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16. Abstract The report investigates the contribution of publicly owned highways and streets to manufacturing cost structure. Specifically, a short-run variable cost function is specified and estimated. Highways and streets capital is treated as one of the fixed inputs in the cost function. We discover that highways and streets capital provides positive marginal benefits to firms in the manufacturing industry. That is, an increase in highways and streets capital reduces manufacturing costs. Subsequently, the productivity in the manufacturing sector is improved. Therefore, a conventional benefit-cost analysis of a specific transportation project should take into account the potential productivity benefit. NOTE: This report is a reprint of report number SWUTC/94/30080-1F previously published as a TTI report.					
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TRANSPORTATION AND MANUFACTURING PRODUCTIVITY

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IMPLEMENTATION STATEMENT

This report should be considered as a preliminary investigation of the complex relationship between transportation infrastructure and manufacturing productivity. Nevertheless, highways and streets capital is found to provide beneficial contribution to manufacturing productivity through the reduction of production cost. Consequently, it is recommended that the potential productivity benefit of transportation investment be considered along with other economic and direct user benefits in the benefit-cost analysis of a specific transportation project. Further research is needed to construct a comprehensive data base of transportation capital in Texas by mode that would allow a detailed analysis of the relationship between investment in different modes of transportation and economic productivity.

DISCLAIMER

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SUMMARY

This report investigates the contribution of publicly owned highways and streets to manufacturing cost structure. A short-run variable cost function is specified and estimated. Highways and streets capital and private capital are treated as fixed inputs in the cost function.

The main result clearly demonstrates that highways and streets capital provides positive marginal benefits to firms in the manufacturing industry. That is, an increase in highways and streets capital reduces manufacturing costs. Subsequently, productivity in the manufacturing sector is improved. This finding also suggests that the current level of highways and streets capital is lower than its long-run desired level. However, this does not imply that the level of transportation capital should be raised without a careful benefit-cost analysis.

The ranking of public transportation investment projects may not have a well-defined objective as found in the profit-maximizing private sector. Some benefits and costs of public projects are difficult to quantify. However, this research shows that the productivity impact of transportation infrastructure investments should be considered in ranking such projects. Therefore, it is recommended that the potential productivity benefit of transportation investment be included as a part of a benefit-cost analysis of a specific transportation project.

CHAPTER I. INTRODUCTION

Tangible capital formation is known to be one of the most important sources of increased labor productivity. Tangible capital includes not only plant and equipment, rolling stock, inventories, and land, but also highways and streets, bridges, water and sewer systems, and other forms of public capital. In 1991, the total nonmilitary net stock of government-owned fixed capital was 2.1 trillion in 1987 dollars, whereas the total private nonresidential net stock of fixed capital was 4.8 trillion in 1987 dollars. Without this public capital, it is undoubtedly impossible that the U.S. would have reached its current level of productivity. However, it is private capital that has been exclusively considered in the productivity literature. Although the importance of public infrastructure has been documented in the economic development literature¹, empirical research has not received much attention until recently.

Aschauer (1989a), Eberts (1986), and Munnell (1990b) laid the empirical groundwork using production analysis. A typical production function consisting of labor and private capital is extended to include nonmilitary public capital. A general conclusion has been reached that public infrastructure is a productive input in the private production process. In some cases, the marginal product of public capital even exceeds the marginal product of private capital. Furthermore, the productivity slowdown of the 1970's and 1980's can be partially explained by a decline in public infrastructure investment during the same period.

Figure 1 shows the ratio of highways and streets capital to private capital from 1925 to 1991. Since 1965, this ratio has declined steadily from about 22% of total private nonresidential net stock of fixed capital to 14% in 1991. This suggests that the investment in transportation infrastructure has not kept up with the investment in private capital. Figure 2 clearly shows that the annual growth rate of highways and streets capital was decreasing during the same period while the growth rate of private capital was higher, but fluctuating according to the business

¹ See for example, Hirschman (1958) and Hansen (1965).

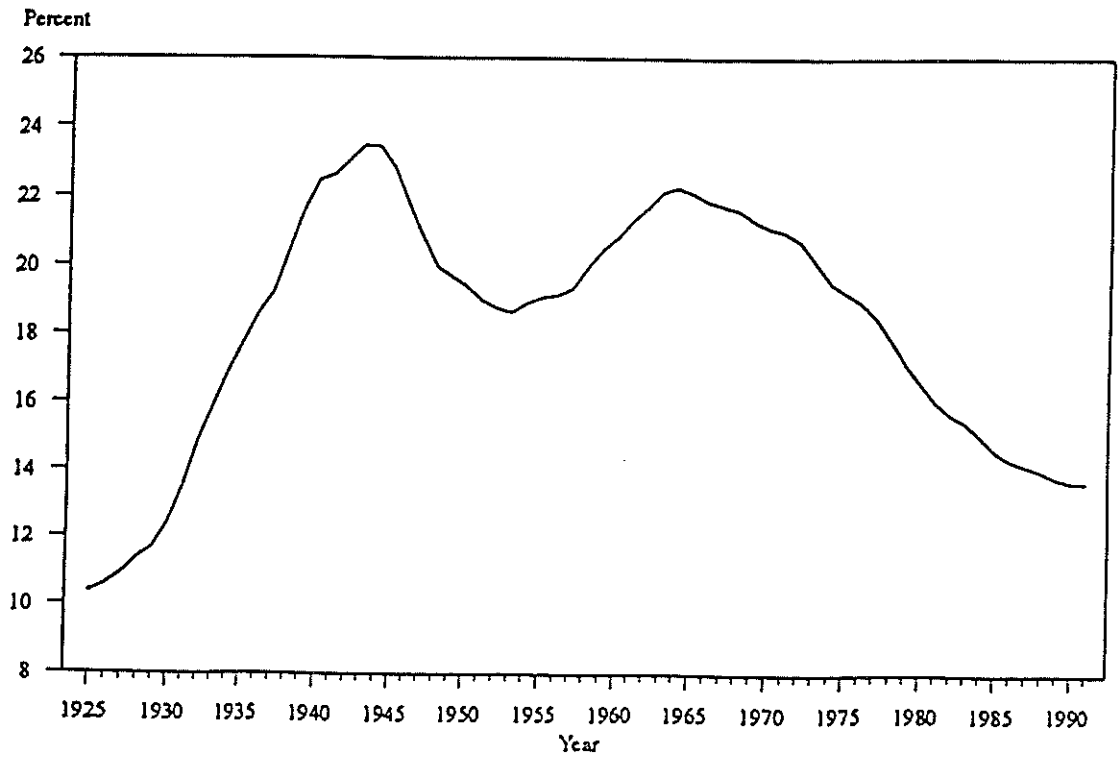


FIGURE 1. — Ratio of highways and streets capital to private capital.

