate before the analytical work even has a chance to start, so change in this regard is unlikely without changes in the data collection process.

Nadiri's research has verified the value of the expansion of the Interstate Highway System over the past four decades. These refinements will help future work define the best kinds of investment for the future.

Charlie Han, Bureau of Transportation Statistics (left), and Arthur Jacoby, Federal Highway Administration

Further Methodological Issues

The forum highlighted several other questions to explore and new refinements for future research projects. Using Nadiri's cost elasticities for individual industries, Arthur Jacoby of the Federal Highway Administration and Charlie Han of the Bureau of Transportation Statistics analyzed the correlation of these cost elasticities with statistical measures to explore possible explanations for the difference in impact of infrastructure on industries. Barbara Fraumeni of the Department of Commerce, Bureau of Economic Analysis, described some of the findings of her project to improve the quality of infrastructure data by clarifying and refining the many assumptions that go into the construction of such data. In the ensuing discussion, participants identified several other potential improvements to the tools of economic analysis.

Searching for the Mechanisms of Cost Reduction

Ishaq Nadiri found that lower costs of production for industries correlated with increases in the highway capital stock. Searching for more information about the mechanisms through which highway capital investment reduces industry costs, Jacoby and Han tried to link the industry cost elasticities estimated in the Nadiri

Charlie Han, Bureau of Transportation Statistics, Arthur Jacoby, Federal Highway Administration, Dennis Lebo, Pennsylvania Department of Transportation, and James March, Federal Highway Administration (left to right)

study with other industry characteristics. Starting with the premise that improvements in highway systems reduce the cost of transporting goods and the time it takes to deliver them, Jacoby and Han concluded that the responsiveness of industry costs to highway capital should be related to industry expenditures for transport.

Jacoby and Han first tested the hypothesis that industries that were extensive users of transportation spent large sums and were most likely to benefit from improvements to highway systems. However, using 1992 data on industry transportation use from the new Transportation Satellite Accounts developed jointly by the Bureau of Transportation Statistics and the Bureau of Economic Analysis, as well as Nadiri's 1981–1991 cost elasticity estimates, they found no significant relationship between the two variables. In fact, the correlation showed a small positive relationship between the two variables. Industries in which total production costs responded more to changes in the highway capital stock tended to have a lower cost of transportation relative to their total costs.

This result led them to refine their study. Highway capital investment can lower not only the cost of transport, but also the time of transport. Therefore, benefits might have accrued to industries not only according to their transportation use, but also according to the importance of the whole logistics process for the industry. The logistics function manages the movement of products over space and time, procuring the raw materials of production, keeping any necessary inventories, and delivering the final product to the customer. With this insight, their hypothesis evolved: The more important that logistics are to an industry, the more sizable the cost elasticity with respect to highway infrastructure would be.

A good piece of evidence supporting the importance of logistics costs to firms is the rise of just-in-time inventory practices. Just-in-time inventory practices demand speed and reliability in freight transportation. Using a suitably constructed proxy for industry logistics cost intensity, Jacoby and Han indeed found a significant negative relationship between their proxy and Nadiri's cost elasticity estimates. Sizable production cost reductions stemming from highway investment identified by Nadiri were associated with industries that had a greater reliance on the logistics function.

This work by Jacoby and Han points out that the evolution of the logistics function within businesses may offer important insights into the benefits gained from highway capital investment. It also serves as a guidepost for future research into the mechanisms by which transportation system improvements are transformed into productivity benefits. Insights into the behavior of firms may provide us with a better ability to forecast the kinds of transportation investment that will be most beneficial in the future. The relative importance of changes in transportation cost, speed, reliability, or access may make some investments more desirable than others.

Improving the Data Used in Analysis

As mentioned earlier in the discussion of Nadiri's research, one of the difficulties facing studies of highway investment effects is the question of how to capture the level of service provided by the stock of highway capital. Investment dollars must be transformed into transportation infrastructure. These physical networks need to be translated into a flow of transportation services.

Barbara Fraumeni has been leading an effort to produce a quality-adjusted public highway capital stock for the Federal Highway Administration. Her work has examined the different components that make up the transportation capital stock and how they fit together as a system to provide transportation services. In her presentation, Fraumeni recommended three major ways to improve highway capital stock measurements:

1. Use productive capital stocks instead of wealth capital stocks.
2. Accurately account for changes in highway construction component expenditures over time.
3. Properly benchmark capital stock estimates.

The difference between a productive capital stock and a wealth capital stock is perhaps best illuminated by the example of a light bulb. A light bulb gives off a certain amount of light while it works. That amount of light is constant as long as it works. However, the light bulb has a limited working lifetime and failure is all at once. Say that the light bulb is expected to work for 12 months. The productive stock value of the capital good light bulb is constant at any given point during the year. Until it stops working, it produces the same illumination. However, if a rational buyer were to offer to purchase the light bulb, the amount that person would be willing to pay for the light bulb would depend on how much expected working life the light bulb had left. After six months of use, this wealth stock measure of the light bulb's value would be about half of what it cost originally.

Wealth stocks, such as those compiled by the Bureau of Economic Analysis, take into account the depreciation of the wealth stock value. Therefore, they can be misleading when trying to capture the productive effects of highway capital stocks. Fraumeni calculates that her productive stock estimates for highways can be as much as 40% higher than the Bureau of Economic Analysis wealth stock estimate.

Fraumeni's second recommendation for improvement addresses the difficulties of assuming the degree to which highway capital stock investment takes the form of

Barbara Fraumeni, Bureau of Economic Analysis

new construction or rehabilitation. These different kinds of investment activities have differently weighted component expenditures for grading, pavement, right-of-way, and structures. Typically, expenditures for grading and acquiring right-of-way will constitute a larger proportion of new construction costs. These construction items will have much longer productive lifetimes than, for instance, the pavement surface. Historically, capital expenditures have been for new construction. In the last two decades, investment has taken the form of more reconstruction and rehabilitation, with a greater proportion of expenditures for pavement and lower share of expenditures on grading and right-of-way. Differentiating between new construction spending and capital maintenance spending is important for translating highway investment flows into accurate capital stock estimates.

Fraumeni's final recommendation for improving the quality of highway capital stock data is to develop a benchmark for capital stock estimates. Because some components of capital stock have very long lifetimes, using a perpetual inventory calculation without a benchmark (or very long time horizon) can lead to underestimates. The problem is most likely to affect state and local estimates, for which the time span covered by the data usually tends to be short.

All of these refinements lead to the development of a better measure of the potential productive services that the highway capital stock could provide.

Ideally, this improved capital stock measure would be converted into an actual flow of productive transportation services. Congestion and road usage influence the amount of productive services produced by the capital stock, as does the location of the facility. The value of the physical inventory of highways needs to take into account which parts are heavily used portions of the network and which are not, and this varies sharply from one part of the network to another. For example, some heavily used routes may actually be devalued because their level of service has deteriorated because of congestion. Other underused routes may have a low value because they are not generating a high flow of productive transportation services based on low utilization. Incorporating the degree of highway use into capital stock measures would clarify the value of the transportation services that our infrastructure system provides. That is, measuring the value of the light instead of the light bulb would help to dispel the shadows surrounding the future of highway investment.

State and Regional Analyses

Clyde Pyers of the Maryland Department of Transportation and Gregory Bischak

Gregory Bischak, Appalachian Regional Council

from the Appalachian Regional Commission offered state and regional analyses of highway investment programs. Both studies found reasonable rates of return on recent investments, pointing to both short-term job creation and construction spending benefits and longer-term industry cost reductions and net travel savings. The discussion afterward reemphasized points made in the discussion of Ishaq Nadiri's study and offered a few additional insights.

Presentation of the Studies

The Maryland State Highway Administration conducted a study to quantify the contribution of highways to the Maryland economy. The analysis measured both the short-term effects of highways on employment and output and the long-term productivity gains that accrue to individual industries throughout the state.

The effects of Maryland highways on employment and output in the state were calculated using an input-output model of the regional economy over the 1991 to 1996 period. An estimate of the state's economic output without the benefit of the highway investment was compared with the level of output with the investment. Spending was broken down by industry to allow calculation of the resulting changes in employment. These results were linked to a model of the Maryland economy, prepared by RESI, a research institute of Towson University, with equations for employment and output at the industry level and linkages to components of population and income.

The long-term productivity effects were calculated using cost functions for nine industry groups from 1982 to 1996. Similar to the Nadiri study, annual industry costs were taken to be a function of wages, the price of capital goods, the stock of highway capital, and a proxy for technological progress (the functional form used was different). Savings in industry costs associated with increases in the highway capital stock were estimated econometrically.

The findings of the Maryland study were reasonably large and of a magnitude generally consistent with Nadiri's nationwide estimates. In the short term, the study found that the roughly $1 billion annual highway system investment from 1991 to 1996 yielded 23,000 additional jobs and roughly a $2.7 billion increase in the output of Maryland goods and services. Most of the jobs created were estimated to be in the construction sector. From this greater business activity, the increase in state tax revenues alone recovered about one-fifth of the initial outlay. Over the long haul, the study estimated an annual rate of return on highway investment of 17%. The rate of return was higher in the early 1980s, with a slight decline in the general trend moving toward 1996, for which the return was calculated as 17.2%. In contrast to the Nadiri study, the bulk of the cost savings accrued to manufacturing firms rather than services or retail trade (manufacturing production costs declined on average by more than 12¢ of the total 17¢ per highway dollar invested). In relation to economic growth, highway investment was found to be responsible for 10% of productivity growth and 45% of total growth in the state.

