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ABSTRACT

In this paper the authors examine the effects of publicly financed infrastructure and R&D capitals on the cost structure and productivity performance of twelve two-digit U.S. manufacturing industries. The results suggest that there are significant productive effects from these two types of capital. Their effects on the cost structure vary across industries and their contributions to growth of labor productivity vary over time as well. Not only is the cost function shifted downward in each industry, generating productivity inducement, but the factor demand in each industry is also affected by the two types of public capitals, suggesting bias effects. The authors also calculate the marginal benefits of these services in each industry and estimate the "social" rates of return to these capitals for the industries in their sample.

JEL-AEA classification: D24, H40, H54, H59

1. INTRODUCTION[1]

A number of recent studies have examined whether and to what extent public sector infrastructure capital, which consists of highways, airports, mass transit, etc., contributes to private sector productivity growth. The results reported in the literature are generally obtained by using an aggregate production function framework, mostly a Cobb-Douglas aggregate production function, to estimate the association between output or total factor productivity growth ($T\dot{F}P$) and public sector capital. The data used are often at high levels of aggregation, either at the economy-wide or private sector levels, or disaggregate at the state level.

The reported elasticities of output and labor productivity with respect to changes in public infrastructure capital formation are very diverse. Using time-series data at the national level, Aschauer (1989), Munnell (1990a), and Holtz-Eakin (1988), report output elasticities with respect to public infrastructure capital that range from 0.30 to 0.40. At the international level Ford and Poret (1991), using cross-sectional data of nine OECD countries, estimate the average elasticity of $T\dot{F}P$ with respect to changes in infrastructure to be about 0.45. On the other hand, the estimates presented by Hulten and Schwab (1991a) and Tatom (1991) suggest there is no statistically significant relation between the growth of infrastructure capital and output growth at the aggregate business sector and total manufacturing levels. Estimating a cost function, Berndt and Hansson (1991)

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find significant effects of changes in infrastructure capital on labor requirement at both the level of total manufacturing and the aggregate business sector of the Swedish economy. They found that the short-run elasticity estimates vary considerably over the sample, both in magnitude and sign. They also report a substitutional relation between labor and private capital inputs but a short-run complementarity between labor input and public capital, which was reversed during the 1970s and early 1980s.

At the state level, the output elasticity of infrastructure capital is shown to be smaller. The elasticities reported by Munnell (1990b), Costa et al. (1987), and Mera (1973) range from about 0.15 to 0.20 while Eberts (1986) and Garcia-Mila and McGuire (1988) report estimates ranging from 0.040 to 0.045. Finally, in a regional study Hulten and Schwab (1991b) find no statistically significant relationship between growth of total factor productivity and growth of public capital. These differences between estimates based on aggregate data and more disaggregated state data may reflect that it is not possible to capture all the payoffs to public sector capital formation at the disaggregated level.

In this study we have attempted to adopt a different approach. Several aspects of our methodology and application should be noted. (1) We disaggregate the public sector capital into two components: infrastructure and R&D capitals. Our primary objective is to see whether any of these types of public capital stocks affect the level and rate of growth of private sector productivity. We also want to measure the "social rates" of return in each of these types of capital. (2) We estimate the effects of public sector capital at a much more disaggregated industry level. We use twelve two-digit U.S. manufacturing industries as bases of our analysis and examine how the various types of public capital stock influence the structure of the production in these industries and affect their rates of labor and total factor productivity growth. (3) Finally, like Berndt and Hansson, we use the duality theory to specify a cost function dual to a production function, which allows us to treat the cost and input shares to be determined simultaneously. We treat the public sector capitals as unpaid inputs affecting the production process in the private sector. The econometric framework of the study is based on previous work by Bernstein and Nadiri (1988, 1991), in which the cost and input demand functions are jointly estimated when private production externalities are present. (4) To check on our results we have estimated the determinants of multifactor productivity directly by regressing $T\dot{F}P$ on the two types of public sector capital and private input growth.

2. MODEL SPECIFICATION

If the cost of production in the private sector is affected by the types and quantities of public sector capital services, the traditional cost functions must be modified to include the "externality" associated with these capital services. We write the cost function for an industry as

$$(1) \qquad C = C(w,\ y,\ g,\ t)$$

where C is the normalized cost and the twice continuously differentiable function; w is the n-1 dimensional vector of relative variable factor prices, y is the output quantity, g is the m dimensional vector of public capitals and t is an index of time representing disembodied technical change.

Public capital services affect the cost structure of an industry in two ways. First, a larger quantity (and better quality) of public capital services will shift the cost per unit of output downward in an industry if it receives any benefit from improved or larger public capital services. This can be called the "productivity effect." Second, firms will adjust their production decisions with respect to their own labor, intermediates and capital stock if public sector capital services are substitutes or complements with their factors of production. That is, the effects of public sector services may not be neutral with respect to private sector input decisions.

