Economic Returns from Transportation Investment

Eno Transportation Foundation, Inc.

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Table of Contents

Preface

From the time of the nation's first transportation plan — the Gallatin Report at the beginning of the nineteenth century — U.S. political leaders have recognized the developmental and economic benefit of investment in transportation. As different ports competed to be the supplier of the original colonies, as different routes competed to be the gateway to the west, as the first national system of post roads was designated, and as the Interstate Highway System was designed, states and regions have competed for access. Transportation facilities are more than magnets that draw growth to one point instead of another: they also create economic growth that is shared by the nation as a whole.

This national economic benefit has been measured in a recent study by M. Ishaq Nadiri, an economist at New York University. He found that there is a strong relationship between the capital stock of highways and the net social rate of return. During the 1950s and the 1960s, the net social rate of return of the nation's highway network was very high, while in the 1970s and 1980s the returns on highway investment were lower – roughly the same as that realized on private capital in those decades. What led to the extremely high returns in the 1950-1970 period, and what future public investments in transportation infrastructure might have similarly massive impacts? Can public policy be targeted to produce such high returns in the future, and continue to benefit the nation's economic health, its international competitiveness, and its quality of life?

The Eno Foundation held a public policy forum on July 23, 1996 to explore these important questions. Leaders in government and industry, specialists on economic development, investment analysts, and other experts came together to examine recent research on this subject, to discuss its possible policy implications, and to identify ways to make such analysis more useful to policy makers.

We are deeply indebted to all the thoughtful leaders, listed at the start of this report, who contributed to these discussions. We are especially thankful to Professor M. Ishaq Nadiri for his stimulating analysis and his willingness to defend this work before a diverse community of interested professionals; to Professor Jose A. Gomez-Ibanez who chaired the forum; to Jeffrey Madrick, who prepared the forum report; and to Jennifer Clinger, who organized the forum and oversaw all the arrangements. We are also grateful to the Federal Highway Administration, the National Cooperative Highway Research Program, and the American Association of State Highway and Transportation Officials for their financial and professional support. Thanks are also due to the forum participants who reviewed the draft report and made useful corrections.

The message that came through loud and clear at the forum is that the economic impacts of transportation are important, and that new findings bearing on them deserves serious attention. The Eno Foundation is pleased that the insights contributed by participants at our forum are now publicly available, and that this report will help to give the economic consequences of transportation the consideration that they deserve.

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Summary

Economic productivity is key to maintaining the nation's global competitiveness and a rising standard of living. However, productivity, along with overall economic growth, has slowed considerably in the U.S. since the 1970s. Investments in transportation infrastructure benefit economic productivity by allowing more efficient processes, economies of scale, changes in distribution or logistics patterns, and reduced costs. Although the impacts of the system surround us, few attempts have been made to estimate the overall, program-wide economic benefits of public investments in transportation facilities.

Recently, Dr. Ishaq Nadiri, an economist at New York University, has found that there has indeed been a significant positive rate of return from public investment in highways in the United States in recent decades, although the magnitude of this return tapered off in the 1980s. As the nation prepares to design highway legislation for the next five years, the implications of this most recent work on economic returns could have major implications.

The Eno Transportation Foundation convened a public policy forum to discuss the economic return on transportation investment. About 35 people with varied perspectives on this issue attended this day-long discussion on July 23, 1996.

The Federal Highway Administrator, Rodney Slater, opened the forum by saying that the FHWA has made fostering productivity growth through investment in highways one of its primary goals. He emphasized the importance of high-quality economic research to find the linkage between highway investments and economic performance.

Professor Nadiri described that there has indeed been a significant positive rate of return from public investment in highways in the United States in recent decades, although the magnitude of this return has tapered off in later decades. During the 1950s and 1960s, the social return on those investments – the total return to business less depreciation — far exceeded those earned on private capital. During the 1980s, these returns were roughly equivalent to the rate of return earned on private capital investment over the same period. Investment in national systems in particular, which usually involve larger networks of roads and highways than local projects, had a higher rate of return than private capital over this period.

The high rates of return in earlier years and their rapid decline in subsequent years were largely the result of at least three factors. First, in the 1950s and 1960s, transportation demand was strong as the American economy expanded rapidly. The investments in the Interstate Highway System naturally produced high returns because the rapid growth in the post-war economy required an expansion in infrastructure to accommodate it. Second, unlike for private capital, the benefits of public investment in transportation were shared by many industries. Third, as initial needs were met and the highway system matured, it was only natural that subsequent investments produced lower rates of return. Nevertheless, recent returns, although lower, are positive and significant.

Nadiri also concluded that investment in highway capital made a significant positive contribution to the economy's rate of productivity growth. But the declining rate of growth in highway capital made only a minor contribution to the slow rate of growth in economic productivity in the 1980s. This refuted the conclusions of earlier studies which showed that there was a dramatically higher contribution to productivity from infrastructure investment than from private capital investment.

While existing studies generally report a positive contribution from infrastructure investment, there is a wide variety of results. Rates of return on public infrastructure investment clearly vary significantly over time, place, and according to the economic context of the region or nation in which the investment is made. Future research should be directed towards determining which kinds of infrastructure investment will make the largest contributions to aggregate and sector productivity growth.

An overriding issue is how to continue to make significant investments in transportation infrastructure in an era of scarce public resources. The use of public-private partnerships may be able to make up for shortfalls in new capacity in the federal, state and local transportation programs. Innovative financing methods involving both public and private sectors may also be effective in a time of more limited public resources.

In general, forum participants agreed that a public awareness must be created for thinking about how infrastructure investment can promote the growth of the nation's productivity. These impacts are significant and of a national, not local, character. They should be at the center of the debate, yet public policy discourse does not yet take into account these far reaching impacts. Participants urged policy makers to apply the results of new economic research to their decision-making processes and to develop new ways to present the case to legislators and to the public that infrastructure investment can improve productivity and economic growth.

While the results of the new research analysis are powerful and promising, it would be self-defeating to exaggerate the new research findings. The new research has corrected many of the flaws of earlier studies, but its results need to be presented cautiously and understandably.

Professor Jose Gomez-Ibanez, Chairman of the forum, summarized the main points of the forum as follows:

First, the Nadiri research shows that there have been significant returns to public highway investment. While these returns have declined over time, they are still significant. They are the equivalent of returns to private capital.

Second, these returns vary significantly, and we do not always understand why this is so. They vary over time. In the 1950s and 1960s, the interstate highways replaced the open-access roads that came before them, which may explain much of the decline in returns. But they also vary according to place. Additional highway investment may be useful in some regions or areas and not in others.

Returns can also appear to vary according to where in the overall sequence they are made. The first roads or highways in a region appear to generate higher returns than subsequent ones.

Returns can also vary depending on the institutional context. If trucking in a nation is a monopoly, the benefits of infrastructure investment will accrue to truckers rather than the economy as a whole. So, for the potential returns of transportation to be fully realized, the context must permit the interacting institutions to exploit new efficiencies.

Infrastructure investments can produce sizable returns, but only if they are the right investments at the right time — investments that create growing room. The fact that policy makers appear to have selected such investment in the 1950s and 1960s does not tell us much about what the best opportunities are today.

Third, we may never know the full effects of highway investment on productivity. This is not merely because our statistical tools are not perfect. New infrastructure creates a context for further innovation that cannot usually be predicted. People are enabled by the new infrastructure to create different ways of doing things that are subtle and have long lead times. They are the sorts of things that can never really be traced out beforehand—or sometimes even after the fact. For example, we still have difficulty disentangling the effects the railroads had on 19th century America.

Finally, how can the new research be used? To be valuable to policy makers it must be phrased in plain English and must not exaggerate findings, which would undermine their credibility. It must also communicate a vision or story that is credible, specific, and moves beyond the abstraction inherent in measures like the rate of return. Such a vision may be more complex and harder to communicate than the case made to justify the interstate highway system in the 1950s. Nevertheless, the public may be prepared for a more sophisticated vision than they were a generation or two ago.

Background and Introduction

A national debate is gathering momentum over whether the U.S. economy can grow faster than it has over the past two decades. During the 1970s and 1980s, the economy's rate of growth slowed dramatically from its historical average. Between 1870 and the early 1970s, the best data show that the American economy grew at an average rate of nearly 3.5% a year. Since 1973, the economy has grown at only 2.4% a year.

Whether the nation is better off in the future depends on whether the rate of growth of productivity can be raised. Productivity is the main source of economic growth and a rising standard of living. Its growth has slowed even more dramatically over the past two decades than did overall growth. Labor productivity — the output of goods and service per hour of work — grew at a rate of more than 2% a year since just after the Civil War. Since 1973, it has managed to grow at only 1% a year. Total factor productivity—the output per unit of labor and capital—has slowed down to a similar degree.

Had productivity grown at its long-term rate since 1973, another $13 trillion in national income would have been produced by the economy. As a consequence, tax revenues would have risen so much that there would be no federal deficit today. In fact, at current levels of federal spending, there would be a substantial budget surplus.

Investments in infrastructure, particularly transportation projects, may have significant impacts upon economic productivity. Governments make investments in transportation facilities to support development, to spur economic growth, to alleviate existing deficiencies, or to increase public convenience. In the 19th century, the large positive economic value derived from investments in transportation systems was taken to be self-evident, and major investments in roads, railroads, and canals were made on this basis. As the U.S. developed, transportation investments were used to transform the economic environment profoundly. Similarly, historians attribute the Industrial Revolution to various transportation investments that preceded it. Today, developing nations view transportation investments as key ingredients for economic development and growth.

No one living in contemporary America can overlook the profound changes brought about by the Interstate Highway System on where people live, work, and shop. It has expanded the

Rodney Slater discusses the rates of return from transportation investments range over which goods can be marketed, has created opportunities for economies of scale and for increased specialization, and has brought the efficiencies of just-in-time inventory systems to businesses across the land. Although the impacts of the system surround us, few attempts have been made to estimate the overall, program-wide economic value of public investments in transportation facilities.

Because of the importance of productivity growth to the economy, and in anticipation of the reauthorization of the nation's surface transportation programs next year, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO), through the National Cooperative Highway Research Program (NCHRP), asked the Eno Transportation Foundation to call a conference of transportation experts and policy makers from the public and private sectors and academia to discuss whether transportation infrastructure investment can play a critical part in improving America's productivity.

In the 1950s, the rate of growth of highway capital surged. After declining slightly in 1950 and 1951, the capital stock grew at an annual rate of 6.2% until 1959. But beginning in the 1960s and on through the 1970s, the rate of growth slowed continuously. Since 1982, highway capital stock has been growing at an average rate of 1.2% a year.

This increased rate of growth has not kept pace with the increase in demand for highway transportation. The slow rate of investment has contributed to increased congestion and poor maintenance. It has also resulted in fewer large-scale transportation projects, and required proportionately more funding from state and local levels of government for transportation improvements.

But has the lower rate of investment in transportation infrastructure since the 1950s contributed significantly to the general slowdown in productivity growth? Can raising the rate of investment in transportation infrastructure enhance overall productivity for the entire nation? The Eno policy forum addressed these fundamental questions.

The starting place for this discussion was a new econometric study by M. Ishaq Nadiri of New York University and the National Bureau of Economic Research and Theofanis P. Mamuneas of the University of Cyprus. It is a comprehensive analysis of how investment in highway infrastructure affects the nation's output, the commercial sector's costs of doing business, and private

(L to R) Jose Gomez-Ibanez of Harvard University, Beth Pinkston of the Congressional Budget Office, and Theresa Smith of FHWA

sector productivity in general. The expert participants agreed that the Nadiri model had corrected the most important flaws of earlier studies on this subject. The general consensus, among both skeptics and supporters of this type of analysis, was that Nadiri's analysis was one of the most comprehensive pieces of work that has been done in the infrastructure area in the last ten years, which is when the main growth of literature has occurred.

Approximately thirty-five professionals from academia and the private and public sectors participated in the forum, including top government officials, academic leaders, and industry executives. There were three general areas of discussion. The first concerned Professor Nadiri's model, and an interpretation of its results. The second concerned the policy implications of new research, and ensuring that investments in highway infrastructure are targeted to have the maximum net benefits. The third area of discussion concerned how to frame public policy issues in light of the new research, as well as how to make the public understand potential contribution to the economy's productivity of infrastructure investment.

The Need for this Forum

Federal Highway Administration (FHWA) Administrator Rodney Slater introduced the topic of the forum by observing that FHWA has traditionally focused its attention on the direct benefits to travelers and commuters of better, faster, safer roads and highways as well as the employment generated by construction and maintenance. But now, FHWA is intensifying its focus on a third area: the benefits that infrastructure investment has for industry, business and the economy in general.

"Until recently, discussions about the relationship between public capital, and economic performance were based on evidence that was largely descriptive in nature," Slater said. However, descriptive and anecdotal evidence is not sufficient to support public investment decisions that have significant social, environmental, and economic impacts. In a fiscally stringent time when every federal expenditure requires justification, he said, "the objective here is to gain the evidence we need, and to carry forth the strong message."

Slater explained that this was why the FHWA funded the Nadiri study. Now that it is completed, the discussion needs to focus on three questions: "What do these findings mean? How are industries affected by what we discover? And what are the implications for future transportation policy?"

Administrator Slater said that he was ready to use well-done research to make the case for infrastructure investment if it is justified. "If truth was self-evident, there would be no need for eloquence," he said. The job, Slater concluded, is, "to create a story that people can understand, buy into, and give themselves to, much as we have given ourselves to creating a rail system, an aviation system, a highway system, and all of the transit facilities that exist around this country. Many people would like to rest on those accomplishments. Well, we are gathered here today to examine the question of why we cannot rest on those accomplishments."

New Research on the Economic Returns from Transportation Investment

Professor M. Ishaq Nadiri, the Jay Gould Professor of Economics at New York University and a member of the National Bureau of Economic Research, explained that his research in how infrastructure investment affects economic output was initiated by several well-known studies in the late 1980s that concluded that infrastructure investment had a dramatic impact on the rate of economic growth. These original studies were done, most notably by Professor David Aschauer, now of Bates College, and later by Alicia Munnel of the Boston Federal Reserve Bank (now on the Council of Economic Advisers). Before Aschauer, Nadiri noted, many applied economists had not estimated how public investments affect the nation's productive capacity. They focused almost exclusively on how private-sector decisions with respect to output, employment, and capital accumulation contributed to economic productivity growth.

The methodology of these first studies was widely challenged by the academic community and the conclusions were severely scaled back. An extensive list of new research then followed. If criticized, however, the Aschauer and Munnel work did serve as a challenging beginning.

Aschauer's model rested on a form of economic analysis known as a production function. It assumes that the output of the economy (Gross Domestic Product) is a function of the total sup-

Rodney Slater of FHWA

"We know the relationship between highway infrastructure investment and economic performance is of pivotal importance to the nation as a whole" - Rodney Slater

ply of labor hours and available private capital stock as well as the rate of technological progress. In trying to measure the impact of infrastructure capital, a production function can be expanded to include the supply of infrastructure investment as a variable as well. If the relationship between changes in infrastructure investment and the economy's output is close, one possible interpretation is that infrastructure investment is an important determinant of economic output.

The main criticism of this methodology is that even though there may be a close relationship between the rate of infrastructure investment and the economy's output, this does not necessarily imply a causal relationship between the two. There can be many other reasons why the rate of change in infrastructure investment and the economy's output would rise and fall simultaneously. When other academic researchers factored out the possible simultaneity and "auto-correlations," which are especially significant when comparing investment and growth, they concluded that infrastructure investment had a much smaller impact on the economy's output than Aschauer initially maintained.

To avoid such ambiguities, Professor Nadiri took a different approach to the issue that bypasses the problems usually associated with production function studies (refer to Appendix A for the complete study). His analysis did not use generalized production functions to represent the economy. Rather, it used a series of cost functions for all the individual industries that make up the economy (there are 35 industry categories in the model). This determines how the costs of doing business are affected by many factors, one of which is the stock of public infrastructure capital. In the case of this model, highway capital is used. In general, this econometric research attempts to take account of all the major factors that might potentially affect productivity growth. It then isolates the contribution made by investment in highways, covering the years of 1950 to 1989.

What are cost functions? The costs of an industry are a function of several key factors, including the cost of capital and labor, the prices of raw materials and other inputs, the level of the industry's output, and the stock of infrastructure capital. Nadiri's analysis also included the rate of technical change and capacity utilization rates. As each of these elements change, so do the costs of production for an individual industry.

But to avoid spurious correlations, the factors that affect costs are not simply taken as constants. Just as it occurs in the real world, a change in one variable in the model will affect the other variables in the equation. For example, if capital stock goes up, there may be less need for labor. The share of labor and its cost will therefore carry less weight in the cost function. Nadiri adjusted for these interrelated changes among all the key factors that affect an industry's costs. In the language of economists, cost factors are arrived at endogenously rather than exogenously.