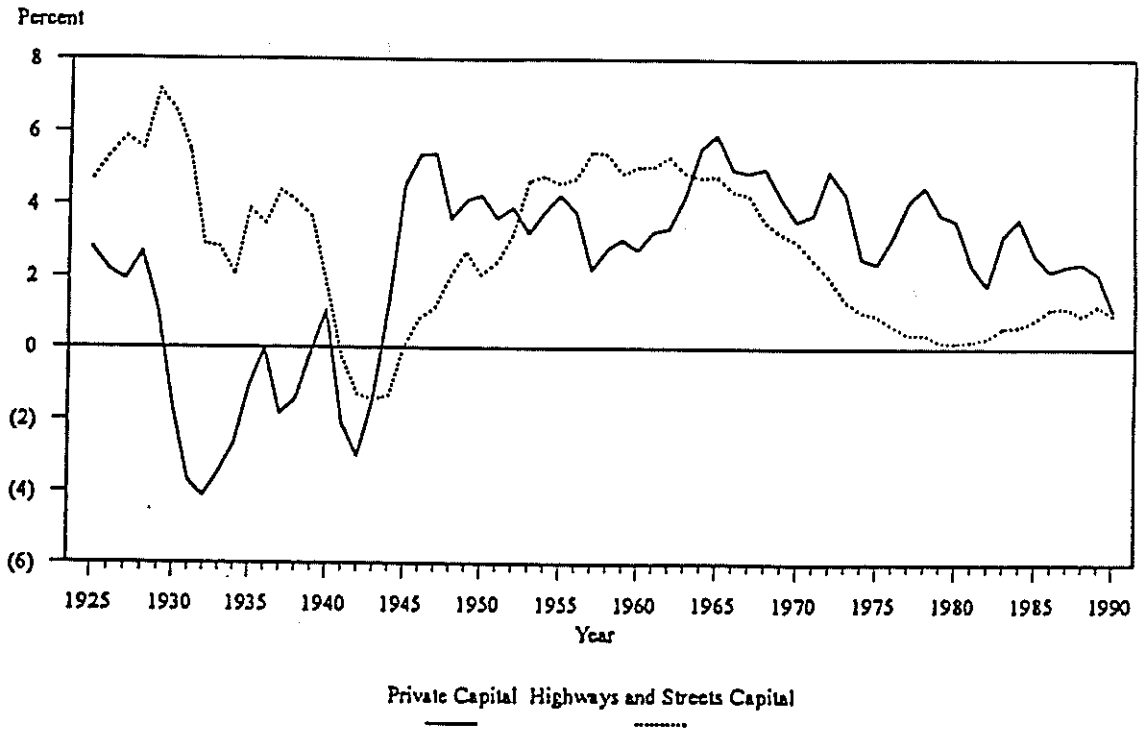


FIGURE 2. — Annual growth rates of private capital and highways and streets capital.

cycle. For Texas, Figure 3 depicts the ratio of highways and streets capital to total public capital during 1971-1987. This ratio has decreased from about 48% in 1971 to 40% in 1987. Finally, the Texas Gross State Product and highways and streets capital are plotted in Figure 4.

Most infrastructure such as highways and streets, water and sewer facilities, electricity and gas facilities, and waste treatment facilities can be considered as public goods. According to Samuelson (1954), nonrivalry is a primary characteristic of a pure public good. Consumption benefits of any one individual do not depend on the benefits realized by any other persons. Some public goods, however, do exhibit some degree of rivalry. For example, a highway user's benefits may be altered (normally decreased) as a highway becomes more and more congested. This is the case of impure public goods.

Based on a purely competitive environment, Meade (1952) distinguishes between two types of external economies or diseconomies. "Unpaid factors of production" refers to the first category of external effects. The second type is denoted as "creation of atmosphere." The primary difference between the two types is the following: for the first category, there exists constant returns to scale for society, but not for an individual industry. For the second category, society does not experience constant returns to scale, but each industry does. The main result of such external effects can be described as the following: a factor used by an industry providing external economies (diseconomies) will always be paid less (more) than its value of marginal net social product. A factor utilized by an industry on the receiving end of external economies (diseconomies) will be rewarded more (less) than its value of marginal net social product. Appropriate taxation and subsidization are proposed to compensate the factor by its marginal net social product. Finally, external effects may not be precisely divided into two distinct classes of unpaid factors of production and creation of atmosphere. It may very well be the case that external economies or diseconomies may comprise both characteristics.

However, not all public goods are considered as consumption goods. Kaizuka (1965)

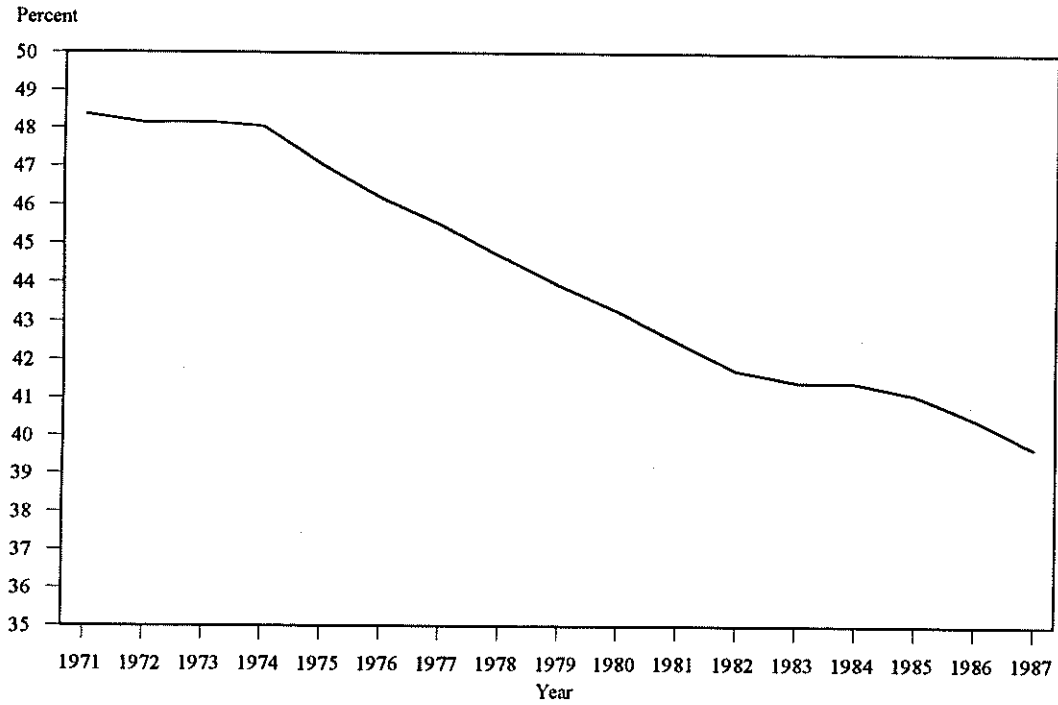


FIGURE 3. — Ratio of highways and streets capital to total public capital in Texas, 1971-1987.

