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INFRASTRUCTURE AND PUBLIC
R&D INVESTMENTS, AND THE
GROWTH OF FACTOR PRODUCTIVITY
IN US MANUFACTURING INDUSTRIES

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ABSTRACT

In this paper we examine the effects of publicly financed infrastructure and R&D capital on the cost structure and productivity performance of twelve two-digit U.S. manufacturing industries. A general framework is developed to measure contribution of demand, relative input prices, technical change, as well as publicly financed capital on total factor productivity growth. The magnitude of the contribution of these sources varies considerably across industries: in some changes in demand dominate while in others changes in technology or relative prices are the main contributors. Publicly financed infrastructure and R&D capital contribute to productivity growth. However, the magnitudes of their contribution vary considerably across industries and on the whole they are not the major contributors to TFP in these industries.

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I. Introduction

Several recent studies have examined the role of public infrastructure investment which consists of highways, airports, mass transit, etc. in increasing private sector productivity growth. The subject has been very controversial; some, like Aschauer (1989), have argued that infrastructure capital contributes significantly to the growth of output and productivity, while others, such as Hulten and Schwab (1991), have denied any significant role for it in this regard. Eisner (1993) has presented evidence based on aggregate economic data in support of the role of public infrastructure investment as a significant contributor to productivity growth.

Aside from the question of whether there is a strong correlation between public capital and productivity, there is the question of the magnitude of the effect of infrastructure capital. 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 TFP with respect to changes in infrastructure to be about 0.45. On the other hand, the estimates presented by Hulten and Schwab (1991) 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) have found 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.

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 (1992) 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 the fact that it is

not possible to capture all the payoffs to public sector capital formation at the disaggregated level.

All of these studies are at high levels of aggregation, using national, regional, or state data. A major beneficiary of any services of public sector capital is the production sector of the private economy. There are, however, very few studies exploring the impact of infrastructure capital on cost and output at the disaggregate industry level. Nadiri and Mamuneas (1993) and Conrad and Seitz (1992) provide evidence for the positive contribution of infrastructure services on productivity growth at the two digit industry level in the U.S. and West Germany, respectively. Their estimates imply lower elasticities than those at the aggregate level. Also infrastructure investment is not the only type of public sector capital that would affect private sector productivity. Another potential candidate is the stock of R&D capital financed by the US government. There is considerable evidence that labor and total factor productivity are influenced by R&D investment, particularly when it is financed by the private sector. The effect of public-sector financed R&D on the growth of output and productivity at the industry level has not been extensively or properly examined. Many of the studies at the industry level provide inconclusive evidence of the effect of federally financed R&D performed by the industries. On the contrary, Nadiri and Mamuneas (1993), Mamuneas and Nadiri (1993), and Mamuneas (1993) have estimated that aggregate federally financed R&D, when treated as a public input, contributes significantly to the private cost reduction of U.S. manufacturing industries.

In this study we analyze the effect of public sector financed capital on total factor productivity growth (TFP) in the context of a general framework. Our analytical framework following the previous work of Nadiri and Schankerman (1981a,b) distinguishes between the contributions of output demand, relative input prices, technical change and publicly financed capital. Analyzing the relative contribution of these types of capital in the context of a comprehensive framework may provide reasonable answers to policy questions. More specifically:

(1) We disaggregate the public sector capital into two components: infrastructure and R&D capital. 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.

(2) We estimate the effects of the two types of public sector capital at a much more disaggregated industry level. We use twelve two-digit U.S. manufacturing industries as

the base 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 total factor productivity growth.

(3) Unlike the prevalent approach in productivity studies, we look at both the output demand and cost functions together to trace the effect of changes in the demand and structure of costs on productivity growth of various industries.

(4) Finally, we use 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.¹

II. The Model

Let the production function of an industry be given by

$$(1) \quad Y = F(X, G, T)$$

where Y is the output of the industry, X is a vector of traditional inputs like labor, capital, and intermediate factors, G is a two-dimensional vector of public capital stocks, and T is the disembodied technology level.

The traditional measure of Total Factor Productivity growth (TFP) is defined by the path-independent Divisia index:

$$(2) \quad \dot{T}FP = \dot{Y} - \sum_i S_i \dot{X}_i \quad i = L, K, M$$

where \dot{X} denotes the rate of growth and $S_i = P_i X_i / P_y Y$ is the value share of the i th private input.