The Nadiri research also estimated independently a demand function for each industry, allowing for likely changes in the demand for the output and productivity of a particular industry. If the output of an industry changes, its costs will also change.

A complex series of regression equations were also run in several stages to arrive at a final relationship between the factors that determine supply and demand. Output and cost elasticities with respect to highway infrastructure capital were calculated for each industry. Elasticity is defined as the amount that output would rise or costs fall for each percent increase in the nation's highway capital stock. The analysis also calculated rates of returns for total highway investment by relating cost reduction benefits to the opportunity costs of public roads. These were then aggregated to arrive at results for the entire economy, which is called the social rate of return. These results were checked against a model for the entire economy as well.

The analysis also broke down the components of the nation's productivity growth so that the contribution made by highway capital could be compared to the contribution made by other factors. Total factor productivity (TFP) is the output of the economy per factor of input—specifically, per hour of work and dollar of capital. The model decomposed TFP growth into four basic determinants. One is exogenous demand for goods and services, which is a function of changes in population and aggregate income on the demand side. A second is the change in relative prices of such key inputs for an industry as raw materials and intermediate products. A third is autonomous technological change, a residual number that includes things that economists usually can't specify. The fourth is, the level of the highway capital stock. The analysis shows the degree to which each of these factors contributes to the nation's productivity growth.

Professor Nadiri points out that his analysis is "a work in progress." As we shall see, there are still certain inconsistencies in results that require explanations. And there is the underlying question that all statistical studies utilizing even the most rigorous regression analysis raises: even when a relationship is found between infrastructure investment and productivity, we cannot be certain based on such techniques alone whether more investment has caused productivity to rise or whether rising demand in the economy has raised the returns on such investments.

Nevertheless, the Nadiri analysis is one of the most comprehensive econometric studies of its kind. As noted, the study circumvents many of the

Annual Rate of Return By Type of Investment

	1950-89	1950-59	1960-69	1970-79	1980-89
Total Highway Capital	28%	35%	35%	16%	10%
Non-Local Highway Capital	34%	48%	47%	24%	16%
Private Capital	13%	13%	14%	12%	11%

problems with former studies, including spurious correlations. It has made key variables endogenous rather than exogenous—that is, rather than being constant, key variables are allowed to change as they are affected by other changes in other variables. This better reflects the real world than do many models based on production functions.

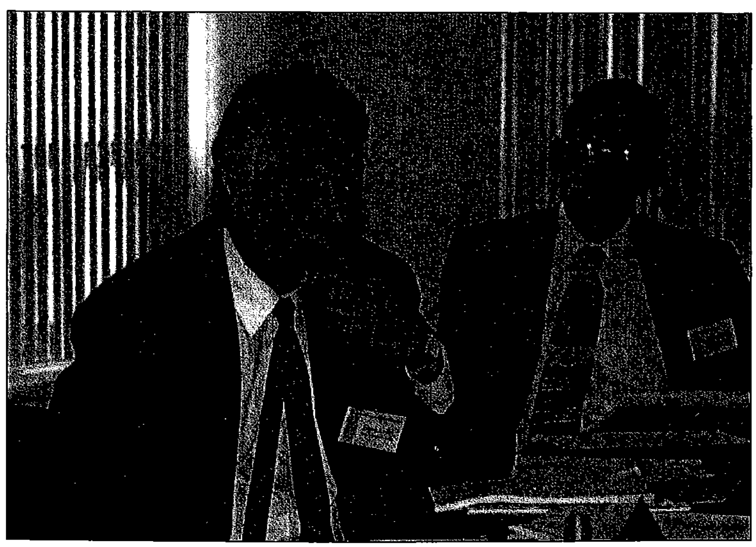
The study's conclusions are also subject to a variety of checks. The study aggregated both the demand and supply sides of his industries to be sure they tally. Bottom-up industry aggregates were compared to an economy-wide model, and they were also in accord. Statistical tests were made to avoid basic errors about spurious correlations.

The social rates of return on public investments in highway capital were positive and significant throughout the 1950s to the 1980s. In the 1980s, these returns were competitive with returns on private capital. Both the returns on highway capital and private capital averaged 10% a year in the 1980s (see the table below). This suggests that public highway investment in all classes of roads should at least be increased at the same rate as total private capital investment.

The rate of return on highway investment in the 1950s and 1960s was much higher than in the 1980s, averaging about 35% a year, much higher than the return on private capital, which averaged about 14% a year in this period. The average rate of return on highway capital over the entire forty-year period was 28%.

Nadiri also estimated the effects of highway capital invested in non-local roads. These larger systems of interconnected higher-order roads make up the network that essentially serves commercial interests. Such investments may presumably contribute more to productivity because their benefits are shared by so many users over a wide geographical area. These may be an example of

"The social rates of return on public investments in highway capital were significant. In the 1980's they were competitive with returns on private capital."



(L to R) Ishaq Nadiri of New York University and Damian Kulash of The Eno Transportation Foundation

network effects. The return on this capital, called non-local highway capital, was significantly higher than it was on total highway capital or on total private capital. Even during the 1980s, it averaged 16% a year.

Of the four factors that determine the nation's total factor productivity, the most important by a significant margin was exogenous demand for goods and services. It accounted for more than half the change in total factor productivity. Highway investment is the second most important contributor to productivity of the four, ranking well ahead of either changes in factor prices or autonomous technological change as a determinant of TFP. It is noteworthy that when TFP was growing fastest, between 1952 and 1973, infrastructure investment accounted for a larger portion of the gain than when TFP growth slowed between 1973 and 1989. Some interpret this as a suggestion, which still needs further corroboration, that large infrastructure programs resulting in added capacity may have contributed more to economic growth and productivity than highway programs focused on preservation and maintenance. Alternatively, the differential in TFP contribution over time implies a synergistic effect between public policy decisions and the general economic condition.

Nadiri also examined the elasticity of highway investments, but did not reproduce the stunning results arrived at by earlier economists. For every additional dollar of infrastructure capital stock, the output of the economy (in terms of physical goods and services) rises by five percent (output elasticity = 0.051). The costs of doing business (cost elasticity) fall by about four percent in response to a 1% increase in highway capital stock (cost elasticity = -0.044). These elasticities are significant, but they are only about one-eighth of the elasticities previous studies estimated.

An important conclusion of the study is that an increase in infrastructure investment reduces costs in almost all manufacturing industries and in many service industries. In some industries, however, costs are raised, though only slightly. This apparent inconsistency provoked considerable discussion among the participants, as is amplified later in the report. Nadiri and most of the forum participants agreed that this is an area where further research should be targeted.

While the direct local and regional

Contributions of Highway Capital and Other Factors to Productivity

	Annual Growth Rates				
	1952-89	**1952-1963**	**1964-72**	**1973-79**	**1980-89**
Total Factor Productivity	.68 %	.94 %	1.03 %	.13 %	.42 %
Exogenous Demand	.60	.30	.60	.75	.84
Highway Capital	.17	.30	.26	.03	.03
Price Changes	-.06	-.06	-.10	-1.70	.07

benefits of highway investments are immediately recognized, investments in a network of facilities may produce productivity gains to entire industries nationwide. Are there efficiencies and productivity gains that result from the fact that resources are pooled by the government to build a broad, flexible system of roads and highways that serves many users simultaneously? Nadiri's work suggests that they do.

What would happen to costs of production if the private sector undertook its own infrastructure investment? Nadiri's analysis created a counter-factual situation in which each industry is responsible for building its own roads, bridges, and highways. For most industries, the returns on such investment would have been negative. Therefore, most industries would not have built the infrastructure. Based on this counter-factual evidence, the system of infrastructure as it currently exists would simply not have been developed.

Since the large majority of industries benefited from the infrastructure system built by government, most industries would have lost the advantages of such a system had it been left to themselves to build one. Without government investment, these network benefits would have been lost.

The forum participants generally applauded the new research. But there were concerns. While Naidiri's analysis accounted for network effects, it did not reflect the possibility that some network benefits can subside over time. Early in the development of a highway system, the second highway in a region usually makes the first highway more valuable by efficiently feeding it traffic from a wider geographical area. In this early stage, highway investment is usually complementary and highly beneficial. But as new transportation investment is made, new roads and highways eventually become substitutes for rather than complements to existing roads and highways. The benefits of new investment naturally diminish. So, while infrastructure investment may well be a public good with significant network benefits, these benefits may diminish rapidly over time. When making new infrastructure investments, such dynamic network effects must be taken into account.

One of the more technical concerns was that infrastructure investment appeared to have no positive impact on the transportation industry itself. If any industry benefits directly from such investment, it should be the transportation industry. Yet the model showed that infrastructure investment raised costs in this industry, if only slightly. The seem-

(L to R) Ishaq Nadiri of New York University and Jose Gomez-Ibanez of Harvard University

ing inconsistency had to be explained, though analytic experts pointed out that such complex models often have some inconsistencies; indeed seasoned analysts feel if there are no such problems, they would question whether the analysis is intricate enough. Nevertheless, such inconsistencies may suggest there are inaccuracies in the model.

In fact, infrastructure investment has a negative impact on service industries in general, according to the Nadiri model. This is counter-intuitive, although there may be several technical explanations for this result. One explanation is that the model is based on average slope variables for classes of industries. The actual production functions of each individual industry may often differ from this dummy variable.

In some cases these negative impacts may be sensible. For example, some kinds of services might suffer if transportation was improved. This is because in service industries, the impacts of transportation costs fall on the customer rather than the business itself, unlike in a manufacturing industry. In addition, some industries do not utilize transportation infrastructure as intensely as others, although this does not mean that they do not benefit from highways at all. For the most part, the negative effects for service industries found by the model are small.

Another technical concern was that highway capital was not broken down according to its quality or the changing nature of the investment over the course of nearly forty years. For example, facilities built during the 1950s and 1960s were built using specifications that would be considered deficient by today's standards, such as standard lane widths, slope gradients, and curve radii. These standards impact the total capacity of a facility, especially as it reaches congested levels. If highway capital could be decomposed according to the types of project or by quality, it could provide more useful information.

In general, the historical patterns of the rates of return – high in the 1950s and 1960s, and lower but equivalent to private capital returns in the 1980s — suggest that the types and categories of investments undertaken may be crucial. In the first twenty years covered by Nadiri's analysis, the nation was making major expansions in the highway network. The question is whether the nation can find similarly productive investments in terms of capacity additions in the future.

Professor Nadiri agreed that a careful assessment of future infrastructure needs is essential. But he concluded that, because the rates of return on infrastructure and private capital were similar, the stock of public investment in infrastructure should at least keep pace with the accumulation of private capital in order to achieve balanced growth.

Methodological Issues

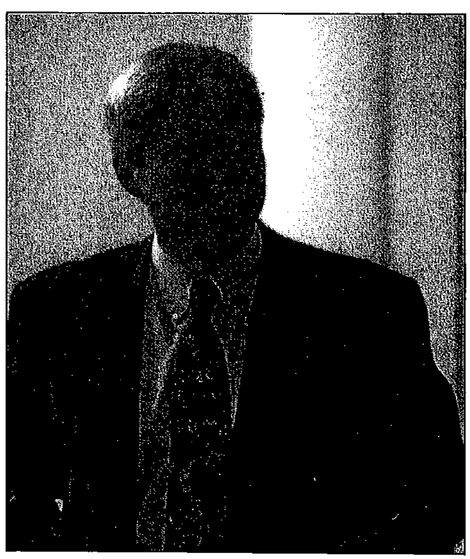
Dr. Randall Eberts, who has long done economic research in this field, pointed out that earlier studies he had completed based on local rather than national data were consistent with the findings of the Nadiri study. In general, he found an elasticity of 0.03.

Dr. Eberts said that we need more research to find out "what is in the black box." In other words, we need to know how improved infrastructure is specifically translated into higher productivity for firms. Infrastructure investment in general must make business inputs more productive. For example, companies should be able to get their workers to the workplace more quickly. Better infrastructure should allow them to draw from a larger labor pool. Inventory can be transported more quickly and inexpensively as well. Improved infrastructure also attracts more companies because, he said, highway infrastructure is probably the number one attraction in the minds of local economic developers. It should also be kept in mind that infrastructure investment is a direct stimulus to growth for most regions. Most of the funding usually comes from outside the community.

Companies orient themselves spatially to the infrastructure that exists. It takes about ten years for a metropolitan area to adjust fully to a large infrastructure investment. There is evidence that high levels of public capital can raise productivity locally through economies of scale due to agglomeration, through higher land prices, and the ability to pay higher wages.

Research on whether infrastructure investment leads or lags economic growth has shown diverse results. One study found that economic growth in the southern U.S. would have occurred anyway even without infrastructure investment. That is, in the south, infrastructure investment may have followed growth. In northern states, however, it appeared to be the other way around. Infrastructure investment was more influential in raising the rate of growth. Eberts also found a correlation between infrastructure investment and openings and expansions of business. Such in-

"We need more research to find out what is in the black box"
- Randall Eberts



Randall Eberts of the Upjohn Institute frastructure investment also seems to slow down the pace of business closings.

Professor Charles Hulten warned about making broad conclusions based on what he calls "uncut econometrics." The new statistical analyses produce an average constant relationship between infrastructure investment and productivity. But there is no reason to think that the average relationship is actually constant. In actuality, the relationship can vary across geographical regions, over time, and in different segments of the economy. Depending on all these criteria, infrastructure investment can produce high or low rates of return.

Dr. Hulten said that more research must be done in these areas. He suggested that public policy analysts and economic researchers should take into account three different mechanisms for determining how public investment may specifically affect productivity. The first is location theory. Why do companies locate where they do? Reduced transportation costs is one reason. There are also economies of scale and scope that accrue due to agglomeration. But this might be offset if a company's demand is spread over a large area. It will make sense to disperse locations under such circumstances. The rate of return on infrastructure investment may depend on the interaction of these three factors.

A second consideration is that infrastructure investments are long-lived and ultimately serve users well into the future. In other words, capacity being built today is partly being banked for the future. Any correlation with contemporaneous growth is therefore questionable because much of the capital is not expected to be consumed until the future. Isolating such time-dependent effects will require more research. Also, it must be kept in mind that public and private investments may have different useful lives. This timing difference should be factored when comparing rates of return between the two.

The third consideration is how the network effect works. It is difficult to assess these effects. The same amount

Forum Chairman Jose Gomez-Ibanez of Harvard University

"Professor Nadiri appears to have solved the essential problem associated with production function studies"

- Jose Gomez-Ibanez

of capital devoted to two different locations may well result in vibrant network effects in one area and almost none in another. Early on in the development of such a system, as noted earlier, the network effect may provide large returns on investment as new roads make existing roads even more valuable. But there will often come a point when capital merely involves a substitution of new or different roads for older ones. At this point, returns can fall dramatically or even turn negative.

Professor Jose Gomez-Ibanez noted that Professor Nadiri appeared to have solved the essential problem associated with production-function studies. He observed that for the study to be praised even by skeptical and vociferous critics of previous studies, Professor Nadiri appears to have done an excellent job. But he also noted that this was nonetheless a pioneering effort, with some unexplainable features such as negative returns to service industries. Additional research in the following areas could further substantiate Nadiri's analysis:

- Disaggregating total infrastructure investment by the quality of investment to determine whether some kinds of projects, perhaps those that are larger in nature, are likely to provide bigger economic payoffs than others projects.
- Adjusting for the longer time spans of infrastructure investment to determine the degree of long-term payoffs that may now be mismeasured.
- Assessing the many ways in which network effects can build upon each other and the duration of network benefits as regional economies mature.
- Micro-level assessments of how transportation affects productivity utilizing location theory, assessing economies of scale, and other factors.

"In general, there has been a high social value from transportation investment"
- Colin Gannon

(L to R) Colin Gannon of the World Bank and Charles Jacobson of Morgan, Angel and Associates

Historical and International Experience

The World Bank has been involved in more than 1,000 transport projects throughout the world totaling about $50 billion of investment. For the most part, the World Bank assesses these projects on a "micro" rather than a "macro" basis. The objectives are to reduce transportation costs for the distribution of products, to improve access to the workplace for workers from a wide geographical area, and to improve access to the site for materials and other inputs. The World Bank also finances projects that specifically develop links from the farm to the factory, ports and onto international markets. To the World Bank, transportation investment is a key engine of economic development.

Colin Gannon, a senior transport economist at the World Bank, provided a table (shown below) of the rates of return on World Bank transportation investments that have been completed. "In general, there has been a high social value from transportation investment", he concluded. The projects documented below were largely undertaken in the late 1970s and early 1980s and the disbursement of funds was completed by 1994. The annual rates of returns are calculated at the time the project was completed, and then brought forward by making a forecast of supply and demand and the expected rate of return in the future.

The average annual return for all transport projects was 22%, similar to that reported by Nadiri. This was higher than the average annual return of 15% for all World Bank projects (within all sectors) over this period.