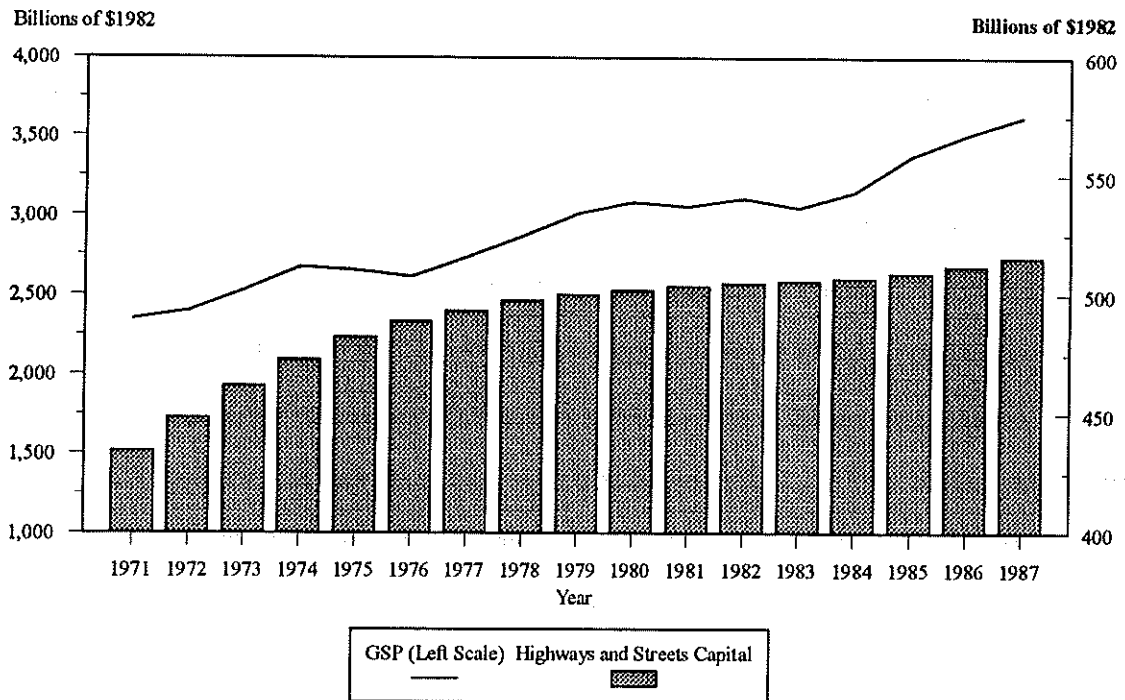


FIGURE 4. — Gross State Product, and highways and streets capital in Texas, 1971-1987.

notes that public intermediate goods clearly have positive marginal physical productivity which should be accounted for in social welfare. However, private firms have no incentive to reveal their true benefits from utilizing such public goods. Aside from being intermediate factors of production, public goods also may be responsible for creating a favorable (unfavorable) atmosphere for private economic activities. This is one example of external economies or diseconomies.

Public capital is also explicitly included, along with private capital and labor, as a factor of production by Arrow and Kurz (1970). They consider both constant and increasing returns to scale cases. Public capital is assumed to be labor-augmenting (i.e., public capital and labor produce “trained” labor) in the increasing returns to scale case. An optimal control technique is used to optimize a discounted social welfare function subjected to such production technology.

Barth and Cordes (1980), in analyzing the impact of government spending on economic activities, relied on a macroeconomic model and a microeconomic foundation. In a system of equations, public capital expenditures are posited as an argument of the private production function (public capital is considered as an intermediate factor). They conclude that the impact of different types of public expenditures on economic activities depends largely upon whether such expenditures are complements, substitutes, or independents. Burgess (1988) adopts Meade’s classification of external effects and applies it to the case of public goods. Public investment in infrastructure, such as roads and dams, and in research and development, provides services that extend the production possibility set of the private sector. This is the case in which public investment tends to raise the marginal productivity of private capital. Thus, public investment complements private investment instead of substituting for it. Furthermore, Burgess suggests that public capital be included in an aggregate production function of the private sector. The complementarity or substitutability between public and private factors should be empirically tested.

Baxter and King (1993) investigate the effect of fiscal policy under a general equilibrium

model. They report that a permanent increase in public investment leads to a long-run increase in private consumption and investment, as long as public capital is even slightly productive. For example, the direct output effect is two times the change in public investment, assuming a conservative estimate of output elasticity of public capital of 0.10. Focusing on the labor market, Erenberge (1993), shows that if public capital had stayed at its 1948-1965 ratio, real wages would have been between 2 to 2.8 percentage points higher.

The most straightforward way to capture the potential contribution of public infrastructure under production theory is to estimate a production function which includes public infrastructure capital. Mera (1973) develops a regional production function under an assumption of constant returns to scale (CRTS) for the Japanese regions. Public infrastructure capital is found to yield a positive and significant contribution to private production. Investigating the effect of transportation infrastructure, Blum (1982) obtains similar findings using a cross-section of 325 German counties in 1976. Ratner (1983) is the first to provide empirical evidence for the United States. An aggregate Cobb-Douglas production function under a CRTS assumption is estimated using time-series data from 1949-1973. The results confirm the hypothesis that government-owned physical capital is productive for the U.S. private business sector. Ratner reports a small contribution of public capital compared to its private counterpart (i.e., the estimated coefficient of the public capital stock is 5.8% compared with 22.2% of the private capital coefficient). This result is consistent with the real yields on government securities as a measure of the marginal rate of return on public capital stock.

However, it is not until Aschauer puts out a series of articles in the middle of the 1980's that the contribution of public infrastructure capital receives significant attention. Relying on a national time-series data set, Aschauer (1989a) estimates a Cobb-Douglas production function with public capital stock. Public infrastructure, especially the "core" infrastructure (e.g., highways and streets, mass transit, airports, electrical and gas facilities, and water and sewer systems), is found to be a productive factor of production. In some cases, public capital stock

is shown to be more productive than private capital. This result virtually starts the so called "Infrastructure Debate".

On the one hand, a group of researchers such as Aschauer (1989a), Eberts (1986), Munnell (1990a and 1990b), and Garcia-Mila and McGuire (1992) employ a production function framework to show that public capital is a productive input. Eberts (1986), using SMSA data for the manufacturing industry, shows that the output elasticity of public infrastructure is 3%; where 39% and 34% are given by Aschauer (1989a) and Munnell (1990a) using national time-series data. Munnell (1990b) and Garcia-Mila and McGuire (1992) employ panel data of the 48 contiguous states and report the estimated output elasticity of public capital (highway capital in Garcia-Mila and McGuire's case) to be 15% and 5%, respectively. In sum, public infrastructure is empirically shown to be a productive factor in the private production process. However, the estimated contribution varies widely among studies. Some components (e.g., "core" infrastructure) of the public capital are more productive than others. More supporting evidence can be found in the following studies: Aschauer (1987, 1989b, 1989c, 1990a, 1990b, and 1991), Attaran and Auclair (1990), Costa et al. (1987), Deno and Eberts (1991), Eberts (1990a and 1990b), and Eisner (1991).

