2009

Understanding the Contribution of Highway Investment to National Economic Growth: Comments on Mamuneas's Study

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Draft

August 31, 2009

Prepared for the
Federal Highway Administration
Department of Transportation

I. Introduction

Since the early 1990s, various researchers have attempted to answer the question: "What is the rate of return of highway investments to the economy?" This follows from the simple proposition that highways provide the arteries for the flow of raw materials, and intermediate goods to producers and access to employment and markets for consumers. Without a highway system producers would not be able to obtain economies of scale to obtain the most efficient operation. Many economists agree that the rate of return to highways during the period 1950 - 1970 exceeded the rate of return available to alternative investments.

Recent studies have indicated that the rate of return to highways has decreased following the initial boost provided by national connectivity. There is strong debate about the actual level of returns in the late 90's to the present day. The level becomes critical because some studies show the rate near or below the rate of return available from alternative investments. The Federal Highway Administration (FHWA) of the U.S. Department of Transportation seeks to continue to provide the best information available to policy makers to understand the benefits and trade-off involved with alternative uses of the scarce federal resources.

To that end, the Theofanis P. Mamuneas recently completed an update of his highway benefit research for the FHWA. During the 1990s Prof. Mamuneas conducted several studies with Prof. Nadiri based on a general equilibrium approach to modeling the returns to highway investments accounting for both consumer and producer benefits. This paper endeavors to place the most recent study authored by Prof. Mamuneas in context with previous results and results from alternative methodologies and data sets. Each study examining the returns to highways employs complex econometrical and data intensive modeling efforts. The studies also yield different and sometimes conflicting results, even though all employ generally accepted economic techniques. Policy makers need a technically skilled and unbiased review of the field in order to use the results of this literature for policy decisions.

The purpose of this paper is to review and summarize current literature relevant to contextualizing the recent update by Mamuneas to the previous Nadiri-Mamuneas estimates of the returns to highway investments. To provide this context, the paper will first provide an overview of the conceptual relationship between highways and output. The next section describes the highway capital stock estimated by Fraumeni and used by Mamuneas. Next, the paper describes the study conducted by Mamuneas and carefully analyzes the results for consistency within the modeling framework and in context with other studies. The paper then briefly summarizes the broad range of estimates from the literature to offer additional context. Finally, the paper offers an overview of the issues that still need to be addressed to provide more definitive estimates.

II. Conceptual Framework of the Relationship between Highways and Economic Growth

There is little doubt that highways are a major part of the infrastructure that supports a developed market economy. The majority of the nation's commodities are shipped by highways. Of the 13 billion tons of products shipped in 2007, 69 percent were shipped by truck. When the value of shipment is used to measure commodity flows, trucks account for transporting 71 percent of the $11.8 trillion of products shipped. Between 1993 and 2007, the use of trucks has increased from 53 percent to 69 percent. Federal, state, and local governments spend about 2 percent of GDP on highway investments each year, which in 2005 amounted to about $160 billion.

Despite this *prima facie* case for the importance of highways, measuring the contribution of highways to economic growth is not straightforward and estimates vary depending upon the methodology, time period, and measures of economic growth. Three methodologies have been employed to estimate the contribution of highways to various measures of economic growth. The first approach estimates the average return over an extended period of time by matching outputs with the inputs used to produce them. The work by Fraumeni (2007) is an excellent example of that approach. A second approach is benefit-cost analysis, which is typically used to estimate whether or not the benefits of a specific project exceed the cost. The third approach estimates the marginal benefits of infrastructure investment. Using econometric techniques, it typically differs from the other two by addressing the question of the benefit of an additional dollar (or other unit) of infrastructure investment. Comparing the marginal benefit with the marginal cost of infrastructure provides insight into whether the economy is under or over invested in highway stock. It is the third methodology that Mamuneas uses to estimate the contribution of highways to national economic growth and thus is the focus of this study.

Before examining these studies, however, it is important to understand the rather complex relationship between transportation and economic growth. These relationships are not well quantified or understood, and many of the econometric studies that estimate this relationship devote little space to laying out the linkages. To establish these linkages, two distinct aspects of the nexus between highways and economic growth should be considered. The first component is the characteristics of the highway system. The idea here is that highway capital stock is a proxy for the services that highways provide. Highway services include getting people or goods from one place to the next with expected speed, reliability, safety, and comfort. Yet, highways cannot produce these services alone; they are only one input in the transportation equation. Highways must accommodate automobiles, trucks and other modes of transportation, which are provided primarily by the private sector, to generate the services. But neither input—highways or vehicles—can generate transportation services without the other. Since the characteristics of highway capital stock vary over time and across regions and this variation affects the flow of services, these differences should be taken into account when estimating highway capital stock. The second aspect is to estimate the effect of the services, as proxied by highway capital stock estimates, on economic outcomes. The first step is basically internal to the highway system, relating the size, type, and condition of the facility to services (or outputs) that the highway system produces. The second step relates the output of the facility to conditions and activities outside the facility.

Key highway characteristics are measured in lane-miles, grade, tightness of curves, pavement condition, number of bridges, bridge load capacity, bridge conditions, or volume capacity. Direct outputs of highway facilities are access, mobility, movement of goods, reliability of service, and safety. The first step as outlined above is to relate lane-miles, grade, tightness of curves, etc., to its ability to produce access, mobility, traffic flow. The second step is to estimate the effect of these outputs on broader outcomes, such as economic productivity, job creation, income generation, improved public health and safety, environmental quality, residential and business location and subsequent job opportunities and income inequality. In this way, the characteristics of the highway facility are related to economic outcomes, but with an appreciation for the intermediate step that the efficiency in which highway infrastructure produces highway services matters.

In addition, these outcomes are geographically distributed, with the scope of possible effects radiating from the location of the facility. For example, job creation may occur at the interchange of two major highways, because of the increased access to transportation services, which increases reliability and reduces freight costs. Lower freight costs, in turn, make the area more attractive to businesses. An increase in business activity attracts other businesses that seek close proximity to suppliers or customers. The outcome of these activities spreads beyond the immediate vicinity of the highway interchange and the system. Increased vehicle usage of a highway system may also affect a broader geographical area, such as an increase in pollution affects an area's air shed.

The type of highway investment is also important to consider. For example, the ability of $1 million of investment in highway infrastructure to generate economic outcomes depends upon the efficiency in which the resulting facility produces output. Size, condition, and type of existing infrastructure will have a bearing on output. A $1 million investment to add a lane to a highly congested segment of highway will likely have a greater effect on improving traffic flow than a $1 million investment in adding a lane to a segment which is grossly underutilized. Furthermore, the same dollar amount of investment in improving pavement conditions may not improve traffic flow to the same extent as adding another lane. The subsequent increase in traffic flow then affects economic outcomes, such as job creation or income growth.

III. Constructing Highway Capital Stock (Fraumeni, 2007)

Estimates of highway capital stock are critical for obtaining accurate estimates of the contribution of highways to economic growth. Highway capital stock estimates reflect the physical assets in place at a point in time, based upon the investments (outlays) that were used to construct the highways, minus the depreciation (retirements) and deterioration (wear and tear) of the assets over time. Gross capital stock is calculated by simply adding up investment or expenditure on highways and deducting retirements or assets withdrawn from service. Net capital stock, which is the stock concept (not necessarily the practice) used in studies estimating productivity, requires that the stock or investment be reduced by the amount of wear and tear on the asset as it ages and asset retirements. The sum of wear and tear, which is termed loss in efficiency, and retirements is deterioration.

Most studies at the national level use estimates generated by the Bureau of Economic Analysis, which includes depreciation (retirements) but not deterioration. Fraumeni revised these estimates using more recent information and revised estimates of pavement conditions, deflators and asset lives. By including pavement conditions, reflective of wear and tear, she estimates productive highway capital stock. BEA estimates, which do not include deterioration, are considered wealth or gross capital stock. The Mamuneas study uses the highway capital stock estimates created by Fraumeni (2007). Fraumeni (2007) updates the estimates she created in 1999, using the same methodology. The 1999 study produced highway capital stock estimates from 1921 to 1995, and the 2007 study extends those estimates through 2005.[1] Therefore, it is worthwhile highlighting the methodology Fraumeni employed in estimating highway capital stocks.

Fraumeni's construction of highway capital stock uses four components: 1) capital outlays and outlay percentage splits, 2) deflators, and 3) pavement curves. Fraumeni uses total capital outlay data from *Highway Statistics*, compiled and published by the Federal Highway Administration. Highway capital outlays are disaggregated into:

- Interstate System
- Non-interstate State System
- Local System

by

- Right-of Way (ROW)
- New construction or reconstruction
- Other than new construction or reconstruction,

and by

- Pavement
- Grading
- Structures.

The allocation of outlays into these various components differs year-by-year reflecting changes in how capital outlays are spent. Pavement conditions are reflected in net efficiency pavement curves. The estimation of net efficiency curves begins with the construction of a pavement serviceability index – time relationship based on the intensity and type of traffic, and the road system: Interstate, Non-Interstate State, or Local System. Pavement serviceability determines the pavement condition, which in turn indicates how productive pavement could be. Net efficiency, which is the basis for productive capacity, is reduced if pavement conditions reduce speed or increase motor vehicle operating cost.

[1] Fraumeni (2007) states that the only difference in the two series of highway capital stock estimates is a slight difference due to different BEA deflators (p. 31).

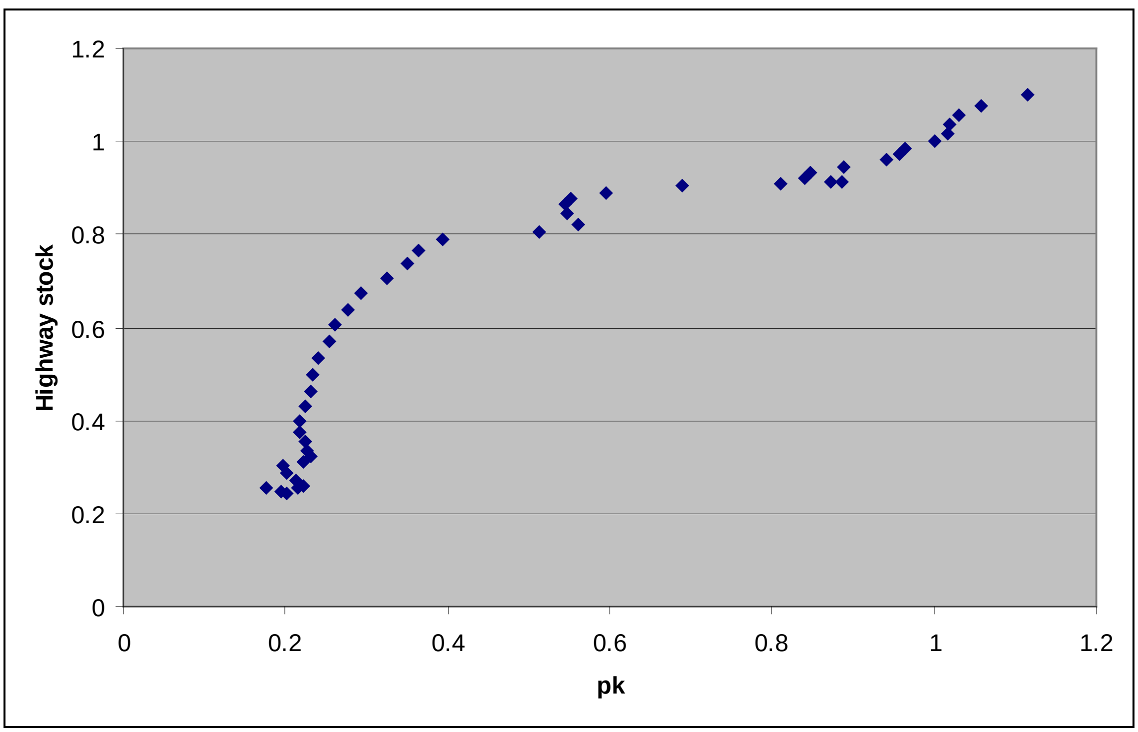
Fraumeni reports that pavement net efficiency on average never gets below 93% for the Interstate System curves; 84% for the Non-interstate System curves; and 72% for the Local System curves (Fraumeni, 2009, p.3).