In many countries the role of government is shifting from being the provider of infrastructure to being an enabler of infrastructure development. Creating too many governmental institutions can be inefficient. Maintenance is being badly neglected. The best route to the improvement of institutions may be carefully managed participation by the private sector with appropriate regulations. The role of the private sector as a partner or initiator of projects was embraced by several forum participants. In recent international research, the efficiency of local institutions appears to be highly important in determining the

Estimated Returns from World Bank Transportation Projects

Type of Project	Number of Projects	Annual Rate of Return
Airports	8	21 %
Highways	306	26 %
Rail	72	14 %
Ports	96	20 %
All Transport Projects	482	22 %
All Sectors	n/a	15%

rate of return on infrastructure projects.

Looking backward in time, transportation investment was a key determinant of economic growth in the 19th and 20th centuries. During these formative years, transportation investment contributed significantly to growth. However, history also reveals many instances in which the nation made poor transportation investments. The most rewarding transportation projects were often the first and most innovative ones, such as the first canals and the early railroads. In retrospect, however, there has probably never been any one optimal transportation scheme. Many combinations of roads, canals, highways and rails lines may have worked as well or better than what was eventually built (Appendix B contains a bibliography of key historical works.)

An overview of international research on the effectiveness of transportation investment since the 1940s shows that these investments have often had substantial economic impact. This research was carried on in the U.S. and in a variety of countries. The use of production functions dominated the older research, but cost functions were occasionally also used. The standard measure of results were cost and output elasticities. Within the U.S., research was done on an aggregate nationwide basis as well as on a state-by-state basis. Similarly, research overseas was done on both a national and regional basis. Total public capital, transportation and highway capital, and other variations of infrastructure investment were the variables most frequently measured in these studies.

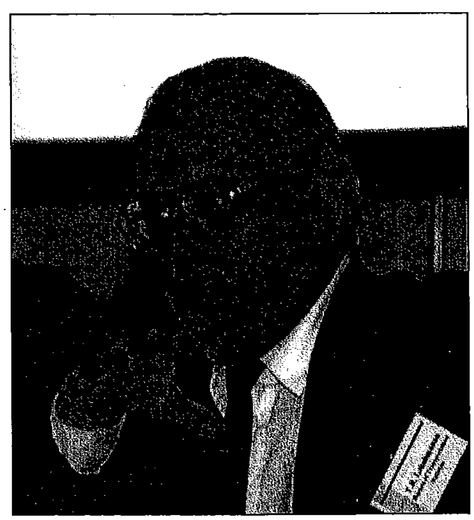
Statistical research was done as early as the mid-1940s to determine the influence of infrastructure investment on a nation's growth. The initial studies found that infrastructure was a positive catalyst for economic development in Eastern Europe and Third World countries. In the early 1970s, research done in Japan was the first to show that public infrastructure investment could contribute to a nation's productivity. This study concluded that the elasticity of output was high. The first study to find that public capital contributed to productivity in the U.S. was undertaken in the early 1980s. The elasticity of output was 0.05, similar to that reported by Nadiri. Aschauer's, and similar studies, such as those based on state-by-state research done by Alicia Munnel, were undertaken in the late 1980s. They concluded that elasticities were as high as 0.4 and 0.5.

The critical reaction to the Aschauer and Munnel studies has been intense, but has also provided positive results. Some of the critical studies yielded sig-

Edith Page of Bechtel Corporation addresses forum participants nificantly lower cost and output elasticities, as well as lower rates of return than those found by Aschauer and Munnell. Nevertheless, many of these showed that infrastructure investment made a positive contribution to productivity. In sum, a wide variety of research shows that infrastructure investment is productive at the margin. Studies in other countries reinforce this suggestion.

Nevertheless, the wide range of different results for rates of returns and elasticities tends to diminish the confidence in this research. Dr. T.R. Lakshmanan of the Bureau of Transportation Statistics summarized this wide variation in previous studies conducted internationally. Appendix C contains a table which summarizes this information, part of which is included in the exhibit below.

Some, but probably not all, of these variations might be explained by such effects as spill-overs from state to state and region to region. One of the contributions of the Nadiri model has been to resolve some of the fundamental concerns of earlier studies. Dr. Lakshmanan predicted, based on his reading of the new study, that "from now on there is going to be a fundamental distinction of before Nadiri and after Nadiri" in the literature on economic impacts of infrastructure investments.



T.R. Lakshmanan of the U.S. Bureau of Transportation Statistics

Investments Must Fit The Context and Create Room for Growth

Forum participants were eager to get beneath the broad, aggregate impacts and to determine how specific infrastructure investment decisions may affect the economy today. More complex times today stand in stark contrast to the simpler, more straightforward decision-making of the 1950s that was required to build the interstate highway system.

One major problem in applying the results of econometric research is that

"From now on there will be a fundamental distinction of 'before Nadiri' and 'after Nadiri' in the literature on the economic impacts of transportation investments."
- T.R. Lakshmanan

Variation of Elasticities Among International Studies

Country	Sample	Type of Capital	Range of Elasticities
United States	Aggregate	All Public	Output: .05 to .39
	By States	Highway	Output: .19 to .26
	By States	All Public	Output: .19 to .26
Japan	Regions	Transport, Communications	Output: .35 to .42
India	Aggregate	Roads, Rail, Electric	Cost: -.01 to -.47

even rigorous regression analyses cannot unequivocally determine the nature of cause and effect. As noted by Robert Gallamore of Union Pacific Railroad, the ancient Greek philosopher Democritus said, "I would rather discover a single causal connection than win the throne of Persia." The question the forum faced is whether investment causes productivity to rise or is fulfilling existing demand that is generated by other forces, even though the research has demonstrated a clear-cut relationship between infrastructure investment and economic productivity. Citing the Princeton economist Albert Hirschman, Dr. Hulten noted that the rate of return is not necessarily what matters most in determining how important investment is for economic growth. What may matter most is whether investment "leads growth or follows it."

A good example is the high social returns on infrastructure investment in the 1950s and 1960s. Dr. Hulten said that the time may have simply been ripe for such investment as the American economy expanded rapidly towards the west and the south. How does one determine whether the same kinds of opportunities exist today? The forum agreed that more research into the value of specific projects and how they improve productivity is necessary. There

"Democritus once said, 'I would rather discover a single causal connection than win the throne of Persia'" - *Bob Gallamore*

Bob Gallamore of Union Pacific Railroad was also widespread agreement that what should be avoided is a "field-of-dreams" approach — that is, just because we construct a facility does not mean that people will automatically come to use it to its full capacity.

Tests and studies can be undertaken to try to isolate the question of cause and effect. For example, Dr. Eberts has conducted additional economic research to try to determine whether infrastructure investment leads or lags economic growth. So far, the research has found the effect can work both ways. According to one study, the growth in America's south would have occurred without infrastructure investment. In the north, however, it appeared that infrastructure investment did produce more growth. His research has also found a significant correlation between infrastructure investment and more openings of new business as well as expansion of existing businesses. He found evidence of the opposite relationship as well. Such infrastructure investment seems to slow down the pace of business closings. In general, however, research aimed specifically at isolating the cause-and-effect issue has found evidence that infrastructure investment both leads and lags economic growth, and may be both a cause and an effect.

It should be clear that the same questions about cause and effect also apply to other types of investment, including private capital investment. Those who claim today that America does not invest enough in plant and equipment, for example, face the same issue. Is private capital investment a cause of growth or a consequence of it? One significant difference between infrastructure investment and private capital investment, however, is the time span of economic payoffs. Infrastructure investment creates conditions for growth that can extend well into the future. To measure the true pay-off of such capital investment is difficult. But it is clear that more than private capital spending, infrastructure investment, as Professor

Charles Hulten of the University of Maryland

"What matters most is whether infrastructure investment leads growth or follows it." - Charles Hulten

Nadiri noted, creates room for future growth.

What must be analyzed is whether creating conditions for future growth will be necessitated by demand. The Interstate Highway System is a successful example. It was underutilized initially, but created room for rapid future growth. But we do not truly know what would have happened had there been no such system. Further complicating these questions is the increasing role of services and telecommunications in the economy. This may reduce the need in the future for traditional means of transportation. Yet, an argument can also be made that they might increase demand more than expected.

The forum participants generally agreed that this is where the debate about economic returns centers. How do we utilize transportation best? Which transportation investments fit the "growing room" of today? This need should be coupled with the need to invest in new technologies — what Stanford economist Paul Romer has called "wetwear". One example of wetwear is the groundbreaking spreadsheet package Lotus 1-2-3. Another is intelligent transportation systems (ITS) technology. These new tools create whole new fields of economic opportunity. Many argue that privatization may be the best way to maximize the benefits of infrastructure investment.

Transportation shares many of the characteristics of new software. It has enabled corporations to take advantage of their existing technologies, as well as new technological developments. So investing in it is much like investing in wetwear – such improvements have the potential to have widespread impacts on many sectors of the economy.

The complementary relationship between transportation and communications, as noted, also needs to be better understood. Many of the benefits of infrastructure improvements have come from its complementarity with the information infrastructure. Looking to the future, particularly to the potential of intelligent transportation systems, this link could be crucial.

How do you select those investments that offer the most growing room for the economy? Looking to past experience, some government investments have been quite rational, but others not at all. Participants identified numerous examples which they felt were ill-timed. Econometric research cannot yet distinguish between periods of rational public infrastructure investment and irrational periods when specific investments are not fruitful. There were many similar mistakes made in the 19th century, often provoked by pork-barrel decision-making but also simply by duplicating what had already existed or once seemed to work. For example, many of America's early canals proved to be poor investments.

Ms. Gloria Jeff, the associate administrator for policy in the FHWA, pointed out that sometimes we do know what the alternatives would have been had the government not made the kind of investments it did. We don't always have to speculate about field-of-dreams exercises that are fictitious in nature. "There are living, breathing examples of alternatives," she pointed out. The southeast Michigan area and the metropolitan Toronto area were almost "twins" until after World War II. But Toronto did not invest in highway infrastructure to the extent Detroit did. Rather it invested in public transportation. "We know the results", she said.

The participants noted, however, that what might be right for one environment is not necessarily right for another. Detroit may have suffered from highway investment, but Seattle has thrived because of its highway system. What might be right for Phoenix is not necessarily right for Philadelphia. Solutions must be tailored to the local conditions that exist.

The World Bank tries to take such local considerations into account when determining what kind of infrastructure investment to make in developing countries. Cities in developing countries are growing rapidly and putting in durable infrastructure capital. But will they grow like Los Angeles or like Amsterdam? These are difficult issues to sort out, and only time will tell the results.

The distinction between visionary targeting of "growing room" and wishful "field of dreams" targeting may be even more difficult to make in advanced industrial nations. Transportation decisions have become extraordinarily complex in Western Europe, where roads are now crowded with trucks. Should these nations encourage short-sea shipping to reduce this congestion? More than at any other time in history, participants believed that vision is now required to make the right investment choices.

Obviously it is not always possible to accurately predict future conditions, but economists are typically very conservative, one participant noted. They want to know exactly what is going to happen. Nevertheless decisions must be made in real time, and in a different

Gloria Jeff of FHWA and Clyde Pyers of the Maryland Department of Transportation

"There are living, breathing examples... Detroit invested in highways and Toronto invested in public transportation. We know the results."
- Gloria Jeff

framework now than in the past. Therefore some level of uncertainty must be accepted as policy-making proceeds.

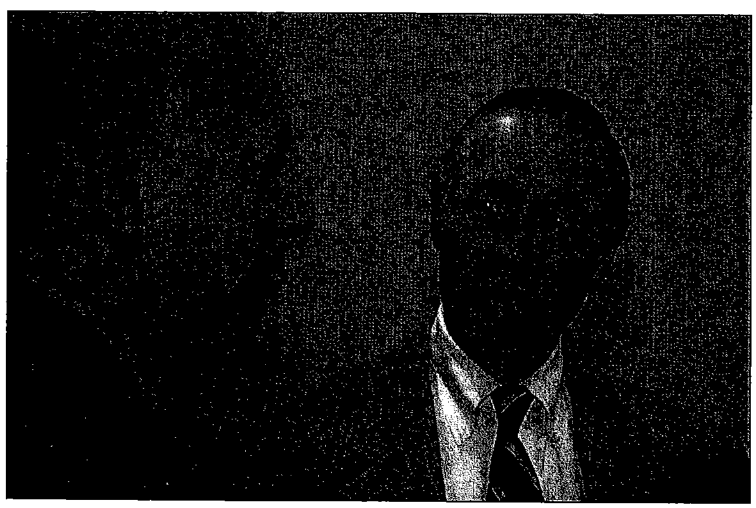
Industry Examples

Private industries must also make projections about where transportation investments are most needed and most likely to occur. As a manufacturer of enzymes, Genencor International must analyze carefully where to place its distribution centers, for example. As the company has grown this has increasingly become an international question. There are four criteria the firm applies when seeking a location. The first and most pertinent is the quality of the infrastructure that is already in place in the area. Genencor situates distribution centers only in locations with a highly dense transportation infrastructure. The other criteria are the ability and availability of the work force, the sophistication of information systems, and taxes, customs and other trade regulations.

One reason Genencor placed a distribution center in Rotterdam, for example, was that it was able to find enough information to give confidence that the infrastructure was adequate. The company could judge the density of infrastructure, including the number of seaports and activity in those seaports, measured for example by the number of containers that go in and out. Information regarding the freight tonnage handled by the airport allowed Genencor to make an "educated decision" rather than merely a guess about the merits of the location. In sum, Genencor will only locate where infrastructure is currently adequate, not where it must await further development.

General Motors spends about $4 billion a year in direct outlays to transportation companies. GM utilizes about 15,000 vehicles daily, many of them tractor-trailers, to handle GM products in the fifty states. Speed of delivery is now the driving force behind many of GM's decisions because of the emphasis the industry places on inventory control and the resulting need "to synchronize transportation with manufacturing cycles."

Highway congestion is becoming an ever-bigger problem for GM as a major shipper. GM is trying to encourage railroads to improve their efficiencies in order to create competition for motor carriers and also to relieve congestion on the road. Currently, shipments to GM via rail average a speed of only about six miles per hour on some links. GM would like to increase that to twenty five



Jeff Madrick and Joe Clapp of Roadway Services (retired) discuss how transportation investments affect business miles per hour.

On the other hand, GM makes highly efficient use of motor transport to meet their just-in-time inventory requirements. One truckload of materials now travels between Windsor, Ontario and Detroit eight to ten times a day. A truck can make the trip across the Ambassador Bridge and through Windsor and Detroit in only forty minutes. This is remarkable given the density of both Windsor and Detroit. One main reason for the efficiency are the improvements that have been made to the Ambassador Bridge. GM is working with the city and state to improve further the access to the highways that serve the bridge. This will not only improve speed, but also increase safety by reducing the number of tight turns.

Another example of how important transportation infrastructure is to making location decisions for plants in the auto-manufacturing industry is Toyota's decision to build in Indiana and West Virginia. These decisions were probably driven by transportation considerations.

(L to R) Eric Beshers of Apogee Research, Edith Page of Bechtel Corp., Bob Gallamore of Union Pacific Railroad, and Jose Gomez-Ibanez of Harvard University

Intermodal transportation promises to be increasingly important for the auto industry in the future. GM has a joint effort underway with the three U.S. auto companies to put up a facility that can coordinate rail and motor vehicles.

GM is not putting more effort into trying to relieve congestion on the roads because it believes that congestion is inescapable. For example, some forecasts predict that Dayton, Ohio will be completely gridlocked by the year 2000 or 2010. The ensuing discussion pointed out that new railroad lines may still be stuck with local congestion to and from the rail head.

Some investment firms are working with private companies to build their own infrastructure. Lehman Brothers has teamed up with Walt Disney Co. in Florida, for example, to put up infrastructure rather than the local government. GM has long put in lanes and bought property around their plants to ease access, although the company has not yet looked into private investment in order to reduce bottlenecks along the delivery lines.

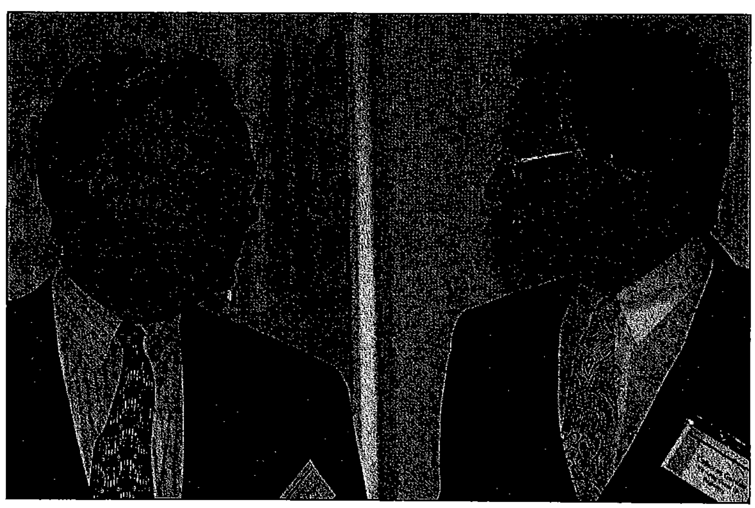
The results of some of the research suggest that the use of general obligation bonds to finance local and regional projects makes sense. The research implies that there are significant network benefits, as noted earlier. An entire community benefits from such pooled investment. However such investments are usually financed through revenue bonds. These bonds are often backed by toll revenue or other user fees. But given that they may have broad benefit for the community, as the new econometric research suggests, other ways to finance them may be practicable. New financial tools such as Section 1012 loans and state infrastructure banks can be used. One important new trend is to get private industry involved, show them how they will benefit, and encourage them to pool together to make a project work.