On the other hand, some researchers find the productive characteristic of public infrastructure to be an artifact of model misspecifications. First, the problem of "spurious regression" is the most cited malady of time-series studies such as Aschauer (1989a) and Munnell (1990a); see, for example, Aaron (1990), Holtz-Eakin (1991), Hulten and Schwab (1991), Jorgenson (1991), and Rubin (1991). The problem arises because there may be a common trend between output and public capital that may lead to a highly significant and sizable point estimate. The simplest way to remedy the spurious regression is to first-difference the data set and proceed with the usual estimation method. It should be noted that if the data are in log form, the result of the first-differencing method implies the data is in annual growth rate form. Munnell (1992) points out that "... no one would expect the growth in the capital stock, whether

private or public, *in one year* to be correlated with the growth of output *in that same year.*” Granger (1990) also does not recommend such a technique because long-run relationship and other important information may be lost with the transformation. Instead, the model should be dynamically specified.

Second, a reverse causation is an equally recognized problem with the research in this area; see for example, Aaron (1990), Hulten (1990), and Hulten and Schwab (1991). It is argued that more public infrastructure may be demanded as output increases. This is a classical case of simultaneous bias which can be treated by the simultaneous equations technique. In fact, Deno and Eberts (1991) employ the simultaneous equations approach to demonstrate the significance of public infrastructure.

In addition, Eberts and Fogarty (1987) utilize the Sims’ test of Granger causation (i.e., *X* causes *Y* if the past history of *X* can be used to predict *Y* better than using the past history of *Y* alone) in order to test the direction of causality between public and private investment in forty Standard Metropolitan Statistical Areas (SMSAs) over the period of 1904-1978. The results are mixed. Public investment is shown to influence private investment for half of the sample cities, whereas no correlation is identified in seven cities.

To directly control for reverse causation, Deno and Eberts (1991) estimate a simultaneous equations model composed of two equations: an equation for per capita personal income is assumed to be a function of per capita public investment, one period lagged per capita public capital stock, and a vector of other exogenous variables (e.g., population, temperature, regional dummies, unemployment rate, etc.). The public investment equation is a function of per capita income, and another set of exogenous variables (e.g., regional dummies, intergovernmental revenue, median house value, property tax rate, etc.). Public infrastructure, nonetheless, is found to have a positive contribution to per capita personal income in the SMSAs. An increase in infrastructure provides both demand and supply effects on per capita income. The demand effect arises from the construction of the infrastructure itself, whereas the supply of

infrastructure enters the private production function as an intermediate factor of production.

The combination of a Cobb-Douglas production function and a CRTS assumption is the third problem of some prior research. It is easy to show that the Cobb-Douglas production function implies substitutability among all inputs. Some studies have shown that public infrastructure complements private capital. Therefore, the choice of functional form should be flexible enough to allow for both complementarity and substitutability among factors of production. Furthermore, the assumption of CRTS may not be realistic since public capital may create externalities that lead to increasing returns to scale. This restriction should be determined by the data. Importantly, a production decision depends not only on the amount of available inputs, but also on input prices. Input prices, however, are not included in the specification of the production function. This could lead to serious biases in estimated technical coefficients. Furthermore, a production function approach alone is incapable of identifying whether the level of public capital stock is inadequate, adequate, or excessive. Table 1 summarizes recent research in the area of public infrastructure and private production processes.

One important question remains unresolved: is public infrastructure undersupplied? Production function analysis alone is not capable of answering that question. Fortunately, cost analysis, a dual of the production function, can be applied to provide answers to the question of undersupply. A short-run variable cost function where some factors (e.g., private and public capital) are quasi-fixed can be used to calculate the shadow prices of these factors. Specifically, the long-run equilibrium level of the quasi-fixed factors can be calculated and compared with their actual levels.

Keeler (1986) is among the first to incorporate a public infrastructure variable in the empirical long-run cost function. Using panel data for twelve Class I motor carriers over 1966-1983, he is unable to find a positive marginal benefit of highway infrastructure. Keeler and

Ying (1988) report that the aggregation problem and the specific sample period may be responsible for the earlier finding. In the subsequent study, highway infrastructure is found to have a significant benefit in terms of cost reduction. Based on a simulation technique, truck cost savings alone cover at least one-third of the total capital cost of highway facilities.

TABLE 1

Summary of recent research in the area of public infrastructure and private production

Author(s)	Data Type	Sample Size	Functional Form	Estimation Technique	Dependent Variable	Public Capital Variable	Output Elasticity
Aschauer (1989a)	National Time-Series	1949-1985	Cobb-Douglas	OLS and Cochrane-Orcutt	output per capital	total	0.4
Aschauer (1990a)	State Cross-Section	1960-1985	Linear	OLS and Weighted 2SLS	per capital income growth	highways	0.25
Aschauer (1991)	State Pooled	1977-1986	Dynamic Growth	SUR	growth of output per labor	transit and highways	0.44 0.29
Attaran & Auclair (1990)	National Time-Series	1950-1985	Cobb-Douglas	OLS	output per capital	highways	0.23
Eberts (1986)	SMSA Pooled	38 SMSAs 1958-1981	Translog	Park's Method	value added	total	0.03
Garcia-Mila & McGuire (1992)	State Pooled	12 industries, 1956-1986	Cobb-Douglas	OLS	GSP	highways	0.05
McGuire (1992)	State Pooled	1970-1983	Cobb-Douglas	Error Components Model	GSP	highways	0.12
Munnell (1990b)	State Pooled	1970-1986	Cobb-Douglas	OLS	GSP	total and components	0.15
Williams & Mullen (1992)	State Cross-Section	1970, 1980, and 1986	Translog	OLS	GSP	highways	0.31

Friedlaender (1990) was, however, the first to sketch a theoretical background for the short-run variable cost function to accommodate public capital. Berndt and Hansson (1992) and Shah (1992) provide supporting empirical evidence in favor of public capital based upon data from Sweden and Mexico, respectively. Using U.S. data, Nadiri and Mamuneas (1991), Morrison and Schwartz (1992), Lynde and Richmond (1992), and Dalenberg and Eberts (1992) present convincing evidence that public infrastructure capital provides positive marginal benefits

to manufacturing firms. However, most of these studies do not focus on the transportation component of the total public capital stock. Highways and streets capital accounts for more than 40% of the total nonmilitary public capital. Table 2 summarizes recent literature in the area of public infrastructure and private cost structures.