The Appalachian Regional Commission also examined the economic development effect of its highway system additions, known as the Appalachian Development Highway System (ADHS). The ADHS is a planned, 3,000-plus-mile network of highways extending through 13 states from Mississippi to New York. To date, nearly 80% of the system has been completed. Wilbur Smith Associates performed the analysis for the commission, identifying 165 counties with 1,400 miles of highway as likely to be most affected by the system.

The Wilbur Smith study estimated changes in population, employment, wages, and value-added in the region as a result of the ADHS, using a regional economic model developed by Regional Economic Models, Inc. The study also examined the travel efficiency benefits of the highway system, such as reduced travel times, lower vehicle operating costs, and fewer accidents, as well as the broader economic development effects from increased roadside business, tourism, and an overall improvement in competitiveness in the region. Results were generated by comparing data from the historical record with an estimate of traffic volumes without the ADHS.

The study estimated that, from its beginning in 1965, the ADHS generated 16,000 additional jobs in the region, with a net increase of 42,000 jobs forecast by 2015. By sector, employment increased most for the construction industry in the first 10 years. However, by 1995, the employment gains were felt most heavily in retail trade and services, a pattern that was forecast to continue through 2015. In general, all sectors of employment showed some level of employment benefit. On a return basis, a dollar's investment in the ADHS generated $1.18 in efficiency benefits. For the more comprehensive economic development benefit measure, which includes tourism and competitiveness effects, the return climbs to $1.32 of benefits for the average dollar invested. Looking at individual corridors within the system, efficiency returns ranged from 5 to 10%. The study also provided an estimate of $2.7 billion as the benefit from increased competitiveness for the entire 1965–2015 period.

Discussion of the Results

The magnitude of the results from both studies is consistent with the results of Nadiri's national study, demonstrating the value of highway infrastructure investment at the state and regional level as well. The main concern about the interpretation of these regional study results was the extent of any negative spillovers not captured in the model. Did regional highway investments create benefits for one area at the expense of other areas? Several participants generally held that these improvements did not constitute a zero-sum game; the gains in productivity provide large enough increases to justify any moves by existing business and increase the competitiveness of the country as a whole. Work performed by Marlon Boarnet of the University of California at Irvine shows a degree of tradeoffs from highway investment between counties within California.

However, more work needs to be done to better identify these interrelationships between localities and the extent to which local highway projects represent economic gains or merely result in shifts in the location of economic activity—transfers from one area to another.

A related issue for area or regional studies is the difficulty in assessing the influence of changes in the area not under study. While the transportation system within the area can be controlled for, changes outside the area may also affect the region's infrastructure. Transportation investments may complement or substitute for those in different areas. A more complete understanding of exactly how individual firms are affected by changes in highway infrastructure may help solve this outstanding issue.

As with the Nadiri study, these two studies most likely underestimate the actual rates of return for their investments. Including consumer benefits from cheaper, faster, and safer highway travel would certainly drive the estimates higher. Ideally, studies also would capture other economic effects such as benefits from improved accessibility to an area, the substitution of products produced locally for goods that would otherwise be imported, and increases in the economies of scale of production. While the Appalachian study did attempt to account for tourism benefits, its authors believe they may have undermeasured this effect. The degree to which all of these effects would alter the calculated benefits for transportation investment is currently unknown.

Several participants raised questions about the implications of the rates of return found in area studies. If such a study finds a rate of return a few percentage points below the typical private-sector rate of return, does it mean that the highway investment should not have been made? Ishaq Nadiri was quick to point out that highway investments are complementary to private investment.

Others questioned the kind of relationship that should be expected between estimates from the national study and regional studies. Should the regional studies be lower because they are not able to capture benefits from the infrastructure investment that accrue outside their area? Different areas are home to different kinds of industries. Gaps of a few percentage points between regions or between a regional and a national estimate are to be expected, since different industries benefit differently.

Trying to compare the two regional studies highlights the need for consistent data. If data could be collected in a consistent manner from state to state, states or regions could use a common framework for their analyses. The necessary research methodology could be developed and then shared, drastically reducing the time and cost of producing this sort of study for localities. It would also provide a better basis for comparing the benefits of investing in different areas.

After all the attention given to pouring pavement in these research studies, participants in the discussion also wanted to discuss ways in which highway investments other than construction can lead to greater transportation system capacity and efficiency. For example, the great changes in freight transportation that followed the deregulation of trucking demonstrate the importance of highway system management.

The use of technology may also be necessary to increase the capacity and safety of highways. Developing and implementing intelligent vehicle highway systems (smart highways) is a promising possibility for the future. Even investing more in the thickness of the pavement itself may generate additional benefits that outweigh the costs.

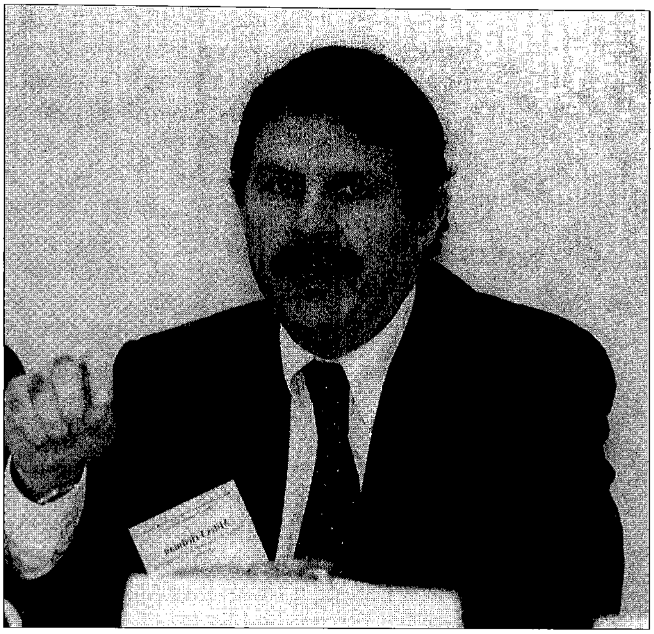
Nor should attention be limited solely to highways. Rail, sea, and air transportation continue to play vital roles in the nation's transportation system. These modes and their interconnections could become even more important in the future. Ultimately, more research and creative thinking will be needed to uncover new ways to make the best use of our existing transportation systems and highway capital stock.

Communicating Results to Policymakers and the Public

After much of the forum focused on recent studies of the relationship between highway investment and economic growth and how to improve future work, a spirited session addressed the importance of communicating these results to policymakers and the public. Miles Friedman of the National Association of State Development Agencies and Terrence Mulcahy from the Wisconsin Department of Transportation drew the group into a wide-ranging discussion of the role that economic analyses play in the decision-making process. Comments highlighted (1) the difference between developing new programs and implementing additional local projects, (2) specific groups to target for communication and outreach, and (3) the roles of state and local transportation agencies.

Friedman discussed the evolution taking place in state economic development agencies and the effect that change has on the role of transportation investment in state development. State development agencies are reaching out to encompass wider geographical areas and are branching out to take on a wider range of development activities (to which the rise in regional development groups, both multistate and multicounty, attests). Development agencies no longer target just heavy industry. They also spur technology development, foster small business growth, promote tourism, and tackle international competitiveness issues. With this expansion in the scope of their responsibility, state development agencies increasingly view themselves as long-term strategic planners, coordinating and facilitating a number of different activities, including investment in the transportation system. Accordingly, transportation decisions should be folded into the planning mix. In this light, transportation investment is best cast as part of other long-term development efforts rather than as the enhancement of a set of facilities.

To illustrate his point, Friedman told the story of a town in Kansas that decided to revive its sagging downtown economy by advertising and promoting a historic fort located nearby. After hiring a professional marketing company to publicize the fort, the number of tourists visiting the fort soared. The downtown, however, remained empty. Upon further reflection, the town leaders realized that the transportation system needed to be part of their solution. They widened the 10-mile highway between downtown and the fort, offered a shuttle service between the two areas, and promoted special events downtown. Only after they considered all of the different facets of their problem, including the transportation environment, did they finally achieve the success they desired in revitalizing an important part of their community.



Miles Friedman, National Association of State Development Agencies

The larger political context in which transportation projects are presented becomes much more important as strategic planning becomes broader and more interconnected. New challenges will arise as transportation investments face the reality of competing with social programs. Environmental concerns and perceptions of favoritism to business can also be stumbling blocks for new projects. At the same time, the bigger picture surrounding transportation investment can provide new opportunities. Good transportation systems can connect people with jobs. New projects can encourage livable communities and spur business development.

Terrence Mulcahy of the Wisconsin Department of Transportation reinforced the need to view transportation in context. The chief concerns of communities in Wisconsin are the effects of transportation on local businesses, economic development, and the quality of life in the state. Roads, railroads, and airports are built to achieve important economic and social objectives, and transportation agencies are responsible for ensuring that these facilities serve the needs of citizens and businesses. In Mulcahy's view, one of the state highway department's primary roles is to provide a forum in which different communities can communicate their experiences to each other. Supporting Friedman's remarks, Mulcahy also urged transportation agencies to embrace the sometimes-disparate elements of commerce, tourism, and the environment.