The Stark County Intermodal Facility in Ohio is an example of such a public-private partnership. One company in this area threatened to move out of the community if it couldn't get a $35 million intermodal service facility built. But this company alone could not provide sufficient demand to convince the railroads that they should make the investment. A group of companies was ultimately combined to guarantee to the railroads that demand was sufficient to make a $24 million investment in the project. The remaining $11 million was borrowed from the state DOT. Every time a box moves through the intermodal facility, the state DOT is now paid a dollar.

One concern expressed at the forum was that much of the discussion focused on the manufacturing industry while the U.S. economy is now dominated by services industries. Participants noted that service companies might well assess a location decision differently than a company such as GM would.

But others indicated that because services industries require large numbers of workers, or often serve many customers, efficient transportation could be even more important to them than to manufacturers. In fact, many services companies have benefited from better transportation systems. Walmart, for example, has become the world's largest retailer in part because of its transportation logistics. The slow growth in consumer price inflation in the economy in general may partly be the consequence of improved logistics at retail outlets.

Indeed, logistics costs as a percentage of GNP have fallen from 17.2% in 1980 to 10.4% in 1995. This has resulted in a $68 billion a year savings to the economy. What accounted for this? Much of it may have been attributable to the deregulation of trucking, according to one participant. But participants pointed out several other contributory factors. Logistics costs were driven down by the building of hundreds of industrial parks across the country with efficient transportation systems. High interest rates in the 1980s especially motivated businesses to seek more efficient transportation in order to keep inventory



Dick Mudge of Apogee Research and Cameron Gordon of the University of Southern California costs low. There are many other examples of how industries have changed the way they do business to accommodate their transportation needs, including new transportation systems, as well as new technologies involving everything from electronic just-in-time inventory controls to high-speed coordination between suppliers and manufacturers.

Nevertheless, different kinds of transportation systems might be necessary for services industries. The FHWA has recently initiated a program to improve the estimates of service sector total factor productivity. This may improve future research in this area.

Implications For Future Policy

While participants agreed that there is more research to be done, there was widespread agreement that the new research has important implications for future policy. Does the research change the emphasis the government should place on its own transportation objectives? How can the government ensure that the right kinds of infrastructure investments are being promoted? Finally, how can the importance of infrastructure investment to the economy as a whole be articulated to a larger audience, especially as we face the reauthorization of ISTEA?

Gloria Jeff of FHWA and Ron McCready of the Transportation Research Board

The new research doesn't only imply that new infrastructure investment can promote economic growth and productivity. It also implies that if capital stock in infrastructure falls, productivity will be reduced. The cost and output elasticities imply that a dollar less capital stock will reduce output, income and consumption as much as a dollar of increased investment will raise it.

The FHWA finds that demand is vastly exceeding additions to highway capacity, even though this capacity is rising by 3% a year. Capacity is also being raised by the addition of HOV lanes and local projects. Nevertheless, Ms. Gloria Jeff of FHWA pointed out that we don't know what will happen if the nation doesn't invest more in capacity but simply concentrates on maintenance and improving efficiency. Other participants noted that we are not thinking about requirements in fifteen or twenty years, not to mention in just five years.

The FHWA has made economic prosperity one of its five main principles for future transportation policy. These objectives are:

- Improving the quality of life
- Enhancing the environment
- Raising the level of safety

- Ensuring national security
- Promoting economic prosperity

In determining how to meet the last objective, many participants agreed that it is not necessarily aggregate demand that is most important. The key question is whether transportation investments are targeted in the right locations and times in order to achieve the highest returns within their respective contexts. Another participant urged the government to keep economic research in "context, context, context." In the current environment, he pointed out, maintenance and managerial issues are what keep coming up. Rather than more investment, people are increasingly talking about disinvestment.

Ms. Jeff noted that the FHWA traditionally has taken a "micro" view of the impact of infrastructure investment. This has usually involved a cost-benefit analysis of specific projects and their immediate effects on localities. In the past, FHWA asked how highway system users would benefit directly from transportation systems. Now, the agency must take a more macroeconomic point of view. The agency asks not only how a transportation system can help companies and workers live better and safer lives, but also how it affects their economic well-being in general.

How can the advantages for the general economy of infrastructure investment be better communicated both to lawmakers and the public? One example of the difficulty is that transportation did not appear as an issue in the Presidential primaries nor has it appeared in the Presidential election race, either. One reason is that transportation issues rarely if ever appear on national polls. This stands in stark contrast to the interests of local communities, where transportation issues do often rank high in the polls. New roads, widenings, truck traffic volumes, congestion and related issues come alive and are concrete at local levels. Localities often vote to finance such projects. When they are

"Congressional Leaders are beginning to ask how productivity can be improved by highway investment."
- Frank Francois

Damian Kulash of the Eno Foundation and Frank Francois of AASHTO raised to a national level, however, these concerns become generalized, abstract, and vague.

This wasn't true historically. In the 1920s, for example, people knew what they wanted from roads. We had to get America out of the mud. In the 1950s, America knew it needed highways. Today, with the Interstate system completed, it is more difficult to explain why investment in highways makes sense. Safety and congestion are two issues that carry weight with people in general, but little else does.

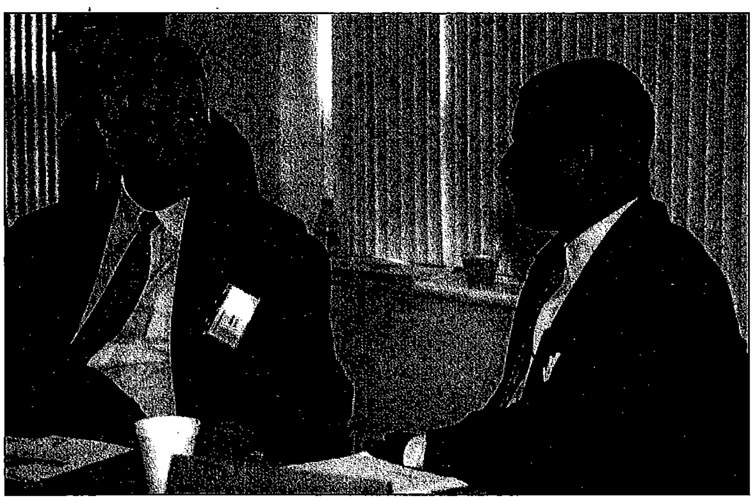
On the other hand, some participants said there is a demand for more information that would demonstrate the impact of infrastructure investment on economic growth. Frank Francois of AASHTO reported that his organization believes economic returns should be part of the argument. He has found that Congressional leaders are beginning to ask how productivity can be improved by highway investment.

This most recent research, and the work of others, can be used to fill this gap. In the Nadiri model, social returns for non-local highway investments averaged well above returns on private capital investment, as noted. In general, even though returns have fallen over the past forty years, they are the equivalent of returns on private capital.

For all their encouragement, however, participants urged that the results of the new research should not be overplayed. Credibility is very important. The results should be neither over-simplifed nor exaggerated.

Conclusions

After several years when research about the effects of infrastructure investment on U.S. economic growth, productivity, and rates of return had little credibility, new research has now reinforced the view that infrastructure investment plays a significant role in the nation's economic health. The new work by Professor Ishaq Nadiri, in addition to a wide range of historical and international studies,



Ishaq Nadiri of New York University and Rodney Slater of FHWA

"The analytic challenge is to see whether the quality of services provided by this type of infrastucture is adequate to meet future needs."

- Ishaq Nadiri

finds that social rates of return on infrastructure investment are significant and positive. They were very high in the 1950s and 1960s, and comparable to returns on private investments in later decades. The research concludes that infrastructure investment has helped raise the nation's productivity and reduce its costs of doing business.

The impacts of transportation vary widely from time to time and from place to place. Rates of return and cost elasticities that come from economic analysis represent average relationships that, in fact, usually vary over time. Most notably, social rates of return have fallen rapidly during the period under study. These returns also vary according to place and the economic environment. The first roads in a region may provide especially strong returns, for example, but eventually new roads are merely substitutes for older ones as localities mature. Returns naturally fall. To maximize the positive economic impacts of transportation investments, we must examine how and when this effect is likely to occur.

Network benefits are especially hard to measure. The new research strongly suggests that they exist — that is, that industries benefit from shared capital investment. But there are dynamic effects that are difficult to assess. One of the most important of these is that infrastructure investment, more than most other types of investment, creates conditions for future growth well into the long run. Not only are these benefits especially hard to estimate: because the total payoffs for such public investment are rarely immediate, they also do not receive much attention from the political system. But they are the key to making successful transportation investments.

In sum, transportation investments have had broad positive impacts upon the economy in general. Future infrastructure investments can also produce sizable returns, but only if they are the right investments at the right time — investments that create growing room; investments compatible with the institutional context. The fact that policy makers appear to have selected such investment in the 1950's and 1960's does not tell us much about what the best opportunities are today. The challenge facing the nation now is to determine how to choose the best infrastructure projects to enhance our growth and productivity.

There are several implications of these results for future transportation policy. First, the objective of public investment in infrastructure is not simply to solve a locality's immediate transportation problem — be it potholes or congestion. Rather, it is to enhance the general prosperity of a region and the nation as a whole. Neglecting public investment in infrastructure can retard economic growth and diminish the nation's productivity. Second, more analysis should be undertaken about the specific conditions needed to maximize the value of investment projects. Third, new means of financing can be linked to the broader economic payoffs of such investments. Finally, these conclusions need to be phrased in a credible, specific vision to guide future transportation policies and investment decisions.

Appendix A

HIGHWAY CAPITAL AND PRODUCTIVITY GROWTH

by

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Recent discussions have emphasized inadequate growth of infrastructure capital as a cause of the slowdown in productivity at the aggregate and industry levels. Numerous studies have been undertaken to clarify the relationship between productivity growth and public infrastructure capital. These studies can be broadly classified as those which estimate a neoclassical production function augmented to include the publicly financed infrastructure capital stock as a factor of production, and those which utilize the dual approach to production function analysis by estimating cost or profit functions. The level of aggregation used in estimating production and cost functions varies considerably among the different studies. Some studies use highly aggregate national or international data and others use regional or state level data. Some studies use cross-section-time series data covering metropolitan SMSAs, while others employ industry-level data. Studies often differ in their coverage of industries, geographic regions, modeling methodology and use of econometric estimation techniques. Because of such analytical differences and data limitations, the statistical results reported in the literature measuring the effects of infrastructure capital on the economy are often quite diverse and sometimes contradictory. Clearly, no consensus has yet emerged on the precise causes of the productivity growth slowdown and the specific contribution of public infrastructure capital in this process.

To provide a context for this study, a literature review is included in the following section. The analytical framework used in this study possesses several advantages over existing models reported in the literature:

- The effect of aggregate demand on the productivity growth of individual industries is explicitly taken into account. That is, the effects of changes in aggregate income and population on industry demand and, consequently, on its productivity growth are estimated.
- Account is taken of the contribution of changes in real factor prices, including wages and capital rental prices, on productivity growth;
- The direct and indirect effects of an increase in highway capital on total and industry output and productivity growth are estimated;
- The impact of highway capital, both total stock and the NLS subset, on demand for inputs such as demand

for employment and private sector physical capital are estimated.

- The industry level estimates are aggregated up to obtain the determinants of aggregate productivity growth.

A unique feature of this study is its comprehensiveness.[1] This study estimates a model which encompasses both demand and supply factors that may influence industry and total economy productivity growth and uses data on 35 industries that covers the entire U.S. economy for the period 1950-1989. The focus of the study is to identify the contribution of highway capital to productivity growth. Two measures of highway capital are used: total highway capital including roads under federal, state, and local government jurisdiction; and the stock of upper level roads excluding local government investments in roads and streets.[2] Since the results of our study did not change much except with respect to the magnitude of some elasticities whichever of these two measures of highway capital are used, the discussion here after will focus on total highway capital. The major changes in the results when non-local highway system (NLS) capital stock is used as a measure of highway capital will be noted at the concluding section.

The relevant policy questions addressed in this research are as follows:

- What is the productivity of highway capital and what is its overall social rate of return?
- Is there any evidence of over- or under-supply of this capital in the postwar period?
- If a shortage of highway capital is evident, can it explain some of the decline in the aggregate productivity growth? If so, by how much?
- What is the optimal level of highway capital from the perspective of the private production sector and how does it compare to its actual level?
- What is the effect of highway capital on the private sector cost of, and demand for, labor, capital, and intermediate inputs?, and
- What are the marginal benefits to the private sector of an increase in highway capital and how do they differ across industries?

Literature Review

A brief review of the literature on the contribution of public infrastructure (highway) capital suggest that:[3]

1. Early estimates based on aggregate production function analyses are likely to have overstated the magnitude of the effects of public infrastructure capital on output and productivity growth;
2. Estimates based on state level data indicate a relatively smaller contribution of infrastructure and that the composition of infrastructure capital matters; some types of infrastructure may have a greater effect on productivity than others;
3. There are serious estimation problems in both aggregate national level time series studies and state and regional level studies that lead to highly disparate results; and

4. Overall, it seems that the recent studies point to a positive but lower elasticity of output with respect to public infrastructure capital of about 0.20 to 0.30 at the national level and possibly a lower range at the regional level.

Similarly, from the view of cost and profit function studies[4] the following statements may be in order:

1. There is a preponderance of evidence that suggests that infrastructure capital contributes significantly to growth in output, reductions in cost and increases in profitability. The magnitude of these contributions, however, vary considerably from one study to another because of differences in econometric methodology and level of data aggregation.
2. There appears to be a convergence toward a much lower estimate of the magnitude of the contribution of infrastructure capital to output and productivity growth than suggested in earlier studies. Output elasticity estimates of infrastructure capital at the national level in the range of 0.16 to 0.25 appear to be in order. Estimates based on state and metropolitan level data suggest elasticities of approximately 0.06 to 0.20.
3. Most studies indicate an under-investment in public infrastructure capital, the degree of which varies among different studies. Most of the cost function studies suggest a substitutional relationship between private capital and infrastructure capital, although some studies report a complementary relationship.
4. The available studies are either too aggregate or partial in their coverage of the economy. Most of these studies, particularly those at the national level, use real GDP, a value added measure, as the dependent variable. However, the appropriate measure for an analysis of the contribution of infrastructure (highway) capital is gross output. Gross output includes purchases of intermediate inputs, along with primary inputs private capital and labor. Because highways are used to transport intermediate inputs, the relationship between public capital and intermediate purchases can be taken into account.[5]
5. Studies at the industry level are generally confined to the manufacturing sector or a specific subset of this sector. Infrastructure capital, however, may have important effects on other industries outside the manufacturing sector as well. It is very important to undertake a comprehensive study that includes all sectors of an economy in order to study the role and degree of externalities generated by publicly financed infrastructure capital such as highway capital.

Most of the studies of both production function or cost function have been challenged on conceptual and econometric grounds.[6]

Estimation Framework and Descriptive Data

The approach developed in our study explicitly incorporates demand and supply forces, including the contribution of highway capital, that may affect industry productivity performance. For each industry, cost and demand functions are estimated separately and the parameter estimates of the model used to decompose Total Factor Productivity (TFP) growth. The critical estimates for decomposition of TFP are the price and income elasticities of output demand and the degree of scale and input substitution derived from the cost function. In formulating industry output demand, changes in quantity demanded in an industry are related to its own price movement in comparison to the GNP deflator and changes in the level of aggregate income and population of the economy. The estimates show that the price elasticity of output demand is negative and statistically significant in almost all industries, and with few exceptions, less than one.

The parameters of the underlying cost function are estimated by using a system of input-output equations which include a labor to output equation, a capital to output equation and an intermediate input to output equation. These input-output ratios functionally depend on private input prices, level of industry output, industry's capacity utilization rate, time trend, and level of total highway capital stock. In order to capture industry specific effects we introduce industry specific intercept terms and a limited number of slope dummy variables.[7] There are of course other more elaborate ways to take account of inter-industry differences that could be undertaken in future research.[8]

Previous studies have been criticized on modeling and econometric estimation issues. This study has responded to these criticisms by accounting for several estimation problems in the estimation process. We examine the possibility of spurious correlation by estimating our model in first difference form. A flexible form for the cost function is used to allow interaction between highway capital and private sector output and inputs. No *a priori* restrictions, such as constant returns to scale are imposed, on the parameters of the cost function. The issue of simultaneity is addressed by estimating the model using appropriate econometric estimation techniques. Extensive hypothesis testing was also carried out to test the specification of the model and the stability of its results.