Fraumeni also experimented with adjusting existing bridge capital stock estimates by the quality and condition of the structures. She found that adjusting the bridge stock estimates for quality increased the annual rate of growth of the highway structure series by about four-tenths of percentage point from 1983-1996 and by about two-tenths of a percentage point from a 1996-2006.

In comparing her 2007 estimates with her 1999 estimates, she found little difference between the two after the 1950s. In the sixties and seventies, the difference is one tenth of one percent and in the eighties and nineties it is one-half of one tenth of a percent or less. She attributes these differences, albeit small, to differences in the implicit price deflators, which depend almost exclusively on the BEA deflators (Fraumeni, 2007, p. 31).

Fraumeni (2007) noted much larger differences between her highway capital stock estimates and BEA's. The differences relate to annual rates of growth as well as the level of the stock. BEA's estimates produce a larger capital stock than Fraumeni's, particularly from 1930 through 2000. The growth rates of Fraumeni's estimates are significantly lower than those of BEA's estimates from the 1970s and 1980s and then are higher thereafter. She attributes this difference to deflators and differences in the component series underlying her estimates (Fraumeni, 2007, p. 33).

Figure 1: Relationship between Highway Capital Stock and the Acquisition Price



Source: Fraumeni (1999)

Figure 1 shows the relationship between Fraumeni's capital stock estimates and the acquisition price, which is the BEA price deflator. Both are normalized to be one in the year 1990. Since the acquisition price increases nearly every year (except for a brief period in the early 1980s), the figure can also be viewed as depicting a time series moving chronologically from left to right. One can see the tremendous growth in the highway system in the early years. Highway capital stock increased 212 percent while the acquisition price increased 79 percent. After that time (from 1973 on), highway capital stock increased 40 percent while the price increased 183 percent. Perhaps much of the slowdown in the increase in highway capital stock was the need to allocate increasing resources to replacing and maintaining the system that was put in place during the pre-1973 period.

IV. Mamuneas (2008)

The purpose of the Mamuneas (2008) paper is to update the previous study that Mamuneas conducted with Nadiri in 2003 that estimated the contribution of highway investment to national economic growth. The primary difference between this paper and the previous one is the use of the most recent NIPA data from BEA and the most recent highway capital stock data constructed by Fraumeni (2007). The methodology used in this paper is the same as the previous paper. It uses a general equilibrium approach to estimate the effect of highway infrastructure on the consumption and production of privately provided goods and services. The primary purpose for updating the paper is to calculate new net rates of return of highway capital and to see if the rate of return of highway capital continues to converge with that of private capital by taking into account five more recent years of data—2001 to 2005.

Methodology

Mamuneas's approach posits that consumers are the final beneficiaries of highway investment. An increase in highway infrastructure may increase transportation services such as shorter commuting times, more reliable arrival times, safer trips, and less wear and tear on privately owned vehicles. Increases in these benefits may be reflected in the consumption decisions of consumers, such as more leisure time, housing decisions (location and size of houses), purchase of motor vehicles, and transportation-related services primarily servicing privately-owned vehicles. Producers of private goods may also be affected by highway investment. Highways are considered an unpaid input in the production function, reducing the cost of production. Highways can also affect the use of other inputs and can expand scale by accessing greater market area. Therefore, highways affect the price of private inputs, which in turn ultimately affect the consumption decisions and well-being of consumers.

The methodology entails minimizing society's loss function due to extracting funds from the private sector to build highway infrastructure. This is a typical approach for evaluating the distorting effects of taxes on the economy. However, it may be better to think of the problem as one of maximizing the social welfare function subject to production relationships and government financing. The optimality conditions are the same, so even though the econometrics are more tractable, thinking of the results in this context may help provide a better understanding of their implications.

Investment Decisions Rules

The primary result of this approach, and of the paper, is to derive conditions for the optimal investment in highway infrastructure. The conditions state that the marginal social value of an additional unit of highway investment should equal the marginal social cost of producing a unit of highway investment. The social marginal value is the value each consumer places on an additional unit of highway investment, summed over all consumers. If the social marginal value is greater than the social marginal cost, then the quantity of highway infrastructure is less than desired (underbuilt) and additional investment is warranted, according to the decision rules generated from this methodology. If the social marginal value is less than social marginal cost, then highway infrastructure is overbuilt, and no additional investment is warranted.

Estimating the Value and Cost of Highway Infrastructure

Estimating the contribution of highways to these consumption and production decisions is difficult. Typical benefit-cost analysis evaluating tangible outcomes, such as whether it is economically viable to produce a marketed good or service, uses market-determined prices as the basis to value benefits and costs. However, the value of highways is less tangible and is not priced by the market. Therefore, the value has to be imputed by estimating how highway investment changes consumption and production decisions, either through changes in relative prices or through changes in income to consumers. This approach estimates shadow prices for highway investment, also known as a consumer's willingness to pay for an additional unit of highways.

In addition, the fact that highways are financed by taxing motor fuel can distort economic decisions, leading to additional social costs. The distortionary effects must also be factored into the social marginal cost of providing an additional unit of highway, which Mamuneas includes in the analysis.[2]

In order to estimate social marginal value (consumers' willingness to pay) of highway capital stock, Mamuneas estimates an expenditure function with housing, motor vehicles, transportation services, residual consumption, and leisure as elements of a representative consumer's well-being. This results in estimates of the marginal benefit of highways to consumers.

Mamuneas also estimates a profit function in order to estimate the effect of highway infrastructure on the cost and thus the price of each of these consumption items.

[2] It appears that Mamuneas includes more taxes than fuel taxes in constructing the distortionary factor. He defines the distortionary factor as "the deadweight loss associated with the financing of public infrastructure capital" (p. 41). He includes taxes in this factor that are not used to finance highways, which may distort the computation of the rate of return of highway capital stock.

Highway-induced changes in price also affect consumer consumption decisions and their well-being.

The crux of Mamuneas's methodology is to derive the optimality condition for highway capital investment for the whole national economy. The optimality condition states that the social marginal benefit of capital (for both consumers and producers) equals the social marginal cost. The marginal benefit for consumers is the amount the consumer would be willing to pay (in the form of reduced consumption) to receive an additional unit (dollar) of highways capital stock. Conversely, it is the amount the consumer would need to be compensated for one less unit of highway capital stock. For the producer, the marginal benefit is the increase in profits (or reduction in costs, holding output constant) resulting from a unit increase in highway capital stock.

The marginal benefit equations are derived from an expenditure function for consumers and a profit function for producers. Taking the derivative of each function with respect to highway capital stock yields the marginal benefit equation. What drives the model is the variation over time in highway capital, prices of outputs and inputs, and a quadratic time trend. Both the expenditure function and profit function are nonlinear in the key variables, and so are the marginal benefit functions. Therefore, the relationships are quite complex. The estimates of the parameters are also constrained by conditions that must hold in order for the functional forms to make economic sense in reflecting expenditure functions and profit functions.

Econometric Issues

Estimating the social marginal value and social marginal costs is difficult. It is difficult to assemble the appropriate variables to provide a sufficiently complete coverage of consumer and producer decisions while providing the detail necessary to show the effects of highways on these decisions, which can be quite subtle. There are also econometric concerns when using time series data to estimate expenditure functions and profit functions. These problems have been well-documented in the literature, particularly the literature on estimating the effect of highways on production relationships. Since the critical result of the paper is to determine if two imputed numbers—social marginal value and social marginal cost—are close to being equal, the precision of these estimates is critical. Issues regarding the stationarity of time series data, particularly GDP-related variables have been well-documented and have been shown to lead to spurious correlation and inflated estimates of precision. In addition, the endogeneity of input prices and the strong correlation among these prices can lead to inconsistent estimates that distort the estimates of social marginal value and marginal costs.

Mamuneas addresses these issues in the estimation. He uses instruments to correct for endogeneity and tests for parameter stability of the final model and concludes that the final estimates are efficient and consistent. He experimented with several sets of instruments and finds that the parameter estimates for producers and marginal benefit estimates for producers are sensitive to the instruments used in the estimation. In fact, Mamuneas attributes the large disparity in estimates of the marginal producer benefits to the choice of instruments.

Mamuneas tackles the issue of non-stationarity through the overall strategy of estimating a system of structural equations, a set of equations for the consumption side and a set of equations for the production side of the model. Because of non-linearity in the variables, the standard approaches for handling non-stationarity do not apply. However, Mamuneas points to the works of Hsiao (1997) and Johnston and DiNardo (1997, p.317), which show that non-stationarity is not so critical when a system of equations is estimated.[3]

Results

The paper for the most part replicates the results of the previous paper, with one notable exception. The estimates of the production function appear to be problematic. The model specification used in Mamuneas and Nadiri (2003) yields estimates that show a strong increase in marginal benefits of producers during the past two decades, which strongly diverges from the declining marginal benefits found in the previous paper. Mamuneas discusses the large difference in the estimates of the marginal benefit to producers that result from adding a few more years to the time series. According to his analysis, the source of the difference appears to be the use of instruments to account for endogeneity of some of the factors in the profit function. While he finds a specification, after trying several, that yields results similar to what he found in the previous paper, the fact that the results are so sensitive to different specifications by adding only a few additional years of data is somewhat puzzling and disconcerting. While the sensitivity of estimates of production relationships to model specifications is not unusual in the literature, the sensitivity to model specification found in this paper underscores the fact that such estimates should be considered approximations and not precise measures of valuation. Furthermore, they should be compared with other estimates using different methodologies in order to check their credibility. I will discuss the results for consumers and for producers separately before combining them to show the total returns to highway capital for the national economy.

Consumers

As mentioned earlier, an increase in highway infrastructure may benefit consumers by providing shorter commuting times, safer trips, more reliable arrival times, and less wear and tear on their automobiles. These benefits in turn may affect consumer decisions regarding leisure time, housing decisions (size and location), purchase of automobiles, and addition time on the road for discretionary purposes. In his analysis Mamuneas estimates the effect of highways on five types of consumption decisions:

[3] Hsiao, G., 1997, "Statistical Properties of the Two-Stage Least Squares Estimator under Cointegration," *Review of Economic Studies*, 64, 385-398. "In a structural approach one needs to worry about the issues of identification and simultaneity bias, but one need not worry about the issues of nonstationarity and cointegration. All one needs to do in structural model building is to follow the conventional wisdom." (Hsiao 1997, p. 395

consumption, housing, motor vehicles, transportation, and leisure. Consumption and transportation are defined as expenditures divided by their corresponding price deflators so as to yields constant dollar annual flows of expenditures. Housing and motor vehicles are constructed as stocks, using the perpetual inventory method, which reflects the actual quantities of housing and motor vehicles in place in any one year. Leisure time is the opposite of time spent working, by subtracting total hours worked from the total number of hours available for leisure and work.

The first set of results estimates the relationships between highway capital and these five consumer decisions, expressed as substitutes or complements. Two goods are considered substitutes if an increase in the quantity of one decreases the quantity of another. Two goods are considered complements if an increase in the quantity of one increases the quantity of the other. These two relationships are the net result of a substitution and expansion (or income) effect. Mamuneas finds that consumption, housing, and motor vehicles are substitutes with highways and that transportation and leisure are complements. With respect to motor vehicles, additional highway stock reduces the stock of motor vehicles. It is evident that the expansion effect is not sufficient to outweigh the substitution effect of fewer motor vehicles. In fact, the expansion effect is quite small in all five cases, leaving the substitution effect to dictate the total effect of highway capital on each of the five expenditure categories.

Table 1: Elasticities of Highway Capital with respect to Consumer Expenditures

Household Decision	Substitution Effect (Hicksian)	Expansion Effect (Income)	Total Effect (Marshallian)	Substitute/ Complement
Consumption	-0.238*	0.046	-0.191*	Substitutes
Housing	-0.413	0.014	-0.399	Substitutes
Motor Vehicles	-0.411	0.037	-0.373	Substitutes
Transportation	0.497	0.020*	0.517	Complements
Leisure	0.495*	0.003	0.498	Complements

Source: Mamuneas (2008), table 3, p. 91. Note: * denotes that the value of the estimate is twice that of its standard deviation.