Differentiating (1) with respect to time, and dividing by the output, we obtain

$$(3) \quad \dot{Y} = \sum_i \frac{\partial F}{\partial X_i} \frac{X_i}{Y} \dot{X}_i + \sum_j \frac{\partial F}{\partial G_j} \frac{G_j}{Y} \dot{G}_j + \frac{1}{Y} \frac{\partial F}{\partial T}$$

Assuming cost minimization of all inputs, public included, and letting P_i be the price of i th private input and Q_s , the shadow price of public input s , we get the following first-order conditions:

$$(4) \quad \frac{\partial F}{\partial X_i} = \frac{P_i}{\mu} \quad \forall i$$

$$\frac{\partial F}{\partial G_s} = \frac{Q_s}{\mu} \quad \forall s$$

where μ is the Lagrangian multiplier, together with the envelope conditions

$$\frac{\partial C^*}{\partial Y} = \mu$$

(5)

$$-\frac{\partial C^*}{\partial T} = \mu \frac{\partial F}{\partial T}$$

where $C^* = \sum_i P_i X_i + \sum_s Q_s G_s = C^*(Y, P, Q, T)$ is the total cost function which includes the shadow cost of the two types of public capital. Eliminating μ from (4) and (5) and substituting (4)-(5) in (3), we get

$$(6) \quad \dot{Y} = \sum_i \frac{P_i X_i}{\frac{\partial C^*}{\partial Y} Y} \dot{X}_i + \sum_s \frac{Q_s G_s}{\frac{\partial C^*}{\partial Y} Y} \dot{G}_s + \frac{-\frac{\partial C^*}{\partial T}}{\frac{\partial C^*}{\partial Y} Y}$$

Firms, however, do not adjust the public capital stock. They are exogenously given. What actually is observed is that firms minimize their private production cost subject to the production function (1). Let the optimal private cost of production, given the output level and public capital, be $C = \sum_i P_i X_i = C(Y, P, G, T)$. Then the marginal benefit of an

increase of public capital at equilibrium will be given by

$$(7) \quad -\frac{\partial C}{\partial G_i} = Q_i .$$

It is not difficult to show by using comparative statistics that the total cost elasticity, η^* , is given by

$$\eta^* = \frac{\partial \ln C^*}{\partial \ln Y} = \frac{\partial \ln C}{\partial \ln Y} / B = \eta / B$$

where $B = 1 - (\sum \partial \ln C) / (\partial \ln G_i) = 1 - \sum \eta_{ca}$ and η_{ca} is the private cost elasticity with respect to public inputs, and η is the private cost elasticity. And the cost diminution due to technical change is

$$\dot{T} = \frac{\partial \ln C^*}{\partial T} = \frac{\partial \ln C}{\partial T} / B$$

Following Caves et al (1981), the total return to scale of the production function is defined as the proportional increase in output due to equiproportional increase of all inputs (private and public, holding technology fixed), and is be given by the inverse of η^* . The private returns to scale, i.e, the proportional increase in output due to equiproportional increase of private inputs holding public inputs and technology fixed, is given by the inverse of η . Thus, we identify two scale effects in our study, one internal and the other total, which is the sum of internal and external scale effects. Substituting (7) in (6) and then in (2) we have

$$(8) \quad \dot{T}FP = \left(\frac{\kappa - \eta^*}{\kappa}\right) \dot{Y} - \frac{1}{\kappa B} \sum_i \eta_{ca} \dot{G}_i - \frac{1}{\kappa B} \dot{T}$$

where $\kappa = (P_Y Y)/C^* = P_Y/AC^*$ is the ratio of output price, P_Y , to average total cost, AC^* . According to equation (8), TFP growth can be decomposed into three components: a gross total scale effect given by the first term, a public capital stock effect given by the second term, and the technological change effect given by the last term.