The data used in this study covers the entire U.S. economy for the period 1947-1989. The industry coverage is derived from a detailed 80 industry classification that Jorgenson, Gollop and Fraumeni carefully aggregated into 35 larger categories.[9] Data for the value of gross output and costs of labor, capital services and intermediate inputs as well as their price indices for all industries are from Jorgenson, Gallop and Fraumeni.[10] Data on capacity utilization rate for the manufacturing industries for the period 1950 - 1966 have been obtained from Klein and Summers (1966) and for the period 1967 - 1989 from the WEFA group (1992). Data on real GNP and population, used to estimate the demand functions, are obtained from the Bureau of Economic Analysis and the Bureau of the Census, respectively.[11]

Data on net highway capital stock are from Apogee Research, Inc., which was constructed using Federal Highway Administration's investment expenditure data on highways from 1921 to 1990. Total net highway capital and non-local net highway capital (NLS) are constructed using the perpetual inventory method with an assumed economic rate of depreciation of 0.9. Capital expenditures are distributed in the following way; 52 percent to paving, 26.5 percent to grading, and 21.5 percent to structures. The average lives of paving, grading, and structures are assumed to be 14, 80, and 50 years, respectively.

An examination of the data indicate substantial diversity among the 35 industries examined in the study. The size of the industries, measured by total cost, vary considerably among industries. Factor cost shares also vary considerably across industry sectors. For example, labor's share ranges from a low of about 0.06 in petroleum refining to a high of 0.51 in trade. Capital's share of total cost ranges from 0.04 in apparel and other textile products to 0.38 in crude petroleum and natural gas. Generally, capital's share in total cost, with few exceptions, is less than labor's share. Material inputs, on the other hand, have

Figure 1
Growth Rate of Highway Capital (%)
1950-1989

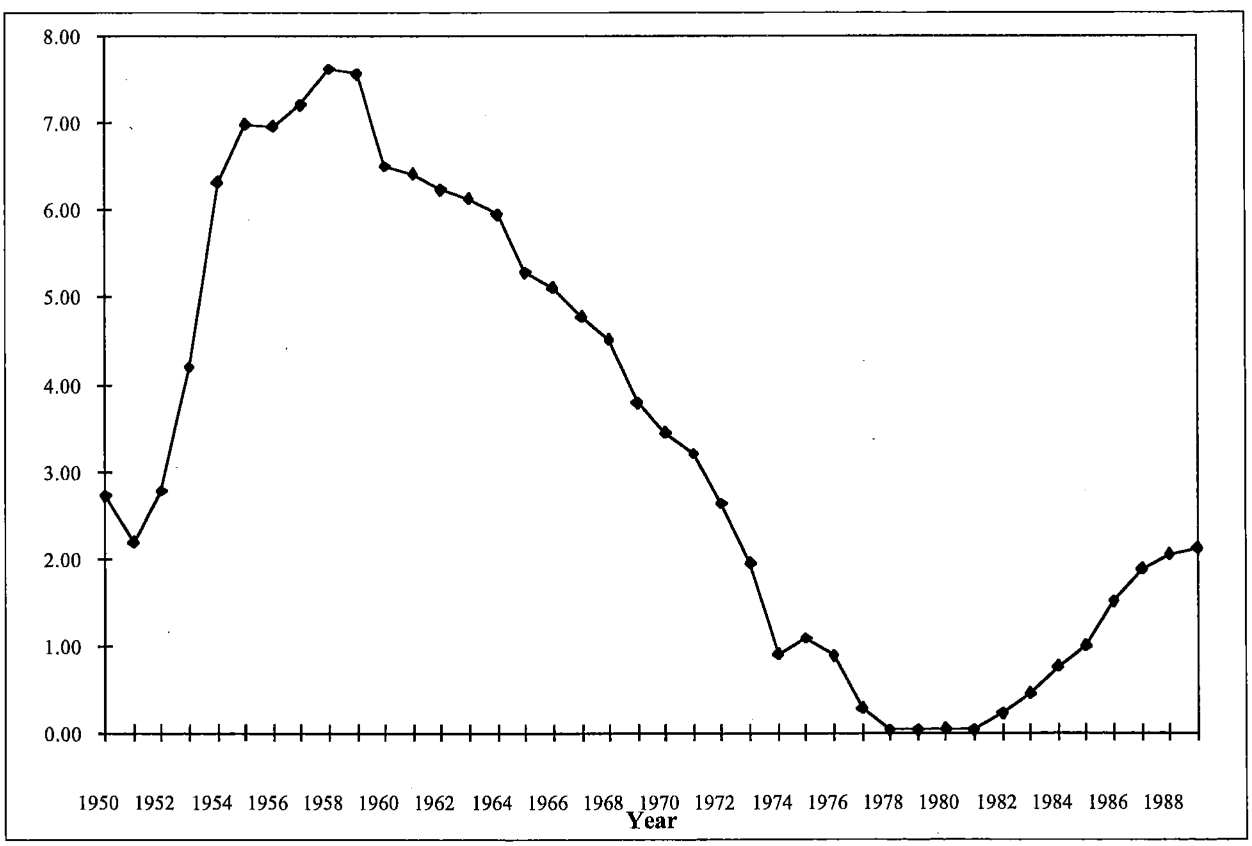


Table 1: Cost Function Elasticities
Averages: 1950 - 1989

Industry Code	Industry Title	Cost Elasticities h_{CS}	h	h^*
1	Agriculture, Forestry and Fisheries	0.0531	0.9573	1.0122
2	Metal Mining	0.0458	0.8049	0.8484
3	Coal Mining	0.0488	0.9271	0.9775
4	Crude Petroleum and Natural Gas	0.0615	0.9302	0.9953
5	Nonmetallic Mineral Mining	0.0591	0.9231	0.9843
6	Construction	0.0683	0.8280	0.8889
7	Food and Kindred Products	-0.1677	0.9204	0.7911
8	Tobacco Manufactures	-0.2245	0.9801	0.8040
9	Textile Mill products	-0.1502	0.9742	0.8494
10	Apparel and Other Textile Products	-0.1463	0.9743	0.8521
11	Lumber and Wood Products	-0.1640	0.9758	0.8401
12	Furniture and Fixtures	-0.1585	0.9639	0.8334
13	Paper and Allied Products	-0.1678	0.9642	0.8273
14	Printing and Publishing	-0.2024	0.9562	0.7972
15	Chemicals and Allied Products	-0.1558	0.9557	0.8295
16	Petroleum Refining	-0.1740	0.9480	0.8096
17	Rubber and Plastic Products	-0.1625	0.9585	0.8262
18	Leather and Leather Products	-0.1676	0.9095	0.7805
19	Stone, Clay and Glass Products	-0.1771	0.9607	0.8174
20	Primary Metals	-0.2164	0.9166	0.7544
21	Fabricated Metal Products	-0.1728	0.9561	0.8169
22	Machinery, Except Electrical	-0.1553	0.9464	0.8206
23	Electrical Machinery	-0.1520	0.9534	0.8297
24	Motor Vehicles	-0.1897	0.9341	0.7872
25	Other Transportation Equipment	-0.1658	0.9599	0.8248
26	Instruments	-0.1876	0.8941	0.7528
27	Miscellaneous Manufacturing	-0.1469	0.9686	0.8464
28	Transportation and Warehousing	0.0287	0.9318	0.9593
29	Communication	0.0264	0.9607	0.9870
30	Electric Utilities	0.0354	0.9559	0.9916
31	Gas Utilities	0.0209	0.9452	0.9672
32	Trade	0.0209	0.7303	0.7431
33	Finance, Insurance, and Real Estate	0.0242	0.7530	0.7689
34	Other Services	0.0315	0.7548	0.7762
35	Government Enterprises	0.0240	0.9698	0.9940

the largest share in total cost in almost all sectors or industries, ranging from 0.86 in petroleum refining to 0.25 in other transportation equipment.

The growth rate of total highway capital is shown in Figure 1. After an initial decline between 1950 and 1951, the growth rate of highway capital surged, growing at the average rate of 6.2 percent during 1952-1959. From 1960 onward, the growth rate declined continuously until 1979. It grew very little during 1979-1981. Since 1982 the highway capital stock has been growing at an average rate of 1.2 percent per annum.

Results at the Industry Level

The model used in this study builds up from industry-level estimates to obtain appropriate results for the economy as a whole. Therefore, the careful estimation of the structure and properties of the disaggregated industries plays a critical role in the design of this research. The following sections present some of the basic industry-level results before describing the contribution of highway capital to the aggregate economy. These results include the impact of highway investments on industry cost reductions and economies of scale; effects upon labor, capital and material inputs; the marginal benefits of highway capital to industries; and the analysis of growth in total factor productivity (TFP).

Cost Reduction and Degree of Scale - The first column in Table 1 shows the elasticity of cost with respect to highway capital (h_{cs}). The magnitudes of the cost elasticities vary among the industries. The cost elasticities in manufacturing industries range from -0.146 to -0.220 while in the non-manufacturing industries they range from +0.02 to +0.06. Positive cost elasticities imply that the demand for highway capital services in these industries is less than the available supply at the price the industries are willing to pay. This does not mean that these industries do not demand highway capital services. What is implied is that these industries face "excess capacity" in highway capital, a situation similar to the notion of excess capacity in private capital stock in a private firm. If the firm cannot freely dispose of this capacity and is instead required to keep its capital stock fully utilized, regardless of changes in demand for its product, the cost to the firm will rise. In the case of highway capital, the entire capital stock enters the cost function of each industry. The optimal level of these services can be estimated from the model which is the level at which the marginal benefit of highway capital is equal to an industry's marginal cost or willingness to pay. As noted later, these estimates imply a set of national subsidies and taxes that would allow industries to use the optimum amount of highway capital services.

The cost elasticities h and h* shown in column 2 and 3 of table 1 have a returns to scale interpretation. The inverse of h represents internal returns to scale, or the effect on output of an equal proportional increase in all inputs except highway capital. Similarly, the inverse of h* represents total returns to scale, meaning that an equal proportional increase in all inputs, including highway capital, yields a 1/h* proportional increase in output. The results show that both 1/h and 1/h* are greater than one for all industries except agriculture, indicating increasing internal and total returns to scale. The degree of internal returns to scale in each industry is smaller, as expected, compared with the degree of total returns to scale which accounts for the contribution of highway capital.

Effects on Labor, Capital and Materials - Highway capital has both direct and indirect effects on the productivity of the private sector. The direct effect of infrastructure capital is measured by the magnitude of the cost reduction due to an increase in highway capital. The indirect effect is given by the magnitude of its effect on the demand for private sector factors of production.

Conditional input demands refer to the demand for labor, capital, and intermediate inputs holding output constant. Elasticities of employment, private capital and intermediate inputs with respect to highway capital vary considerably across industries.[12] The general conclusion that arises from the empirical results is that changes in total highway capital have significant effects on the demand for private sector inputs in all industries. The conditional demand for labor, private capital and material inputs in the manufacturing industries will decline when investment in highway capital is increased. In the non-manufacturing industries, however, demand for la-

Table 2: Marginal Benefits (MB) of Highway Capital
Mean Values 1950 - 1989

Code	Industry	MB	Tax(+) / Subsidy(-)
1	Agriculture, Forestry and Fisheries	-0.01174	-0.01518
2	Metal Mining	-0.00041	-0.00061
3	Coal Mining	-0.00125	-0.00163
4	Crude Petroleum and Natural Gas	-0.00483	-0.00681
5	Nonmetallic Mineral Mining	-0.00071	-0.00092
6	Construction	-0.03465	-0.04384
7	Food and Kindred Products	0.04464	0.03936
8	Tobacco Manufactures	0.00339	0.00295
9	Textile Mill products	0.00735	0.00639
10	Apparel and Other Textile Products	0.01059	0.00927
11	Lumber and Wood Products	0.00816	0.00721
12	Furniture and Fixtures	0.00414	0.00367
13	Paper and Allied Products	0.01309	0.01168
14	Printing and Publishing	0.01624	0.01448
15	Chemicals and Allied Products	0.02228	0.02007
16	Petroleum Refining	0.02052	0.01858
17	Rubber and Plastic Products	0.01301	0.01178
18	Leather and Leather Products	0.00200	0.00164
19	Stone, Clay and Glass Products	0.00904	0.00791
20	Primary Metals	0.02850	0.02413
21	Fabricated Metal Products	0.01887	0.01667
22	Machinery, Except Electrical	0.02582	0.02308
23	Electrical Machinery	0.02073	0.01870
24	Motor Vehicles	0.02711	0.02382
25	Other Transportation Equipment	0.01726	0.01519
26	Instruments	0.01016	0.00919
27	Miscellaneous Manufacturing	0.00398	0.00353
28	Transportation and Warehousing	-0.00718	-0.01080
29	Communication	-0.00348	-0.00472
30	Electric Utilities	-0.00468	-0.00627
31	Gas Utilities	-0.00275	-0.00400
32	Trade	-0.02178	-0.03594
33	Finance, Insurance, and Real Estate	-0.02331	-0.03530
34	Other Services	-0.02805	-0.03873
35	Government Enterprises	-0.00219	-0.00328

bor and material is increased while demand for private capital is decreased in response to an increase in highway capital. However, if the level of output is free to change, the demand for employment, capital and materials inputs in each industry will increase as a consequence of an increase in highway capital. This arises because the direct cost reduction effect of highway capital will in turn lead to the expansion of output. This expansion in output will require more inputs which will likely offset the substitutional effects at a given level of output.[13]

Marginal Benefits - Table 2 reports the average marginal benefit (MB) of highway capital in current dollars for each industry over the sample period. The marginal benefits indicate how much each industry is willing to pay for an additional unit of highway capital services. The magnitudes of the marginal benefits vary considerably across industries and over time. After taking into account price changes, however, the marginal benefits in real terms appear to increase from 1950 to 1969 but decrease from 1970 to 1989 in each industry. Another interesting feature is that all manufacturing industries have positive marginal benefits, i.e., they would be willing to pay a positive amount for additional highway capital services, the amounts ranging from 0.002 in the leather and leather products industry to 0.029 in primary metals. Non-manufacturing industries, on the other hand, are willing to pay negative amounts, i.e., require a subsidy, to use the entire stock of highway capital. That is, the estimated demand for highway capital services in these in-

Table 3: Decomposition of Total Factor Productivity Growth
Mean Values: 1951 - 1989

Industry Code	Industry Title	Exogenous Demand	Relative Input Price	Highway Capital	Adjusted $\dot{TFP}$	$\dot{TFP}$
1	Agriculture, Forestry and Fisheries	0.002	-0.052	-0.107	1.510	1.353
2	Metal Mining	0.234	0.058	-0.060	-0.432	-0.200
3	Coal Mining	0.030	0.010	-0.098	1.120	1.060
4	Crude Petroleum and Natural Gas	0.015	-0.021	-0.123	-1.243	-1.372
5	Nonmetallic Mineral Mining	0.098	-0.005	-0.105	0.883	0.856
6	Construction	0.453	0.162	-0.158	-0.345	0.092
7	Food and Kindred Products	0.399	-0.169	0.430	-0.126	0.577
8	Tobacco Manufactures	0.117	0.022	0.558	-0.421	0.209
9	Textile Mill products	0.292	-0.103	0.353	0.746	1.293
10	Apparel and Other Textile Products	0.082	-0.141	0.390	0.841	1.282
11	Lumber and Wood Products	0.330	-0.321	0.406	0.206	0.621
12	Furniture and Fixtures	0.409	-0.347	0.503	0.035	0.639
13	Paper and Allied Products	0.589	-0.426	0.420	-0.300	0.280
14	Printing and Publishing	0.684	-0.562	0.649	-0.808	-0.048
15	Chemicals and Allied Products	0.729	-0.592	0.384	0.386	0.904
16	Petroleum Refining	0.518	-0.121	0.427	0.111	0.933
17	Rubber and Plastic Products	0.827	-0.508	0.429	0.173	0.938
18	Leather and Leather Products	-0.441	0.237	0.474	0.258	0.537
19	Stone, Clay and Glass Products	0.419	-0.268	0.445	-0.287	0.310
20	Primary Metals	0.196	-0.146	0.667	-0.956	-0.285
21	Fabricated Metal Products	0.444	-0.246	0.440	-0.172	0.460
22	Machinery, Except Electrical	0.792	-0.427	0.400	0.298	1.072
23	Electrical Machinery	0.752	-0.409	0.406	0.722	1.512
24	Motor Vehicles	0.635	-0.355	0.645	-0.748	0.368
25	Other Transportation Equipment	0.973	-0.480	0.420	-0.364	0.548
26	Instruments	1.543	-0.750	0.469	-0.279	0.989
27	Miscellaneous Manufacturing	0.263	-0.196	0.412	0.824	1.280
28	Transportation and Warehousing	0.105	0.056	-0.043	0.927	1.060
29	Communication	0.075	0.356	-0.038	2.079	2.457
30	Electric Utilities	0.056	0.041	-0.048	1.168	1.222
31	Gas Utilities	0.125	-0.208	0.014	-0.188	-0.256
32	Trade	1.071	0.301	-0.026	-0.386	1.005
33	Finance, Insurance, and Real Estate	1.033	0.118	-0.028	-0.894	0.218
34	Other Services	0.768	0.086	-0.098	-2.169	0.091
35	Government Enterprises	0.034	-0.802	-0.044	-0.330	-1.144

dustries at a price they are willing to pay, falls short of the available supply.