Consideration of the reasonableness of these estimates helps to substantiate the credibility of the rate of return estimates, which are the focus of the analysis. The rate of return estimates are derived from the same parameter estimates and will be discussed later. Of the various relationships estimated in the paper and shown in Table 1, the relationships between highway capital stock and motor vehicles and housing appear to be the most problematic, running contrary to expectations and to much of the literature on this topic. Before making comparisons, it should be noted that the values of only two estimates of the substitution effect—consumption and leisure—are more than twice the magnitude of its standard deviation. The others are not precisely estimated.

Looking first at the positive relationship between leisure and highway stock, the estimates suggest that more highways increase leisure time. This may come about because of reduced commuting times due to less congestion and more direct routes between home and work. However, the relationship may be more subtle than this simple statistical relationship can delineate. For example, Levinson and Kanchi (2002), using the 1990 and 1995 Nationwide Personal Transportation Surveys and Federal Highway Administration data, found that total travel time did not significantly change in that five-year time period. Rather, as a result of additional highway capacity, there was a significant change in activity duration: workers spent less time working and commuting and more time at home doing other activities. Those not working, on the other hand, traveled more and spent more time shopping and at home, but less time at other activities. The authors concluded that increased highway capacity provides real gains to people because time, not travel time, is the deciding factor for choosing activities.

The relationship between consumption and highways is also strongly negative, suggesting that an increase in highways reduces consumption. This result suggests that the financing and construction of highways has reduced the spending potential of consumers with public spending crowding out private spending. The positive income effect, perhaps from shorter travel time, is not of sufficient magnitude to overcome the substitution effect. This represents the willingness to pay (in lower consumption) by consumers of an additional amount of highway infrastructure. Taking the negative of this value translates it into the value consumers place on additional highway stock. There is also an accompanying expansion effect of additional highway stock, which may come about because of less commuting time. Less time on the road may mean more time at work (earning additional income). However, the estimates reveal that the expansion effect is small relative to the substitution effect, -0.238 versus 0.046.

Motor vehicle stock is also negatively related to highway stock. This seems counterintuitive since an increase in highway capacity and thus relatively less congestion and greater reliability in travel should encourage greater use of motor vehicles. Perhaps in the short run, the fixed stock of motor vehicles could be driven more and the relationship appears negative. But in the long-run, which is the focus on this study, the stock of motor vehicles would have to increase. As mentioned previously, this estimate is not statistically significantly different from zero, so it could be that there is no relationship between the two, which is also difficult to comprehend.

The relationship between housing and highway capital is at face value also difficult to understand. Mamuneas finds that an increase in highway stock decreases housing stock. This result differs from that found in Mamuneas and Nadiri (2003), using similar data and methodology but only through 1995. Mamuneas defends the difference in results between the two papers by suggesting that housing demand and supply may have changed during the most recent years. Even so, the change in the relationship between highways and housing would have to be dramatic to reverse in 10 years a pattern that persisted for at least 45 years prior to that. This sensitive in results may reflect the instability of results, given the complex non-linearity of the estimation equations.

However, a review of the literature on the direct relationship between housing activity and location and highway projects shows that these studies appear to support the positive relationship found in Mamuneas's study. Several studies have shown that highway capacity expansion stimulates development activity, both residential and nonresidential, in the corridors served by the expanded facilities" Hansen, Gillen, and Puvathingal (1998) examined the eight corridors in California and found that single and multi-family residential building increased sharply immediately after construction of the corridors and then slowed over time. Siethoff and Kocekelman (2002) looked at the link between property values and highway expansion in a single corridor in Austin, Texas, in which the highway had been upgraded from an unlimited-access to a wider, limited-access facility with frontage roads and also found that the timing of the project was correlated with an increase in housing prices. However, Boarnet and Haughwout (2000) in reviewing available studies at the time concluded that highways may have more of a distributional effect that an aggregate on housing activity. Evidence suggests that highways influence land prices and housing activity near the highway construction but may have drawn this activity from areas without the highway activity. Therefore, from a national perspective highways may not have an effect on housing activity and the most defensible result is one that is not statistically significantly different from zero, which is what Mamuneas found in the most recent paper.

Producers

Mamuneas estimates a profit function for producers, which yields estimates of the relationship between various categories of output and inputs and highway capital. In all categories of outputs except exports, an increase in highway stock increases output. For the two inputs, highway capital has a positive relationship, indicating that it is a complement to the two inputs. As Mamuneas describes, many studies that estimate production, or cost functions, with highways included as an unpaid input find highway capital and labor to be complements. Mamuneas's use of imports as a factor of production is quite unusual in the literature and there are no studies to my knowledge with which to compare results.[4]

In general, examining the relationships within the expenditure functions and within the production functions provides some sense of the reasonableness of the estimates. Estimates of the relationship between highways and consumption categories reveal some anomalies that are difficult to reconcile with the existing literature. Most notable are the relationships between highways and motor vehicles and highways and housing. They could be dismissed as unimportant because the estimates are not statistically significant. However, the same coefficients that yielded the values of these elasticities are also used to calculate marginal value and rate of return. While such anomalies do not nullify the results, they do call for closer scrutiny of the estimates.

[4] One could justify using imports in the production function if they were all intermediate products used in the production process. However, that is definitely not the case, with automobiles and other finished products comprising a large share of imports.

Marginal Benefits of Highways

Consumers

The marginal benefit of consumers is derived from estimates that relate consumer expenditures to highway capital (g), prices and income. These relationships (in that the parameter estimates are time invariant) are fixed for the entire time period over which the analysis is performed (1948-2005). The estimate of the marginal benefit of consumers varies over time because the variables (highway capital, prices, and income) it is based on vary over time. A time trend is included in the estimation, but that reflects a shift in preferences over time, not a shift in the relationships between expenditures and the exogenous variables mentioned. The important point here is that the relationships are time invariant but the marginal benefits (and thus the rate of return) vary over time because of the change in the explanatory variables over time.

In the paper, Mamuneas reports marginal benefits for consumers and producers in ten-year averages. These estimates are replicated in table 2. The average value of consumer marginal benefit over the entire period from 1949 to 2005 is 0.052. The values from the table appear to be stable over most of the time period with the largest deviation from the mean occurring in the 1980s and 1990s. The values in the table represent consumers' willingness to pay for a dollar of infrastructure. On average, consumers are willing to pay $0.057 for each dollar of additional infrastructure. Is this a reasonable number? It is difficult to assess since few if any studies have used this approach to estimate the marginal benefit of highways to consumers. There is, however, a large literature on valuing time, which is used to estimate the value of time saved in travel through relieving congestion. If infrastructure investment can reduce congestion sufficiently then consumers may be willing to pay $0.057 per dollar of infrastructure investment to save travel time.

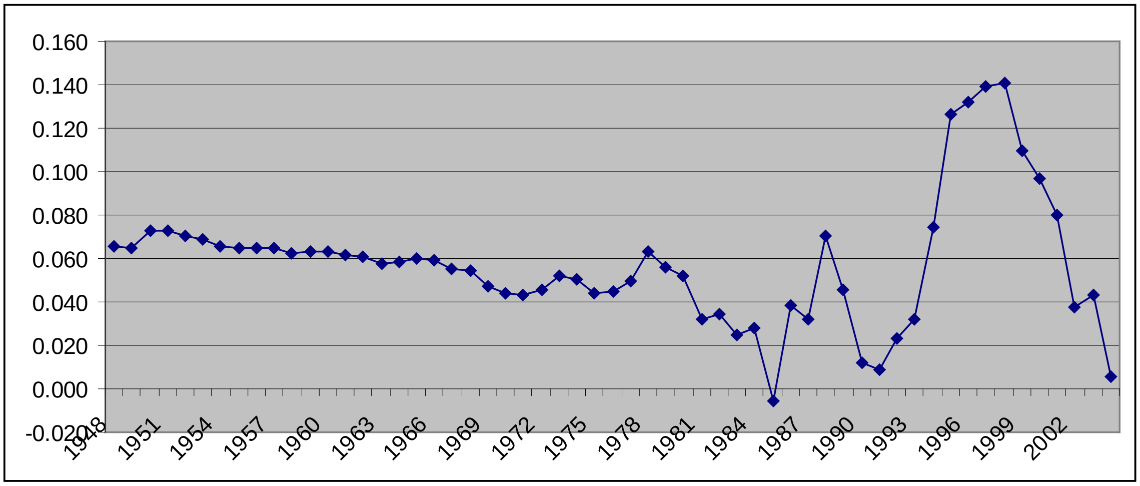
Table 2: Consumer and Producer Marginal Benefits

Period	Marginal Benefit	
	Consumer	Producer
1949-1959	0.067	0.021
1960-1969	0.059	0.050
1970-1979	0.048	0.079
1980-1989	0.036	0.122
1990-2000	0.076	0.146
2001-2005	0.052	0.094
1949-2005	0.057	0.084

Source: Mamuneas (2008)

However, examining annual variations in estimates of consumer marginal benefit reveal much larger variations in recent year. Figure 2 displays the variation in the estimates of consumer marginal benefit over time. Note that from 1948 until the early 1980s, the values of consumer marginal benefit were quite stable, varying only a few percentage points. However, beginning in the 1980s, large swings in the values are evident, rising from -0.005 to 0.14 in a ten-year period and then falling to nearly zero five years. This large fluctuation raises some concern about the reasonableness of the estimates, and warrants further investigation.

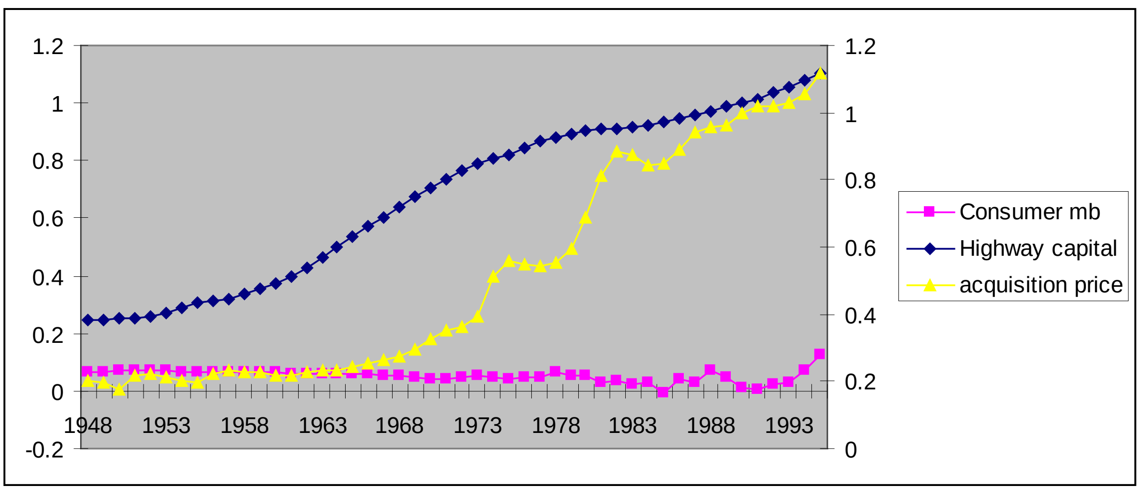
Figure 2: Consumer marginal benefit



Source: Mamuneas (2008)

As mentioned earlier, variations in highway capital stock, prices and income account for the variation in consumer marginal benefit. Figure 3 shows two factors (highway acquisition costs and highway capital estimates) that drive the marginal benefit estimates over time.[5] These factors were chosen because they are obviously directly related to the highway system, and highways are our primary interest. The two factors do not display the same volatility after the early 1980s that consumer marginal benefit does.