The next step is to further decompose the scale effect. We assume that the price of output is related to private marginal cost according to

$$P_Y = (1 + \theta) \frac{\partial C}{\partial Y}$$

where θ is a markup over the marginal cost. The markup will depend on the elasticity of demand as well as on the conjectural variations held by the firms within an industry. Using the definition of the output elasticity, η , along the private cost function, we obtain

$$(9) \quad P_Y = (1 + \theta) \eta \frac{C}{Y}$$

Time differentiating (9), the pricing rule implies

$$(10) \quad \dot{P}_Y = (1 + \dot{\theta}) + \eta + \dot{C} - \dot{Y}$$

where (\cdot) denotes growth rate. Differentiating private cost function with respect to time and using Shephard's lemma, we have

$$(11) \quad \dot{C} = \eta \dot{Y} + \sum_i \hat{S}_i \dot{P}_i + \sum_i \eta_{\omega_i} \dot{G}_i + \dot{T}$$

where $\hat{S}_i = \frac{P_i X_i}{\sum_i P_i X_i}$ is the share of the i th input in private cost, C .

In order to obtain the equilibrium of \dot{Y} we assume a log linear demand function (see

Nadiri and Schankerman (1981a)) in the growth rate form

$$(12) \quad \dot{Y} = \lambda + \alpha \dot{P}_Y + \beta \dot{Z} + (1 - \beta) \dot{N}$$

where \dot{Z} and \dot{N} are the growth of aggregate income and population, respectively, and λ reflects a demand time trend. Substituting (11) in (10) and the result in (12), we obtain the reduced form function for the growth rate of total factor productivity.

$$(13) \quad \begin{aligned} \text{T}\dot{\text{F}}\text{P} = & A [a\eta + a(1 + \theta)] + A\alpha \sum_i \hat{S}_i \dot{P}_i + A [\lambda + b\dot{Z} + (1 - b)\dot{N}] \\ & + A\alpha \sum_i \eta_{ci} \dot{G}_i - \frac{1}{\kappa B} \sum_i \eta_{ci} \dot{G}_i + A\alpha \dot{T} - \frac{1}{\kappa B} \dot{T} \end{aligned}$$

where $A = \frac{\kappa - \eta^*}{\kappa} / [1 - a(\eta - 1)]$.

Equation (13) decomposes $\text{T}\dot{\text{F}}\text{P}$ into components:

- (i) a factor price effect $A\alpha \sum_i \hat{S}_i \dot{P}_i$;
- (ii) an exogenous demand effect $A [\lambda + b\dot{Z} + (1 - b)\dot{N}]$;
- (iii) a public capital effect $[A\alpha - \frac{1}{\kappa B}] \sum_i \eta_{ci} \dot{G}_i$; and
- (iv) disembodied technical change $[A\alpha - \frac{1}{\kappa B}] \dot{T}$.

The underlying model is an equilibrium model in which there is minimization over all inputs, the level of public capital is adjusted at its optimal level by the government until it earns its social rate of return. The public capital and disembodied technical change effects can be further decomposed into direct and indirect effects. The direct effect of infrastructure, for instance, is given by $(\eta_{ci}/\kappa B) \dot{G}_i$ while the indirect effect is given by $A\alpha \eta_{ci} \dot{G}_i$. Thus an increase of public infrastructure initially increase total factor

productivity by reducing the private cost of production, which in turn leads to lower output price and higher output growth. Change in output growth in turn leads to changes in TFP growth.

The important parameters in (13) are the price and income elasticities of demand and the cost elasticities of private cost function. Note that if the demand function is completely inelastic ($\alpha = 0$) then shifts in the cost function due to real factor price changes, public capital, or disembodied technical change have no effect on output and hence TFP. Second if there are constant returns to scale including the public inputs,

$$\eta^* = \kappa = 1, \text{ then (13) collapses to } T\dot{F}P = -\frac{1}{B} \sum_i \eta_{ca} \dot{G}_i - \frac{1}{B} \dot{T}.$$

III. Empirical Application

The decomposition of TFP based on equation (13) requires nine parameters: on the demand side the price and income elasticities α, β and the parameter of the shift variable λ ; on the cost side, we need the cost elasticities with respect to infrastructure and public R&D capital and output cost elasticities η^* and η . For the markup θ we have $\theta = (P_Y Y/C - \eta)/\eta$, and we assume that $\kappa = 1$. Given these parameter values, the procedure is to compute the contributions of the demand, real factor price, and public capital on TFP growth, and then to retrieve the technical change effect as a residual using equation (13). Discrete (Tornqvist) approximations to the Divisia indices in (13) are used. The demand elasticities are obtained by estimating the demand function in a rate of growth form:

$$\dot{Y} = \lambda + \alpha \dot{P}_Y + \beta \dot{Z} + (1 - \beta) \dot{N}$$

where \dot{Y} is the growth rate of industry output, \dot{P}_Y , \dot{Z} , and \dot{N} are the growth rates of industry output price, real GNP and population respectively.