The implied taxes and subsidies for various industries are shown in Table 2. These refer to the differences between the amount an industry is willing to pay for highway capital services and the actual price required to use the entire amount of available capital. These estimates are calculated at the optimal level of highway capital services demanded for both manufacturing and non-manufacturing industries. The magnitudes of taxes and subsidies vary considerably. The largest taxes in manufacturing are in food and kindred products, chemicals and chemical products, primary metals, machinery (except electrical), and motor vehicles. Construction, trade, finance, insurance, real estate, and other services require relatively large subsidies to encourage them to use the entire highway capital. Those that would "pay" the lowest taxes are tobacco manufacturing and leather and leather products. The lowest subsidies are in three industries: metal mining, coal mining and nonmetallic mineral mining.

More careful analysis is required to examine further the size and pattern of these implied taxes and subsidies. It is important to note that the benefits of highway capital vary across industries. Demand for highway services are likely to diverge over time and the degree of benefits of any new highway capital expansion may differ considerably among industries. That is, there is an important distributional effect of the public highway capital across industries

Industry TFP Growth Decomposition- The decomposition of TFP growth estimates at the industry level are provided in Table 3. These estimates reflect the effects of:

Exogenous Demand: This refers to increased demand due to growth of real national income, aggregate population and changes in the utilization rate.

Relative Input Price: This factor captures the growth of input prices.

Highway Capital: This factor captures the combined direct and indirect effects of the growth of highway capital.

In general, changes in exogenous demand contribute over half of TFP growth, mainly in the manufacturing industries. Its contribution in agriculture, extractive and mining industries and government enterprises are rather small. In construction, instruments, transportation equipment and trade and finance, the contribution of an increase in demand is relatively large. The contribu-

Table 4a:
Effect of Total Highway Capital, S, on Cost and Factors of Production, Sum of Marginal Benefit, Cost Elasticities
Average Values

Total Highway Capital	h_{CS}	h_{LS}	h_{KS}	h_{MS}	h	h^*	$\sum_{E-1}^{F} m_E$
"Aggregated"	-.044	-.083	-.122	-.013	.862	.826	.18

tion of relative input prices could be positive or negative depending on whether industry factor price changes exceed those of the general economy. When an industry's rate of input price inflation exceeds the national inflation rate, productivity growth is hampered. Generally, growth in relative input prices contributes negatively to TFP, and the magnitude of its effect varies across industries. Compared to the contribution of exogenous demand, the effects of relative input prices on TFP growth are small.

The contribution of highway capital to TFP growth is positive in all the manufacturing industries. In some of these industries its contribution is relatively large, accounting for almost one-third of TFP growth. In non-manufacturing sectors, growth in highway capital contributes negatively to productivity growth. As explained earlier, this indicates that the supply of highway capital exceeds the demand at the prices these industries are willing to pay. When the effects of exogenous demand, relative input price changes, and highway capital are accounted for, the rate of technological change is much smaller than conventionally calculated. In general, the main causes of TFP growth in the manufacturing industries are exogenous shifts in demand, relative price changes, and highway capital, while in the non-manufacturing industries the dominant factor is the scale effect, or exogenous technological change. Highway capital plays only a minor role in the acceleration or deceleration of TFP growth at the industry level.[14] The evidence supports the notion that total highway capital contributes at varying degrees to the long term growth of TFP in different industries, and its contribution to the short run acceleration or deceleration of industry TFP growth over the sub-periods is negligible.

Contribution of Highway Capital at the Total Economy Level

To calculate the contribution of highway capital stock to the total productivity of the aggregate economy, we explored two different approaches: (1) the individual industry elasticity estimates were averaged (using industry input and output shares as weights) to obtain the "*aggregated*" estimates; (2) the industry level data were summed to the national level and the model was re-estimated with the aggregate data to obtain the "*aggregate*" estimates for the

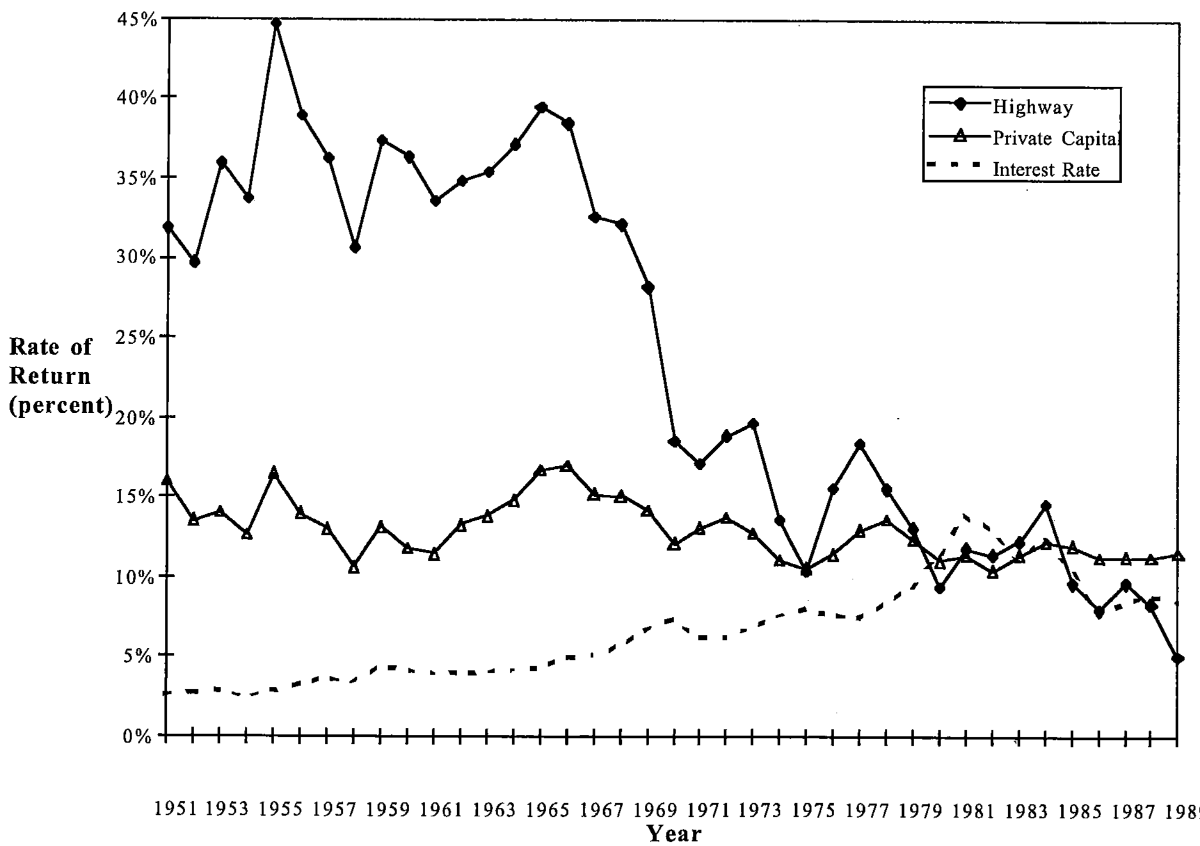
Table 4b:
Output Elasticities of Factor Inputs, Total Highway Capital, Utilization Rate, Rate of Technical Change

Model	Labor	Capital	Materials	Highway capital output	Utilization rate	Technology
"Aggregated"	.384	.185	.605	.051	.142	.001

cost and demand equations. The results were quite similar. In what follows we present the results based on the "aggregated" estimates.

Aggregate Output and Cost Elasticities - Table 4 presents the effect of the total highway capital stock, respectively, on aggregate private sector cost and aggregate input demand functions. The "aggregated" cost elasticity is about -.044, which is considerably smaller than estimates from previous studies. The elasticity of labor with respect to highway capital is negative, which suggests that any increase in highway capital is labor-saving at the aggregate economy level when the level of output is held constant. The elasticity of private capital with respect to total highway capital is also negative and slightly higher than that of labor. The elasticity of intermediate inputs with respect to total highway capital is negative and very small. Cost elasticities (h and h*) suggest increasing returns to scale and the sum of marginal benefits (SMB), shown in last column is approximately 0.18. The output elasticities of inputs, the utilization rate, and the rate of technical change at the aggregate economy level show that the output elasticity of material inputs is large (around 0.60 to 0.70), followed

Figure 2
Net Rate of Return of Highway Capital, Private Capital, and Private Interest Rate (1951-1989)



by that of labor (approximately 0.40 to 0.45), and private capital (approximately 0.20). The rate of autonomous technical change is comparatively small (about 0.001). The output elasticity of highway capital is also relatively small compared to materials, labor, and private capital, averaging 0.051 for the period as a whole.

Compared to the results reported in the literature, this estimate of output elasticity of highway capital is very small. In fact, the elasticity estimates originally reported in Aschauer (1989), Holtz-Eakin (1991) and Munnell (1990) are about eight times as large as our estimates for the national economy. Our estimates are more comparable to output elasticities of public capital reported in Duffy-Deno and Eberts (1989) and Eberts (1986) for the highly disaggregate level of the Metropolitan Area. In particular, the output elasticity of private sector capital is clearly larger than the output elasticity of highway capital. The results indicate that a one percent change in private capital stock contributes almost four times as much to economic output as a one percent change in highway capital stock to growth of output of the economy.

Net Social Rates of Return - Past literature has questioned whether public capital is over- or under-supplied. One way to determine whether public capital is provided optimally is to compute the rate of return to highway capital and compare it with the rate of return to private capital for the whole economy. The optimal provision of public capital requires that the rates of publicly provided and private capital be equalized. Thus, if the rate of return of highway capital is higher than that of private capital, highway capital is under-supplied and an increase of public investment is necessary. The net

Table 5
Net Rate of Return from Total Highway Capital,
Private Physical Capital, and Interest Rates

Net Social Rate of Return	1950-1959	1960-1969	1970-1979	1980-1989	1950-1989
Total Highway Capital	.352	.348	.161	.100	.281
NLS Capital	.479	.474	.238	.161	.338
Private Capital Stock	.134	.140	.120	.110	.133
Interest Rate	.04	.05	.08	.110	.07

Table 6
The Ratio of Optimal to Actual Stock of
Highway Capital (S*/S)

Ratio of S*/S	1950-1959	1960-1969	1970-1979	1980-1989	1950-1989
Total Highway Capital	3.057	1.678	1.112	0.995	1.710
NLS Capital	3.831	1.851	1.186	1.043	1.978

social rate of return of highway capital can be derived as the ratio of the sum of industry marginal benefits to cost minus the depreciation rate of highway capital. This calculation assumes that the user cost of highway capital includes the acquisition price, the relative discount rate, the depreciation rate of highway capital, and the price distortion effect of taxes levied to finance highway capital.[15]

Table 5 presents the net social rate of return to total highway capital, the net rate of return to private capital stock and interest rates for four different sub-periods. The social rate of return on total highway capital was very high during the 1950's and 1960's, reflecting the shortage of highway capital stock during the 1950's when the Interstate Highway System was under construction. This rate has declined continuously since the late 1960's and in 1989 it is barely above the level of the long term interest rate. The time profile of the net social rate of return for total highway capital is presented in Figure 2. The rate begins at a relatively high level, rises to its maximum level in 1955, and fluctuates around 37 percent until 1968. Thereafter, the rate starts to decline and falls from 10 percent in 1985 to about 5 percent in 1989. When the net rate of return is compared to the long-term interest rate on government securities from 1950 to 1989, the gap between the two is very large until the 1970s. The gap narrows considerably and almost disappears in the 1980s. The net rate of return on private capital averaged approximately 14 percent from 1950 to 1969, and then declined in the 1970s and 1980s. However, it exceeded the interest rate over most of period, as shown in Figure 2.

Our estimates of the rate of return on highway capital are much lower than

Table 7

Aggregate $\dot{TFP}$ Decomposition

Total Highway Capital Mean Values

$\dot{TFP}$	Exogenous Demand	Relative Price	Highway Capital	Capacity Utilization	Adjusted $\dot{TFP}$
.6783	.5960	-.0571	.1767	.0069	-.0484

Aggregate $\dot{TFP}$ Decomposition

NLS Capital Mean Values

$\dot{TFP}$	Exogenous Demand	Relative Price	Highway Capital g_1	Highway Capital g_2	Capacity Utilization	Adjusted $\dot{TFP}$
0.6783	0.6029	-0.0571	0.1649	0.0118	0.0069	-0.0411

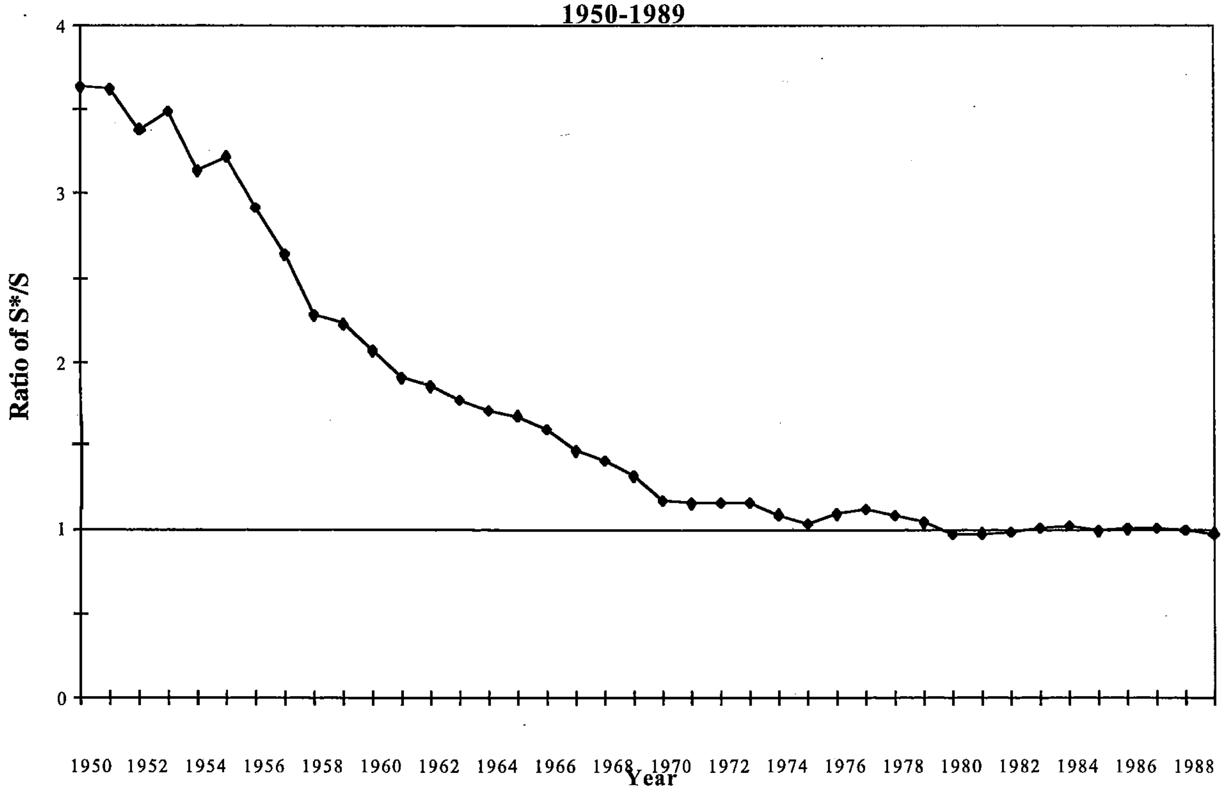
g_1 = highway capital stock NLS

g_2 = other than NLS highway capital

reported in previous literature. Recently, Fernald (1992) estimated the rate of return to investment in roads using essentially the same set of data as used in this study. He concluded that "a conservative statement — is that the data strongly supports the view that roads investments are highly productive, offering rates of return of 50% to 100%, perhaps more."[16] Our results suggest rates of return well below Fernald's lower bound estimated rate of return. Our average rate of return for the period of 1950 to 1989 is 28 percent, about half of his rate of return of 50 percent. The rate of return over the postwar period has still been quite impressive, although in recent years the returns to highway capital are more similar to those estimated for private capital stock.