TABLE 2
Summary of empirical studies in public capital and private cost

Author(s)	Data Type	Sample Size	Functional Form	Impose CRTS	Estimation Technique	Dependent Variable	Public Capital Variable
Keeler (1986)	Trucking Firms Pooled	1966-1983	Translog	No	SUR model with fixed effects	total cost & cost share	transportation
Keeler & Ying (1988)	Trucking Firms Pooled	1950-1973	Translog	No	SUR model with fixed effects	total cost & cost share	transportation
Berndt & Hansson (1992)	Sweden Time-Series	1960-1988	Generalized Leontief	No	ML	total cost & input-output	total
Morrison & Schwartz (1992)	Statewide Pooled	4 regions 1970-1987	Generalized Leontief	No	SUR model with fixed effects	total cost & input-output	total
Nadiri & Mamuneas (1991)	Industries Pooled	12 industries, 1956-1986	Generalized Cobb-Douglas	Yes	SUR model with fixed effects	total cost & cost share	total and R&D
Lynde & Richmond (1992)	Time-Series	1958-1989	Translog	No	SUR model with fixed effects	total cost, cost share, and shadow share	total
Dalenberg & Eberts (1992)	SMSA Pooled	31 SMSAs 1976-1978	Translog	Yes	SUR model with fixed effects	total cost & cost share	total

This study investigates the contribution of publicly owned highways and streets to manufacturing cost structure. Specifically, a short-run variable cost function is employed to provide a theoretical basis for temporary equilibrium. Furthermore, the shadow price of highways and streets capital can be estimated. Since the costs of building and using transportation infrastructure are not directly borne by the firms, non-negative shadow prices signify that transportation infrastructure is undersupplied. That is, the marginal value of highways and streets capital to manufacturers is the reduction in their variable costs from a

marginal addition to the stock of input. Hence, the question of undersupplied public capital can be answered.

Lastly, the internal rates of return to the quasi-fixed factors are provided as a basis for comparing different investment projects. These results have significant policy implications. A policymaker needs to know whether the claim that public infrastructure is undersupplied has any empirical support. Importantly, the Internal Rate of Return to investment in public infrastructure may be used in evaluating its overall benefits (e.g., from both consumers and producers).

The organization of this research is the following: Chapter I provides an overview and a literature survey. The theoretical model and data sources are presented in Chapter II. Chapter III illustrates our empirical findings and Chapter IV concludes.

CHAPTER II. MODEL AND DATA

Let a production process be described as

$$(1) \quad y = f(x, z, t),$$

where y is output, x is an n vector of variable factors, z is an m vector of quasi-fixed factors, and t is a time trend. Under some regularity conditions, a total cost function can be derived from (1):

$$(2) \quad C = g(y, w_1, \dots, w_n, p_1, \dots, p_m, t),$$

where w is an n vector of variable input prices and p is an m vector of quasi-fixed factors prices.

In the short-run, only x can be altered. Given z , a variable cost function is

$$(3) \quad VC = h(y, w_1, \dots, w_n, z_1, \dots, z_m, t).$$

To implement the model (3), we specify a translog variable cost function as:

$$(4) \quad \begin{aligned} \ln VC = & \ln \alpha_0 + \sum_{i=1}^n \beta_i \ln w_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} \ln w_i \ln w_j + \sum_{k=1}^m \gamma_k \ln z_k \\ & + \frac{1}{2} \sum_{k=1}^m \sum_{l=1}^m \gamma_{kl} \ln z_k \ln z_l + \sum_{i=1}^n \sum_{k=1}^m \delta_{ik} \ln w_i \ln z_k \\ & + \beta_y \ln y + \frac{1}{2} \beta_{yy} (\ln y)^2 + \sum_{i=1}^n \beta_{iy} \ln y \ln w_i + \sum_{k=1}^m \gamma_{ky} \ln y \ln z_k \\ & + \beta_t t + \frac{1}{2} \beta_{tt} t^2 + \sum_{i=1}^n \beta_{it} t \ln w_i + \sum_{k=1}^m \gamma_{kt} t \ln z_k + \beta_{ty} t \ln y . \end{aligned}$$

For empirical estimation, it is useful to incorporate additional equations reflecting economic optimization behavior. Cost-minimizing demand equations for variable factors are derived by applying Shepard's lemma to (4). The i th variable factor share, S_i , equation is

$$(5) \quad \frac{\partial \ln VC}{\partial \ln w_i} = \frac{p_i x_i}{VC} = S_i = \beta_i + \sum_{j=1}^n \beta_{ij} \ln w_j + \sum_{k=1}^m \delta_{ik} \ln z_k + \beta_{iy} \ln y + \beta_{it} t ,$$

where $i = 1, \dots, n$. Profit maximization behavior in a perfectly competitive output market² can also be included by recognizing that $\partial VC / \partial y = \text{marginal cost} = p_y$, output price:

² See for example, Berndt and Hesse (1986), Morrison (1988), and Lynde and Richmond (1992).

$$(6) \quad M_y = \frac{\partial \ln VC}{\partial \ln y} = \frac{p_y y}{VC} = \beta_y + \sum_{i=1}^n \beta_{iy} \ln w_i + \sum_{k=1}^m \gamma_{yk} \ln z_k + \beta_{yy} \ln y + \beta_{yt} t .$$

The shadow value of the k th fixed input, r_k , is defined as

$$(7) \quad r_k = \frac{\partial VC}{\partial z_k} < 0 .$$

Therefore,

$$(8) \quad M_k = \frac{\partial \ln VC}{\partial \ln z_k} = \frac{r_k z_k}{VC} = \gamma_k + \sum_{i=1}^n \delta_{ik} \ln w_i + \sum_{l=1}^m \gamma_{kl} \ln z_l + \gamma_{ky} \ln y + \gamma_{kt} t ,$$

where $k = 1, \dots, m$. Since the cost function must satisfy the theoretical restriction of homogeneity of degree one in input prices, the following restrictions together with symmetry of β_{ij} and γ_{ij} will be imposed:

$$(9) \quad \sum_{i=1}^n \beta_i = 1 , \quad \sum_{i=1}^n \beta_{ij} = \sum_{k=1}^n \delta_{ik} = \sum_{i=1}^n \beta_{iy} = \sum_{i=1}^n \beta_{it} = 0 , \quad \forall j = 1, \dots, n.$$

The system of equations (4)-(6) and (8) with (9) can be empirically estimated, provided all appropriate data are available. Since the variable factor shares sum to unity, there are only $n-1$ linearly independent share equations. One of the variable share equations must be omitted. The estimates from Zellner's (1962) Iterative Seemingly Unrelated Regression (ISUR) are independent of which share equation is dropped since ISUR is asymptotically equivalent to the maximum likelihood method. As with all flexible functional forms, global concavity (convexity) in the w (z) variables is not ensured. However, the required curvature can be tested at each observation; that is, whether the matrix of $\partial^2 h(\cdot) / \partial w w'$ ($\partial^2 h(\cdot) / \partial z z'$) is negative (positive) semidefinite.