The cost elasticities are obtained from a generalized Cobb-Douglas average-cost function of the following form:

$$\begin{aligned}
\ln(C/P_M) - \ln Y &= \beta'_0 + \sum_i \beta'_i \ln W_i + \beta'_T T + \sum_i \sum_j \beta'_{ij} \ln W_i \ln W_j \\
(14) \quad &+ \sum_i \beta'_{iT} \ln W_i T + \sum_s \varphi'_s \ln G_s + \sum_i \sum_s \varphi'_{is} \ln W_i \ln G_s, \\
& \quad \quad \quad i, j = L, K; \\
& \quad \quad \quad s = I, R.
\end{aligned}$$

There are three private sector inputs, labor, intermediate inputs, and capital, and two public inputs, infrastructure and R&D capital. 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. The parameters φ_s and φ_{is} capture the effects generated from the public capital services, G_s . Note that the above specification implies constant returns to scale in terms of private inputs and thus by assumption, η is equal to one.

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

$$\begin{aligned}
(15) \quad \hat{S}_i &= \beta'_i + \sum_j \beta'_{ij} \ln W_j + \beta'_{iT} T + \sum_s \varphi'_{is} \ln G_s, & i, j = L, K, \\
& & s = I, R
\end{aligned}$$

where $\hat{S}_i = P_i X_i / C$. The share of the input used for the normalization is calculated by $\hat{S}_m = 1 - \sum_i \hat{S}_i$. Input shares in each industry depend not only on relative input prices and technological change, but also on publicly financed infrastructure and R&D capital.

The 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 public capital are computed using

$$\begin{aligned}
(16) \quad \eta_{cs} &= \partial \ln C / \partial \ln G_s = \varphi'_s + \sum_i \varphi'_{is} \ln W_i & i = L, K \\
& & s = I, R
\end{aligned}$$

IV. Data Description

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 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 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 from 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 after-tax rental rate of physical capital is measured as $P_k = q_k (r + \delta_k) (1 - \tau_k - u_c z)$, 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, τ_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); 8% is used for 1981 and 7.5% for 1982 to 1986. The present values of capital consumption allowances are constructed as $z = \rho (1 - \theta \tau_k) / (r + \rho)$ (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) have 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 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 industry capacity utilization rate obtained from Klein and Summers (1966) for the period 1956-1966 and from WEFA Group (1992) for the period 1967-1986. The stock of public R&D has been adjusted by the intensity of R&D investment of each industry. The data of our financed R&D investment have been obtained from the National Science Foundation (1988, and earlier issues). Finally, the GNP and Population variables have been obtained from the Citibase Data Bank.

V. Estimation Results

The demand function (12) and cost function (14) and share equations (15) are estimated using the data for twelve two-digit US manufacturing industries for the period 1956-1986. These industries were selected because of the availability of continuous R&D data over the sample period. In Table 1 we provide the sample mean values of the costs, input prices, and the rates of growth of input quantities, output, cost and price of output.

There are considerable variations among industries in terms of costs, and output and input growth. In some industries the growth of labor input is small and sometimes negative. Similarly, the output growth rate varies considerably and it is negative (-.5%) in Primary Metals industry (SIC 33). There are some contrasting patterns among the input shares, particularly with respect to the share of capital, and growth rate of output price and private cost. The growth rates of the infrastructure and publicly financed R&D as well as the growth rates of gross national income and population growth are shown at the bottom panel of table 1.

We have pooled the industry time-series data. In the case of a single industry, the data often move closely together, thereby generating severe multicollinearity, which makes it difficult to estimate the parameters of the production and cost functions without imposing restrictive assumptions. The pooled industry data are generally more variable and therefore allows for a better chance to identify parameter estimates such as scale, technological bias, etc. of the underlying cost of production functions. In our estimation we have allowed considerable latitude for industry effects. In fact, every parameter of the underlying cost function incorporates industry dummy variables;⁴ this amounts to estimating the model separately for each industry.