Optimal Highway Capital Stock - The optimal level of highway capital is obtained by comparing the industry marginal benefits for each year to the actual level of highway capital. The average ratio of optimal highway stock to actual highway capital is reported in Table 6. The striking result that emerges from this comparison is that the ratio is very high during the 1950s, then declines dramatically thereafter until 1989, when the ratio is approximately one. This suggests that there was significant underinvestment in highway capital immediately after World War II but the gap between optimal and actual capital stocks

Figure 3
Ratio of Optimal to Actual Highway Capital
1950-1989



narrowed between 1959 and 1969 as the Interstate Highway System and other road systems were completed. The ratio of optimal to actual stock of highway capital declined by about 50 percent from 1960 to 1969 and further decreased from 1970 to 1979. Interestingly, in the 1980s there is no significant evidence of overall under- or over-investment in the highway capital stock.

The decline in the ratio of optimal to actual highway capital shown in Figure 3 is due in part to public investment decisions and to economic and demographic changes. Growth in the stock of highways and streets, as shown in Figure 1, rose sharply from 1955 to 1975, the period when the U.S. Interstate Highway System was under construction, and leveled off since that time as construction of the Interstate slowed and previously built highways depreciated. The net stock of total highway capital grew at an annual rate of approximately 5 percent from the mid-1950s to the late 1960s. It began to decline in the 1970s, reaching a minimum growth rate of 0.7 percent in 1983. Since then it has gradually increased, but the growth rate of 2.3 percent in 1993 is still less than half the average growth rate of the mid-1950s to late 1960s period.[17]

Decomposition of Aggregate Total Factor Production (TFP) Growth - The results in Table 7 indicate that growth in exogenous demand is the most important contributor to aggregate TFP growth between 1950 and 1989, as almost 87 percent of TFP growth is accounted for by changes in aggregate demand. Input price movements contribute negatively to TFP growth (about 8 percent) while highway capital contributes positively (about 25 percent) to TFP growth. The contribution of the capacity utilization rate is very small (about 1 percent). Table 8a and 8b demonstrate that the same patterns are evident over different sub-periods. The contribution of highway capital to TFP growth was much larger in the early periods, but has declined significantly since 1972. This reflects two sets of factors: the pattern of marginal benefits of highway capital stock; and, more importantly, the growth rate of highway capital stock exhibited in Figure 1. Highway capital's contribution to TFP growth was less than 0.18 until 1953 when the investment in Interstate Highway System started; its contribution rose to almost twice as much during the period of 1954 to 1967. After 1967, the contribution declined considerably until reaching about .001 in 1981. After 1981, the contribution of highway capital to TFP growth grew to about 0.06 in 1989.

A central issue in the debate on the role of infrastructure or highway capital is its contribution to the deceleration of TFP growth in the period 1973-1979. Aschauer (1989), Munnell (1990a) and others claim the decline in this period was mainly, if not exclusively, due to the decline in growth of infrastructure capital. Hulten and Schwab (1991a), Gramlich (1994) and others have argued for minimal contribution of infrastructure capital to productively slowdown.

When TFP growth is decomposed into trend and deviation from the trend, the trend TFP growth is highly correlated with the trend contribution of highway capital, trend exogenous demand and trend in relative factor prices. The deviation from trend of TFP growth is correlated with deviation of the exogenous demand and relative prices from their trend. The conclusion to be drawn is that highway capital stock contributes to growth of total factor productivity; its contribution is much smaller in comparison of the contribution of exogenous demand.

Most of the contribution of highway capital to productivity growth occurred in the 1950s and 1960s. Since 1973, highway capital has made a small contribution to trend TFP. Highway capital, whether measured by total highway capital or NLS (non-local system) capital, does not contribute much to the acceleration or deceleration of TFP growth.

These results stands in contrast to those reported by Aschauer, Munnell and other proponents of large contributions to infrastructure and also to those reported by researchers who have denied

Table 8a:

Average growth rate of $\dot{TFP}$ and contributions of exogenous demand, total highway capital and relative prices

1952-1989 and sub periods

	1952-1989	I 1952-1963	II 1964-1972	III 1973-1979	IV 1980-1989
$\dot{TFP}$	.68	.94	1.03	.13	.42
EXD	.60	.30	.60	.75	.84
TGG	.17	.30	.26	.03	.03
PFP	-.06	-.06	-.10	-.17	.07

Table 8b:

Average growth rate of $\dot{TFP}$ and contributions of exogenous demand, NLS highway capital,

other highway capital and relative prices

1952-1989 and sub periods

	1952-1989	I 1952-1963	II 1964-1972	III 1973-1979	IV 1980-1989
$\dot{TFP}$	0.6783	0.9402	1.034	0.1327	0.4255
EXD	0.6029	0.3185	0.5945	0.7392	0.8563
TGI	0.1649	0.2966	0.2463	0.0195	0.0353
TGO	0.0118	0.0188	0.0121	0.0080	0.0058
PFP	-0.0571	-0.0566	-0.1089	-0.1698	0.0678

EXD: Exogenous Demand TGG: Total Highway Capital TFP: Relative Input Prices

TGI: NLS Highway Capital TGO: other than NLS Highway Capital any role for infrastructure in enhancing the growth rate of productivity. Our analysis suggests that highway capital stock has contributed to the expansion of the productive capacity of the economy. It has contributed to total TFP growth of the US economy, although its contribution has been much smaller than has been claimed in the production function research. Expansion of highway capital has had significant effects on the pattern of, and demand for, labor, capital and material inputs in different industries.

Summary and Policy Implications

Summary of Main Results - The specific quantitative results of this report can be briefly summarized as follows:

- Total highway capital and NLS capital contribute significantly to economic growth and productivity at the industry and national economy levels. Their contribution varies across industries and over time. The magnitude of the elasticity of output with respect to total highway capital at the aggregate level is about 0.05, which is much smaller than comparable estimates reported in previous literature.

- The contribution of highway capital to TFP growth is positive in almost all industries, except in some non-manufacturing industries. In these non-manufacturing industries, the supply of capital exceeds that which the industries are willing to pay at that price. The magnitudes of the contribution varies among industries, although the most significant contribution of highway capital is to the productivity of manufacturing industries. At the aggregate level, highway capital contribution to TFP growth is about .17.

- There is some evidence of increasing returns to scale in most industries and at the national level. Both at the industry and national levels, the contribution of private capital to economic output dominates that of total highway capital or NLS capital by almost four times. This is in sharp contrast to the results reported in the literature.

- Total highway capital and NLS capital have a significant effect on employment, private capital formation and demand for materials inputs in all industries. For a given level of output, an increase in highway capital and NLS capital can lead to a reduction in demand for all inputs in manufacturing, while in non-manufacturing industries the pattern is mixed. The magnitude of these effects varies among the three inputs in a given industry and among the industries, and does not consider output expansion aspects of lower costs.

- The marginal benefits of total highway capital and NLS capital at the industry level were calculated by using the estimated cost elasticities. Demand for highway capital services varies across industries as do the marginal benefits. The marginal benefits are negative for all non-manufacturing industries, but their magnitudes are small suggesting that the demand for highway capital services at the price these industries were willing to pay (if free disposal condition was operative) is slightly less than the available supply. This issue, however, requires further research (Appendix B includes a summary of important issues that require future research).

- The results indicate that net social rate of return on total highway capital was high (about 35 percent) in the 1950s and 1960s, then declined considerably until the 1980s to about 10 percent. The same pattern holds for NLS capital although the net social rates of return are higher for NLS, approximately 16 percent. In the 1980s the rates of return on total highway capital and private sector capital seem to have converged, and are basically equal to the long term rate of interest.

- The ratio of optimum to actual highway capital, measured by either total or NLS highway capital, was high in the 1950s and then declined throughout the 1960s as construction of the Interstate Highway System neared completion.

- The main contributor to productivity both at the industry and aggregate level is aggregate demand. Relative prices, the capacity utilization rate and technical change also contribute to the growth of TFP, but their contributions are generally smaller and vary across industries. The contribution of highway capital is to long run trend TFP growth and only minimally to its acceleration or deceleration over different periods such as the period 1973-76.

Policy Considerations - The results of this research suggest a number of policy implications:

- To have high and sustained TFP growth both at the industry and national level it is very important that aggregate demand be sustained and sectoral input price inflation rates are kept in check. This would require appropriate fiscal and monetary policies to maintain growth rate of the aggregate demand in conjunction with public infrastructure policy.

- The analytical challenge is to see whether the quantity and quality of services provided by this type of infrastructure is adequate to meet future needs. Two sets of policies are needed: one is to look specifically at the quality of services and potential utilization of the existing highway capital network. To achieve this aim a more intensive look at quality adjustment of highway capital stock and construction of a more appropriate index of utilization of this capital. The other challenge is to elaborate the future needs for highway capital to potential growth of the economy and the spatial distribution of economic activities.

- The distinction between gross and net investment in highway capital require proper estimation of the depreciation rate of the capital stock. If the depreciation rate is under estimated, the net expansion of highway capital for the future will be understated. Adequacy of investment allocations can be best evaluated if the replacement investment for highway is correctly determined first. This would require an evaluation of existing and future policies for repair and maintenance of the highway network.

- Since the benefits of highway capital services differ across industries, one policy consideration is the need of the industries in planning of future highway services.

- The externalities of highway capital services to the production has been well documented but two further policy issues require attention. They are the benefits of highways to generate public (consumers) and the geographical distribution of these benefits among different states and localities. The contribution of highways to local and regional areas is an important issue for policy decision process because of the rate of this type of infrastructure to regional economic development.

- Finally, policies for investment allocation and financing of highway capital require closer attention. Such assessments require that highway capital investment be compared in terms of importance and rates of return to long term private sector capital investment.

Future Research

This study raises a number of important issues which should be addressed in future research. These issues include: adjustments for additional variables not included in this research; examining the productivity effects of highway capital under varying levels of output; estimated depreciation rates; further detail about industry types; and the welfare benefits of highway capital to groups other than private sector industries.

Omitted Variables - One of the most important issues to consider in future research is the effect of omitted variables on our results. Two types of adjustments are desirable: one related to quality changes in highway capital stock and the other is the contribution of infrastructure capital other than highway capital. The quality adjustments can take different dimensions. For example adjustments are needed to account for the effects of congestion and other environmental factors such as noise, smog, etc. The highway capital stock needs to be adjusted for quality of roads, degree of maintenance and intensity of use. Besides these types of adjustments, the effects of infrastructure capital other than highway capital should be specifically introduced in our model. Clearly there is considerable evidence that other types of public infrastructure contribute to growth of output and productivity. Including the "other" infrastructure capital may affect the magnitudes and even sign of the elasticities and marginal benefits of highway capital (or NLS) reported in this study.

Allowing Output to Vary - In this study we have evaluated the productivity effect of highway capital and its effect on demand for labor, capital and materials under the assumption that the level of output is given. This assumption needs to be relaxed to take account of output expansion induced by investment in highway capital. Highway capital investment reduces costs, i.e. the average cost shifts downward (productivity effect). This in turn, given a downward sloping output demand curve, leads to a decline in output prices and an increase in quantity demanded. The induced output expansion leads to increases in demand for each of the private sector inputs. This indirect expansion effect of highway capital investment will likely to offset any potential substitution effects on demand for labor, capital and materials. This issue is an important challenge to be taken up also in future research.

Depreciation of Highway Capital. - Another issue is to examine more closely the depreciation rate estimates that are used to generate the total highway or NHS capital. If the depreciation rate is not an accurate measure of the decline in production services then the results on marginal benefit, net social rate of return and productivity contribution of highway capital reported here will be affected. Analytical models are available to estimate the depreciation rate from available investment data. Also, availability of data on maintenance expenditures and other relevant data may allow estimating a more precise measure of the depreciation rate and thus better measures of total highway and NHS capital stocks.

Further Industry Detail - In this study, industries were divided into three broad categories. A more refined classification such as that used by Fernald may be necessary to capture the industry variations in demand for highway capital services. As a result, our measures of industry marginal benefits, social rate of return and contribution to productivity at the industry and aggregate level are likely to be affected. Also, we need to improve our estimation of the output demand function. Furthermore, the demand and cost functions are estimated separately. What is required is to jointly estimate the two functions and allow for the effect of highway capital on the demand for output of an industry.

Benefits to Other Groups - Finally, in this study we have concentrated on the benefits of highway capital to private sector industries. The welfare benefits of highway capital services to the consumers have not been addressed. To do so requires modeling the consumption sector of the economy and integrating it with the production sector in a general equilibrium model. Such an attempt, though extremely important, at present remains outside the scope of our current research.

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[1] For a full description see Nadiri and Mamuneas, "Contribution of Highway Capital Infrastructure to Industry and Aggregate Productivity Growth," March 1996, a report prepared (Apogee Research Inc.) for the Federal Highway Administration Office of Policy Development, Work Order No. BAT-94-008.

[2]The latter includes the federal-aid highway system, with the exception of expenditures on secondary rural roads, and represents approximately 70 percent of total highway capital stock. It is referred to in this paper as the non-local highway system, or NLS.

[3]See Nadiri and Mamuneas, (1996) "Contribution of Highway Capital to Industry and National Productivity Growth," opt. cit, for a more comprehensive survey of substantive and technical issues.

[4]Opt. cit.

[5]Use of value-added data can be justified if there is no substitution between intermediate inputs such as materials and energy and the primary factors of production like capital and labor. If intermediate input prices are relatively stable, the use of value added in productivity analysis can be justified on practical grounds. However, oil price shocks substantially affected the course of the U.S. economy in the 1970's and 1980's. Similar effects to a lesser extent were associated with price increases in other

intermediate inputs. Therefore, it is important to explicitly include energy and material inputs in the productivity analysis.

[6] See Nadiri and Mamuneas, "Contribution of Highway Capital Infrastructure to Industry and Aggregate Productivity Growth," opt.cit., 1996 for further discussion.

[7] In principle, we could introduce a full set of slope dummy variables (102 additional parameters) but it not possible in an already complicated model. Rather, we classified the 35 industries into three groups - manufacturing (industry codes 7 through 27), service industries (industry codes 28 through 35), and other industries (industry codes 1 through 6).

[8] An interesting approach is suggested by Fernald (1992). He uses "vehicle intensity" as a proxy for use of road infrastructure. It is measured as the ratio of the stock of trucks and cars in an industry to its total output. If an industry is vehicle-intense, then presumably it receives a lot of direct productive services from roads.

[9] See Nadiri and Mamuneas, "Contribution of Highway Capital Infrastructure to Industry and Aggregate Productivity Growth," opt. cit. for further details.

[10] For a description of data construction, see Jorgenson, Gallop, and Fraumeni (1987). Also see Jorgenson (1990).

[12] The magnitudes of the labor elasticity ranges generally from 0.06 in industry 29 to a high of 0.97 in industry 16. The elasticities are generally small in industries 28 through 35 except for industry 31. The elasticities of private capital with respect to total highway capital are larger in magnitude in the manufacturing industries than in non-manufacturing industries. The magnitudes of elasticities of intermediate inputs with respect to total highway capital are generally small, particularly in industries 1 through 6. They are relatively larger and positive in transportation, trade, and services. The pattern that emerges from these elasticities is that highway capital is a substitute for private capital in all industries, a substitute with labor in all manufacturing (industry codes 7-27) and services (industry code 28-35) while it is a complement to labor in other industries (industry codes 1-6). Finally, highway capital and intermediate inputs are complements in non-manufacturing industries and substitutes in the manufacturing industries.

[13]In the next phase our study the level of output will be allowed to vary and the new set of results will separate the likely substitutional and expansion effects on private sector inputs of a given increase in highway capital.

[14] The sample period was divided into four sub-periods: period I, 1952-1963; period II, 1964-1972; period III, 1973-1979; and period IV, 1980-1989. In a few industries, the contribution of highway capital to the deceleration of TFP growth between periods II and III was fairly large, but in the majority of industries, there was little or no systematic relationship. The magnitudes of the contribution of highway capital between to the rate of change of TFP periods III and IV were generally very small.

[15] See Jorgenson and Yun (1990)) This distortion effect arises because no country relies extensively on head taxes to finance infrastructure capital. Distortionary taxes (e.g., an income tax) are often used to fund public investments. Therefore, the social cost of additional public capital is the sum of the direct burden of the taxes needed to pay for the infrastructure and the dead weight cost associated with these taxes. The issue of an appropriate cost of investment of highway system require a careful analysis in future research.

[16] Fernald (1992) p. 26

[17] One factor contributing to the growth pattern in highway capital was the sharp rise in the price of gasoline in the 1970s that increased the cost of travel significantly.

Appendix B

ECONOMIC RETURNS FROM TRANSPORTATION INVESTMENT: NINETEENTH CENTURY EXPERIENCES AND CONTEMPORARY ISSUES

by

Charles David Jacobson, Morgan, Angel & Associates

Views expressed here are not necessarily those of Morgan, Angel & Associates

This short bibliography represents a sample of some of the more important works in what is a vast economic and historical literature on nineteenth century transportation infrastructure. More recent scholarship on post World War II infrastructure development is not included.