Figure 3: Consumer Marginal Benefit and Two Components

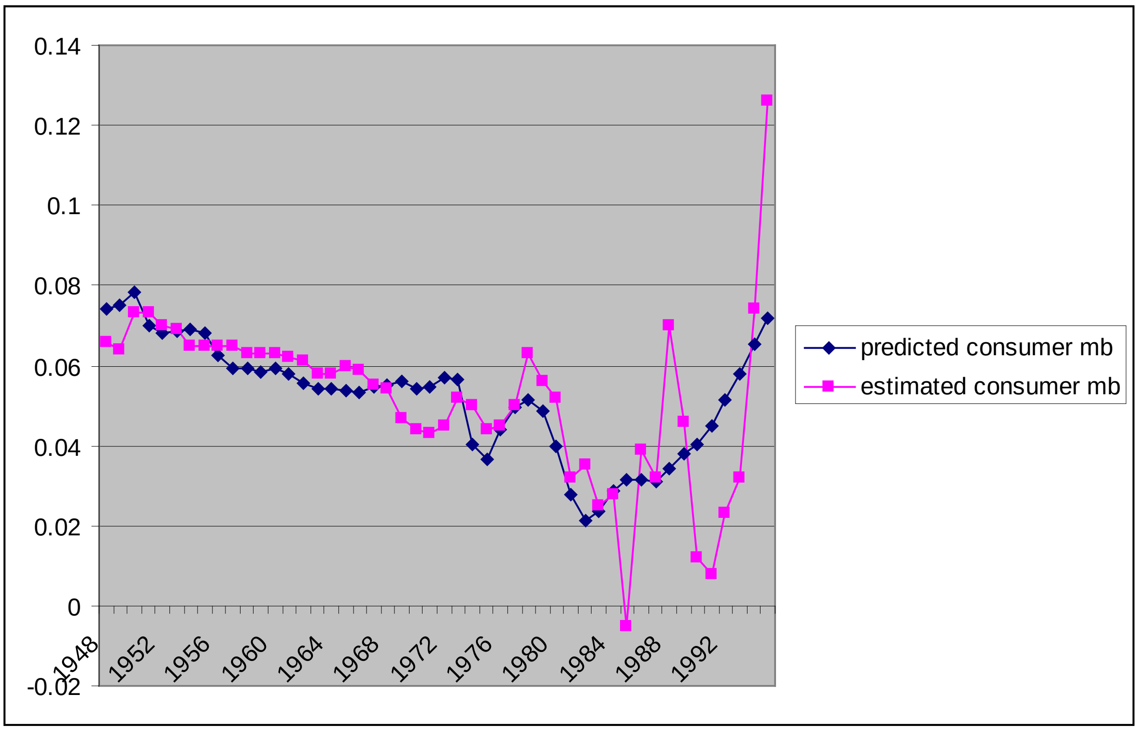


Source: Mamuneas (2008)

[5] I did not have the latest Fraumeni highway capital estimates so figures that include the highway stock estimates show the results only up through 1995.

To explore this further, I regressed Mamuneas's estimates of consumer marginal benefit against highway stock and acquisition price (including quadratic terms). Results show that the two factors explain about 46 percent of the variation in consumer marginal benefit. Furthermore, each factor contributes nearly equally to explaining the variation. Using these estimates to predict consumer marginal benefit reveals that these factors track the actual estimates closely until around the mid-1980s and then the estimates vary widely from the predicted estimates (figure 4).[6] It is difficult to explain the large fluctuation in consumer marginal benefit, and it is evident that neither highway stock or acquisition price explains much of the variation.

Figure 4: Predicted Estimates of Consumer Marginal Benefit Using Highway and Acquisition Price as Explanatory variables



Source: Authors' calculations of Mamuneas (2008) estimates of consumer marginal benefit and Fraumeni's (1999) estimates of highway capital stock and acquisition cost

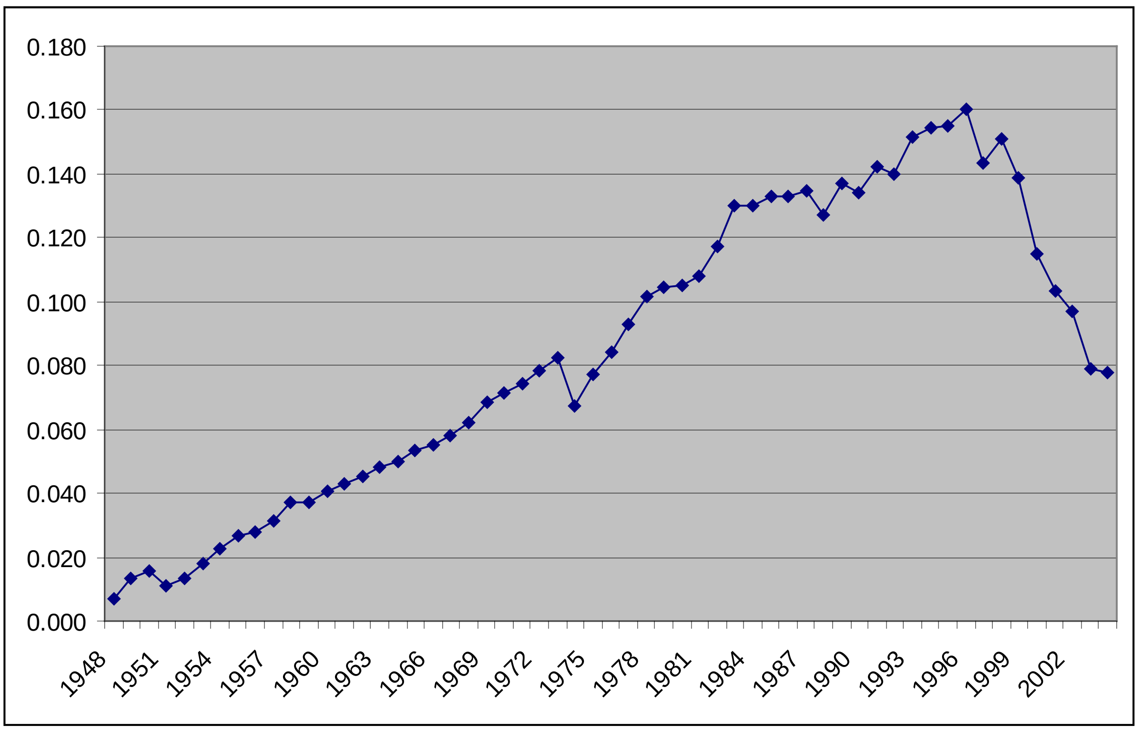
Producers

The marginal benefit of highways to producers is estimated from relationships between producer output and highway capital stock and prices and between producer inputs and highway capital stock and prices. A system of non-linear equations is estimated for producers, so the effect of highways on the marginal benefit of producers is non-linear in the explanatory variables.

[6] The predicted value of consumer marginal benefit using only the acquisition price and the distortion factor to predict consumer marginal benefit for the entire 1948-2005 period follows fluctuation of the estimate to some degree but there is considerably more volatility than what the two factors can explain for that period, as is the case with including highway capital stock for the shorter period.

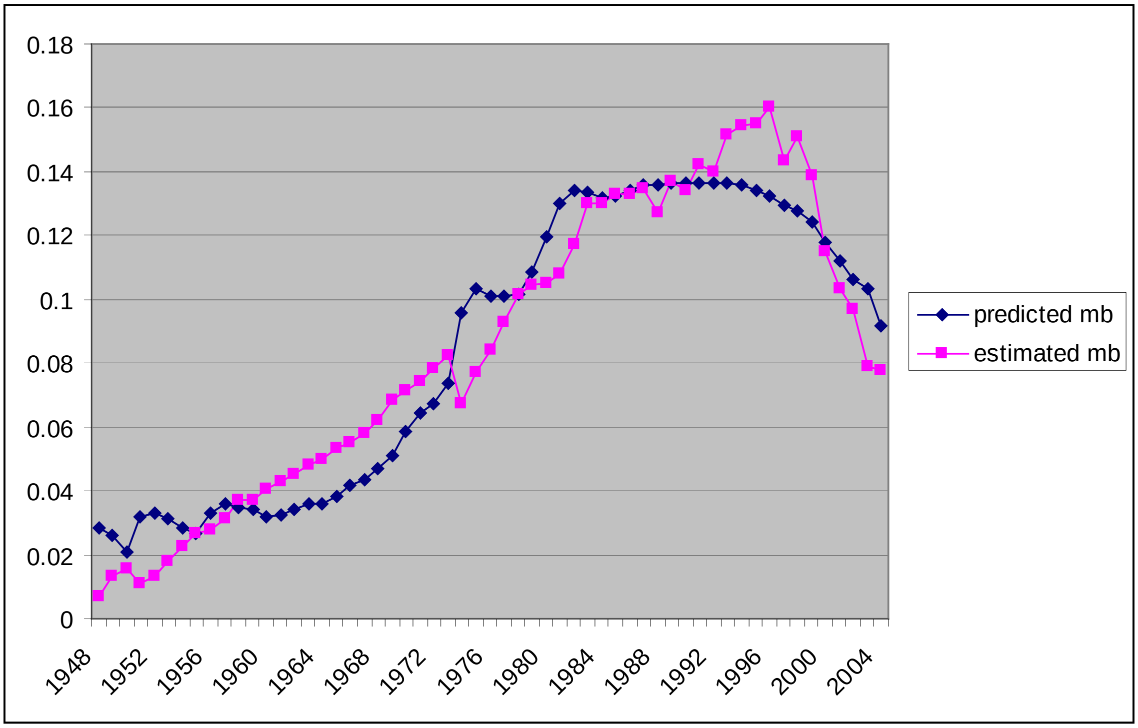
Table 2 above displays the marginal benefit of highways to producers over the decade-long internals. The average for the 56-year period is 0.084. As shown in figure 5, the estimate increases steadily from less than 0.02 in 1948 to 0.16 in 1996 and then falls dramatically thereafter. Since highway stock and acquisition price are major components of producer marginal benefits, we regressed those two factors on producer marginal benefit to better understand the relationship. In this case, the two factors (and the squared terms) explain 98 percent of the variation in producer marginal benefit. Since highway stock and acquisition price are highly correlated (0.90), each factor separately explains a large portion of the variation in producer marginal benefit (R-squared>0.90). Since I do not have Fraumeni's highway capital stock estimates past 1995, I use the acquisition price to predict producer marginal benefit. Figure 6 displays the predicted value of producer marginal benefit using the estimated coefficients from the regression and the values of highway acquisition price. As evident in the figure, the predicted value closely tracks the actual estimate, much more than for the consumer marginal benefit.

Figure 5: Marginal Benefit of Producers



Source: Author's analysis using Mamuneas's data

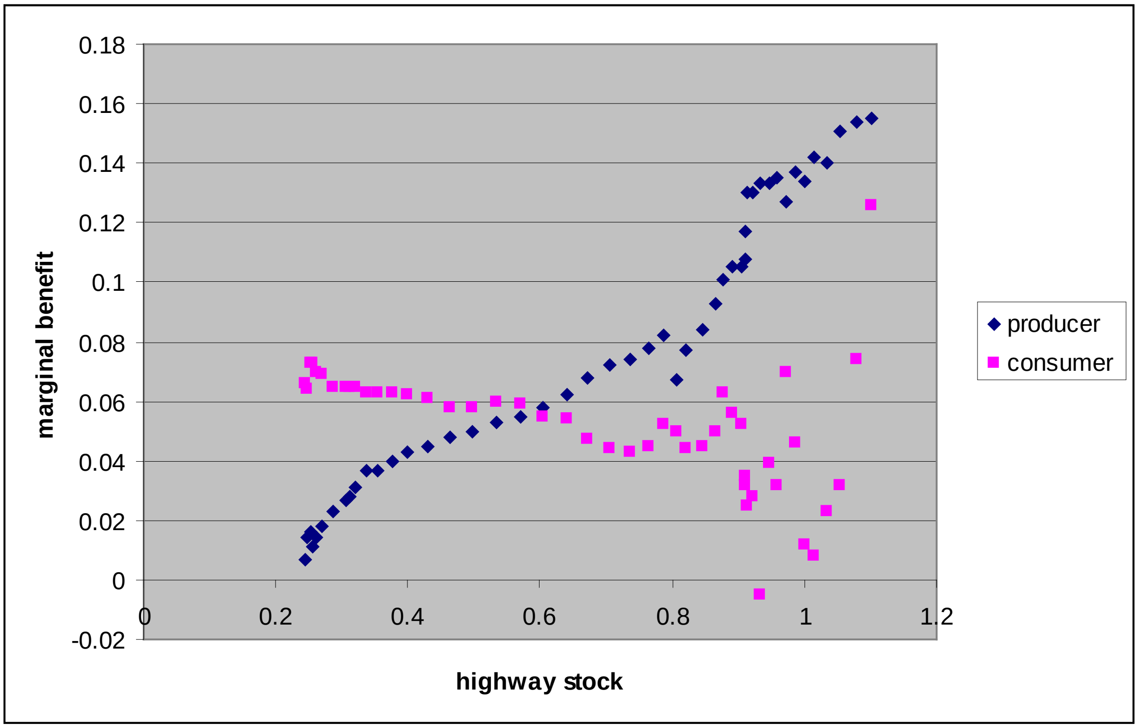
Figure 6: Predicted Estimates of Producer Marginal Benefit Using Highway Acquisition Price as the Explanatory Variable



Source: Author's analysis using Mamuneas's data

Since the concept of marginal benefit provides an estimate of consumers' willingness to pay of a unit of highway, it is interesting to examine the estimates of marginal benefits relative to the amount of capital stock in place. Figure 7 plots the marginal benefit of highways for consumers and producers against highway stock (normalized so that it equals 1 in 1990). One can see that the level that consumers valued highways remained constant around 0.06 until highway capital stock reached the normalized value of 0.9, about $760 billion (US 1992$) in 1980. After that level of capital stock was achieved, consumer's valuation fluctuates wildly. The value producers place on a unit of highway capital stock steadily increases as capital stock increases. Their willingness to pay for a unit of highway was less than 2 cents on the dollar when capital stock was small ($205 billion, US1992$) and increased to 16 cents per dollar when highway capital reached $920 billion (US 1992$). So according to the estimates, producers are willing to pay more as the system grows whereas consumers are on average willing to pay the same regardless of the size of the highway system.