In order for the cost function to be concave in input prices, the Hessian matrix $[\partial^2 C / \partial w_i \partial w_j]_i$ of the cost function should be negative semi-definite. Also, the cost function should be nondecreasing in output and linear homogeneous in input prices. 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. The underlying system of equations is estimated with full information maximum likelihood and all regularity conditions required by producer theory were satisfied (for more details see Nadiri and Mamuneas (1993)). The product demand growth equations for each industry were estimated with ordinary least squares.

Table 2 summarizes the parameter estimates of interest of the demand and cost functions for the twelve two-digit industries. The demand parameters are roughly similar to those reported in the literature. There are some price elasticities which are rather low, such as in industries 26, 29, and 38, and some elasticities that are not statistically significant and therefore imprecisely estimated. The parameters associated with per capita income, β , in the output demand equation is highly significant statistically in every industry

Table 1: SIC Classification and Descriptive Statistics of Industries
(mean values)
1956-1986

SIC	Industry	C	\hat{S}_L	\hat{S}_M	\hat{S}_K	\hat{S}_Y	\hat{Y}	\hat{L}	\hat{M}	\hat{K}	\hat{P}_Y	\hat{P}_L	\hat{P}_M	\hat{P}_K
20	Food and Kindred Products	29.40	.333	.538	.129	1.270	.040	.014	.041	.017	.037	.063	.047	.063
26	Paper and Allied Products	15.46	.352	.503	.145	1.080	.033	.007	.031	.036	.043	.066	.045	.062
28	Chemicals and Allied Products	31.07	.325	.521	.154	1.230	.041	.009	.037	.036	.036	.068	.051	.064
29	Petroleum Refining and Related Industries	42.47	.078	.704	.218	0.910	.020	-.009	.015	.028	.055	.067	.060	.063
30	Rubber Products	12.80	.350	.565	.085	1.130	.046	.025	.043	.046	.034	.055	.038	.061
32	Stone, Clay and Glass Products	11.67	.395	.475	.130	1.090	.015	.004	.018	.025	.048	.063	.051	.062
33	Primary Metals	29.79	.341	.524	.135	0.992	-.005	-.016	.009	.025	.047	.064	.041	.066
34	Fabricated Metal Products	36.32	.464	.487	.050	1.146	.027	.014	.029	.040	.048	.060	.050	.067
35	Machinery	37.41	.452	.475	.073	1.117	.044	.011	.032	.044	.032	.063	.048	.062
36	Electrical Equipment	30.02	.467	.467	.065	1.120	.051	.018	.032	.062	.030	.064	.046	.059
37	Transportation Equipment	48.93	.377	.557	.066	1.100	.021	.002	.022	.038	.045	.067	.047	.065
38	Scientific Instruments	9.84	.478	.463	.059	1.189	.048	.020	.048	.060	.040	.064	.044	.062

\hat{G}_I	\hat{G}_R	\hat{Z}	\hat{N}
.030	.052	.029	.012

and its magnitude varies considerably among the industries ranging from about 1.0 in SIC 29 to 3.6 in SIC 36.

The estimated cost elasticities of infrastructure capital and publicly financed R&D capital are all negative and statistically significant except in industry 20 where η_{ci} is positive but statistically insignificant. The magnitude of these cost elasticities suggest the degree of cost diminution due to increase in public infrastructure and R&D investments. The cost elasticity estimates in table 2 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 in SIC 33 to -0.21 in SIC 29. The cost elasticities for publicly financed R&D capital are much smaller. They range from about -0.02 in SIC 26 to about -0.06 in SIC 37 and vary considerably across industries. There is no clearly discernible pattern except that the magnitudes of the elasticities tend to be higher in durable manufacturing industries such as SIC 35, 36, 37, and 38. The overall cost elasticities, η^* , are all below unity, implying increasing returns to scale and are statistically significant. The values of η^* vary somewhat among the industries, but generally they range between .82 to .97.

We have used the demand and cost parameter estimates in table 2 to decompose the TFP growth for each industry. The results are recorded in table 3. The decomposition of TFP in table 3 is very comprehensive; it includes the contributions of technical change, factor prices, exogenous output demand changes, and those of public infrastructure and publicly financed R&D. As we noted earlier there are two effects associated with the variables such as technology, and two types of public capital. The direct effect measures the downward shift in the cost function associated with an increase in these variables. As the cost shifts downward because the demand function for output is downward sloping, the level of output changes and causes the indirect inducement effects.