Fishlow, Albert, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge: Harvard University Press, 1965

In this volume, Fishlow attempts to "quantify the social savings of the railroads and their impact through forward and backward linkages on the various branches of the economy..."[1] Whereas Fogel's Railroads and American Economic Development (published at about the same time) was concerned with whether US could have developed without the railroad, Fishlow asks "How much stimulus did the railroad afford to the economy of the United States and by what means?[2]" Fishlow identifies three major ways in which transportation innovation can be expected to benefit other areas of the economy:

1) Innovations have direct consequences in lower costs of carriage. When costs are lower, resources can be applied to other tasks.

2) Increased size of markets affects production decisions of manufacturers and farmers, by making possible greater specialization and ability to exploit economies of scale elsewhere.

3) Resource demands of building and operating transport systems can themselves stimulate other areas of economy. These in turn might create benefits elsewhere.

Fishlow concludes that before 1859 the direct advantages of the railroad were fairly modest because of the prior development of the canal and the steamboat. These innovations lowered transport costs far more than did the railroad in its turn. But even during this early period, Fishlow concludes railroad investment paid off in social terms.

"... railroad returns to capital, in the shape of net earnings and transport cost savings alone, fully justified the investment even before 1860. Fifteen percent per annum on the investment despite the arbitrary time horizon, and the limited calculation of returns is impressive. It is difficult to imagine the country doing much better than that in any reasonable alternative.[3]"

Fishlow concludes that railroad development played a role in stimulating agricultural expansion and specialization. Demands on the part of railroads themselves, Fishlow concludes, also played a role in disseminating industrial skills through out the economy and afforded stimulus to the development of iron and steel industry. [4] However, these effects were limited.[5] Nor did railroad development stimulate ante-bellum industrialization in the South despite hopes that it do so.

Overall, Fishlow concludes, railroads can not be said to have caused economic growth. Indeed the benefits of railroad development were so great in some cases only because other human and geographical and institutional conditions for growth were already present. Fishlow also concludes that government subsidy and competition amongst railroads themselves tended in some cases toward over-building and wasteful expenditure of resources. [6]

Fogel, Robert William <u>Railroads and American Economic Growth: Essays in Econometric History</u> (Baltimore: Johns Hopkins, 1964)

This is a controversial and influential book. Fogel evaluates the claim that railroads were essential to economic growth in the nineteenth century by setting forth a hypothetical world in which railroads do not exist. Fogel concludes that while railroad development and rates structures could determine the destinies of individual firms and even entire cities and regions, railroads were not indispensable to the economy of the United States during the nineteenth century. Other forms of transportation could and would have been developed more intensively in the absence of railroads. More broadly, Fogel asserts that economic growth can best be understood not as the product of any single kind of technology but of knowledge applied to development of multitude of innovations in a broad range of domains.

Emphasis on the multiplicity of opportunities does not mean that the particular nature of the solutions society selects are without significance. Cheap inland transportation was a necessary condition for economic growth . Satisfaction of this condition did not entail a specific form of transportation. The form by which the condition was in fact satisfied did effect, however, particular features of the observed growth process. In other words, the fact that the condition of cheap transportation was satisfied was satisfied by one innovation rather than another determined, not whether growth would take place, but which of many possible growth paths would be followed.[7]

Goodrich, Carter, <u>Canals and American Economic Development</u> (New York: Columbia University Press, 1961)

Goodrich's collection, first published in 1961, was the product of Columbia University's Graduate workshop on the Economic Development of the Industrial Countries. The aim of the workshop was to reexamine the economic history of developed industrial areas of the world in light of contemporary concerns with Third World development. The essays conclude that, overall, development of canals did make a significant contribution to economic growth in the United States. While the Erie Canal was a spectacular success, many other canals were almost certainly failures no matter how evaluated. Causes of failure included ill-conceived and poorly designed projects and railroad competition.

Hoy, Suellen and Michael C.. Robinson, <u>Public Works History in the United States: A Guide to the Literature</u> (Nashville, TN: American Association for State and Local History, 1982)

This annotated bibliography is an indispensable resource. The work does not cover railroads but contains a good selection of entries on the history of roads, streets, and highways in the United States.

Lee, Susan and Peter Passell, <u>A New Economic View of American History</u> (New York: W.W. Norton, 1979)

This textbook written for advanced undergraduates contains good overview on debates amongst economic historians concerning nineteenth century transportation and economic development. The book also contains extensive bibliographical material.

Rostow, Walter, <u>The Stages of Economic Growth</u> (Cambridge: Cambridge University Press, 1960).

Rostow suggests that largely because of demand for materials, railroads played a leading role in propelling industrial take-off in the United States during the 1840s. The book is largely important as a foil for subsequent scholars who found that elements of the chronology do not fit. Much industrial development took place in the United States, for example, before railroads were significant as either a source of demand for materials or as a form of transportation itself.

Rauch, James E., "Bureaucracy, Infrastructure, and Economic Growth: Evidence from U.S. Cities during the Progressive Era" <u>American Economic Review</u> Vol. 85, No. 4 September 1995.

On the basis of a regression analysis, Rauch finds that investment in road, water, and sewer systems in early twentieth century American cities was statistically correlated with growth in manufacturing employment.

Rose, Mark H. <u>Interstate: Express Highway Politics, 1941-1956</u> (Lawrence: The Regents Press of Kansas, 1979)

This is a detailed historical account of the political maneuvering that culminated in passage of laws establishing the Interstate Highway System. Rose describes tensions amongst engineers concerned with moving the traffic, economic and regional interest groups, and those who viewed highways as means to realize broader planning and urban redevelopment objectives.

Scheiber, Harry N. , The Ohio Canal Era: A Case Study of Government and the Economy, 1800-1861 (Athens: Ohio University Press, 1969)

This is a richly detailed account written by an historian of the development of a major system of canals in Ohio before the Civil War. The book contains much discussion of the effects of canal and later railroad development on patterns of trade. Scheiber finds that the Ohio and Erie Canal completed in 1827 was a "spectacular success" in its contribution to population growth and economic development in the region served. Population and land values increased, farmers enjoyed higher prices for grains and turned to commercial agriculture, and development of manufacturing was stimulated due to lower prices for raw materials and development of water powers from the canal itself. Canals completed in other parts of the state, Scheiber maintains, had similar effects.

ENDNOTES

[1] Alexander Gerschenkron, "Foreword" in Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) viii.

[2] Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) ix.

[3] Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) 301.

[4] Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) 302.

[5] Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) 303.

[6] Albert Fishlow, American Railroads and the Transformation of the Ante-Bellum Economy (Cambridge, Mass, Harvard University Press, 1965) 310.

[7] Robert William Fogel, Railroads and American Economic Growth: Essays in Econometric History (Baltimore: Johns Hopkins, 1964) 237.

REVIEW OF INTERNATIONAL STUDIES OF THE PRODUCTIVITY EFFECTS OF HIGHWAY INFRASTRUCTURE

by

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July 1996

Table C-1
Summary of International Studies of the Productivity Effects of Highway Infrastructure or Other Capital

Study	Country/Sample	Type of Estimation	Sector or Output Measure	Public Infrastructure		Private Inputs		Notes
				Type	Elasticity	Type	Elasticity	
Mera 1973, '75	Japan 8 regions 1954-1963 (time series/cross section)	production function, Cobb-Douglas	primary secondary tertiary	transportation and communication ; 3 other categories	0.35** for transport and communications in secondary; 0.39-0.42 in tertiary; transp. and comm. Not used in primary	capital labor	K: 0.15-0.33 L: 0.55-0.85, according to sector	
Elhance and Lakshmanan 1988	India national 1950-79 (time series) and 6 states 1970-71 (cross section)	cost function, translog, with endogenous private adjustment to publicly supplied infrastructure	manufacturing value added	economic infrastructure (roads, rail, electric capacity); social infrastructure (hospital beds, etc.)	economic infrastr. cost elasticities; at state level, -0.04 to -0.47; at national level -0.01 to -0.03	capital labor energy materials		adjustment period of about 5 years
Johansson 1992 Johansson and Karlsson 1994	Sweden 280 and 284 munic. 1980-88 (time series/cross section)	production function, Cobb-Douglas	aggregate income, industry-level income	highway capital public transit capital road accessibility	highway 0.12-0.18; public transp. 0.18-0.20; road accessibility 0.20-0.27	capital labor	K: 0.47-0.50	adjustment periods of 14 -26 years, depending on industry
Seitz 1993	Germany 1970-89 (time series/cross section)	cost function, translog, industry fixed effectime series	real output, 31 industries	road mileage road capital	negative and significant	capital labor		roads complementary to private capital, substitute for labor; these effects small
Seitz 1994	Germany 1970-89 (time series/cross section)	cost function, translog, industry fixed effectime series	real output, 31 industries	public capital "core" public capital	on demand for K: 0.36 on demand for L: -0.13 to -0.15	capital labor	rental elasticity of K demand, -0.04; wage elasticity of L demand, -0.09	

Table C-1
Summary of International Studies of the Productivity Effects of Highway Infrastructure or Other Capital (continued)

Study	Sample	Type of Estimation	Sector or Output Measure	Public Infrastructure		Private Inputs		Notes
				Type	Elasticity	Type	Elasticity	
Conrad and Seitz 1994	Germany, 1961-89 (time series/cross section)	cost function, translog	gross output, 3 sectors: manufacturing, construction., trade and transportation	public capital	negative and significant	capital labor material		estimated shadow price of public infrastructure approx. half of user cost of private capital; decrease in pub infrastr. Partially responsible for observed productivity decline
Lynde and Richmond 1992	United Kingdom aggregate, 1958-89 (time series)	cost function, translog	manufacturing	public capital	significant cost reduction effect	capital labor		public capital complemntary to private capital; aggregate constant returns to scale with public capital
Lynde and Richmond 1993	United Kingdom aggregate 1966: 1-1990; 2 (time series)	cost function translog (cointegrated)	manufacturing value added	public capital	significant cost reduction effect	capital labor materials		public capital contributes 17% of manufacturing productivity growth
Anderson, Anderstig and Harsman 1990	Sweden 70 commuting regions, 1970 and 1980 (cross section)	production function, variable returns to scale	aggregate income	main roads railroads airport capacity accessibility	roads significant in 1980; rail significant in 1970; airports significant only when interacted with R&D	capital labor	K: 0.25 L: 0.28; 0.57-0.75 combined with knowledge capital	
Prud'homme	France, 22 regions, 1981-88 growth (cross section), 1988 (cross section)	production function, Cobb-Douglas	aggregate income/L	public capital	significant only when measured per unit of L times land area	capital/labor	K/L:0.20-0.26	

Table C-2
Summary of U.S. Studies of the Productivity Effects of Highway Infrastructure or Other Capital

Study	Sample	Type of Estimation	Sector or Output Measure	Public Infrastructure		Private Inputs		Notes
				Type	Elasticity	Type	Elasticity	
Ratner 1983	U.S. aggregate, 1949-73 (time series)	production function, Cobb-Douglas	private business sector output	public capital: non-military, gov't owned equipment and structures	0.05 - 0.06	labor/capital, capital adjusted for capacity utilization	L: 0.71-0.72 K: 0.22	
Costa, Ellson and Martin 1987	U.S. 48 states, 1972 (cross section)	porduction function, translog	all sectors manufacturing non-agriculture	state and local public capital	0.20 for all sectors, .19 for manufacturing, 0.21 - 0.26 for non-agr	capital labor	K: -0.06 - 0.11 L: 0.77 - 1.02	public capital complementary to labor
Keeler and Ying 1988	U.S. 9 regions, 1950-73 (time series/cross section)	cost function, translog	trucking industry	federal-aid highway capital stock	cost elasticity -0.07	capital, labor fuel, other materials and services		
Deno 1988	U.S. 36 metropolitan areas, 1970-78 (time series/cross section)	profit function, translog	manufacturing	highways and bridges; water; sewer	output supply elasticity of highway / bridge 0.31-0.57; 0.06 (not sig.) in declining regions	capital labor		highway capital complementary to private capital in growing regions; complementary to labor in full sample
Duffy-Deno and Eberts 1991	U.S. 28 metropolitan areas, 1980-84 (time series/cross section)	simultaneous equations: personal income and public investment	per capita personal income	public capital	personal income elasticity of public capital 0.08	capital labor energy		
Aschauer 1989	U.S aggregate, 1949-85 (time series)	production function, Cobb-Douglas	GNP/private capital	non-military public capital and core public capital	non-military 0.39 core 0.24	labor/ private capital	0.38	
Munnell 1990	U.S. aggregate, 1948-87 (time series)	production function, Cobb-Douglas	GNP	core public capital	0.31 - 0.39	capital labor	K: 0.56 L: 0.11	
Aschauer 1990	U.S. 48 states (cross section)	determinants of average annual growth rate	state per capita income	average total highway mileage, 1960-85; disaggregated into rural and urban mileage	total: 0.22-0.37 rural: 0.24-0.40 urban: 0.10-0.17			higher pavement quality contributes to growth; vehicles/highway mile as congestion measure retards growth

Table C-2
Summary of U.S. Studies of the Productivity Effects of Highway Infrastructure or Other Capital (continued)

Study	Sample	Type of Estimation	Sector or Output Measure	Public Infrastructure		Private Inputs		Notes
				Type	Elasticity	Type	Elasticity	
Eisner 1991	U.S., 48 states, 1970-86 (time series, cross section, and time series/cross section)	production function Cobb-Douglas and translog	GSP	public capital; highway capital, water and sewer, other	public capital insignificant, highway 0.05-0.07 in time series; public capital 0.16, highway 0.06 in cross section	capital labor	K: 0.29 L: 0.77	uses data from Munnell 1990; estimates of first differences sensitive to scale constraints
Tatom 1991	U.S. aggregate 1950-88 (time series)	production function, translog, 1st differences	private business sector output	public capital	0.03, not significant	capital labor energy	L/K: 0.69 E(price): -0.06	energy price variable derived from 1st order condition on energy use
Garcia-Mila and Mcguire	U.S. 48 states, 1969-83 (time series/cross section)	production function, Cobb-Douglas	GSP	highway capital	0.04	capital structures, capital equipment labor	total K: 0.47 L: 0.36-0.45	
McGuire 1992	U.S. 48 states, 1969-83 (time series/cross section)	production function, Cobb-Douglas (state fixed effects); translog	GSP	highway capital	C-D (fixed eff.): not significant Translog: 0.24	capital labor	K: 0.23-0.46 L: 0.70-75	return to scale of 1.2-1.3 in state fixed effects model; CRS in random effects model
Pinnoi 1992	U.S. 48 states, 1970-86 (time series/cross section)	production function, Cobb-Douglas	GSP	highway capital	0.06 - 0.08	capital labor	K: 0.30 L: 0.70	first-differencing to correct measurement errors in public capital yielded insignificant highway output elasticities
Jones, Miaow, Lee and Rickert 1993	U.S. 48 states, 1983-89 (time series/cross section)	production function, Cobb-Douglas, 5-eqn system	GSP/L	lane mileage, vehicle miles traveled, separate urban and rural, different groups of highway classes	VMT: 0.16-0.23 LM, total: 0.09-0.14 urban VMT, LM: positive rural VMT,LM: negative	capital/ labor	K/L: 0.36-0.38	endogenous congestion and VMT
Moomaw and Williams 1991	U.S. 48 states, 1954-76 (time series/cross section)	multifactor productivity	manufacturing	highway density	significant positive effect			use regional dummies with state data

Table C-2
Summary of U.S. Studies of the Productivity Effects of Highway Infrastructure or Other Capital (continued)

Study	Sample	Type of Estimation	Sector or Output Measure	Public Infrastructure		Private Inputs		Notes
				Type	Elasticity	Type	Elasticity	
Hulten and Schwab 1991	U.S. 9 regions, 1951-76 (time series)	multifactor productivity	manufacturing	none		capital labor		no observed role for public infrastructure in different interregional growth rates
Hulten and Schwab 1991	U.S. 9 regions, 1951-86 (time series)	multifactor productivity	manufacturing	public capital	not significant	capital labor materials		model predicts significant coef.ficient on K if public capital operates through production function.; but K coef.ficient is significant and public capital coefficient is insignificant; interpretations unclear
Carlino and Mills 1987	U.S. approx. 3000 counties, 1970-80 growth (cross section)	determinants of county employment and population growth, simultaneous equation estimation	total employment, manufacturing employment, population	interstate highway density	over decade: 0.06 total employment; 0.06 manufacturing employment.; 0.03 population			
Mills and Carlino 1989	U.S. approx. 3000 counties, 1970-80 growth (cross section)	determinants of county employment and population growth, simultaneous equation estimation	total employment, manufacturing employment, population	interstate highway density	over decade: 0.54 total employment.: 0.17 population			

Note- all reported coefficients are statistically significant unless explicitly noted otherwise
Source: Dr. T.R. Lakshmanan, Director, Bureau of Transportation Statistics, USDOT

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