Figure 7: Marginal Benefit of Consumers and Producers relative to Highway Stock



Source: Author's calculations of data from Mamuenas (2008) and Fraumeni (1999).

Rate of Return to Highways

The rate of return of highways is estimated by dividing the marginal benefits of consumers ($-N \cdot E_g$) and producers (Π_g) by the social marginal cost ($p_g(1+t_g)$). The social marginal cost is the acquisition price of highways (p_g , the BEA price deflator) plus the deadweight loss associated with financing highway investment (t_g), defined as a percentage of the acquisition cost of highways ($p_g t_g$). Thus the gross rate of return of highways is defined:

$$\rho_g = (-N \cdot E_g + \Pi_g)/(p_g(1+t_g)).$$

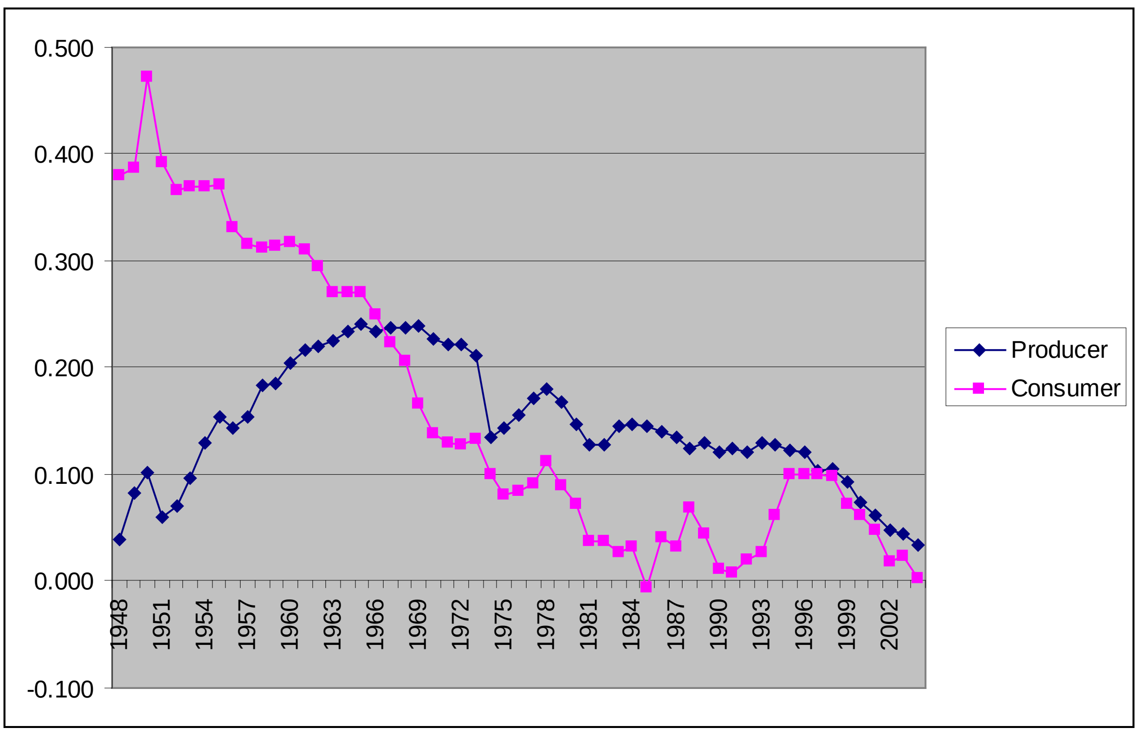
The net rate of return subtracts the depreciation rate of highway capital from the gross rate of return. The depreciation is constant at 0.02 throughout the entire period. Therefore, the variation over time of the net rate of return reflects the variation in the same factors as did the variation in marginal benefit.

Table 3: Marginal Benefit and Gross Rate of Return of Highways to Consumers and Producers

Period	Consumer		Producer	
	Marginal Benefit	Gross rate of Return	Marginal Benefit	Gross rate of Return
1949-1959	0.067	0.369	0.021	0.117
1960-1969	0.059	0.273	0.050	0.223
1970-1979	0.048	0.117	0.079	0.191
1980-1989	0.036	0.043	0.122	0.141
1990-2000	0.076	0.057	0.146	0.120
2001-2005	0.052	0.031	0.094	0.052
1949-2005	0.057	0.161	0.084	0.146

Source: Author's calculations of Mamuneas's data

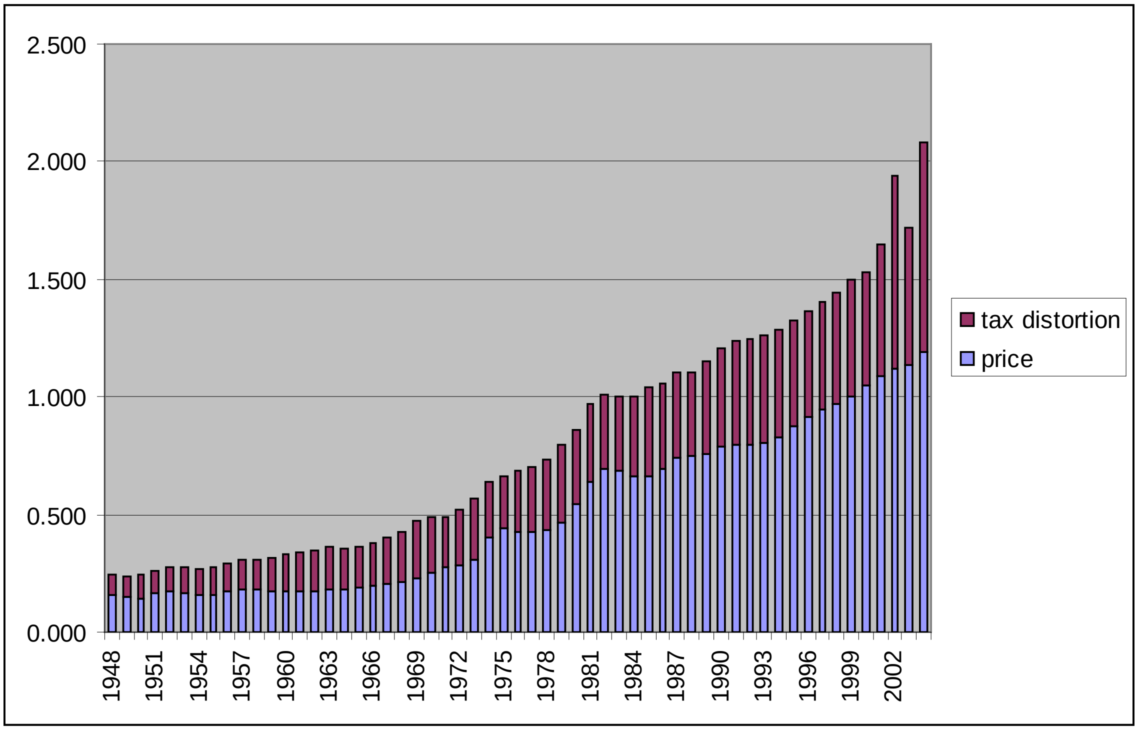
Figure 8: Gross Rate of Return of Highways to Consumers and Producers



Source: Author's calculations of Mamuneas's data.

One can see in Figure 8 the general trends displayed in table 3 for gross rate of return. Dividing the marginal benefit by an ever increasing acquisition price, as shown in figure 9, converts increasing marginal benefit estimates to generally declining gross rate of return estimates. Except for the first 20 years of the estimates, the gross rate of return of highways to producers generally declines, and the gross rate of return of highways for consumers declines throughout the entire period, except for an uptick in the early 1990s followed by a decline in the 2000s.

Figure 9: Highway Acquisition Price and Tax Distortion Estimate



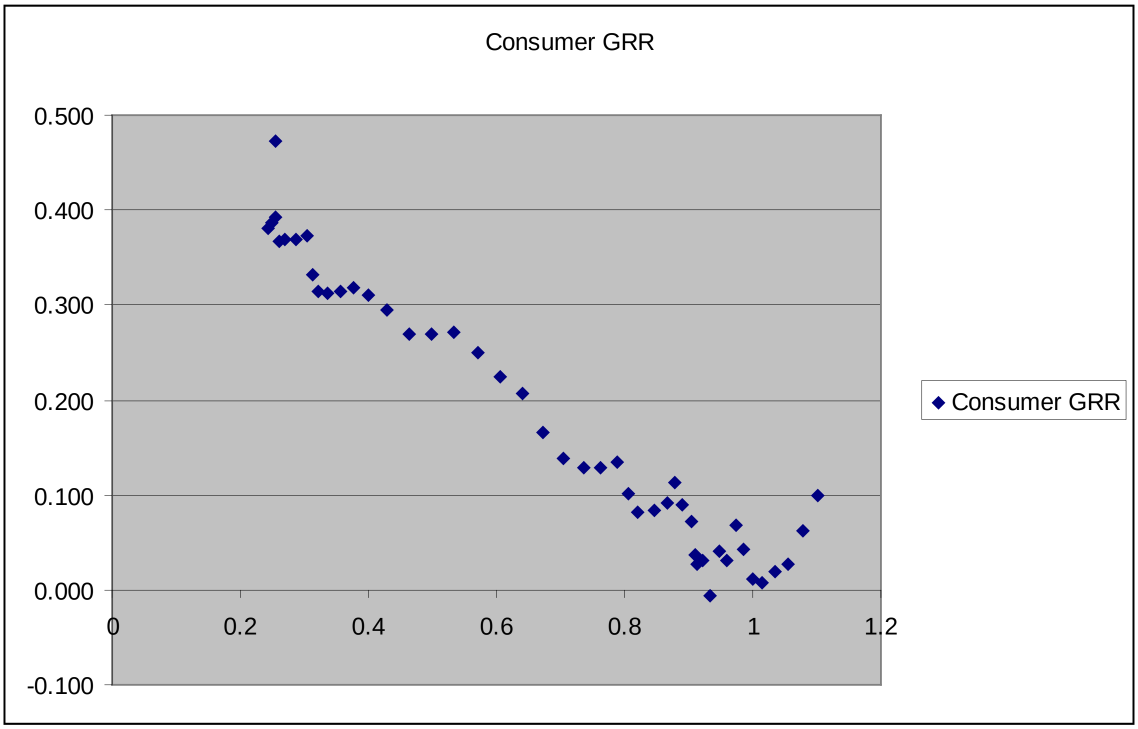
Source: Author's calculations of Mamuneas's data.

In the private sector, one typically expects to find a negative relationship between the rate of return on capital and the quantity of capital in the short run. The notion here is referred to as diminishing marginal returns and it occurs because of the fixity of another input and the congestion caused by increasing one input without the other. For highways to exhibit such a pattern over the long run, another input into the national production process would have to be fixed, increasingly creating a bottleneck with that input as highways continue to increase. One such input could be the continuous shortage of labor or private capital. Since all three inputs have expanded over time, we would not necessarily expect to see such a relationship in our graphs. On the other hand, if highways were the bottleneck early in the development of the national highway system then marginal benefit would be much higher than its cost initially until the system grew to achieve more optimal proportions with the other inputs.