The results in table 3 point to several interesting issues. The growth of exogenous demand plays a very significant role in determining the growth of TFP. The magnitude of its contribution, however, varies considerably across industries ranging from 0.16 in SIC 20 to about 0.80 in SIC 38, which as a percentage of each industry's TFP is 9% to 41% respectively. In most cases the contribution of demand to TFP growth is about 20% to

Table 2: Demand and Cost-Function Elasticities in Two-Digit Manufacturing Industries
 1956-1986
 (Standard Error in Parenthesis)

SIC	Demand			Cost		
	λ	σ	β	η_{CI}	η_{CR}	η^*
20	.0021 (.0107)	-.5917 (.2141)	1.1766 (.3571)	.0234 (.0348)	-.0487 (.0102)	.975 (.0302)
26	-.0060 (.0076)	-.1562 (.1645)	1.5260 (.2630)	-.1436 (.0246)	-.0207 (.0101)	.859 (.0171)
28	-.0053 (.0081)	-.3016 (.1474)	1.7984 (.2977)	-.1490 (.0237)	-.0335 (.0098)	.846 (.0166)
29	-.0101 (.0064)	-.1010 (.0373)	1.0618 (.2216)	-.2113 (.0222)	-.0088 (.0093)	.820 (.0143)
30	-.0175 (.0089)	-.8104 (.2358)	2.3631 (.3230)	-.1412 (.0240)	-.0318 (.0099)	.853 (.0166)
32	-.0343 (.0073)	-.2163 (.2978)	2.1886 (.2544)	-.1498 (.0232)	-.0263 (.0099)	.850 (.0162)
33	-.0800 (.0122)	-.3282 (.2291)	3.5829 (.4254)	-.1153 (.0226)	-.0375 (.0101)	.868 (.0166)
34	-.0397 (.0100)	-.3204 (.2658)	3.0345 (.3420)	-.1299 (.0250)	-.0279 (.0101)	.864 (.0176)
35	-.0303 (.0102)	-.6906 (.2581)	2.9615 (.3433)	-.1182 (.0237)	-.0300 (.0101)	.871 (.0172)
36	-.0137 (.0100)	-.7626 (.4039)	2.3127 (.3396)	-.1368 (.0241)	-.0450 (.0102)	.846 (.0163)
37	-.0555 (.0138)	-.7800 (.4806)	3.6394 (.5145)	-.1089 (.0235)	-.0557 (.0103)	.859 (.0164)
38	.0078 (.0097)	-.1781 (.3140)	1.5259 (.3267)	-.1730 (.0290)	-.0353 (.0103)	.828 (.0189)

30%. The smaller contribution of demand in industry 20 is mainly due to the lower value of the scale parameter, $1/\eta^*$, estimated for the industry. There is one other exception to note; in industry SIC 33 growth of demand contributes negatively to TFP. The reason as we noted earlier, is that output growth in this industry has been small but more importantly negative over the sample period.

Rise in real factor prices contributes negatively to TFP, its contribution also varies considerably among industries; it ranges between -0.10 in SIC 20 to -0.62 in SIC 37. In terms of percentage of TFP increase in real input prices contribute as little as about 8% in SIC 20 and as high as 77% in SIC 37. Again the small contribution of the relative input prices is due to the small scale parameter estimate, noted earlier for this industry. The largest effect of price changes are concentrated in industries 30, 32, 33 and 38; in most other industries the contribution of rise in real factor prices is about 20%.

As noted earlier, we have distinguished between the direct and indirect contributions of the two public capitals to total factor productivity growth. These contributions are shown in columns (c) to (f) of table 3. The contributions of infrastructure and public R&D capital also vary considerably across industries. In most industries the direct contribution of infrastructure is about .30 to .35. In industry 29 and 38, it is about .55 and .41 respectively. The indirect contribution of infrastructure capital to TFP shown in column (d) of table 3 is positive but very small, about one-tenth of its direct effect. The magnitude of the contribution of publicly financed R&D are smaller than those of the infrastructure capital in most industries. The contribution of R&D capital also varies considerably among industries, ranging between a high of almost 0.32 in industry SIC 37 to a low of about .03 in industry SIC 29. Aside from these extreme cases, the contribution of publicly financed R&D capital to average annual growth of TFP falls about 10% to 15%, which is not negligible. The indirect contribution of publicly financed R&D is much smaller than its direct contribution as we expect, but it is also smaller than the indirect contribution of the infrastructure capital.