All data used in this study pertain to the manufacturing sector. Panel data of the 48 contiguous states from 1970-1986 are employed. Labor (L) and energy (E) are the two variable factors, whereas private capital (K) and highways and streets capital (H) are treated as quasi-fixed inputs. Gross State Product (GSP) is used as output. Labor, wage (w_L), GSP, and output price (p_y) data are from the Bureau of Economic Analysis (BEA). Energy expenditures are from the Annual Survey of Manufacturing (ASM). Industrial energy prices (w_E) are from the

Energy Information Administration (EIA). Private capital and highways and streets capital data are from the Federal Reserve Bank of Boston.³ Since data on user cost of capital are not available on a state-by-state basis, equation (8) is not included in the estimation process. The shadow values, however, can be retrieved by substituting the estimated parameters from (4)-(6) into (8).

³ The author would like to thank Alicia H. Munnell and Leah Cook for providing this data set.

CHAPTER III. RESULTS

To empirically implement our models, a random disturbance is added to each of the equations (4)-(6). The constant term in the variable cost function (4) is dropped and BEA regional dummies⁴ are added. The system of equations (4)-(6) and (9) is estimated using ISUR⁵. The energy share equation is excluded. The full set of the estimated parameters is given in Table 3. The curvature conditions for variable and quasi-fixed factors are satisfied at each observation as required by the theory. In addition, the predicted shares are positive over the whole sample. The p -values given in Table 3 indicate that most parameter estimates are statistically different from zero at the 1% level of significance.

The shadow shares (M_K and M_H) and shadow values (r_K and r_H) of private capital and highways and streets capital can be retrieved for each observation by substituting the estimated parameters into (8). The estimated shadow shares and shadow values of private capital and public capital are less than zero over the whole sample. This result suggests that private capital and public capital yield positive marginal benefits to manufacturing firms in terms of reductions in variable costs. Since the firms do not pay directly for transportation infrastructure, non-negative shadow prices signify that transportation infrastructure is undersupplied. Based on the average shadow shares over the whole sample, a 10% increase in private capital stock leads to a 3.6% reduction in variable costs, while a 10% increase in highways and streets capital stock induces a 2.9% reduction in variable costs. Dalenberg and Eberts (1992), using pooled SMSA data from the manufacturing sector, report similar results for the shadow shares of total public capital. Figures 5 and 6 depict the shadow shares of private capital and highways and streets

⁴ The eight BEA regions are given in Appendix A.

⁵ This is done using SAS[®] PROC MODEL. The values of the estimated parameters are robust to alternative starting values.

TABLE 3
Estimated parameters for translog variable cost function

Parameters	Estimates	Standard Errors	<i>t</i> -ratio	<i>p</i> -value
β_y	-0.6844	0.199	-3.44	0.0006
β_{yy}	-0.089	0.00818	-10.88	0.0001
β_{Ly}	0.13613	0.00505	26.93	0.0001
γ_K	-0.0843	0.41165	-0.2	0.8377
γ_{KK}	0.01972	0.01437	1.37	0.1705
δ_{LK}	-0.1191	0.00512	-23.24	0.0001
γ_H	0.3536	0.55915	0.63	0.5273
γ_{HH}	-0.0216	0.02722	-0.79	0.4287
δ_{LH}	-0.0216	0.0039	-5.55	0.0001
β_l	-0.0296	0.03094	-0.96	0.3389
β_{ll}	-0.0008	0.00021	-3.89	0.0001
β_{Ll}	-0.0033	0.00045	-7.26	0.0001
β_L	0.9032	0.05513	16.38	0.0001
β_{LL}	0.007	0.00244	2.87	0.0042
β_{ly}	0.0063	0.00127	4.96	0.0001
β_{Kl}	-0.0213	0.002	-10.68	0.0001
β_{Hl}	0.01706	0.00254	6.72	0.0001
γ_{Ky}	0.10318	0.01775	5.81	0.0001
γ_{Hy}	0.11759	0.01603	7.33	0.0001
γ_{KH}	-0.1013	0.03392	-2.99	0.0029
Region 1	8.45877	3.76477	2.25	0.0249
Region 2	8.36046	3.76696	2.22	0.0267
Region 3	8.30238	3.7706	2.2	0.028
Region 4	8.51529	3.77373	2.26	0.0243
Region 5	8.78455	3.77306	2.33	0.0202
Region 6	8.57035	3.77162	2.27	0.0233
Region 7	8.5391	3.77086	2.26	0.0238
Region 8	8.39101	3.76784	2.23	0.0262

capital based on annual and regional averages. The shadow share of private capital increases from 29% in 1971 to 47% in 1987⁶. Conversely, the shadow share of public capital decreases during the same period. This may be due to the fact that investment in highways and streets has declined during this same period. Figure 6 shows that the shadow share of highways and streets capital is similar across all regions. For Texas, the shadow share of highways and streets capital is about 36%, exceeding the national average of 28%.

The internal rates of return to quasi-fixed factors can be estimated using the results from the restricted equilibrium model. According to Schankerman and Nadiri (1986), the IRR, π_k , to the k th quasi-fixed input can be computed by numerically solving the following equation:

$$(10) \quad e^{\psi\pi_k}(\pi_k + \phi + \delta_k - q) - \frac{e^{\psi\rho_k}(\phi - q)(\rho_k + \delta_k)}{(\pi_k + \delta_k)} = -\frac{\partial VC}{\partial z_k},$$

where ψ represents the gestation lag between the investment and its impact on VC , ϕ denotes the rate of adjustment of the output price toward the new level of variable cost, δ_k indicates the rate of depreciation in the k th quasi-fixed factor, ρ_k corresponds to the market rate of interest with respect to the k th quasi-fixed factor, and q denotes the rate of growth of output demand. $\partial VC/\partial z_k$ can be retrieved from equation (8). Again, the Newton technique is used to numerically evaluate equation (10). The results, which do not vary with respect to the starting values, are presented in Table 4. The IRR to private capital, π_K , is consistently higher than the IRR to highways and streets capital, π_H . With a one year gestation lag, the average π_K is about 9.4%. Landefeld, Lawson, and Weinberg (1992) report that the rate of return for investment made by all U.S. businesses is 8.4%, which is slightly lower than our finding.

Investment in public projects is likely to take some time before businesses can fully adjust to the new environment. For example, firms may restructure their production processes and

⁶ Since private and public capital stock are measured at the end of the year, their values are lagged one year. Therefore, the estimated shadow shares and values correspond to the capital stock in time $t + 1$.