How do research studies influence the public and policymakers? The reasonably good recent rates of return estimated in Nadiri's study provide some justification for implementing new transportation investment policies. Studies that show evidence of huge benefits from particular kinds of new programs, such as the Aschauer and Munnell results, may be readily apparent to the public or key beneficiaries. At the same time, when the benefits are not dramatic, information about returns alone may not be sufficiently compelling to the general public and legislators. With many competing interests in the public arena, gaining attention for transportation investment may be difficult.

Terrence Mulcahy, Wisconsin Department of Transportation (left), and Madeleine Bloom, Federal Highway Administration

The importance of success stories—anecdotes that vividly and succinctly convey the effect of a specific transportation project in a particular place—cannot be overstated. Linda Thelke of the Wisconsin Department of Transportation provided the group with a powerful example. The Harley-Davidson Company is an important employer in her home state of Wisconsin, providing high-quality, good paying jobs to local workers. In meetings with government officials, the president of Harley-Davidson has emphasized the importance to the company of good access to the transportation system. Good transportation allows the company to run with 35-minute delivery windows for moving products between their plants. With this kind of transportation system performance, the company can keep their costs lower and stay competitive without having to move their plants and jobs overseas to lower-wage countries. As Curt Wiley, the chair of the forum and the Commissioner of the Indiana Department of Transportation, put it, "[O]ne Harley-Davidson in a governor's ear probably takes the place of whatever study there was."

Case studies and individual stories often prove to be effective calls to action. Stories of successful transportation projects can provide the edge needed to generate wider appeal for larger programs. However, the group did not fully resolve whether studies and stories have different influences on national programs, state programs, and local projects. One tendency is to argue for programs using studies and to offer anecdotes to facilitate local projects, partially as a result of better data availability for larger-scale programs and funding constraints for smaller-scale projects.

Either studies or stories can provide a starting point for discussions of the pros and cons of projects or programs. In the current transportation environment of moderate benefits from investment, the question of how to effectively communicate results really becomes a question of how best to tie together these local anecdotes and program-wide estimates.

One solution is to use stories and studies in tandem. One participant likened the relationship between the use of national studies and anecdotes to using logic and emotion—a successful combination of both makes for the most compelling argument. National and state studies may provide a context for local anecdotes and at the same time reinforce them.

Another solution is to make the results more closely address the questions that policymakers and the public want answered. People want to know about transportation's relationship not only with growth, but also with quality of life, community development, and local commerce. Because of its role as a facilitator of activity, transportation analysis should be incorporated into the strategic planning of a state or region and tied into its economic development. Different regional development priorities will lead to different research needs—the effects on urban versus rural areas, manufacturing versus service-sector businesses, retail versus wholesale trade, and tourism versus job access. A closer match between the community's concerns and the scope of research may make studies more effective.

Not only the style and content, but also the vehicle of a transportation agency's message, must be considered. Groups such as the press and the business community are worth particular attention because of their influence. Miles Friedman found that thorough briefings with the press facilitated better coverage and a better ability to carry the messages to the public. The business community is also viewed as a vital group with which to communicate. The business community has a general level of influence with the public and policymakers. Its opinion tends to carry even more weight because it is significantly affected by highway investment. The forum participants were more divided on the usefulness of having a very persuasive and visible individual as a proponent. Better outreach to the press and the business community will help the effectiveness of whatever kinds of studies and anecdotes transportation agencies use.

Conclusion

The next wave of transportation research must move outward from the center created by Ishaq Nadiri's work. In one direction, new research needs to delve further into the effects of transportation investment on businesses, examining firms' responses to changes in transportation systems. Research also must better understand the geographic variation in the return to transportation investment, grappling to measure the spillover effects and interrelationships between investment in different locations. Such detailed information will help determine the kinds of infrastructure investments that hold the most promise for the future.

In a second direction, though, research needs to move beyond the realm of infrastructure investment to consider the full range of transportation policies that could be used to improve the nation's productivity. Policies that can bring new technologies to bear on the problem of congested highways or other new approaches to the management and operation of our infrastructure may ultimately prove more attractive than infrastructure expansion.

Transportation researchers should not forget to reach out to the public and seek to embrace a whole range of relatively new concerns: competitiveness, job access, tourism, and the environment. Policymakers and the public are the ultimate consumers of transportation research, and the most effective research efforts will be those that discuss the kinds of issues in which these consumers are most interested. Effectively communicating new transportation research means being sophisticated in using the right combination of study results and compelling stories to reach policymakers and the public.

Appendix A: A Summary of *Contributions of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries*

Arthur Jacoby, Federal Highway Administration

September 1998

Background

A number of research studies by and for the Federal Highway Administration (FHWA) Office of Policy Development document the effects of public highway capital on logistics system and commercial sector economic performance. A notable example is Professor M. Ishaq Nadiri's 1996 study,[1] which examined the contributions of total highway capital and nonlocal highway capital to the output growth and productivity of 35 industry sectors comprising the U.S. economy. His 1996 econometric analysis provides empirical evidence of the positive impacts of public highway capital on private-sector costs of production. It also (1) evaluates the effects of highway capital investment on the production sector's demand for labor, private capital formation, and materials; (2) estimates the marginal commercial benefits of road system investments; (3) calculates the net social rate of return on highway infrastructure spending; and (4) identifies the contribution of highway capital and other economic factors to the productivity growth rate in the U.S. economy between 1950 and 1989.

The Current Study

Professor Nadiri's most recent effort reflects several extensions and improvements to his 1996 study.[2] First, underlying economic data are extended to include the period 1947 to 1991 and take into account recent revisions in national income accounting industry reclassifications. Second, other types of public infrastructure capital are introduced into the analysis to address concerns about the effects of omitted explanatory variables. Third, assessments of highway capital's impact on the private sector's demand for labor, capital, and intermediate goods are broadened to consider the output expansion effect of public road investments.[3] Finally, detailed estimates of the effects of highway capital during the subperiod 1981 to 1991 are provided to enhance contemporary policy discussions.

The main goal of this research is to measure the historical impacts of publicly provided highway capital on the production sector of the U.S. economy. Empirical assessments of the relationships between highway investment spending and industry economic performance are aggregated to produce national economic measures. It is important to note that the benefits of infrastructure to the consumer sector are not considered in the current work. Although some interactions between the producer and consumer sector benefits are likely, consumer benefits are largely additive to the commercial-sector benefits estimated in the current study.

The sophisticated nature of the analysis, the relatively large number of interrelated economic measures, the comprehensiveness of the industry sectors considered, the long time frame of the study, and the variations in empirical estimates across industries and over time make a succinct statement of research findings in a nontechnical manner very difficult. Therefore, this summary of Professor Nadiri's 1998 research for the FHWA is organized in the form of brief answers to several basic questions about the economic impacts of road investments on the commercial sector of the economy.

1. *What are the effects of highway capital on private-sector production costs; level of output; and demand for labor, capital, and intermediate goods?*

A principal conclusion of this research is that an increase in the stock of U.S. highway capital has an initial direct productivity effect on business: It reduces the total cost of producing a given level of output in almost all industries. The cost-reducing "productivity effect" of highway capital varies in magnitude across industries and over time. The size of the highway capital productivity effect on each of the 35 industry sectors that make up the

U.S. economy is indicated by the "cost-elasticity" measure.[4] Cost reductions due to highway capital investment are relatively large (i.e., cost elasticities greater than -0.08) in such industries as agriculture, food and kindred products, transportation and warehousing, trade, construction, and other services. In most manufacturing industries cost elasticities range between -0.04 to -0.06.

To obtain a national-level estimate of the initial cost-reducing impact of highway capital investment, industry cost-elasticity measures are weighted by the industry's share of total national output and summed. The average cost elasticity with respect to total highway capital for the U.S. economy during the period 1950 to 1991 is about -0.08. This is approximately double the -0.04 estimate reported in Nadiri's 1996 study.

The economic impact of highway investment on the various industry sectors does not stop with the direct productivity effect. Cost reductions permit products to be sold at lower prices, and lower prices can be expected to lead to output growth. This is termed the "output effect" of highway capital investment. The size of industry output expansion depends on the nature of the demand for products and, therefore, varies across industry sectors. Of course, at higher production levels, a producer's total costs will increase because of the additional labor, capital, and materials required to make the additional output. An important empirical finding of the current research is that the higher total production costs associated with the output expansion effect are "financed" almost entirely by the cost-saving productivity gains of highway capital investments.

Given the cost-reducing and output-expanding impacts of highway capital, it is not surprising that road investments have a significant effect on the production sector's demand for labor, capital, and materials. The magnitude of the effect, which is termed conditional factor demand, varies among the three inputs (labor, capital, materials) and across industries, and depends on whether we are examining industry's demand for resources in the context of the "productivity effect" alone (i.e., when output level is held fixed) or after allowing for the "output effect" (i.e., when the level of output is allowed to increase in response to the cost-saving/price-reducing effects of highway investment).

The study indicates that highway capital's initial "productivity effect" results in a reduction in the demand for labor and materials but an increase in the demand for private capital in all industries. However, the current work also evaluates changes in the production sector's demand for labor, capital, and materials when industry production levels vary (increase) due to the "output effect" of highway capital. While the direction of the impacts on business demand for labor, capital, and materials remain the same as under the productivity effect alone (i.e., highway capital increases result in reductions in demand for labor and materials but increases in demand for private capital), the magnitude of the change in demand for labor and materials is substantially reduced while the demand for private capital increases significantly. That is, the output effect of highway capital investment leads to an even larger "crowding in" of private capital formation. We can generally conclude that the productivity and output effects of road investment substantially change the input ratios of the production function in all industries, point toward an important role for public capital spending in contributing to investment-led economic expansions, and imply that highway capital may be a prerequisite for growth in private capital investment.