To estimate the effects of public-financed capital on the productivity and production structure of the industries we specify a simple cost function:

$$\begin{aligned} &\ln (C/p_m) = \beta_0' + \textstyle\sum_i \beta_i' \ln w_i + \beta_y \ln y + \beta_t t \\ (2)\qquad &+ \textstyle\sum_{i\neq j} \sum_j \beta_{ij} \ln w_i \ln w_j + \sum_i \beta_{iy} \ln w_i \ln y + \sum_i \beta_{it} \ln w_i\, t + \beta_{yt} \ln y\, t \\ &+ \textstyle\sum_s \phi_s \ln g_s + \sum_s \sum_i \phi_{is} \ln w_i \ln g_s, \end{aligned}$$

$$i,j = L,K; \quad s = I,R.$$

There are three private inputs, labor, intermediates, and capital, and two public inputs, infrastructure and R&D capitals. The cost variable C is defined as $C = \sum_i p_i x_i$ where p_i and x_i refer to the prices and quantities of the inputs; w_i is the relative input prices defined as $w_i = p_i/p_m$, where p_m is the price of intermediates. The subscripts i and j denote the private inputs and s the public inputs. To account for industry differences we have introduced dummies in the intercept and slope coefficients of linear input price variables. That is, $\beta_0' = (\beta_0 + \sum_h \alpha_{0h} D_h)$ and $\beta_i' = (\beta_i + \sum_h \alpha_{ih} D_h)$, where D_h refers to industry dummies taking values 1 and 0 and h is an identification industry index. The parameters ϕ_s and ϕ_{is} capture the effects generated from the public capital services, g_s.

Applying Shephard's lemma, the following share equations are obtained:

$$(3) \qquad s_i = \beta_i' + \textstyle\sum_{j \neq i} \beta_{ij} \ln w_j + \beta_{iy} \ln y + \beta_{it}\, t + \sum_s \phi_{is} \ln g_s, \qquad \begin{array}{l} i = L,K, \\ s = I,R \end{array}$$

where $s_i = p_i\, x_i / C$. The share of the input used for the normalization is calculated by $s_m = 1 - \sum_i s_i$. Input shares in each industry depend not only on relative prices, output, and technological change, but also on the publicly financed infrastructure and R&D capitals; the parameters ϕ_{is} determine the magnitude of the factor bias effects associated with these types of capital stocks.

In order for the cost function to be concave in price inputs, the Hessian matrix $[\partial^2 C/\partial w_i\, w_j]_{ij}$ of the cost function should be negative semi-definite. Also, cost function should be nondecreasing in output and linear homogeneous in input prices. Finally, in order for public capital input to have a meaningful context the cost function should be nonincreasing in g_s. We assume that the errors attached on the above equations are optimizing errors and are jointly normally distributed with zero expected value and with a positive definite symmetric covariance matrix.

3. CONSTRUCTION AND DESCRIPTION OF THE DATA

Data on quantities and price indices of output, labor, physical capital and intermediate inputs for all manufacturing industries at the two digit level were obtained from the Bureau of the Labor Statistics (BLS). These data are the same as those used by Gullickson and Harper (1986, 1987) to estimate total factor productivity indices for the manufacturing sector.[2] All price

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[2] See the above-mentioned papers for a detailed description of the data.

indices have been normalized to be equal to one at 1982 value.

For each industry the quantity of output is measured as the value of gross output divided by the output price index. The labor input quantity is measured as the cost of labor divided by the price of labor index. The price of intermediate inputs is derived by a Tornqvist index of the price indices of materials, energy and purchased services. The quantity of intermediate inputs is measured as the total cost of materials, energy and purchased services divided by the price index of intermediate inputs. The prices of labor and intermediate inputs are multiplied by one minus the corporate income tax to convert them to after-tax prices. The physical capital stock is defined as the sum of structures and equipment capital stock. The deflator of physical capital is derived as a Tornqvist index of the investment price deflators of structures and equipment.

The rental rate of physical capital is measured as $p_k = q_k\ (r+\delta_k)\ (1 - \iota_k - u_c\ z)$, where q_k is the physical capital deflator, r is the discount rate, which is taken to be the rate on Treasury notes of ten-year maturity obtained from Citibase, δ_k is the physical capital depreciation rate, ι_k is the investment tax credit, u_c is the corporate income tax rate, obtained from Auerbach (1983), and Jorgenson and Sullivan (1981), and z is the present value of capital consumption allowances. After 1983 the corporate income tax rate is taken to be 0.46, the constant rate over 1979-1982. The investment tax credit until 1980 is taken from Jorgenson and Sullivan (1981); for 1981 8% is used and for 1982 to 1986 a rate of 7.5% is used. The present values of capital consumption allowances are constructed as $z = \rho\ (1 - \theta\ \iota_k)/(r + \rho)$ (see Bernstein and Nadiri (1987, 1988, 1991)), where ρ is the capital consumption allowance rate obtained by dividing the capital consumption allowances by the capital stock, and θ takes value 0 except for the 1962-1963 period in which the firms under the Long Amendment had to reduce the depreciable base of the assets by half the amount of the investment tax credit.

Annual data on fixed nonresidential government net capital stock (federal, state and local) has been obtained from the Bureau of Economic Analysis (BEA). The total net government physical capital stock is measured as the sum of federal, state, and local net capital stock of structures and equipment, excluding military, at constant 1982 prices.[3] The acquisition price of capital is constructed as a Tornqvist index from the government's gross investment series on structures and equipment obtained from the same source.