Consumers may also experience diminishing marginal utility in the consumption of goods. In this case, the more one consumes a specific good relative to other goods, the less utility they receive from each additional unit. Time may be the key fixed input that consumers bump up against, and increasing the highway system does not free up that much additional time to do other activities.

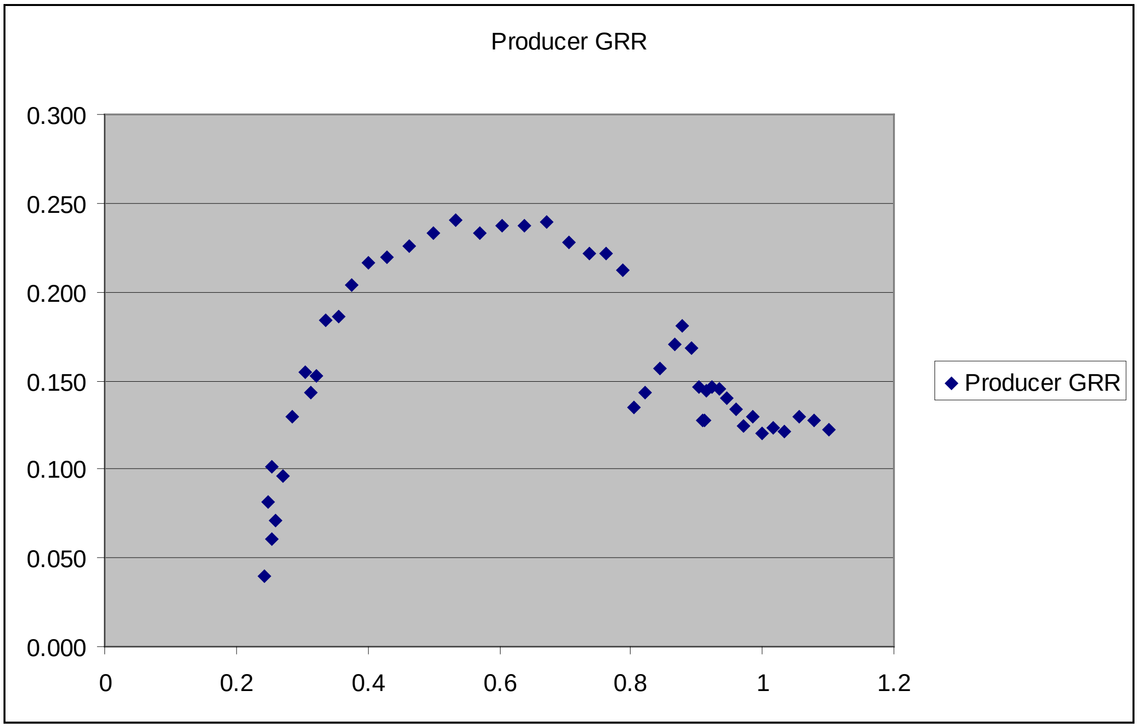
Figures 10 and 11 display the relationship between gross rate of return of consumers and producers and highway capital stock. Figure 10 shows a downward sloping relationship, which is consistent with the notion that consumers value an additional unit of highways, as highway consumption grows in larger proportion to the rest of the goods and services they consume. The relationship between gross rate of return and highways is an inverted U-shaped function, which peaks at around 0.60-0.70. That level was reached in the 1970s, when the interstate system was beginning to connect much of the country. After than time, according to the principle of diminishing returns, the level of highway capital stock expanded faster than other inputs and its marginal product falls.

Figure 10: Consumer Gross Rate of Return Relative to Highway Stock



Source: Author's calculations of Mamuneas's data.

Figure 11: Producer Gross Rate of Return Relative to Highway Stock



Source: Author’s calculations of Mamuneas’s data.

Optimal Provision of Highway Capital

Mamuneas’ model of estimating the contribution of highway to the national economy is based on a general equilibrium model of the economy that takes into account key factors that affect the decision of providing highway capital. These factors include the value placed on highways by consumer and producers and the cost of financing capital stock, both directly and indirectly as taxes distort economic decisions. Of course, the question of the optimal provision (from an efficiency perspective) of highway capital is complicated by the fact that for the most part it is a non-exclusive good that is provided by the government. Consumers and producers do not pay for highways directly, except in a relatively few cases where tolls are collected. Therefore, we cannot rely on prices to reveal the marginal benefit and thus equate marginal benefits with marginal costs. Instead, we have to look at other ways in which consumers and producers reveal their preference for an additional unit of highway infrastructure.

To construct a decision rule for optimal allocation of government-provided, non-exclusive goods, Mamuneas uses a standard model in which the government chooses taxes and the level of highways to maximize the value to consumers and producers subject to a budget constraint of financing highway investment. The optimality conditions can be expressed in two ways, even though they are equivalent, under the standard assumptions. The user-cost version states that the amount that consumers and producers are willing to pay for an additional unit of highway capital is equal to the user cost of highway capital. If the marginal value is greater than the user cost, then the government (society) has underinvested in highway capital stock; if it is less than the user cost, then the government has over-invested. Of course, since other aspects of the economy change over time, so might these decisions.

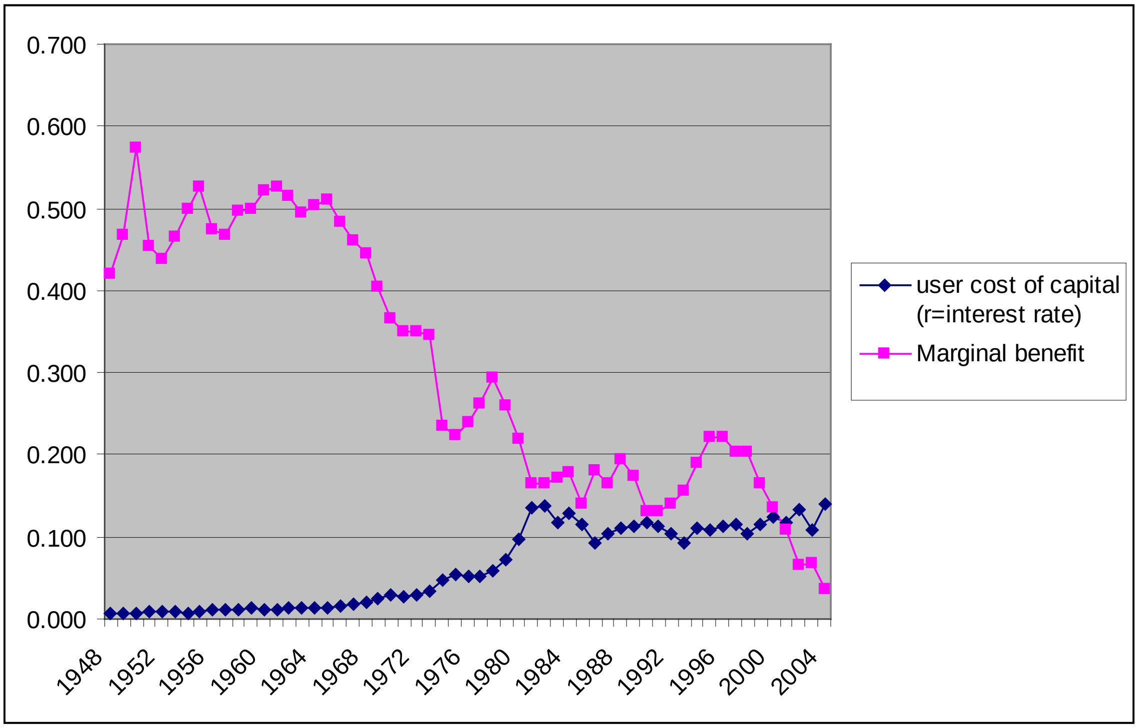
The other, equivalent, decision rule is that the net rate of return of highway capital should be equal to the rate of return of private capital. Again, if the net rate of return of highway is greater than the rate of return of private capital, then the government has underinvested in highways relative to private capital. If the net rate of return is less than the rate of return of private capital, then the government has overinvested in highways.

Following the formula for the user cost of highway capital described in Mamuneas (2008, p. 61), I construct the user cost for each year using the interest rate as the rate of return of private capital. The values are plotted in figure 12 along with the total marginal benefit. Up until the 1980s, there was a large gap between the two, suggesting that the government had underinvested in highways during that period. During the late 1970s and early 1980s, the user cost of highway capital increased substantially and the marginal benefit continued to fall. With the margin of error expected from these estimates, one could conclude that user costs and marginal benefits have been in line since the early 1980s.

Figure 13 shows the user cost relative to producer marginal benefits. Since most other studies of the contribution of highways to the national economy have focused only on the production side, this perspective is useful. Here again, it appears that the user costs and benefits came into alignment during the early 1980s and without the marginal valuation of consumers to increase total marginal benefit, producer marginal benefits value below user costs in the late 1990s, suggesting an overinvestment in highways during the past five or so years.

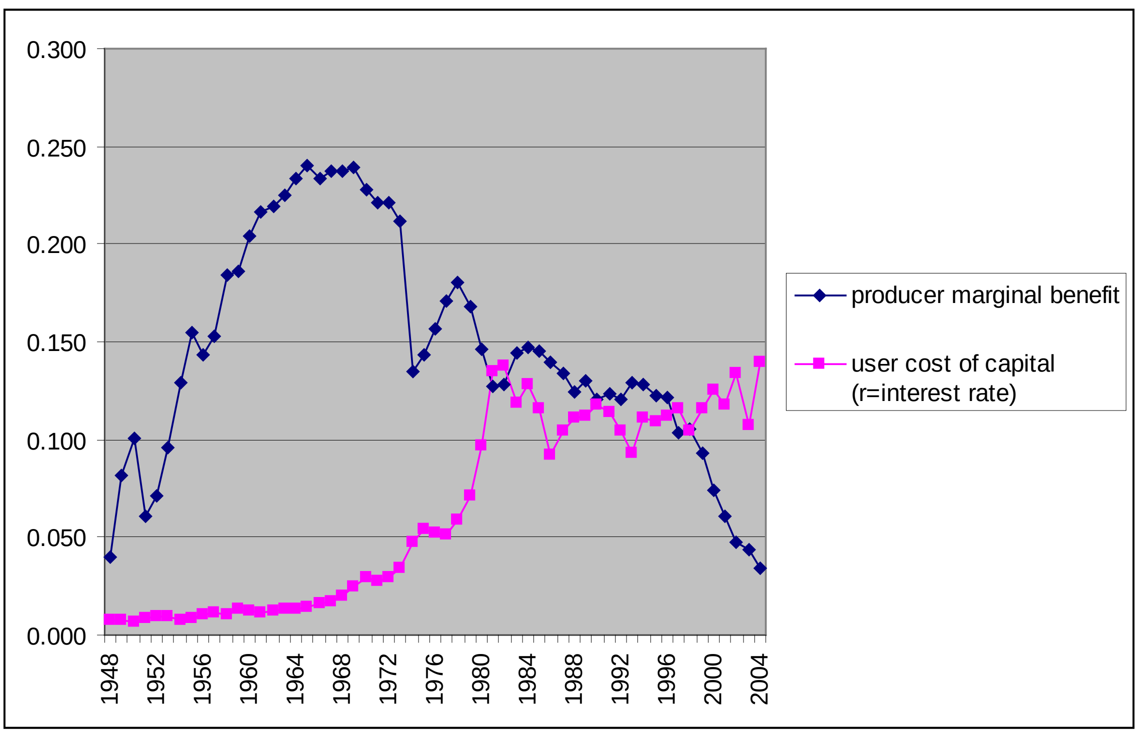
The second decision rule generally shows a similar pattern, as displayed in Figure 14, with one exception. Since the interest rate declines during the most recent two decades, the gap between the net rate of return of highways and the interest rate has grown. It is only because of the fairly sharp drop in the net rate of return of highways during that period that the two rates intersect in 2002. Therefore, using this version of the optimal decision rule, it would appear that only in the past few years has the highway system matured and the optimal level has been reached. Using the user-cost version of the rule would suggest instead that the highway system matured in the 1980s and that it has remained at the optimal level until recently when it appears that the system may be overbuilt.