2. What are the marginal benefits to industry sectors and the aggregate economy of an increase in highway capital?

The marginal benefit of highway capital is measured in terms of its initial cost-reducing impact (i.e., the productivity effect). The magnitude of cost reduction depends on the industry's elasticity of cost with respect to highway capital and the industry's total costs of production relative to the size of the highway capital stock. The current research indicates the marginal benefits of highway capital are positive in all but three fairly small industries. Marginal benefit estimates can be interpreted as a measure of producer's "willingness to pay" for an additional unit of highway capital and vary considerably across industries and over time. For most industries, particularly manufacturing industries, the marginal benefits of a $1.00 increase in highway capital range between 0.2¢ and 0.6¢. Industry marginal benefit estimates can be translated into a dollar value of cost reduction in each industry for a given amount of highway capital spending. The simplest way to do this is to multiply the measure of marginal benefit in each industry by the net increase in highway capital for a particular year or period.

The calculation of the marginal benefit of highway capital investment at the national economy level assumes that the use of the road system by one industry does not preclude or reduce the value of its use by any other industry (i.e., we assume nonrival consumption of the highway public good). Therefore, industry marginal benefits are additive across the 35 sectors. The average sum of marginal benefits across all industries is about 0.294. That is, a $1.00 increase in the net capital stock generates approximately 30¢ of "cost-saving" producer benefits per year. Assuming highway spending covers the depreciation charges required to maintain the net capital stock value, benefits can be thought of as continuing over the design life of the underlying road improvements. The 30¢ aggregate marginal benefit estimate for total highway system spending is somewhat larger than the amount reported in the 1996 study, which estimated a marginal benefit of 18¢ for total highway system capital. It also exceeds the 24¢ estimate given in the earlier study for nonlocal highway system capital.

3. *What is the contribution to productivity growth of highway capital, and what is the overall social rate of return on road investments?*

The contribution of highway capital to productivity growth is positive in all industries. In the previous study, highway capital increased productivity mainly in manufacturing industries but not in nonmanufacturing industries. Although the current results show a more pervasive influence of highway capital on industry productivity growth, the magnitudes of the contribution of highway capital vary across industries. In some industry sectors, the effect can be quite large. At the aggregate economy level, highway capital's contribution to total productivity growth is about 25%. This contribution is somewhat larger than the 18% reported in the 1996 work. Nevertheless, the current study confirms the previous finding that the main contributor to productivity growth, both at the industry and aggregate economy levels, is exogenous demand (representing the effects of aggregate income and population growth).

Nadiri calculates the net social rate of return to total highway capital as the sum of industry marginal benefits divided by the cost of highway capital, minus the depreciation of public capital. The estimated cost of highway capital is adjusted to account for the price distortion effect of taxes levied to finance highway capital, which effectively raises the cost of highway capital approximately 46% above the combined government long-term bond rate and highway capital depreciation rate. As in the previous study, current results indicate that the net social rate of return on total highway capital was very high during the 1950s and the 1960s, but declined considerably during the 1970s and 1980s. The average net rate of return on total highway capital investment for the 1950 to 1991 analysis period was 32% per annum. Although net rates of return on total highway capital investment are generally larger in the current study than in the 1996 effort, the trend since the 1970s remains downward. In the 1980s, the rate of return on highway capital and private-sector capital appear to have converged at approximately 16% per annum.

The declining rates of return on highway capital investment since the 1970s are likely to be an important concern of policymakers. No doubt the rates of return on highway capital during the 1950s and

1960s were very high indeed. These high returns can be interpreted as signaling a severe shortage of highway capital during the early stages of the Interstate highway construction era. One view of the declining rate of return trend since the late 1970s is simply that as interconnective, upper-level roads were put in place, commercial transportation needs were addressed, and subsequently the rates of return on highway capital from the production side of the economy declined to more normal and sustainable levels. That is, over time, real reductions have occurred in the flow of commercial benefits from further additions to the public highway capital stock. Alternatively, declining returns may reflect the economic effects of relative disinvestment in road capital during this period. Crumbling roads and bridges were of great concern to transportation policy makers in the 1980s and the extent of the "infrastructure crisis" was documented in several important studies.[5] If the rate of public-capital investment during this period slipped relative to private-sector investment and growth in the economy, increasing demands placed on the available quantity and quality of public-capital stock would be manifest by a declining performance contribution. In terms of Professor Nadiri's econometric approach, the ratio of total highway capital stock to production-sector total cost and output levels is very important, because it is a component of industry cost elasticity, and thus affects the value of the industry's marginal benefits and the rate of return.

4. *What evidence is there of over- or under-supply of highway capital in the postwar period?*

An important public policy question is whether public highway capital is over- or under-supplied. Economic efficiency requires an amount of publicly provided highway capital such that the sum of the marginal benefits to producers and consumers from one more unit of highway capital is just equal to the marginal cost of providing the additional unit of highway capital. Since consumer marginal benefits are not known at this time, an alternative method for determining whether public capital is optimally provided is used. That method is to compare the rate of return to highway capital with the rate of return to private capital for the whole economy. If the rate of return on highway capital investment is higher than that of private capital, highway capital is under-supplied. An increase in public highway investment is therefore desirable when the economic benefit of an additional unit of highway capital exceeds its cost and the rate of return that is available from alternative uses of the required resources.

In the current study, net social rates of return for total highway capital are compared to those of private capital for several time periods. Although the average rate of return for the entire analysis period (1950–1991) is 32%, as previously noted, it has declined continuously since the 1970s. For example, the average net rate of return fell from 54% in 1960–1969, to 27% in 1970–1979, and to 16% for the period 1980–1991. The net social rate of return in the 1980s is approximately equal to the average rate of return on private capital in the 1980s, implying a close-to-optimal amount of total highway capital. However, two points that bear on this finding should be noted. First, the equality between public and private capital rates of return is only a partial macroeconomic assessment because it does not consider consumer-sector benefits of the road system. Consumer benefits may be considerable. Second, Nadiri's previous study indicates the rate of return on nonlocal highway capital, the main focus of federal-aid highway program spending, are approximately 5% to 7% greater than those for the total highway capital.

5. *How do results for the 1980–1991 period differ from those for earlier decades and the entire 1950–1991 analysis period?*

Examination of industry economic data for the 1980s indicates a pattern of input usage, output growth rates, and costs that are similar to previous periods. The effects on industry output from additional amounts of labor, private capital, and materials are basically of the same magnitude as the averages for the entire study period. However, it is noticeable that industry internal and total returns to scale for the 1980s are larger in most industries than the modest increasing returns to scale observed over the entire 40-year analysis period.

The pattern of the distribution of highway benefits across industries for the 1981–1991 subperiod is also similar to that for the entire analysis period. The initial effect of an increase in highway capital investment on producer's demand for inputs is similar to that observed in earlier periods—highway capital substitutes for labor and materials, but private capital and highway capital are complements (i.e., the demand for private capital increases when investment in highway capital rises).

When an accounting is made for the output expansion effect induced by the productivity gains from highway capital, we also see ostensibly similar results. In the 1980s, the induced increase in total costs associated with higher output levels is approximately of the same magnitude as the cost reduction or "productivity effect" of highway capital. This phenomenon, which is observed at both the industry and aggregate economy levels, is due to the size of the output cost elasticities (the reciprocal of the degree of returns to scale noted above), which suggest that a 1% increase in output generates almost the same increase in cost. That is, the productivity gain of highway capital offsets the increased cost associated with the induced output expansion.

The most significant change in analysis results between the 1981–1991 period and the rest of the study period involves the elasticity of cost with respect to highway capital. The average percentage change in producer total cost associated with a 1% change in the net highway capital stock for the 1981–1991 is much smaller. The average cost-elasticity value is about -0.039 in the 1980s, compared to an average value for all periods of about -0.08 (see above). Furthermore, the economic impact of highway capital on producer cost continues to decline during the 1980s. To illustrate, while the average rate of return on highway capital for the period 1981–1991 is about 16%, the rate of return declines to approximately 10% by the end of the period (i.e., in 1991).

Concluding Comments

In this study, Nadiri concentrates on calculating the commercial benefits of highway capital to the production sector of the economy. The welfare benefits of highway capital to consumers are not addressed. However, the magnitude of consumer benefits, including employment-related trips that are not directly included in the production-sector analysis, are likely to be significant. Efforts to account for the total effect of highway capital on the economy will require modeling the consumption-sector impacts and ultimately integrating these results with the production sector in a general equilibrium model framework. Work in this area has just begun and is expected to continue for some time.

A careful analysis of the size and pattern of industry marginal benefits is needed. The needs of different industries for highway services diverge over time and the degree of benefits of new highway capital differ considerably across industries. Because public highway capital creates important distributional effects across industries, further analysis of the sign and magnitude of industry marginal benefits at a more desegregated level is highly desirable from a transportation policy standpoint.

Finding measures to account for quality changes in the highway capital stock and intensity of use of the capital stock are another consideration for future research. Efforts to differentiate between wealth- and productivity-based assessments of the public capital stock are now under way in collateral research.[6] Nevertheless, the challenge to find ways of converting productive potential capital stock measures into service flow measures remains. This requires adjustments for utilization of highway capital, taking into account congestion, intensity of use by different industries, and the overall level of business activity.