Data on research and development financed by the government for the sample period 1970-1986 were obtained from the U.S. Statistical Abstracts (various issues). For the period 1953-1970 it was obtained from the series W 109-110 of Historical Statistics, Colonial Times to 1970 (1975). The implicit price deflator of government purchases of goods and services, obtained from the above sources, was used to deflate the R&D expenditure series. The government R&D capital stock is constructed using the perpetual inventory method with a 10% depreciation rate. The 1952 benchmark is estimated by dividing the R&D expenditures by the sum of government R&D

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[3] Federal structures include industrial, educational, hospital and other buildings, highways and streets, construction and development, and other structures. State and local structures include educational, hospital and other buildings, highways and streets, construction and development and other structures. "Other buildings" consists of general office buildings, police and fire stations, courthouses, auditoriums, garages, passengers' terminals, etc. "Other structures" consists of electric and gas facilities, transit systems, airfields, etc.

depreciation rate and the average growth rate of the infrastructure capital stock prior to the sample period.

In our model we have used the utilized services of publicly financed infrastructure capital. It is important to convert the stock of public capital to service measures provided by these capital stocks. As Hulten (1990) has pointed out, public capital stock should be adjusted for capacity utilization because there is evidence of significant variation in the intensity with which public capital is used. We have multiplied the infrastructure capital by the manufacturing sector capacity utilization rate obtained from Citibase and normalized to be one at 1982 value. For the stock of R&D we have assumed a utilization rate of unity. Both publicly financed capital stock variables, infrastructure and R&D, have been lagged once in the estimation of the model.

Table 1 identifies the industries included in this study. They were selected because they are high R&D industries and the major recipients of government funded R&D. In table 2 we provide the mean values of the cost, input shares and the rates of growth of gross output and the inputs for each industry. There are considerable variations among the industries in terms of cost, and output and input growth. There is some contrasting pattern among the input shares as well, particularly with respect to share of capital.

4. ESTIMATION RESULTS

The estimation model consists of the cost equation (2) and the share equations (3) for labor and capital. We have used pooled time-series cross-section data for twelve two-digit U.S. manufacturing industries for the period 1956-1986 to estimate the model. For estimation purposes we have imposed

TABLE 1

SIC Classification

SIC	Industries
20	FOOD
26	PAPER AND ALLIED PRODUCTS
28	CHEMICALS AND ALLIED PRODUCTS
29	PETROLEUM REFINING AND RELATED INDUSTRIES
30	RUBBER PRODUCTS
32	STONE, CLAY AND GLASS PRODUCTS
33	PRIMARY METALS
34	FABRICATED METAL PRODUCTS
35	MACHINERY
36	ELECTRICAL EQUIPMENT
37	TRANSPORTATION
38	SCIENTIFIC INSTRUMENTS

TABLE 2

Descriptive Statistics of Industries

(industries in descending order of output growth)
(mean values)
1956-1986

SIC	C	s_L	s_M	s_K	$\dot{y}$	$\dot{L}$	$\dot{M}$	$\dot{K}$
20	29.40	0.333	0.538	0.129	0.040	0.014	0.041	0.017
26	15.46	0.352	0.503	0.145	0.033	0.007	0.031	0.036
28	31.07	0.325	0.521	0.154	0.041	0.009	0.037	0.036
29	42.47	0.078	0.704	0.218	0.020	-0.009	0.015	0.028
30	12.80	0.350	0.565	0.085	0.046	0.025	0.043	0.046
32	11.67	0.395	0.475	0.130	0.015	0.004	0.018	0.025
33	29.79	0.341	0.524	0.135	-0.005	-0.016	0.009	0.025
34	36.32	0.464	0.487	0.050	0.027	0.014	0.029	0.040
35	37.41	0.452	0.475	0.073	0.044	0.011	0.032	0.044
36	30.02	0.467	0.467	0.065	0.051	0.018	0.032	0.062
37	48.93	0.377	0.557	0.066	0.021	0.002	0.022	0.038
38	9.84	0.478	0.463	0.059	0.048	0.020	0.048	0.060

	Infrastructure Capital Stock	Infrastructure Service	R&D Capital Stock
Level	1172.26	1352.36	273.93
Growth Rate	0.030	0.027	0.05
Acquisition price	0.509		0.495

C = cost
s_L = cost share of labor
s_M = cost share of intermediate inputs
s_K = cost share of capital
$\dot{y}$ = growth rate of output
$\dot{L}$ = growth rate of labor
$\dot{M}$ = growth rate of intermediate
$\dot{K}$ = growth rate of capital stock

constant returns to scale (CRS) with respect to private sector inputs, i.e., $\beta_y = 1$, $\beta_{iy} = 0$, and $\beta_{yt} = 0$ in equations (2) and (3). This was necessary in order to distinguish technological change from the scale effect and to compare our results with those of the relevant literature, which often adopts the CRS assumption. To capture industry variations in costs and factor shares, we have included appropriate industry dummies as part of the estimation.