Figure 12: User Cost and Marginal Benefit of Highway Capital



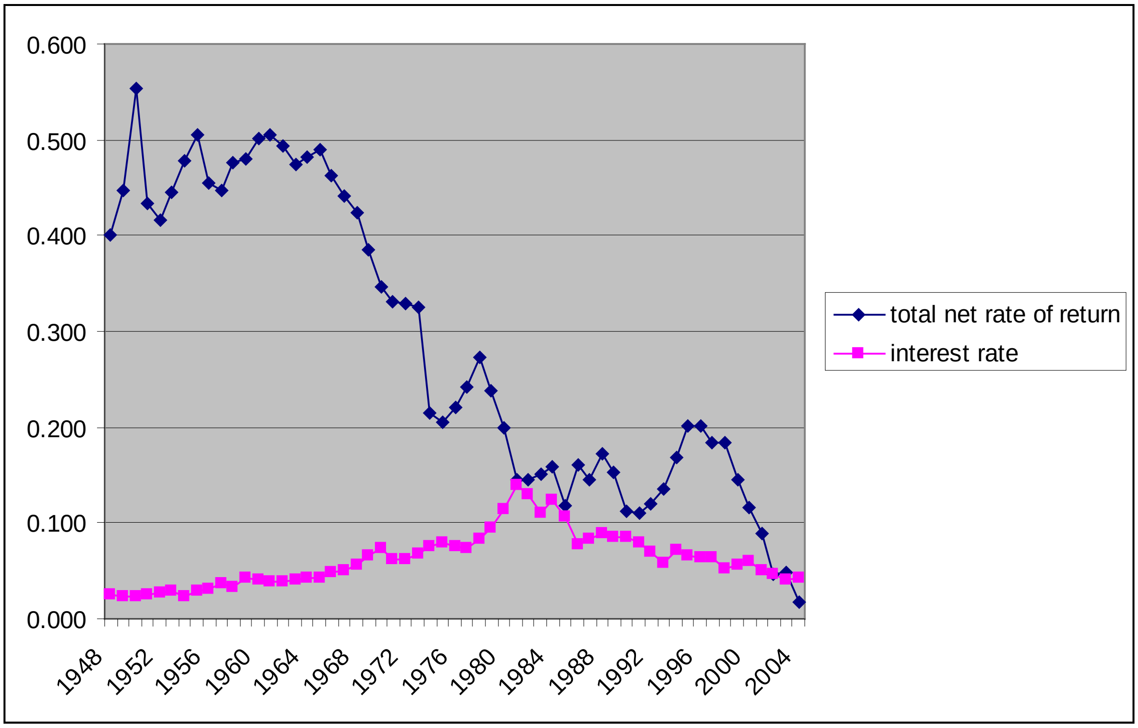
Source: Author's calculations of Mamuneas's data.

Figure 13: Producer Marginal Benefit and User Cost of Highways



Source: Author's calculations of Mamuneas's data.

Figure 14: Net Rate of Return of Highways and Interest Rates



Source: Author's calculations of Mamuneas's data.

V. Comparisons with Other Studies

Mamuneas concludes his paper by relating his findings to those of others. Since few studies provide empirical estimates of the social marginal value of highways to consumers, Mamuneas focuses on comparisons with those studies that focus on the production side of the economy to estimate such contributions. He reports in Table 6 in his paper that the current estimates rates of return are quite close to the estimates obtained in the earlier paper (Mamuneas and Nadiri, 2003). His results differ from those of Shirley and Winston (2004) who estimate a return to highways based on the benefit-cost analysis of the savings in logistic (transportation and warehousing) costs due to highway capital stock. Shirley and Winston estimate a rate of return of 17.6 percent in the 1970s, which declines to 4.9 percent in the 1980s and 1 percent in the 1990s. Mamuneas finds a similar decline in the net rate of return of highways during that period but his estimated rates of return are at least twice as high over this time period. Mamuneas rightfully points out that Shirley and Winston examine only one aspect of the economy that highways could affect, resulting in lower estimates.

Mamuneas also compares his work with Fernald's (1999) study of the effect of highways on total factor productivity. Fernald finds a large rate of return 75 percent before 1973 and a zero return afterward. The decline in net rate of return over this period is consistent with Mamuneas's findings, although the levels are different.

Although researchers have devoted considerable time and effort exploring the contribution of highways to the economy, their studies vary so much by time period, methodology, and level of aggregation that is difficult to take that large body of research and come up with a general consensus. This frustration is somewhat evident in Mamuneas's conclusion. His paper provides an extensive summary of the literature on topic, but can find only a handful of papers, three of which are his, that are useful in comparing his current estimates with those obtained previously. In looking at this literature, the rule and not the exception is that the estimates vary, and they vary by time period, technique, and level of aggregation.

Many (but not all) of the econometric studies have found a positive relationship between net public capital stock investment and private sector economic performance. However, results vary widely across studies, and results of some studies, particularly those using a fixed-effect methodology, have been negative and statistically insignificant. For those production function estimates that are statistically significant, the output elasticities of highways range from a low of 0.04 percent to a high of 0.41 percent.

The magnitudes vary by time period, technique, and level of aggregation. As shown in table 1, estimates differ significantly by time period. Using national-level production function estimates, similar to the technique used by Aschauer (1989), estimates are large, positive, and statistically significant for the period between 1949 and 1967. However, during the 1968 to 1985 period, the estimates turn negative and are statistically insignificant. The same decline in returns over time is found for highway investment. Nadiri and Mamuneas (1998), using a cost function approach at the national level, find that the output elasticity of highway capital is 0.084 between 1950 and 1991 and half that amount (0.039) between 1981-1991. Fernald (1999), using the same output and private input data as Nadiri and Mamuneas but estimating a production function, also finds that the productivity effects of highways decline over time.

Table 4: Public Capital Elasticities

I. Split Time Periods	
1949-1985	0.42
1949-1967	2.32
1968-1985	-0.08
II. Time-series	
Differenced	Statistically insignificant
Cointegration	Statistically insignificant
III. State-Level Equation	
Pooled	0.15
State dummies included	-0.02
State and Time dummies	-0.03
Year dummies	0.16
Regional dummies	0.09

One problem with time series estimation is the possibility of spurious correlation. Variables dominated by long trends produce strong correlations that offer a false sense of explanatory power. Studies, such as Tatom (1991), that correct for the spurious correlation by first differencing or using other methods of correcting for nonstationarity in the data find much smaller and even negative and statistically insignificant effects of infrastructure on output.

Production functions using cross-section data and cross-section time-series (panel) data for states or metropolitan areas typically yield estimates that are much smaller than national level estimates. For instance, Munnell (1990) finds that the output elasticity of public capital is less than half as large as her time-series estimates using aggregated state data. Garcia-Mila and McGuire (1992), using Gross State Product as the measure of output, find that highway capital per square miles has a positive and statistically significant effect with an elasticity of 0.04. Holtz-Eakin (1994) argues that estimates based on cross-section time-series data are biased because they do not account for differences across states in factors that could affect output. Using methods to correct for these differences, Holt-Eakin finds that infrastructure does not contribute to output. He interprets these results to suggest that some critical threshold level of infrastructure is essential to economic performance, but expansion in infrastructure beyond this level does not increase output.

Estimates also appear to vary somewhat systematically across different levels of aggregation. The general tendency is for national-level estimates to register the largest magnitudes, followed by state-level, and then by metropolitan levels. Munnell and others have argued that this ranking may reflect that narrower levels of aggregation do not capture the indirect effects of infrastructure as well as broader levels. For instance, according to this argument, metropolitan-level estimates would not include the network and other spillover effects that may be captured in national-level estimates. Of course, this relation between the size of estimates and level of aggregation may change depending upon specifications and the controls for nonstationarity that are included in the estimation, which may undermine this argument.

It is difficult to reconcile the different results obtained from different data, methodologies, time periods, and levels of aggregation. Garcia-Mila, McGuire, and Porter (1994) attempted to find a preferred production function specification based on various econometric tests. However, their preferred model, which controlled for nonstationarity and state-fixed effects, yielded results that suggest that public capital, both in aggregate and separated by type, has no significant effect on output.

The conclusion most supported by the literature is that there is no definitive estimate of the effect of infrastructure in general and transportation infrastructure more specifically on output. Different studies yield different estimates. Therefore, policy makers must understand the sensitivity of results to a host of factors, not least important of which is the effect of transportation within various economic circumstances, such as the robustness of the local economy and the availability of other economic factors that affect economic growth.

VII. Conclusion

Mamuneas addresses the question of the contribution of highways to the national economy by estimating the value placed on highways by consumers and producers. He finds that from 1949 through 2005, the net rate of return of highways averages 28.7 percent. He compares this rate with the return on private capital (as reflected in interest rate on the 10-year U.S. Treasury security) averaged over the same time period. Finding that the net rate of return on highways (28.7 percent) is higher than the average long-term interest rate (6.2 percent), he concludes that highways make a contribution to the economy and the country has been underinvested in highway capital stock until recently when the net rate of return fell below the interest rate.

Is this a reasonable estimate and conclusion?

There appears to be a long-standing desire to find a single rate of return to highways that can then be used to show its impact on the economy. In the private sector, the rate of return to capital is derived from market forces that value the stream of services produced from a stock of capital. For highways in general, this is not possible since highway services are not priced directly by the market. The market prices the goods and services required to build and maintain highways, so we have most of the denominator in the rate of return equation, but the market does not directly value the stream of services from highways. The valuation must be estimated from other market-related activities that may be affected by the presence of highways.

Since the market does not yield a direct reference, what is a reliable reference point? One of the major issues with government spending is the possibility that resources are taken away from the private sector that may be able to make better use of those funds than the public sector. Furthermore, economic theory shows that even for government-provided goods such as highways, the efficiency conditions of marginal costs equals marginal benefits holds, under certain assumptions. Therefore, using the rate of return of the private sector as the benchmark, the question is whether the estimated net rate of return of highways is higher or lower. Mamuneas uses the interest rate of the 10-year Treasury bill as the rate of return of private capital, which is the opportunity cost of government spending money on highways. Some may argue that this rate of return is low. Many businesses in deciding whether to invest an additional dollar on plant and equipment expect nothing less than a 15 percent rate of return of their investment. The BEA has estimated government R&D to return 15 percent, and private investment (after tax) to return at least 11 percent (Okubo, et. al., 2006, p. 33).[7] Increasing the interest rate to 11 to 15 percent would move the breakeven point back to the early 1980s. After that, the net rate of return of highways fell below the interest rate, except for a brief period in the mid-1990s.

Fraumeni (2007) used various assumptions of the rate of return to government assets in highway capital (from 0 percent to 11 percent) to estimate the contribution of the growth in highway inputs to GDP growth. She estimated that the contribution of highways ranged from 2.2 percent to 5.8 percent between 1950 and 2005. She describes this estimate as an average return on the entire system over that time and not the rate of return on the last dollar invested.

Fraumeni's methodology, although not designed to directly address the question posed by Mamuneas, brings attention to another aspect of testing reliability. This has to do with the reasonableness of the magnitudes of the relevant factors in calculating the rate of return. For instance, Fraumeni calculates that the share of highway productive capital in GDP is only 1.5 percent in recent years. Combining that share with the recognition that highway capital stock grew at a slower rate than GDP growth over that period would lead to a relatively small estimate of the average net return to highway.

Another measure of reliability is the ability to explain the variations in estimates over time. This paper looked closely at the patterns of estimates over time in order to determine if they were consistent with economic theory and with what could be surmised about the factors affecting the estimates. We found some anomalies that were difficult to

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[7]Okubo, Sumiye, Carol A. Robbins, Carol E. Moylan, Brian K. D. Sliker, Laura I. Schultz, and Lisa S. Mataloni, R&D Satellite Account: Preliminary Estimates," September 28, 2006.

explain. The wide variations in the estimates of consumer marginal benefit during the more recent years were difficult to explain. Another interesting pattern was the sharp decline in the marginal benefit of producers in the post-1990. This could be explained by changes in the factors driving the marginal benefit equation, which helps to put this estimate into context.