Your comments and inquiries are welcome and should be directed to

Dr. Arthur Jacoby
Office of Policy Development, HPP-10
Federal Highway Administration
400 Seventh Street, SW
Washington, DC 20590
Phone: (202) 366-9248
Fax: (202) 366-7696
e-mail: arthur.jacoby@fhwa.dot.gov

Endnotes

[1]Nadiri, M. Ishaq and Theofanis Mamuneas, *Contributions of Highway Capital to Industry and National Productivity Growth*, September 1996, Final Report, FHWA Work Order BAT-94-008. The report is available online at www.fhwa.dot.gov/reports/growth.pdf or from the FHWA homepage at www.fhwa.dot.gov. Select "Publications and Statistics" and click on the above title.

[2]Nadiri, M. Ishaq and Theofanis Mamuneas, *Contributions of Highway Capital to Industry and National Productivity Growth*, September 1996, Final Report, FHWA Work Order BAT-94-008. See recommendations in Directions for Future Research, pp. 116–118. Also, the main results of the 1996 study are presented in section III of the current work to provide a context for evaluating new modeling techniques and the effects of extended and revised data.

[3]In Nadiri's 1996 study, industry output levels were held fixed when calculating the productivity benefits of highway investment. The overall substitution of highway capital for private inputs initially produces a "productivity effect" in firms and industries by reducing the cost of producing a given level of output. However, highway capital investment can also be expected to induce an output expansion effect that will further affect producer demand for labor, capital, and materials. That is, the downward shift in production cost leads to a reduction in product price. At the lower price, more of the product is demanded. The resulting increase in the quantity of the product demanded is termed the "output effect" of highway capital. Firms require greater quantities of labor, capital, and materials to produce the additional output. Therefore, the total impact of highway capital investment on the private sector's demand for labor, capital, and materials must reflect both the initial productivity effect and the subsequent output effect. Changes in industry output due to an increase in highway capital investment were not considered in the 1996 model.

[4]Industry measure of "cost elasticity with respect to highway capital" is one basic empirical result of Professor Nadiri's econometric model. Econometric studies can generate a number of different cost and output elasticity measures. This can be a source of confusion. The simplified term "cost elasticity" is used in this summary when the source of the effect on total production cost is unambiguously attributable to highway capital investment. The cost-elasticity value indicates the percentage change in the total cost of producing a given level of output that is associated with a 1% change in the value of the highway capital stock. It is mathematically derived from the econometric estimation of the industry cost function by taking the first partial derivative of the total cost function with respect to highway capital. A negative signature (sign) indicates that an increase in highway capital results in total cost reduction.

[5]See, for example, *Fragile Foundations: A Report on America's Public Works*, National Council on Public Works Improvement, February 1988, and *High Performance Public Works*, U.S. Advisory Commission on Intergovernmental Relations (ACIR), Report SR-16, November 1993.

[6]The Quality Adjustment of Public Capital Stock research is under the direction of Professor Barbara Fraumeni, Northeastern University. A pro forma "productive" highway capital stock assessment for use in future econometric studies was produced in February 1999.

Appendix B: A Preliminary Assessment of the Similarity Between Nadiri's Industry Cost Elasticity and TSA's Transport Intensity Measure

Arthur C. Jacoby and Xiaoli Han

February 1999

Introduction

The U.S. Transportation Satellite Accounts (TSA) for 1992 were jointly developed by the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation and the Bureau of Economic Analysis of the U.S. Department of Commerce. The primary purpose of this project was to address the under-representation of transportation activities in national economic accounts. The magnitude of transportation services has long been underestimated in national economic data used by government and private-sector decisionmakers. One reason is that, until now, national measures of transportation services only included the value of for-hire transportation, that is, transportation services provided by transportation firms to industries and the public on a for-hire basis. The sizable quantity of transportation activities performed by nontransportation industries, or in-house transportation, were not explicitly identified, and their output was counted as part of those nontransportation industries' output, rather than transportation output.

The publication of TSA 1992 in April 1998 provided, for the first time, much more complete and accurate estimates of transportation activities in the U.S. economy and their contributions to Gross Domestic Product. More important, the TSA 1992 provides this information on an industry basis. Detailed data on the use of transportation services at the industry level reveal several important features concerning the role of transportation in industry production, and transportation intensity coefficients from the TSA provide an empirical basis for productivity study.

Contribution of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries, by Nadiri and Manuneas, analyzed and measured the contribution of highway capital to private sector productivity growth. Using disaggregated data for 35 industry sectors, Nadiri's model identified the determinants of productivity growth for each industry, including the contribution of public highway capital. The cost elasticities with respect to highway capital for each of the 35 industry sector in Nadiri's study indicated that an increase in highway capital reduced cost in all but three industry sectors. There is a fairly wide range in the magnitudes of the cost elasticities across industries. Why is this so? Nadiri speculated that industries with large negative cost elasticities were probably intensive users of the highway network while industries with small cost elasticities were less intensive users. (See page 39 of *Contribution of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries,* Nadiri and Manuneas, 1998.)

The goal of this research note is to test Nadiri's speculation through correlation analysis of the cost elasticities with respect to highway capital reported in Nadiri's latest study and the transportation intensity coefficients from TSA 1992.

Match Industry Classification of TSA 1992 with that in Nadiri's Study

The first step of our analysis was to match industry classifications used in TSA 1992 with the 35 industry sectors used in Nadiri's study. In TSA 1992, the industry classification is much finer, consisting of about 500 industry classifications. Hence, the natural choice to bring the industries in the two projects to a comparable basis is to aggregate the 500 industries in TSA 1992 into the 35 industries. Since industry classifications in both Nadiri's study and TSA 1992 were based on Standard Industry Classification (SIC) codes, the aggregation was relatively straightforward.

Table 1 presents the 35 industry classifications used by Professor Nadiri, their average cost elasticities with respect to highway capital for the period 1981–1991, and their corresponding aggregated transportation intensities from TSA 1992.

Table 1: Nadiri's Cost Elasticity Estimates and TSA's Transportation Intensity Estimates by Industry Sector

Industry	1981–1991 average CE to highway infrastructures	Total transportation intensity coefficient	HW transportation intensity coefficient	Logistic cost per $ output (Proxy A)	Logistic cost per $ output (Proxy B)	Total intermediate inputs per $ output
1 Agriculture, forestry, fishery	-0.054	0.080	0.069	0.173	0.159	0.637
2 Metal mining	0.013	0.060	0.051	0.118	0.108	0.626
3 Coal mining	-1.279	0.089	0.052	0.148	0.111	0.445
4 Crude petroleum and natural gas	-0.041	0.021	0.016	0.220	0.214	0.542
5 Non metallic mineral mining	0.002	0.102	0.094	0.156	0.148	0.457
6 Construction	-0.073	0.077	6.976	0.190	0.186	0.584
7 Food and kindred products	-0.063	0.038	0.027	0.101	0.090	0.702
8 Tobacco manufacture products	-0.013	0.009	0.006	0.128	0.125	0.360
9 Textile mill products	-0.029	0.028	0.020	0.076	0.068	0.663
10 Apparel and other textile products	-0.031	0.021	0.017	0.104	0.099	0.657
11 Lumber and wood products	-0.031	0.048	0.036	0.100	0.088	0.642
12 Furniture and fixtures	-0.018	0.051	0.045	0.118	0.111	0.571
13 Paper and allied products	-0.041	0.052	0.036	0.108	0.091	0.622
14 Printing and publishing	-0.045	0.029	0.021	0.130	0.122	0.458
15 Chemical and allied products	-0.052	0.036	0.022	0.144	0.130	0.582
16 Petroleum refining	-0.047	0.048	0.009	0.096	5.757	0.868
17 Rubber and plastic products	-0.043	0.048	0.035	0.117	0.104	0.607
18 Leather and leather products	0.008	0.037	0.033	0.111	0.107	0.641
19 Stone, clay, and glass products	-0.028	0.095	0.070	0.157	0.133	0.535
20 Primary metals	-0.048	0.056	0.036	0.115	0.095	0.695
21 Fabricated metal products	-0.041	0.028	0.021	0.094	0.087	0.582
22 Machinery, except electrical	-0.054	0.021	0.015	0.082	0.077	0.582
23 Electrical machinery	-0.050	0.016	0.010	0.084	0.079	0.539
24 Motor vehicles	-0.052	0.036	0.027	0.129	0.120	0.795
25 Other transportation equipment	-0.045	0.020	0.013	0.083	0.076	0.542
26 Instruments	-0.040	0.012	0.007	0.094	0.089	0.426
27 Miscellaneous manufacturing	-0.018	0.028	0.022	0.128	0.123	0.573
28 Transportation and warehousing	-0.061	0.111	0.004	0.241	0.150	0.435
29 Communication	-0.052	0.007	0.004	0.195	0.192	0.444
30 Electrical utility	-0.050	0.039	0.006	0.113	0.080	0.356
31 Gas utility	-0.036	0.012	0.003	0.064	0.055	0.761
32 Trade	-0.087	0.048	0.044	0.223	0.218	0.377
33 Finance, insurance, real estate	-0.082	0.007	0.005	0.228	0.226	0.296
34 Other services	-0.090	0.025	0.021	0.243	0.238	0.380
35 Government enterprises	-0.037	0.036	0.016	0.143	0.123	0.416

The cost elasticity with respect to highway capital in Nadiri's study was defined as follows:

$$\eta_{cs} = - (\partial C/\partial S) \times (S/C)$$

Where η_{cs} is the cost elasticity with respect to highway capital; C is an industry's total production cost and ∂C is the change in the total cost; and S is the total highway capital and ∂S is the change in highway capital.