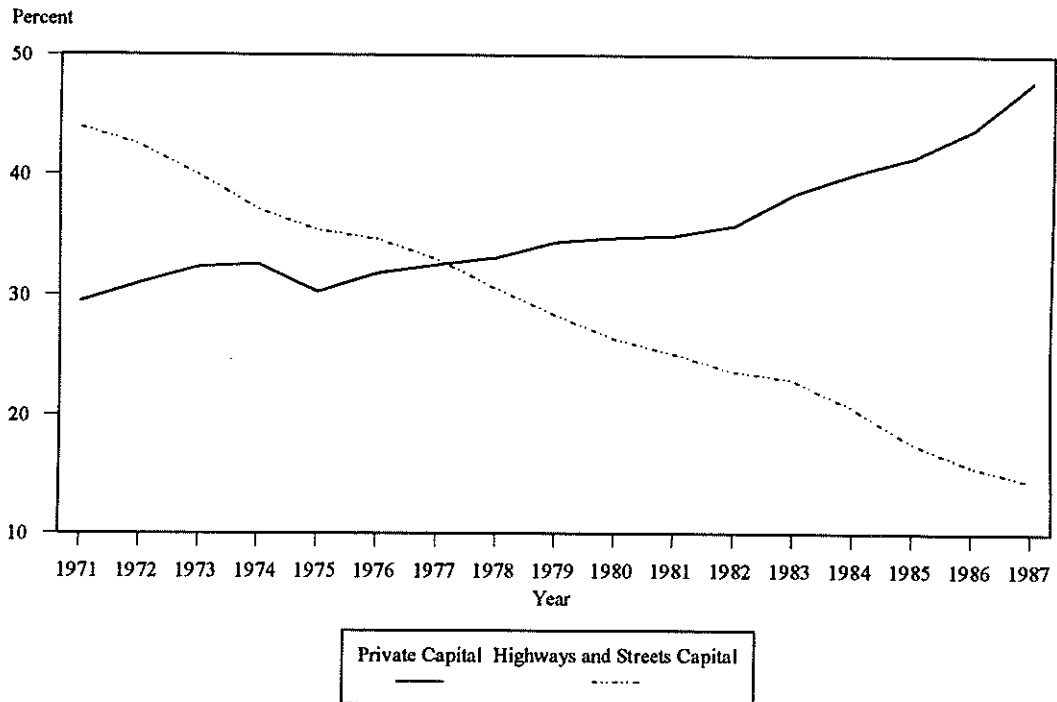


FIGURE 5. — The estimated shadow shares of private capital and highways and streets capital, annual averages.

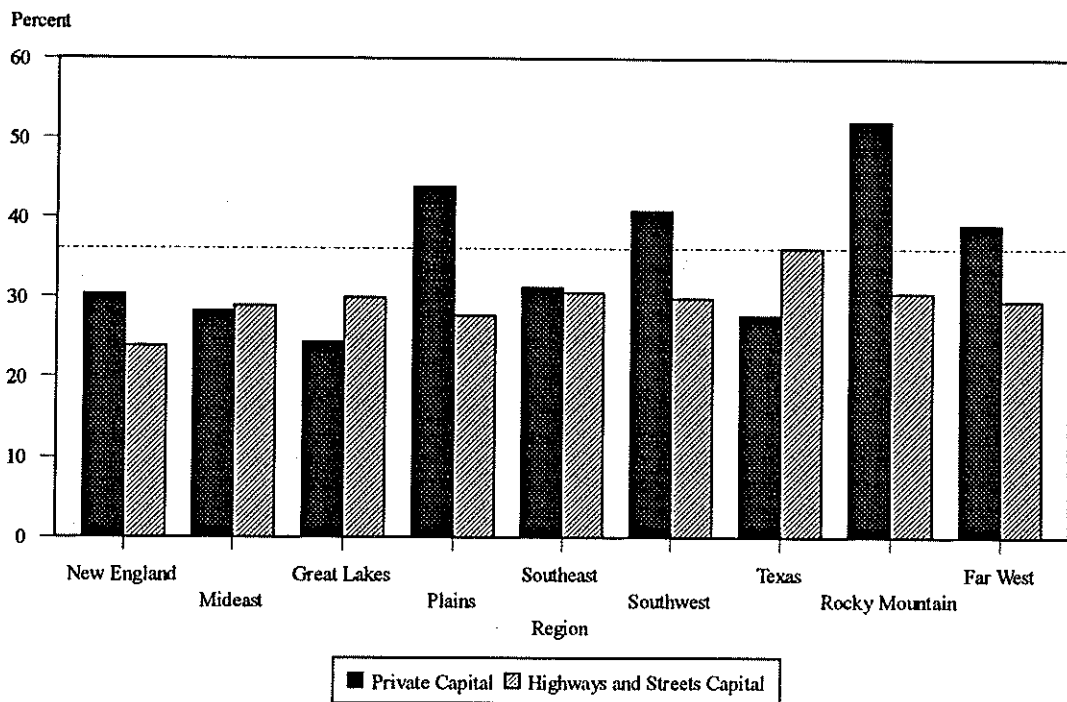


FIGURE 6. — The estimated shadow shares of private capital and highways and streets capital, regional averages.

logistics to take advantage of an improvement in highway networks⁷. This adjustment, however, does not occur immediately. With a gestation lag of five years, for instance, π_H is approximately 7.5%. Nadiri and Mamuneas (1991), using national data of twelve two-digit U.S. manufacturing industries, find the IRR to public capital is 6.8%. In Figure 7, using different regional averages of $\partial VC/\partial H$, π_H , at a five-year gestation lag, reaches its highest value of 9.12% for the Great Lakes region. The lowest value of π_H at 6.52% is obtained from the Rocky Mountain region. For Texas, the IRR to highways and streets capital is 7.89%; that is larger than the average for the Southwest region. Our results reconfirm the notion that the return to public capital is the greatest in regions that have relatively older facilities.

⁷ See for example, Apogee Research, Inc. (1991) and Lewis (1991).

TABLE 4

Net rates of return to private capital and highways and streets capital

$\phi \downarrow, \psi \rightarrow$	0	1	2	5	10	Row Avg.
Private Capital						
0.2	0.10038	0.09255	0.08747	0.07973	0.07625	0.08284
0.25	0.10023	0.09339	0.08895	0.08229	0.07947	0.08503
0.3	0.10012	0.09403	0.09009	0.08424	0.08188	0.08669
0.35	0.10003	0.09455	0.09101	0.08578	0.08374	0.08799
0.4	0.09996	0.09497	0.09175	0.08702	0.08524	0.08905
0.45	0.0999	0.09532	0.09237	0.08806	0.08647	0.08992
0.5	0.09984	0.09562	0.09289	0.08892	0.08749	0.09065
Col. Avg.	0.10006	0.09435	0.09065	0.08515	0.08293	0.08745
Highways Capital						
0.2	0.09397	0.08738	0.08268	0.07433	0.06845	0.07687
0.25	0.09111	0.08558	0.08161	0.07454	0.06959	0.07669
0.3	0.08899	0.08425	0.08082	0.07469	0.07041	0.07656
0.35	0.08737	0.08323	0.08022	0.07481	0.07104	0.07645
0.4	0.08609	0.08242	0.07974	0.0749	0.07153	0.07636
0.45	0.08506	0.08177	0.07935	0.07498	0.07193	0.0763
0.5	0.08422	0.08123	0.07903	0.07504	0.07226	0.07624
Col. Avg.	0.08811	0.08369	0.08049	0.07476	0.07074	0.0765

The parameter values used are: $q = 0.031689$ (average over the sample period), $\delta = 0.084097$ for K and $\delta = 0.033557$ for G (average over 1971-1987), $\rho = 0.099218$ for K (average Moody Aaa bond yield rate over 1971-1987) and $\rho = 0.0757$ for G (average Standard and Poor's municipal bond yield rate over the same period), $\partial VC/\partial K = -0.18553$, and $\partial VC/\partial H = -0.15164$ (average over the sample).