The technical change effect is computed residually, and therefore captures all contributory factors not accounted for by the model (including measurement error). This residual accounts for a substantial amount of TFP growth. In fact, in terms of percentage

Table 3: Decomposition of TFP Growth in Two-Digit Manufacturing Industries
1956-1986

Industry SIC	Exogenous Demand (a)	Factor Price (b)	Sources					Residual Technical Change (g)	TFP (Average Annual Rates) (h)
			Infra- structure Capital Direct (c)	Infra- structure Capital Indirect (d)	Public R&D Direct (e)	Public R&D Indirect (f)			
20	.160	-.142	.000	.000	.284	.010	1.500	1.820	
26	.450	-.122	.352	.009	.098	.002	.310	1.220	
28	.577	-.274	.360	.019	.176	.009	1.120	2.020	
29	.376	-.117	.554	.014	.026	.000	-.527	.325	
30	.511	-.563	.338	.046	.163	.021	.983	1.500	
32	.224	-.187	.365	.014	.131	.005	.016	.571	
33	-.093	-.230	.271	.013	.210	.009	-.552	-.380	
34	.324	-.242	.320	.015	.136	.006	.256	.811	
35	.410	-.503	.284	.028	.156	.014	1.960	2.350	
36	.580	-.649	.325	.044	.238	.032	2.150	2.720	
37	.263	-.617	.250	.032	.319	.038	.514	.796	
38	.794	-.166	.421	.016	.170	.006	.689	1.930	

of TFP in a few industries it is the primary contributor, eg. SIC 20, 28, 35 and 36. The contribution of technical change as a percentage of TFP is on the average about 40% to 60%. In two industries, SIC 29 and SIC 33, the contribution of technical change is negative which suggests that technical change in the industries accelerated at the same time that TFP declined. This unexpected result may also be partly due to measurement error.

Conclusions

In this paper we have formulated a general framework for decomposition of total factor productivity in order to estimate the contribution of different sources including publicly financed infrastructure and R&D capital to TFP growth. Demand and cost functions were estimated using data for twelve two-digit U.S. industries for the period 1956-1986. Using the estimated demand and cost function parameters, we decomposed TFP into several components: exogenous demand effect, real factor price effect, direct and indirect contribution of two types of public capital, and the effect of technical change.

The contribution of each of these sources of TFP growth vary among the industries. In some industries changes in aggregate demand or relative prices dominate, while in other cases technical change matters more. Both types of publicly-financed capital affects industry TFP significantly. The contributions of infrastructure is about twice as large as the contribution of publicly-financed R&D. The magnitudes of these contributions of infrastructure capital is generally much smaller than has been reported in the literature. To our knowledge no estimates of the contributions of aggregate publicly financed R&D capital (as distinct from industry-specific publicly funded R&D) to growth of TFP have been reported in the literature. We find that its contribution is significant but much smaller than that of infrastructure. Also note that when we assess the role of infrastructure capital within a general framework of TFP decomposition its contributions do not dominate. In fact, it is the growth of aggregate demand, rise in real input prices and particularly the growth rate of technical change which are the principle actors in determining TFP growth at the industry level.

Notes

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1. The econometric framework of the study is based on previous work by Nadiri and Schankerman (1981) and Bernstein and Nadiri (1988, 1991), and Nadiri and Mamuneas (1993).
2. See Nadiri and Mamuneas (1993) for a detailed description of the data.
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.
4. That is, $\beta'_0 = \beta_0 + \sum \alpha_{0h} D_h$, $\beta'_i = \beta_i + \sum \alpha_{ih} D_h$, $\beta'_t = \beta_t + \sum \alpha_{th} D_h$, $\beta'_j = \beta_j + \sum \alpha_{jh} D_h$, $\beta'_{it} = \beta_{it} + \sum \alpha_{ith} D_h$, where D_h refers to industry dummies taking values 1 and 0 and h is an industry identification index. In addition, in order to capture differences due to variable usage of public capital by the industries we have assumed that $\varphi'_s = \varphi_s + \sum \alpha_{sh} D_h$ and $\varphi'_{is} = \varphi_{is} + \sum \alpha_{ish} D_h$.