The transportation intensity from TSA 1992 was defined as follows:

$$I_t = T/Q$$

Where I_t is the transportation intensity of an industry, or transportation cost per unit output; T is the transportation cost of the industry or the industry's use of transportation services; and Q is the output of the industry or the industry's production cost plus profit.

In Professor Nadiri's results, the industries with the largest cost elasticities during the 1980s, in a descending order, were as follows:

Industry Number	Industry Name	Cost Elasticity
34	Other services	-0.090
32	Trade	-0.087
33	Finance, insurance, real estate	-0.082
6	Construction	-0.073
7	Food and kindred products	-0.063
28	Transportation and warehousing	-0.061
1	Agriculture	-0.054
22	Machinery except for electrical	-0.054

The industries that had small cost elasticities were coal mining (3) (-0.013), tobacco manufacturing (8) (-0.013), furniture and fixture (12) (-0.018), and miscellaneous manufacturing (27) (-0.018).

Three industries that had counterintuitive signs for their cost elasticities were metal mining (2) (+0.013), nonmetallic mineral mining (5) (+0.002), and leather and leather products (18) (+0.008). But, Professor Nadiri notes that "much should not be made of this result. These are very small industries and the magnitudes of these elasticities are very small and probably not well estimated."

Using TSA 1992 information, two transportation intensity measures were calculated for this analysis: highway transportation intensity and total transportation intensity. Highway transportation intensity is the share of highway transportation cost in total output of each industry. Total transportation intensity is the share of the sum of all mode transportation costs (e.g., highway plus rail, air, water, and pipeline) to total output of each industry. Since highway transportation cost is part of total transportation cost, highway transportation intensity is always smaller than total transportation intensity. However, for most industries, the differences between the two are not large because highway transportation cost is the dominant portion of total transportation cost. Industries that are most highway transportation intensive, in descending order, are as follows:

Industry Number	Industry Name	Cost Elasticity
5	Nonmetallic mineral mining	0.094
6	Construction	0.073
19	Stone, clay, and glass products	0.070
1	Agriculture	0.069

The industries that were least highway transportation intensive are gas utility (31) (0.003), communication (29) (0.004), finance, insurance, and real estate (33) (0.005), electricity utility (30) (0.006), and tobacco manufacturing (8) (0.006).

Initial Hypothesis

Nadiri's estimates of cost elasticity with respect to highway capital are highly correlated with TSA's 1992 estimates of highway transportation intensity. An industry with large highway transportation intensity would be expected to have a large cost elasticity with respect to highway capital and industries with low highway transportation intensity would be expected to have a small cost elasticity.

The underlying rationale for this hypothesis is that an increase in highway capital contributes directly to productivity growth of highway transportation services, and higher productivity of highway transportation services reduces the cost of highway transportation. Other things being equal, industries with high transportation intensity would benefit more from a reduction in highway transportation cost than industries that use highway transportation less intensively.

Results of Testing the Initial Hypothesis

The first test we conducted was to calculate the correlation coefficient between the 35 industries' cost elasticities with respect to highway capital in Nadiri's study and the same industries' highway transportation intensities from TSA 1992. Since cost elasticity and highway transportation intensity have different signs, we would expect a large negative correlation coefficient if the initial hypothesis is true. The correlation coefficient resulting from our calculation was 0.269. This correlation coefficient was not only small, but also had a wrong sign. We were forced to accept the conclusion that there is no correlation between Nadiri's estimates of industry cost elasticities and industry's highway transportation intensity estimates from TSA 1992. This result is evident in the scatter plot presented in Figure 1.

A second test we conducted was to calculate the correlation coefficient between the 35 industries' cost elasticities with respect to highway capital in Nadiri's study and the same industries' total transportation intensities from TSA 1992. We suspected that highway transportation intensity of an industry might not be a good indicator of the marginal benefit of

Figure 1: Correlation Between Cost Elasticity and Highway Transportation Intensity Coefficient (0.269)

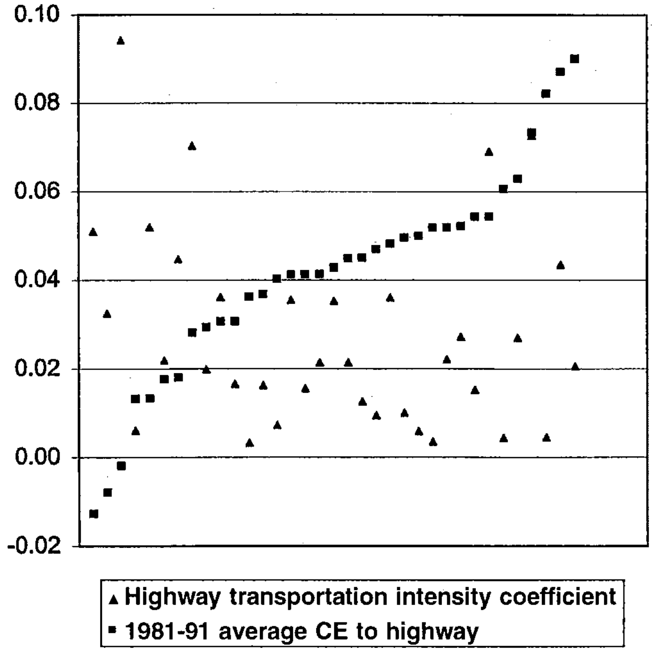
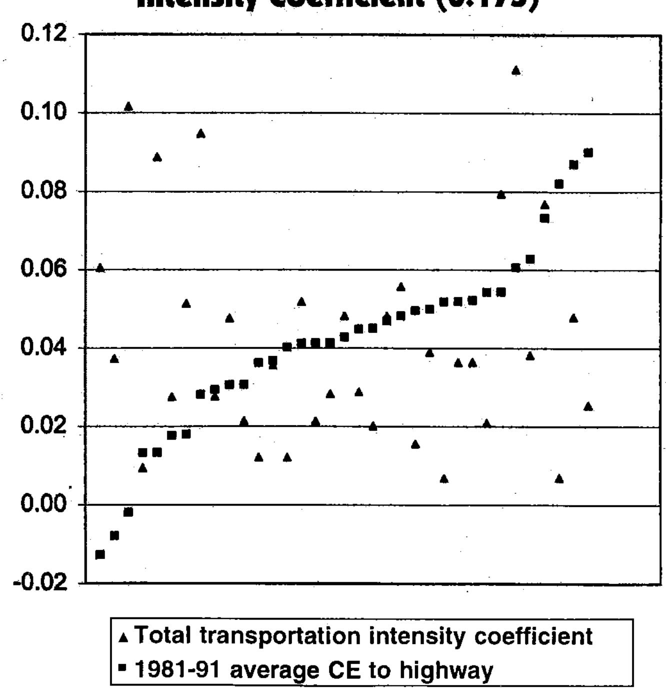


Figure 2: Correlation Between Cost Elasticity and Total Transportation Intensity Coefficient (0.173)



highway capital to that industry. The reason is that highway is only one of the transportation modes, and there is high substitutability between highway transportation and other modes, such as rail transportation and air transportation. An industry with a low highway transportation intensity might benefit greatly from highway investment and increased productivity of highway transportation services, because its total transportation intensity is high. The industry may substitute another mode with highway to fully take advantage of increased productivity in highway transportation. Hence, total transportation intensity might be a better indicator of marginal benefit of highway capital to an industry.

However, the result of our second test also showed no correlation between Nadiri's estimates of industry's cost elasticities and industry's total transportation intensity estimates from TSA 1992, either. The correlation coefficient between industry's cost elasticity and industry's total transportation intensity was very small (0.173) and not correctly signed. Figure 2 presents the result of the second test.

Modified Hypothesis

Cost elasticity with respect to highway capital is highly correlated with industry's logistic cost. Industry with high logistic cost would be expected to have large cost elasticities with respect to highway capital and industries with low logistic cost would be expected to have small cost elasticities.

The rejection of our initial hypothesis was against our intuition and led us to think deeper about the underlying mechanism through which highway capital affects industry production. The next idea we explored was that in addition to increasing the efficiency of highway transportation, and hence reducing transportation cost, highway capital benefits industry production by enabling businesses to organize their production in new and different ways. "Just-in-time" inventory practices are a good example of a mechanism through which highway capital benefits industry production in more ways than just reducing transportation cost. The "bottom line" interest of businesses to reduce total production cost and cost elasticities is in fact a measure of the change in total production cost (not just transportation cost). Therefore, more efficient transportation may actually increase rather than decrease the share of transportation cost in total production cost as business substitutes transportation for other production inputs. We asked, within an integrated production system, which subsystem will be affected most by changes in transportation? Our answer was the logistics system. Transportation is an important link of the logistic chain. Changes in transportation characteristics, such as speed, reliability, and flexibility, directly affect the way that business organizes components of the distribution system, which in turn affects total logistics costs. Therefore, the share of logistic cost in an industry's production cost might be better than the share of highway transportation cost as an indicator of the magnitude of potential benefits that the industry might receive from increases in highway capital.