The results shown in table 3 indicate that the model is estimated well. The square of the correlation coefficients between the actual and predicted values is high and the standard errors of each equation are small. In addition, all the required regularity conditions are satisfied at each point in the sample. The likelihood ratio test indicated a decisive rejection of the hypothesis that the coefficients of the industry dummies are zero (the $\chi^2 = 1960$ with 33 degrees of freedom), suggesting that interindustry differences are present in the cost structure of the industries under consideration. Similarly, the hypothesis that the coefficients of public capital services are zero was rejected with a $\chi^2 = 228$ and 6 degrees of freedom.[4]

The estimates in this table show that the coefficients of the model are statistically significant and have the correct sign. Particularly, the parameters of the public capital services φ_s and φ_{is} (s=I,R) are statistically significant and suggest negative cost elasticities. However, when the

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[4]

Parameter Restriction		Log of Likelihood	Degrees of Freedom	
$\alpha_{0h} = \alpha_{Lh} = \alpha_{Kh} = 0$	$\forall_h$	1460	33	$\chi^2 = 1960$
$\varphi_s = \varphi_{is} = 0$	$\forall_{i,s}$	2341	6	$\chi^2 = 228$

TABLE 3

Estimation Results

Parameter	Estimate*	Standard Error
β_0	2.465	0.406
β_L	0.455	0.782E-01
β_K	0.703	0.823E-01
β_t	0.598E-02	0.152E-01
β_{LK}	0.759E-02	0.397E-02
β_{Lt}	-0.510E-02	0.305E-03
β_{Kt}	0.493E-02	0.309E-03
φ_I	-0.324	0.759E-01
φ_{LI}	-0.528E-01	0.146E-01
φ_{KI}	-0.102	0.153E-01
φ_R	-0.101E-01	0.300E-01
φ_{LR}	0.654E-01	0.573E-02
φ_{KR}	0.122E-01	0.606E-02

Equation	Standard Error	R^2
Cost	0.809E-01	0.987
Labor Share	0.172E-01	0.976
Capital Share	0.182E-01	0.900
Log of likelihood	2455	

* The coefficient of dummies are not reported.

infrastructure capital was not adjusted for the utilization rate, either its coefficients became statistically insignificant or the cost elasticity of infrastructure capital became positive. The sign and magnitudes of other coefficients of the model, particularly those of public R&D, did not change much whether the infrastructure capital was adjusted for utilization or not. This underscores the crucial point made by Hulten that infrastructure should be adjusted for utilization.

The general effects of public capital services reported in table 3 are confirmed by an alternative approach suggested by Hulten and Schwab (1991b). We regressed the $T\dot{F}P$ directly on the growth rates of private inputs and the two public capital services as well as a time trend. That is:

$$(4) \qquad T\dot{F}P = \underset{(4.250)}{-.041} + \underset{(4.688)}{.0017\,t} - \underset{(1.401)}{.047\,PIN} + \underset{(8.414)}{.292\,\dot{I}} + \underset{(4.022)}{.248\,\dot{R}} \qquad R^2 = .263$$

where PIN, $\dot{I}$ and $\dot{R}$ are respectively the growth rates of private inputs (weighted by their cost shares), infrastructure capital services, and R&D capital.[5] Note that the coefficient of PIN suggests that the assumption of constant returns to scale may not be too far off the mark. Also, the elasticities of TFP with respect to changes in public infrastructure and R&D capital services are somewhat higher than those implied by the estimates of the cost function. These results contrast with those reported by Hulten and Schwab, who did not find any statistically significant coefficient between $T\dot{F}P$ and infrastructure capital growth. The significance of the coefficient of $\dot{I}$ in the above equation deteriorated and even changed sign when the stock of

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[5] These results were stable when we included industry dummies and when we replaced PIN with growth rate of capital stock in each industry.

infrastructure was not adjusted for the utilization rate.

It is interesting to note that the public R&D variable in the TFP equation as well as in equation system (2) and (3) consistently has a significant coefficient with the correct sign. Except for agriculture, the effects of government-financed R&D on the private sector performances have received relatively little attention in comparison with the effects of privately financed R&D. Evidence on the direct effect of publicly financed R&D has been controversial, often pointing towards its being weak or nonexistent (Griliches (1986), Griliches and Lichtenberg (1984), and Levy and Terleckyj (1983)). The evidence on the indirect or induced effects of public R&D is measured by its effect on private sector R&D expenditure. Some studies suggest that public R&D crowds out privately funded R&D (Carmichael (1981) and Lichtenberg (1984, 1988)), while others suggest a complementary relationship (Levin and Reiss (1984), Jaffe (1989), and Scott (1984)). Our results indicate that there is a direct effect of publicly funded R&D on the cost structure and productivity growth in the U.S. manufacturing sectors in our sample.