Comparing estimates with those obtained from other studies is of course an obvious measure of reliability. As previously mentioned, there are several studies that attempt similar estimates and find results that while not necessarily the same magnitude follow similar patterns. One advantage of the model used in the Mamuneas study is that it incorporates within the same framework the various aspects of financing public goods, such as tax distortion, that are not necessarily captured by a simple production function approach. It obviously includes the consumer side, which is neglected by studies that estimate only production (or cost) relationships. The downside of this approach, perhaps, is the statistical burden placed on estimating these subtle effects using only the variation that is produced by aggregate time series data. However, Mamuneas has addressed these econometric issues, as described earlier in this paper.

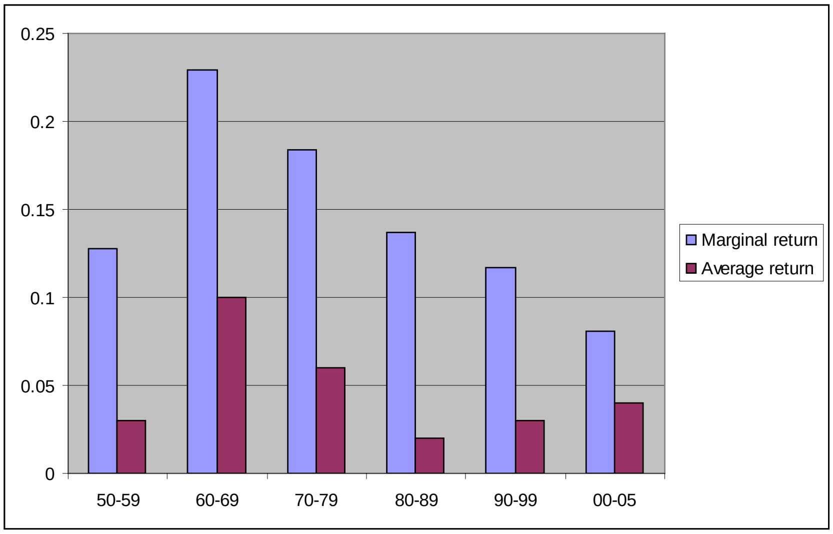
Is this the right question?

This is perhaps a strange question to ask at the end of the conclusion, but it is one that needs investigating. The expectation of the research on the contribution of highways to economic growth has been to converge on a rate of return number that most can agree upon as representing the contribution of highways to the economy. Once determined, the expectation is that it can be used to justify (or not) future investment in highways. In some ways, this expectation appears to combine two notions. The first is that of the average return to highways; the second is that of the contribution to economic growth of investing in an additional dollar of highway infrastructure. Even though the first in many ways is the culmination of the myriad of decisions to investment in highway projects across the country over a period of time, the two concepts represent possible approaches to answering two different questions and we would not expect the two to yield the same results.

Fraumeni (2007) distinguishes between the two questions by stating: “An average net rate of return should be applied to the total capital stock; a marginal net rate of return should be applied to the last dollar of capital outlay, which is the marginal increment to the capital stock” (p. 46). Mamuneas (2008) and his previous work use a marginal approach. She adds that “recognizing the essential difference between the two net rates of return explains in part why the Nadiri and Mamuneus estimated net rates of return are so high when the Interstate System was being built” (p. 46). The average net return represents a highway system as a steady and dependable input in the production process. Her approach to estimating the average net rate of return is to look at the growth in highway capital input and GDP over time and including assumptions about the rate of return of government assets.

As shown in figure 15, the average rates estimated by Fraumeni’s and the net rate of returns estimated with Mamuneas’s marginal approach follow similar patterns until the last two time periods when the average returns start to increase. In addition, the levels are quite different, as stated previously.

Figure 15: Average Net Return versus Net Rate of Return



Source: Fraumeni (2007) and Mamuneas (2008)

Estimating the net rate of the return of the last dollar invested in highway capital stock raises a host of other issues. Highway investment takes place in specific locations that have specific characteristics, such as congestion, growth, proximity to firms and consumers, connectivity to highway networks, all of which can affect the rate of return of that particular investment. That additional dollar may be invested in a location one year in which the conditions are more favorable for positive impacts than it is in another year. For instance, as the interstate was developed, the benefits of relieving bottlenecks in the Northeast corridor may have produced greater economic benefits than connecting Denver with Omaha. Furthermore, as the interstate system became more connected, the benefits also multiplied. The location of projects and the type of investments change each year. Finding a net rate of return to describe on average the economic benefit of the last dollar invested is therefore difficult. As Mamuneas has done over the past decade, updates using a consistent methodology and data sources should continue to be made periodically.

Mamuneas's most recent study of the contribution of highway investment on national economic growth uses a general equilibrium model to estimate the social marginal benefits of highways on the economy. The model provides a framework to estimate benefits for the entire economy and derives conditions for the optimal allocation of funds to highway investment. Mamuneas's results are similar to his findings in previous studies: highways make a contribution to the economy and in recent years the highway system has matured to the point where the estimates suggest that the U.S. is no longer underinvested in highways.

While there may not be a consensus in the literature on the absolute value of estimates of the rate of return to highways, and perhaps that may not be possible given the different methodologies and levels of aggregation used in the literature, it appears that there is a convergence of thought that the U.S. highway system is maturing and that the system is no longer underbuilt. However, that does not mean that funding for the highway system should be reduced. As a mature system, highways require maintenance, upgrading and replacement to provide the same level of services as before. And with a large infrastructure, that requires considerable investment to maintain highways in the condition that they were originally built. In addition, as the economy continues to expand over the long-run, the proportion of highway stock to other factors of production will need to be maintained so that if the economy is at an equilibrium state in which the rates of return are roughly equal, that relationship can be maintained into the future.

Bibliography

Aschauer, David Allan. "Is Public Expenditure Productive?" *Journal of Monetary Economics* 23, 1989, pp. 177-200.

Bartik, Timothy J. *Who Benefits From State and Local Economic Development Policies?* W.E. Upjohn Institute for Employment Research, Kalamazoo, MI, 1991.

Bell, Michael E., and Therese J. McGuire. *Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance*. National Cooperative Highway Research Program Report 389, Transportation Research Board, National Academy Press, 1997.

Boarnet, M. and A. Houghtwout, 2000. *Do highways matter? Evidence and policy implications of highways' influence on metropolitan development*. Washington, DC: Brookings Institution Center on Urban and Metropolitan Policy.

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

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

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

Eberts, Randall W., "Some Empirical Evidence on the Linkage Between Public Infrastructure and Local Economic Development," in Henry W. Herzog and Alan M. Schlottmann (eds.) *Industry Location and Public Policy*, The University of Tennessee Press, 1991, pp. 83-96.

Eberts, Randall W. and Joe A. Stone. *Wage and Employment Adjustment in Local Labor Markets*," W.E. Upjohn Institute for Employment Research, Kalamazoo, MI, 1992.

Eberts, Randall W., "Highway Infrastructure: Policy Issues for Regions," Working Paper for Conference on *Assessing the Midwest Economy*, sponsored by the Federal Reserve Bank of Chicago, 1997.

Eberts, Randall W. and Daniel P. McMillen. "Agglomeration Economies and Urban Public Infrastructure, in P. Cheshire and E. Mills (eds.) *Handbook of Regional and Urban Economics*, Vol. 3, (forthcoming 1999).

Eberts, Randall W., Douglas Holtz-Eakin, and Catherine Buffington. "Highway Infrastructure and Industrial Productivity," Draft Report, Federal Highway Administration, U.S. Department of Transportation, April 1999.

Fernald, John, "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity" *American Economic Review*, June 1999 89(3), pp. 619-638.

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

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

Ford, Robert and Pierre Poret. "Infrastructure and Private-Sector Productivity," *OECD Economic Studies,* vol. 0, no. 17, Autumn 1991, pp. 63-89.

Forkenbrock, David J., Thomas F. Pogue, Norman S.J. Foster, and David J. Finnegan. *Road Investment to Foster Local Economic Development*, Public Policy Center, The University of Iowa, May 1990.

Fraumeni, Barbara. "Productive Highway Capital Stock Measures," Final Report for Federal Highway Administration, U.S. Department of Transportation, January 1999.

Fraumeni, Barbara 2007. "Productive Highway Capital Stocks and the Contribution of Highways to Growth in GDP: Volume I," Federal Highway Administration, Department of Transportation.

Fraumeni, B. 2009. "The Contribution of Highways to GDP Growth," NBER Working Paper 14736.

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

Garcia-Mila, Teresa, Therese J. McGuire, and Robert H. Porter. "The Effect of Public Capital in State-Level Production Functions Reconsidered,"*Review of Economics and Statistics*, February 1996.

Hansen, M., D. Gillen, and M. Puvathingal, 1998. *Freeway Expansion and Land Development: An Empirical Analysis of Transportation Corridors,* January. Berkeley, CA: Institute for Transportation Studies, University of California, Berkeley.

Holtz-Eakin, Douglas. "Public-Sector Capital and the Productivity Puzzle," *Review of Economics and Statistics,* February 1994, 76(1), pp. 12-21.

Hsiao, G., 1997, “Statistical Properties of the Two-Stage Least Squares Estimator under Cointegration,” *Review of Economic Studies*, 64, 385-398.

Hulten, Charles R., “Public Capital and Economic Growth: The Micro-Macro Linkages,” in *Infrastructure in the 21st Century Economy*; *Volume II Three Conceptual Papers Exploring the Link Between Public Capital and Productivity,* U. S. Army Corps of Engineers, 1993.

Hulton, Charles R. and Robert M. Schwab. “Public Capital Formation and the Growth of Regional Manufacturing Industries,” *National Tax Journal,* vol. 43, Part 1, December 1991, pp. 121-34.

Johnston, J. and J. DiNardo, 1997, *Econometric Methods*, Chapter 9, 4h Edition, McGraw-Hill.

Levinson, David M. and Seshasai Kanchi (2002), Road Capacity and the Allocation of Time, Journal of Transportation and Statistics v5, n1 25-45.

“Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance,” NCHRP Report 389, Transportation Research Board, National Research Council, National Academy Press, Washington, D.C., 1997.

Mamuneas, T. and M. Nadiri, 1996. “Public R&D Policies and the Cost Behavior of the US Manufacturing Industries,” *Journal of Public Economics*, 63: 57-81.

Mamuneas, T. and M. Nadiri, 2003. “Production, Consumption and the Rates of Return to Highway Infrastructure Capital,” mimeo.

Mamuneas, T. 2008. “Contribution of Highway Investment to National Economic Growth,” mimeo.

Martin, Randolph C. “Federal Regional Development Programs and U.S. Problem Areas,” *Journal of Regional Science*, vol. 19, no. 2 (May 1979), pp. 157-70.

McGuire, Therese, “Highways and Macroeconomic Productivity: Phase Two,” Final Report to the Federal Highway Administration, 1992.

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

Mera, Koichi. “On the Urban Agglomeration and Economic Efficiency,” *Economic Development and Cultural Change*, vol. 21, no. 2, January 1973, pp. 309-24.

Munnell, Alicia H. “How Does Public Infrastructure Affect Regional Economic Performance?” *New England Economic Review*, September/October 1990, pp. 11-32.

Munnell, Alicia H. “Retirement and Public Policy: Proceedings of the Second Conference of the National Academy of Social Insurance,” Washington, DC, Kendall/Hunt Publishing Company, 1991.

Nadiri, M. Ishaq and Theofanis P. Mamuneas. “Contributions of Highway Capital to Output and Productivity Growth in the US Economy and Industries,” [Online]. Available: http://www.fhwa.dot.gov/aap/gro98evr.htm [24 Feb.1999].

Okubo, Sumiye, Carol A. Robbins, Carol E. Moylan, Brian K. D. Sliker, Laura I. Schultz, and Lisa S. Mataloni, R&D Satellite Account: Preliminary Estimates,” September 28, 2006.

Shirley, C. and C. Winston, 2004. “Firm Inventory Behavior and the Returns from Highway Infrastructure Investments,” *Journal of Urban Economics*, 55(2): 398-415.

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

Ten Siethoff, B. and K.M. Kockelman. 2002. “Property Values and Highway Expansion: timing, Size, location and Use Effect.” Transportation Research Record 1812: 191-200.