To test the modified hypothesis, we constructed two logistic cost proxies using data from TSA 1992. In Proxy A, the total transportation intensity measure is augmented by the TSA cost coefficients for the finance, insurance, and real estates sector, the other services sector, and the government enterprise sector. In Proxy A, the highway transportation intensity measure is augmented by the TSA cost coefficients for the finance, insurance, and real estates sector, the other services sector, and the government enterprise sector. The reason for these augmentations is that cost coefficients for these three sectors capture the most logistics costs. The cost coefficient for the finance, insurance, and real estates sector includes the costs of motor vehicle insurance, commodity broker and insurance, real estate broker, and warehouse rents. The cost coefficient for the other services sector includes the costs of automotive rental and leasing, automotive repair shops and services, and automotive parking and car washing. The cost coefficient for the government enterprises sector includes the costs of postal services and government passenger transit.

Results of Testing the Modified Hypothesis

We again started our test by calculating the correlation coefficients. The correlation coefficient between the 35 industries' cost elasticity with respect to highway and logistic cost Proxy A was -0.46, while the correlation coefficient for Proxy B was -0.45. Not only did the absolute value of the correlation coefficients increased significantly, but, more importantly, the coefficients also were correctly signed. Since Professor Nadiri's cost elasticity estimates for metal mining (2), nonmetallic mining (5), and leather and leather products are admittedly questionable, they are considered as outliers. When these three industries were removed from the data set, the correlation coefficient for Proxy A increased to -0.55 and correlation coefficient for Proxy B increased to -0.57. The corresponding R^2 for the two coefficients are 0.31 and 0.32, respectively, indicating that about one-third of the variance in cost elasticity across industries reflects or can be explained by the variance in industries' logistic costs. These results are shown in Figure 3 and Figure 4.

The second step was to test whether the correlation coefficients would be statistically significant. We ran a simple regression analysis between cost elasticity and logistic cost proxies, which automatically generated F-test results about the correlation coefficients. The F value for the correlation coefficient of Proxy A was 13.2. And the F value for the correlation coefficient of Proxy B was 14.3. Both are about two times as large as the critical value (7.56) of F test with degrees of freedom of (1, 30) and significance level of 0.01. In other words, the F-test states that the modified hypothesis can be accepted with 99 percent confidence.

Figure 3:
Correlation Between Cost Elasticity and Logistic Cost Coefficient (Proxy A, -0.458)

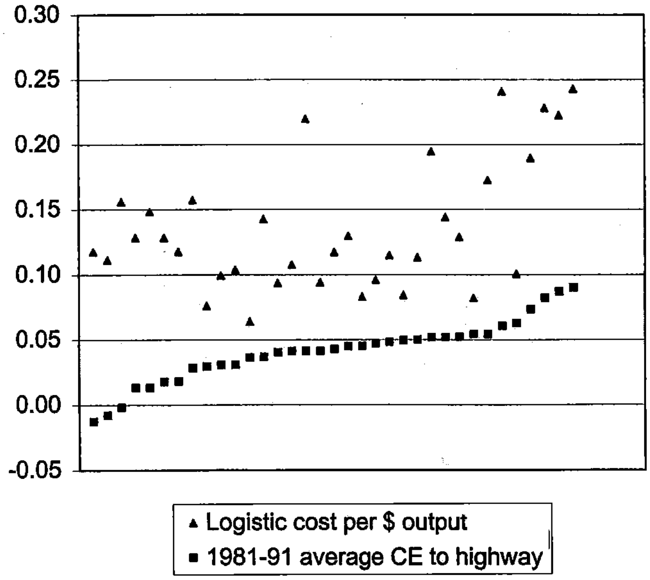
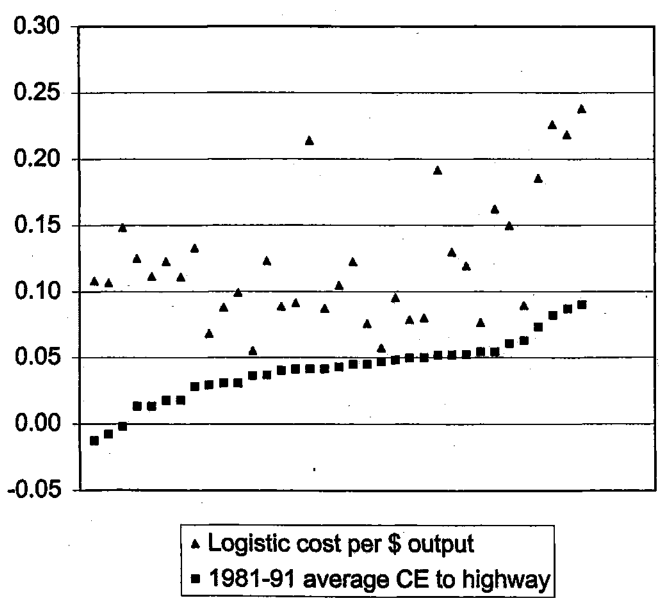


Figure 4:
Correlation Between Cost Elasticity and Logistic Cost Coefficient (Proxy B, -0.447)



Conclusion

1. Highway capital affects industry production in much broader ways than just reducing highway transportation cost. Faster, more flexible, and more reliable highway transportation enables industries to organize productions in new and different ways.
2. There is no correlation between Nadiri's estimates of industry cost elasticities with respect to highway capital and the transportation intensity coefficients (total or highway only) from TSA 1992. However, there is statistically significant correlation between cost elasticity with respect to highway capital and total logistic cost. These findings indicate that the share of logistics cost in an industry's production cost might be a better object of analysis than the share of highway transportation cost in future researches about the magnitude of potential benefits from increases in highway capital investment.

Table 2: Correlation Analysis of Cost Elasticity of Nadiri Study with Industry Transportation Intensity Coefficients of TSA 1992

Correlation	Cost Elasticity of Nadiri study	Cost Elasticity of Nadiri study**
All transportation intensity coefficient	0.17	0.01
Highway transportation intensity coefficient	0.27	0.02
Total intermediate input coefficient	0.20	0.21
Logistic cost coefficient (Proxy A)	-0.46	-0.55
Logistic cost coefficient (Proxy B)	-0.45	-0.57
Industry use of all transportation services	-0.66	-0.72
Industry use of highway transportation services	-0.62	-0.70

**Correlation coefficients were based on a modified data set in which three industries with positive signs for cost elasticity were removed. These three industries were metal mining, nonmetallic mining, and leather and leather products.

Table 3: Results of Statistical Significance Test

A. Regression of cost elasticity with logistic cost coefficient (proxy A)

Regression Statistics	
Multiple R	0.553
R Square	0.306
Adjusted R Square	0.282
Standard Error	0.016
Observations	32

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.00353	0.00353	13.20131	0.00103
Residual	30	0.00802	0.00027		
Total	31	0.01155			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.01760	0.00830	-2.12139	0.04226	-0.03455	-0.00066
X Variable 1	-0.20698	0.05697	-3.63336	0.00103	-0.32331	-0.09064

B. Regression of cost elasticity with logistic cost coefficient (proxy B)

Regression Statistics	
Multiple R	0.569
R Square	0.324
Adjusted R Square	0.301
Standard Error	0.016
Observations	32

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.00374	0.00374	14.34765	0.00068
Residual	30	0.00781	0.00026		
Total	31	0.01155			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.01939	0.00755	-2.56836	0.01544	-0.03480	-0.00397
X Variable 1	-0.21611	0.05705	-3.78783	0.00068	-0.33262	-0.09959

Appendix C: Productive Highway Capital Stocks

Barbara M. Fraumeni[†]

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Introduction

Capital stock information is an important component of economic studies examining the relationship between public infrastructure investments and private-sector performance. In order to determine the productivity of public infrastructure, more broadly all forms of public capital, an accurate measure of public capital is needed. A number of studies have examined the productivity of public infrastructure and use capital stock as a primary input, notably those of Aschauer (1989), Munnell (1990), and Nadiri and Mamuneas (1996). There are other studies whose primary focus is the estimation of highway or other types of transportation capital stock, notably those of Faucett and Scheppach (1974), Bell and McGuire (1994, 1997), Dalenberg and Eberts (1994). Unfortunately the capital stock imbedded or constructed in each of these studies and the majority of other studies suffer from at least one of three shortcomings.

A project recently undertaken for the Federal Highway Administration constructs a highway capital stock and describes the underlying concepts and methodologies (Fraumeni, 1999). The three major shortcomings of other studies are as follows:

1. The use of wealth instead of productive stocks
2. An implicit new construction or reconstruction assumption
3. An insufficient number of years from stock calculation starting point or the lack of a benchmark.

These concerns are briefly outlined in this paper.

Use of Wealth Instead of Productive Capital Stocks

Very few researchers are aware of the difference between productive and wealth capital stock. Productive capital stock is the stock which has been adjusted for the decline in the potential productive services of an asset as it ages. Wealth capital stock is the capital stock evaluated at its market value. Productive capital stock is clearly the relevant measure for analysis of productivity or the contribution of infrastructure to economic growth. Unfortunately, the majority of previous studies were contaminated by direct use of wealth capital stocks, use of assumptions from wealth capital stock studies, or controlling or benchmarking to wealth capital stock estimates.

Economists favor the light bulb example to explain the difference between the two types of stock. Assume a light bulb is capable of shining for 12 months. At any point in time over that 12 months, until the bulb stops shining, it is 100 % productive because the intensity of light is constant. However, if one sold the light bulb after 6 months of use, a rational buyer would only be willing to pay approximately half of the original purchase price. In stock measurement, at the 6 month point, the productive capital stock of the light bulb is about double the wealth capital stock.