A. Costs, Input Demands, and Public Sector Capital Services

The spillover effects of public sector capital on cost and input shares of our sample of two-digit industries are captured by the magnitudes and signs of the parameters ϕ_s and ϕ_{is}. The cost elasticities with respect to each of the public sector capital services are shown in table 4. These elasticities are computed using

$$(4) \qquad \eta_{csh} = \frac{\partial \ln C_h}{\partial \ln g_s} = \varphi_s + \textstyle\sum_i \varphi_{is} \ln w_{ih} \qquad \begin{array}{r} i = L,\ K \\ s = I,R \end{array}$$

where s stands for types of public sector capital and h is an industry identification index. The elasticity estimates in table 4 measure the "productivity effect" of public sector capitals. The results indicate that both types of public capital services reduce costs in each industry. The magnitudes of the cost elasticities with respect to infrastructure capital are in general much smaller than reported in previous studies, ranging from -0.11 to -0.22. The cost elasticities for public-financed R&D capital range from about -0.03 to -0.05. These elasticities vary considerably across industries; there is no clearly discernible pattern except that the magnitudes of the elasticities tend to be higher in durable manufacturing sectors, as in industries SIC 35, 36, 37, and 38.

The "factor bias effect" of public capital services, defined as $\partial s_{ih}/\partial \ln g_s$, is measured by the estimates of parameters ϕ_{is} in equation (3). The factor bias effects as percentage of the share of each input are reported in table 5. If the factor cost share increases, decreases, or does not change, public capital services are factor using, factor saving, or neutral. The results shown in table 5 vary considerably between the two types of public capital services. Infrastructure capital services are labor and capital saving but intermediate using in each industry. On the other hand, the factor bias effect of public R&D is labor and capital using and intermediate saving--the opposite pattern to that of infrastructure.

The total effects of public sector capital services on input demand are shown in table 6. The total elasticities of these services are calculated

TABLE 4

The Cost Elasticities with Respect to Infrastructure, and R&D Capital Services

$(\eta_{csh} = \varphi_s + \sum_i \varphi_{is} \ln w_{ih})$

SIC Industry	Infrastructure Capital Services	Public-Financed Stock of R&D Capital
20	-0.133	-0.041
26	-0.150	-0.035
28	-0.160	-0.032
29	-0.227	0.009*
30	-0.143	-0.035
32	-0.157	-0.031
33	-0.119	-0.046
34	-0.123	-0.039
35	-0.109	-0.050
36	-0.118	-0.046
37	-0.129	-0.041
38	-0.117	-0.047

* From 1979 to 1985, the average elasticity is equal to -0.02 .

TABLE 5

Bias Effects over Share

$(\text{bias}_{ish} = \varphi_{is}/s_{ih})$

	INFRASTRUCTURE CAPITAL SERVICES			PUBLIC-FINANCED R&D CAPITAL STOCK		
SIC	Labor	Interm.	Capital	Labor	Interm.	Capital
20	-0.159	0.287	-0.787	0.196	-0.144	0.095
26	-0.150	0.307	-0.700	0.186	-0.154	0.084
28	-0.163	0.296	-0.660	0.202	-0.149	0.080
29	-0.690	0.219	-0.467	0.847	-0.110	0.056
30	-0.150	0.273	-1.196	0.187	-0.137	0.144
32	-0.134	0.325	-0.781	0.165	-0.163	0.094
33	-0.155	0.296	-0.783	0.191	-0.149	0.090
34	-0.114	0.317	-2.017	0.141	-0.160	0.243
35	-0.117	0.325	-1.399	0.145	-0.163	0.168
36	-0.113	0.329	-1.583	0.140	-0.166	0.191
37	-0.140	0.277	-1.522	0.174	-0.139	0.184
38	-0.110	0.333	-1.749	0.137	-0.167	0.211

TABLE 6

The Elasticities of Input Demand with Respect to Public Capital Stock Services

$(\eta_{ish} = \eta_{csh} + \text{bias}_{ish})$

	INFRASTRUCTURE CAPITAL SERVICES			PUBLIC-FINANCED R&D CAPITAL STOCK		
SIC	Labor	Interm.	Capital	Labor	Interm.	Capital
20	-0.293	0.154	-0.949	0.158	-0.185	0.058
26	-0.302	0.157	-0.870	0.153	-0.190	0.051
28	-0.324	0.136	-0.837	0.172	-0.181	0.049
29	-0.917	-0.008	-0.694	0.856	-0.101	0.065
30	-0.295	0.130	-1.339	0.154	-0.173	0.120
32	-0.292	0.169	-0.738	0.136	-0.194	0.067
33	-0.275	0.177	-0.902	0.147	-0.196	0.046
34	-0.238	0.194	-2.140	0.103	-0.200	0.297
35	-0.227	0.215	-1.508	0.096	-0.213	0.142
36	-0.232	0.211	-1.701	0.095	-0.212	0.181
37	-0.271	0.148	-1.651	0.140	-0.181	0.175
38	-0.228	0.215	-1.866	0.090	-0.215	0.216

using the relation

$$\text{(5a)} \qquad \eta_{ish} = \frac{\partial \ln x_{ih}}{\partial \ln g_s} = \eta_{csh} + \frac{\varphi_{is}}{s_{ih}}, \qquad \begin{array}{r} s = I,R \\ i = L,K \\ h = 1..n \end{array}$$

which is the sum of the "productivity effect" and the "factor bias effect". If the sign of the expression in (5a) is positive, negative or zero, it implies that the particular publicly financed capital services and the ith private input are complements, substitutes, or neutral, respectively. Note that the sign of η_{ish} depends on the sign and magnitude of productivity and factor bias effects; they could reinforce or offset each other. The elasticity of intermediate inputs is found by

$$\text{(5b)} \qquad \eta_{msh} = \eta_{csh} - \frac{\sum_i \varphi_{is}}{1 - \sum_i s_{ih}}, \qquad \begin{array}{r} s = I,R \\ h = 1,\ldots,n \end{array}$$