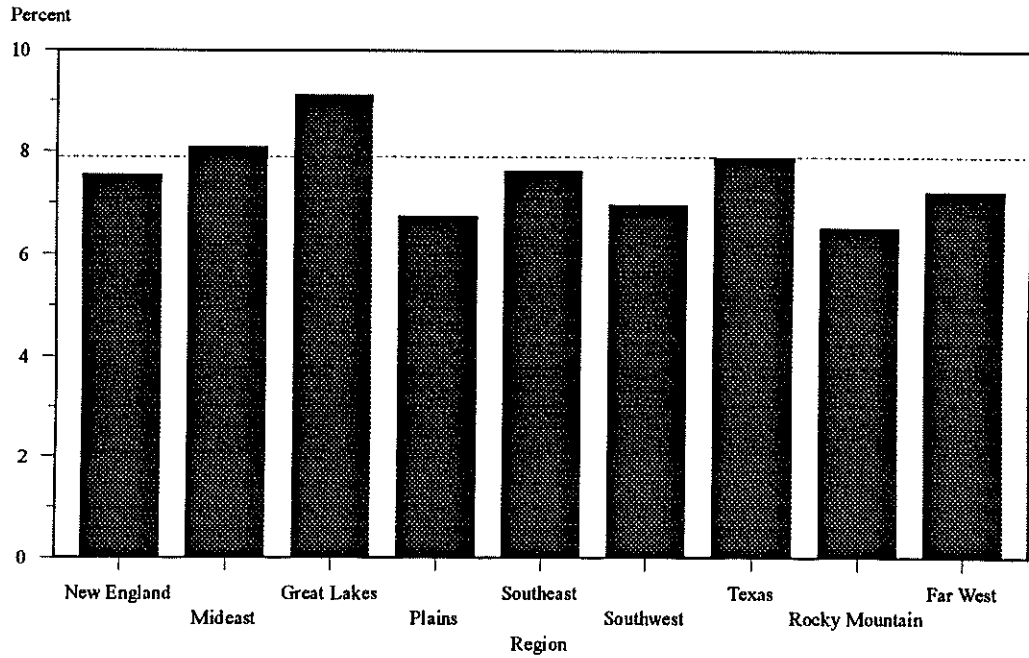


FIGURE 7. — Internal rate of return (IRR) to highways and streets capital, at five-year gestation lag.

CHAPTER IV. CONCLUDING REMARKS

Since the “public infrastructure” debate begun in late 1980s, one question remains largely unresolved: is public infrastructure undersupplied? The short-run variable cost function with two quasi-fixed factors (private capital and highways and streets capital) is utilized to answer this question. This study focuses on the U.S. manufacturing industry in the 48 contiguous states over the period of 1970-1986. We discover that public infrastructure capital provides positive marginal benefits to the manufacturing cost structure. That is, an increase in public capital reduces manufacturing costs. However, the contribution of private capital is greater than that of public capital, and not the reverse, as suggested by some previous studies. Importantly, the long-run equilibrium levels of private and public capital are not attained. We find the internal rates of return to K and H to be in line with other studies. The recent productivity slowdown may be partially explained by utilizing suboptimal levels of capital, both private and public.

Our main result confirms that investment in private and public tangible capital raises manufacturing productivity. However, it does not necessarily follow that the more investment in tangible capital the better. Investment in research and development (R&D) and labor training (including education) may be even more profitable. Nadiri and Mamuneas (1991) show that the internal rates of return from R&D financed by the government are higher than the returns to public infrastructure investment.

Services from public infrastructure can be simultaneously utilized not only by manufacturers, but also by other business sectors and the general public. Our research, however, does not incorporate any other benefits than that of manufacturers. When the net benefits from all parties are included, the economy-wide marginal benefits of public infrastructure are likely to be larger than reported in this study. Financing of public infrastructure is another area that is not pursued. Small, Winston, and Evans (1989) and Gramlich (1990) provide further discussion in this area.

Finally, this research cannot replace a thorough benefit-cost analysis of a specific transportation project; however, the potential productivity benefit from the investment in transportation and other public projects must be properly accounted for.

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APPENDIX A: LIST OF STATES AND REGIONS

Region 1 (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

Region 2 (Mideast): Delaware, Maryland, New Jersey, New York, and Pennsylvania.

Region 3 (Great Lakes): Illinois, Indiana, Michigan, Ohio, and Wisconsin.

Region 4 (Plains): Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.

Region 5 (Southeast): Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

Region 6 (Southwest): Arizona, New Mexico, Oklahoma, and Texas.

Region 7 (Rocky Mountain): Colorado, Idaho, Montana, Utah, and Wyoming.

Region 8 (Far West): California, Nevada, Oregon, and Washington.

APPENDIX B: CONSTRUCTION OF USER COST OF CAPITAL

The imputed user cost of private capital is calculated according to $p_K = (1 + \tau_t)\rho_K(\theta_t + \delta_t)$. τ_t is the effective rate of corporate taxation proxied by an average corporate tax rate, computed as the ratio of corporate tax liability to corporate profits. The annual data are from the *Economic Report of the President*, February 1990, Table C-87. The implicit price deflator for the manufacturing capital stock, ρ_K , is computed as the ratio of BEA current and constant dollar values of national manufacturing sector net capital. The rate of return to private capital, θ_t , is approximated by the Moody Aaa bond yield rate. The depreciation rate, δ_t , is computed as a ratio of total annual depreciation of equipments and structures in the manufacturing and the net stock.

Since the expenditures on public capital are not subject to corporate taxation, the imputed user cost of public capital is computed as $p_G = \rho_G(\theta_t + \delta_t)$. ρ_G is calculated as the ratio of BEA current and constant dollar values of national nonmilitary public net capital. The rate of return to public capital, θ_t , is approximated by the highgrade municipal bond (Standard & Poor's) yield rate. The depreciation rate, δ_t , is computed as a ratio of total annual depreciation of equipment and structures of the nonmilitary public owned capital and the net stock. All national data for manufacturing capital and public capital are from the BEA's *Wealth* computer tapes.