Until recently, the Bureau of Economic Analysis published estimates of wealth capital stocks (BEA, 1993) which differed from the corresponding productive capital stocks. Wealth capital stocks are needed for the national income and product accounts, which are produced by BEA. Although BEA documentation warns users not to use wealth stocks for productive stocks, this warning apparently was overlooked or unheeded by most researchers.

[†]This paper represents views of the author and is not an official position of the Bureau of Economic Analysis or the Department of Commerce. The research described in this paper was conducted while the author was at Northeastern University.

For components of the stock for which the concepts differ, the Fraumeni productive stock is as much as 1.4 times the corresponding wealth capital stock.[1] For most assets, there is no longer a difference between BEA wealth stocks and the corresponding productive stocks (Fraumeni, 1997; Katz and Herman, 1997); however the Fraumeni FHWA study suggests changes in the BEA highway wealth stock methodology that would imply differing estimates for wealth and productive capital stocks.

Implicit New Construction or Reconstruction Assumption

The distribution of basic components capital outlays for newly constructed or reconstructed roads are clearly different from the distribution of basic components outlays for other types of capital outlays. For example, in the *1997 Cost Allocation Study*, rural other principal arterials capital outlay for grading as a percentage of outlays for pavement plus grading varied from 6.30% for resurfacing to 37.6% for new construction. The Faucett and Scheppach (1974) pavement, grading, and structure split undoubtedly reflects the distribution of basic components outlay for new construction or reconstruction. Approximately one-third of the studies surveyed in Fraumeni (1999) use Faucett and Scheppach (1974) distribution splits. In 1921, new construction and reconstruction was only 8.5% of total capital outlays on locally administered roads, in 1995 the corresponding figure is 10.4%.[2] The corresponding figure for state-administered roads, excluding Interstates, is 25.5% in 1921 and 31.2% in 1995. Accordingly, new construction and reconstruction splits are inappropriate for most capital outlays.

Number of Years from Calculation Starting Point or the Lack of a Benchmark

Some of the components of a highway have a very long service life, for example, commonly grading is assigned an 80-year service life and structures are assigned a 50-year life. Researchers frequently use the perpetual inventory method to calculate capital stocks without an initial year benchmark. The post-World War II stock estimates of only a few studies, notably those of Faucett and Scheppach (1974) and the Bureau of Economic Analysis (1993), are unaffected by this problem as their initial years are as early as the 1870s. Failing to benchmark estimates can significantly downward bias capital stock estimates in studies with an initial capital outlay year in the 20th century. The Fraumeni 1921 benchmarked estimates are 10 times larger than the comparable Bell and McGuire (1994, 1997) and Dalenberg and Eberts (1994) estimates in 1931, their initial year. Although between 1950 and 1960 the difference drops from 0.9 times to 0.08 times larger, the difference persists in the 1970s, 1980s, and 1990s, the Fraumeni estimates varying from 0.08 times to 0.25 times larger than the Bell and McGuire estimates. The danger of underestimation is particularly high for state or local estimates, as the time span for capital outlay series is typically fairly short.

Conclusion

Prior estimates of highway productivity or its contribution to economic growth may be incorrect because of problems in construction of the all-important capital stock input to these studies. The extent of the potential problem does vary by study. The Nadiri and Mamuneas (1996) capital stock estimates are the closest to the Fraumeni estimates of all estimates examined.

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[1]A light bulb's pattern of decline in efficiency or potential productive services is a polar case.

[2]In the case of Interstates, it is assumed that all capital outlays are for new construction or reconstruction from 1956 to 1975 and that all capital outlays beginning in 1976 are for other than new construction or reconstruction.

Appendix D: Participant Contact List

Susan Binder
Federal Highway Administration
400 7th Street, SW, Room 3422
Washington, DC 20590
Phone: (202) 366-9208

Gregory Bischak
Senior Economist
Appalachian Regional Commission
1666 Connecticut Avenue, NW
Washington, DC 20235
Phone: (202) 884-7790

Madeleine Bloom
Director
Office of Policy Development
Federal Highway Administration
400 7th Street, SW, Room 3317
Washington, DC 20590
Phone: (202) 366-0587

John L. Carr
Deputy SHE Intermodal Planning
Kentucky Department of Transportation
State Office Building
High & Clifton Streets
Frankfort, KY 40622
Phone: (502) 564-3730

John Collins
President
ITS America
400 Virginia Avenue, SW, Suite 800
Washington, DC 20024-2730
Phone: (202) 484-2890

Eugene Conti
Assistant Secretary
U.S. Department of Transportation
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-4454

Maryann Feldman
Center for Logistics and the Economy
The Johns Hopkins University
3400 N. Charles Street
Wyman Park Building, 5th Floor
Baltimore, MD 21218
Phone: (410) 516-7174

Barbara Fraumeni
Chief Economist
Bureau of Economic Analysis
1441 L Street, NW
Washington, DC 20230
Phone: (202) 606-9603

Miles Friedman
Executive Director
National Association of State
Development Agencies
750 First Street, NE, Suite 710
Washington, DC 20002
Phone: (202) 898-1302

Charlie Han
Bureau of Transportation Statistics
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-8927

Charles Hulten
University of Maryland
Tydings Hall, Room 3105
College Park, MD 20704
Phone: (301) 405-3549

Arthur Jacoby
Office of Policy Development, HPP-10
Federal Highway Administration
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-9248

Anthony R. Kane
Executive Director
Federal Highway Administration
400 Seventh Street, SW, HOA-3
Washington, DC 20590
Phone: (202) 366-2242

Ronald J. Kopicki
Principal Private Sector Development
Specialist
World Bank
1818 H Street, NW
Washington, DC 20433
Phone: (202) 473-6193

Rick Kowalewski
U.S. Department of Transportation
Office of Budget and Programs
400 7th Street, SW
Washington, DC 20590

Chris Kubik
Indiana Department of Transportation
100 North Senate Avenue
Indianapolis, IN 46204-2249
Phone: (317) 232-5640

Damian J. Kulash
President and Chief Executive Officer
Eno Transportation Foundation
One Farragut Square South, Suite 500
Washington, DC 20006-4003
Phone: (202) 879-4700

T.R. Lakshmanan
Executive Director
Center for Energy and Environmental Studies
675 Commonwealth Avenue
Boston, MA 02115
Phone: (617) 353-7551

Jim Lebenthal
Lebenthal and Company
120 Broadway
New York, NY 10271
Phone: (212) 748-5590

Dennis Lebo
Pennsylvania Department of Transportation
1200 Transportation and Safety Building
Commonwealth and Forster
Harrisburg, PA 17120
Phone: (717) 783-9776

Larry Magid
General Counsel
National Governors' Association
444 North Capitol Street, Suite 267
Washington, DC 20001
Phone: (202) 624-7822

James March
Federal Highway Administration
400 7th Street, SW, Room 3422
Washington, DC 20590
Phone: (202) 366-9237

Gary Maring
Federal Highway Administration
400 7th Street, SW, Room 3422
Washington, DC 20590
Phone: (202) 366-0180

David Marks
Federal Highway Administration
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-5022

Ron McCready
Senior Program Officer-NCHRP
Transportation Research Board
Cooperative Research Programs (Div D)
2101 Constitution Avenue, NW
Washington, DC 20418
Phone: (202) 334-3034

Richard Mudge
Hagler Bailly Services, Inc.
1530 Wilson Boulevard, Suite 300
Arlington, VA 22209-2406
Phone: (703) 351-0300

Terrence Mulcahy
Deputy Secretary
Wisconsin Department of Transportation
4802 Sheboygan Avenue
Madison, WI 53707
Phone: (608) 266-1114

Ishaq Nadiri
New York University
269 Mercer Street, 8th Floor
New York, NY 10003
Phone: (212) 998-8968

Clyde Pyers
Maryland Department of Transportation
P.O. Box 8755
Baltimore-Washington International Airport, MD 21240
Phone: (410) 545-0340

Edward Rastatter
National Industrial Transportation League
1700 North Moore Street, Suite 1900
Arlington, VA 22209-2406
Phone: (703) 524-5011

Edward Rosen
Eno Transportation Foundation
One Farragut Square South, Suite 500
Washington, DC 20006-4003
Phone: (202) 879-4700

Kyle E. Schilling
Director
Institute for Water Resources
7701 Telegraph Road
Alexandria, VA 22315-3868
Phone: (703) 428-8250

Ashish Sen
Director
Bureau of Transportation Statistics
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-1270

Chad Shirley
University of California at Berkeley
1174 Amherst Avenue, #306
Los Angeles, CA 90049

Walter L. Sutton, Jr.
Associate Administrator for Policy
Federal Highway Administration
400 7th Street, SW
Washington, DC 20590
Phone: (202) 366-0585

James T. Taylor
Managing Director
Bear, Stearns & Co., Inc.
Public Finance Department
245 Park Avenue, 10th Floor
New York, NY 10167
Phone: (212) 272-3482

George I. Treyz
President
Regional Economic Models, Inc.
306 Lincoln Avenue
Amherst, MA 01002
Phone: (413) 549-1169

Curtis A. Wiley
Commissioner
Indiana Department of Transportation
100 North Senate Avenue
Indianapolis, IN 46204-2249
Phone: (317) 232-5526

Eno Transportation Foundation

One Farragut Square South
Washington, DC
20006-4003
phone: 202-879-4700
Fax: 202-879-4719
www.enotrans.com