The results in table 6 indicate the effects of the two types of public-financed capitals on private factor demand for labor, intermediates, and capital. The estimates form a systematic pattern. An increase in infrastructure capital service leads to a decline in demand for labor and capital in each industry while it has a positive effect on demand for intermediates. These results are similar to the short-run estimates of Berndt and Hansson with respect to labor and intermediates but not private capital stock. They report elasticities of demand of -0.60 for labor, 0.02 for materials, 1.39 for energy and 0.86 for capital for the Swedish total manufacturing sector in 1975.[6] Our estimates for labor are much smaller:

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[6] The elasticity estimates for intermediate inputs shown in table 6 are comparable to those of Berndt and Hansson because our measure is a weighted average of their figures elasticities for energy and materials.

approximately -0.2 to -0.3. The major difference between the two studies is that we find a substitutional relationship while Berndt and Hansson have reported complementarity between public infrastructure and private capital stock. The magnitudes of these substitutions and complementarities vary considerably among various industries. Generally the magnitudes of these elasticities are highest for capital input followed by those for labor input and intermediates. The magnitudes of the effect on demand for capital are surprisingly large, particularly in durable manufacturing sectors.

An increase in the stock of publicly financed R&D reduces demand for intermediates but increases demand for labor and capital stock. The magnitudes of the elasticities are higher for intermediates. The elasticities of intermediates with respect to R&D stock range from -0.10 to -0.22 while these elasticities are smaller for labor, ranging in magnitude from 0.09 to 0.17. There is one exception, the petroleum refining industry, SIC 29, which is highly capital intensive and where the share of labor in gross output is about 0.08.[7] The elasticity of capital implies complementarity between capital and publicly financed R&D, ranging from 0.05 to 0.3. Again, the magnitude of the effect on demand for capital is higher in durable manufacturing sectors.

B. Marginal Benefits and "Social" Rates of Return

From the estimates presented in table 3 it is possible to calculate the marginal benefits of the two types of public capitals in each industry. These

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[7] Note that input share enters in the denominator of the second term on the right hand of expressions (5a) and (5b).

benefits are measures of the implicit willingness of the private sector to pay for the services of the public sector capitals. They are calculated as the magnitude of cost reductions experienced by an individual industry as a result of increase in public sector capital services, that is

$$(6) \qquad b_{sh} = -\frac{\partial C_h}{\partial g_s} = -\eta_{csh}\frac{C_h}{g_s} \qquad \begin{array}{l} s = I,R \\ h = 1,\ldots,n \end{array}$$

The estimates of marginal benefits for each industry are given in table 7. The magnitudes of the marginal benefits of infrastructure services are fairly small, ranging on average from 0.0015 for industry SIC 32 to 0.0060 for industry SIC 29. For R&D, they range on average from less than 0.001 in industry SIC 29 to 0.0064 in industry SIC 37. The marginal benefits of publicly financed R&D are lower in industries SIC 20 to 32 but higher in several durable manufacturing industries, SIC 33 to 38, than the corresponding infrastructure benefits. The small magnitudes of these benefits are partly due to the relatively large size of the government public sector capital stocks compared to total costs in each industry, that is, the magnitude of the ratio C/g_s in expression (6). The sum of the marginal benefits for the two types of public capital services is approximately the same.

The "social" rate of return is calculated by adding the marginal benefits of each type of public capital services to various industries and dividing the sum by the cost of obtaining one additional unit of public-financed capital. That is,

TABLE 7

Marginal Benefits
$(\beta_{sh} = -\eta_{csh} C_h/g_s)$

	Infrastructure	R&D
20	0.0033	0.0036
26	0.0019	0.0017
28	0.0040	0.0029
29	0.0059	0.0005
30	0.0016	0.0014
32	0.0015	0.0012
33	0.0029	0.0048
34	0.0037	0.0044
35	0.0039	0.0058
36	0.0035	0.0043
37	0.0053	0.0064
38	0.0011	0.0014

$$(7) \qquad S_s = \sum_h \frac{b_{sh}}{q_s} \qquad\qquad \begin{array}{l} s = I,R \\ h = 1,\ldots,n \end{array}$$

where q_s is the marginal cost of publicly financed capital and assumed to be equal to the acquisition price of publicly financed capital. The measurement of q_s is controversial. Jorgenson and Yun (1990), Ballard et al. (1985) and others have argued that public sector capital formation is generally financed through taxation and have significant distortive effects on private sector decisions. Ballard et al. put the marginal cost of public sector investment about $1.17 while Jorgenson and Yun estimate this cost to be about $1.47 for each dollar of benefits. Using these cost figures we calculate the "social" rates of return for the three types of public capital. These rates of return are listed in table 8.

TABLE 8

Social Rates of Return on Public Capital

Type of Cost Type of Capital	I	II Jorgenson-Yun	III Ballard et al.
Infrastructure capital	.068	0.046	0.058
R&D capital	.096	0.066	0.082

Several aspects of these figures are interesting. First, the R&D capital has a higher rate of return than the infrastructure capital. Second, the rates of return on federally financed R&D are small compared to the social rates of return calculated for private sector R&D (see, e.g., Bernstein and

Nadiri (1988, 1991)). Third, the rates shown in table 8 pertain only to our sample of industries. Of course, these publicly financed capital services provide benefits to other producers in the economy and also contribute to the quality and quantity of consumption activities of the entire economy. When they are appropriately measured, the economy-wide rates of return on these public capital services are likely to be larger.

C. Labor Factor Productivity Growth

To address this issue we decompose the sources of $\dot{TFP}$ using the estimated coefficients of our model. The traditional measure of total factor productivity growth is defined:

$$(8) \qquad \dot{TFP} = \frac{d\ln y}{dt} - \sum_i \frac{p_i\, x_i}{C} \frac{d\ln x_i}{dt} \qquad i = M,L,K,$$

where, $C = \sum_i p_i\, x_i$, is the total cost of private sector inputs.The labor factor productivity growth is defined as

$$(9) \qquad \frac{d\ln y}{dt} - \frac{d\ln x_L}{dt} = \dot{TFP} + \sum_{i \neq L} \frac{p_i\, x_i}{C} \left(\frac{d\ln x_i}{dt} - \frac{d\ln x_L}{dt}\right)$$

where x_L refers to labor input. Under the restriction of constant returns to scale,[8] $\dot{TFP}$ growth can be decomposed as

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[8] The definition of TFP growth under general conditions of nonconstant returns to scale and public sector externality can be decomposed as:

$$(8a) \qquad \dot{TFP} = (1 - \rho^{-1}) \frac{d\ln y}{dt} - \sum_i (s_i - z^{-1}\, s_i) \frac{d\ln x_i}{dt}$$

$$(10) \qquad T\dot{F}P = - \textstyle\sum_s \eta_{cs} \dfrac{\partial \ln g_s}{\partial t} - \dfrac{\partial \ln C}{\partial t}$$

Combining (9) and (10), we obtain the labor factor productivity decomposition for each industry.[9] The results of the decomposition for several subperiods are shown in table 9. They suggest some interesting patterns. The contributions of the private sector inputs as well as the components of TFP, i.e., the public sector infrastructure capital and publicly financed R&D capital and technical change differ across the subperiods and among industries.

As a general proposition the contribution of infrastructure was fairly large in the periods 1969-73 and 1973-79, government's R&D contribution was relatively large in the slowdown between the periods 1956-69 and 1969-73, and

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$$- \textstyle\sum_s z^{-1} \eta_{cs} \dfrac{d\ln g_s}{dt} - z^{-1} \dfrac{\partial \ln C}{\partial t}$$

where $\rho = [1-\sum_s \eta_{cs}]/\eta_{cy}$, $z = \rho . \eta_{cy}$, and $\eta_{cy} = \partial \ln C/\partial \ln y$. The first term on the rhs of (8a) is referred to as the <u>total</u> scale effect (the sum of the private and public elasticities), the second term measures the effect of unpaid inputs such as public sector capital. The external effects of public capital are measured by the third term while the effect of pure exogenous technical change is captured by the last term in the equation. The missing input effect disappears if public inputs are paid their marginal contribution.

Under constant returns to scale, $\eta_{cy} = 1$, then the above expression becomes

$$T\dot{F}P = (1 - \rho^{-1})\ T\dot{F}P - \textstyle\sum_s \rho^{-1} \eta_{cs} \dfrac{\partial \ln g_s}{\partial t} - \rho^{-1} \dfrac{\partial \ln C}{\partial t}$$

or the equation (10) in the text.

[9] The elasticities and shares are the weighted averages of current and previous year values, estimated by the cost function.

technical change has played a large role in the slowdown since 1979. Both the level and slowdown of labor productivity growth have been affected by public sector capitals and rate of technical change. The magnitude of the contributions, however, varies over different periods, reflecting the different growth rates of these variables in relation to those of labor productivity.

TABLE 9

Decomposition of Labor Factor Productivity Growth (in %)

SIC	Period	Labor Productivity	Private Inputs	Infrastructure	R&D	Technological Change
20	1956-86	2.32	1.52	0.31	0.27	0.23
	1956-69	2.75	1.46	0.46	0.56	0.28
	1969-73	1.63	0.79	0.50	0.09	0.25
	1973-79	3.40	2.84	0.30	-0.01	0.23
	1979-86	0.24	0.06	0.04	0.02	0.01
26	1956-86	2.44	1.64	0.37	0.24	0.19
	1956-69	3.13	1.83	0.56	0.52	0.22
	1969-73	1.94	1.04	0.63	0.06	0.21
	1973-79	2.45	1.86	0.39	-0.01	0.20
	1979-86	1.26	1.08	0.04	0.02	0.12
28	1956-86	2.65	1.87	0.65	0.22	0.17
	1956-69	3.28	2.02	0.59	0.46	0.21
	1969-73	4.19	3.26	0.68	0.06	0.19
	1973-79	2.61	2.03	0.41	-0.01	0.17
	1979-86	0.66	0.50	0.05	0.02	0.09
29	1956-86	3.36	2.51	0.65	-0.08	0.28
	1956-69	4.83	3.63	1.02	-0.16	0.33
	1969-73	4.03	2.82	1.04	-0.10	0.26
	1973-79	3.28	2.47	0.56	-0.00	0.26
	1979-86	1.41	1.13	0.06	0.01	0.21
30	1956-86	1.94	1.12	0.34	0.24	0.24
	1956-69	2.96	1.65	0.48	0.50	0.32
	1969-73	2.73	1.77	0.62	0.06	0.28
	1973-79	0.78	0.19	0.39	-0.01	0.21
	1979-86	0.02	-0.15	0.05	0.02	0.09
32	1956-86	1.93	1.13	0.38	0.21	0.21
	1956-69	2.75	1.48	0.58	0.44	0.26
	1969-73	1.80	0.88	0.63	0.06	0.24
	1973-79	2.04	1.43	0.41	-0.00	0.21
	1979-86	0.37	0.22	0.03	0.02	0.10

TABLE 9 (cont'd)

SIC	Period	Labor Productivity	Private Inputs	Infrastructure	R&D	Technological Change
33	1956-86	2.69	1.85	0.28	0.32	0.24
	1956-69	3.14	1.79	0.38	0.67	0.29
	1969-73	3.25	2.40	0.49	0.11	0.24
	1973-79	2.42	1.82	0.35	-0.01	0.25
	1979-86	1.27	1.07	0.03	0.03	0.15
34	1956-86	1.70	0.85	0.29	0.24	0.31
	1956-69	1.91	0.59	0.43	0.51	0.38
	1969-73	2.80	1.91	0.47	0.09	0.33
	1973-79	1.13	0.52	0.31	-0.01	0.31
	1979-86	1.14	0.90	0.04	0.03	0.17
35	1956-86	2.08	1.25	0.24	0.33	0.25
	1956-69	2.32	0.98	0.34	0.70	0.30
	1969-73	3.07	2.27	0.44	0.12	0.24
	1973-79	2.48	1.93	0.32	-0.01	0.25
	1979-86	0.83	0.60	0.02	0.03	0.18
36	1956-86	1.79	0.96	0.29	0.31	0.25
	1956-69	1.57	0.25	0.37	0.65	0.30
	1969-73	3.29	2.44	0.45	0.12	0.28
	1973-79	2.09	1.52	0.35	-0.01	0.23
	1979-86	1.09	0.88	0.04	0.02	0.16
37	1956-86	2.09	1.26	0.31	0.28	0.24
	1956-69	2.25	0.92	0.46	0.60	0.28
	1969-73	5.37	4.49	0.52	0.09	0.28
	1973-79	0.96	0.36	0.34	-0.01	0.26
	1979-86	0.54	0.32	0.04	0.02	0.17
38	1956-86	2.32	1.51	0.26	0.30	0.24
	1956-69	2.77	1.47	0.37	0.64	0.30
	1969-73	2.87	2.03	0.45	0.12	0.27
	1973-79	2.31	1.77	0.31	-0.01	0.23
	1979-86	1.11	0.91	0.04	0.02	0.14

5. CONCLUSION

We have examined the effects of publicly financed infrastructure and R&D capitals on the cost structure and productivity performance of twelve two-digit U.S. manufacturing industries. The results suggest that there are significant productive effects from these two types of capital. Their effects on the cost structure vary across industries and their contributions to growth of labor productivity vary over time as well. Not only is the cost function shifted downward in each industry, generating productivity inducement, but the factor demand in each industry is also affected by the two types of public capitals, suggesting bias effects. We also calculate the marginal benefits of these services in each industry and estimate the "social" rates of return to these capitals for the industries in our sample.

There are several issues that require further research. As noted before, the positive contribution of infrastructure capital to productivity growth depends on whether this variable is adjusted for variation in the utilization rate. Another issue that requires further examination is the CRS assumption which could affect the econometric results and the contributions of publicly financed capital services to productivity growth. Further, we have adopted a simple generalized Cobb-Douglas production function to estimate the underlying technologies of the industries in our sample. Further we have not introduced possible adjustment costs for the quasi-fixed inputs such as private capital stock. Also, we have not introduced the stock of private R&D separately in the model; therefore it has not been possible to examine the relationship between privately and publicly financed R&D. One further problem worthy of attention is that a large portion of government funded R&D is for military purposes. Finally, we need to model the determinants of infrastructure investment and public R&D expenditures and examine in that context the possibilities of reverse causation between these variables and TFP growth. This list provides a challenging agenda for future research.

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