REFERENCES

- Aschauer, D. A. (1989), "Is Public Expenditure Productive?" *Journal of Monetary Economics*, 23, 177-200.
- Auerbach, J. A. (1983), "Corporate Taxation in the United States," *Brookings Papers and Economic Activity*, 2, 451-513.
- Berndt, E. R. and B. Hansson (1991), "Measuring the Contribution of Public Infrastructure Capital in Sweden," Paper Presented at IUI, Sweden, March.
- Bernstein, J. and M. I. Nadiri (1991), "Product Demand, Cost of Production, Spillovers, and the Social Rate of Return to R&D," NBER Working Paper 3625, January.
- _____ (1988), "Interindustry R&D, Rates of Return, and Production in High-Tech Industries," *American Economic Review*, 78(2), 429-34.
- _____ (1987), "Corporate Taxes and Incentives and the Structure of Production: A Selective Survey," in *The Impact of Taxation on Business Activity*, J. Mintz and D. Purvis (eds.), J. Deutsch Institute for the Studies of Economic Policy, Kingston Ontario.
- Caves, D. W., L. R. Christensen, and J. A. Swanson (1981), "Productivity Growth, Scale Economics, and Capacity Utilization in U.S. Railroads, 1955-1974," *American Economic Review*, 71(5), 994-1002.
- Conrad, K. and K. Seitz (1992), "The Economic Benefits of Public Infrastructures," mimeo.
- Costa, J. da Silva, R. W. Ellson and R. C. Martin (1987), "Public Capital Regional Output, and Development: Some Empirical Evidence," *Journal of Regional Science*, 27, 419-437.
- Eberts, R. (1986), "Estimating the Contribution of Urban Public Infrastructure to Regional Growth," Federal Reserve Bank of Cleveland Working Paper 8610, December.
- Eisner, R. (1993), "Real Government Saving and the Future", presented at the session of the American Economic Association Annual Meetings on Public Investments, Infrastructure and Economic Growth, Anaheim, California.
- Ford, R. and P. Poret (1991), "Infrastructure and Private Sector Productivity, OECD Working Paper 91, January.
- Garcia-Mila, T. and T. J. McGuire (1992), "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*.

- Gullickson, W. and M. J. Harper (1987), "Multifactor Productivity in U.S. Manufacturing, 1949-83," *Monthly Labor Review*, 110 (10), 18-28.
- _____ (1986), "Multifactor Productivity Measurement for Two-Digit Manufacturing Industries," paper presented at the meeting of the Western Economic Association, July.
- Holtz-Eakin, D. (1988), "Private Output, Government Capital, and the Infrastructure 'Crisis'," Columbia University, Department of Economics Discussion Paper 394, May.
- Hulten, C. R. (1990), "Infrastructure: Productivity Growth and Competitiveness," Committee of Banking, Finance and Urban Affairs, #101-117.
- Hulten, C. R. and R. M. Schwab (1991), "Is There Too Little Public Capital? Infrastructure and Economic Growth," Conference Paper, American Enterprise Institute, February.
- Jorgenson, D. W. and M. A. Sullivan (1981), "Inflation and Corporate Capital Recovery," in *Depreciation, Inflation and the Taxation of Income from Capital*, Charles R. Hulten (ed.), Urban Institute: Washington, D.C.
- Klein, L. and R. Summers (1966), *The Wharton Index of Capacity Utilization*, Studies in Quantitative Economics, No. 1, University of Pennsylvania.
- Mamuneas, T. P. (1993), "Spillovers from Publicly Financed R&D Capital in High-Tech Industries," mimeo.
- Mamuneas, T. P. and M. I. Nadiri (1993), "Public R&D Policies and Cost Behavior of the U.S.A. Manufacturing Industries," paper presented at the 68th Annual Western Economic Association's International Conference, June.
- Mera, K. (1973), "II. Regional Production Functions and Social Overhead Capital: An Analysis of the Japanese Case," *Regional and Urban Economics*, 3, 157-186.
- Munnell, A. H. (1990a), "Why Has Productivity Growth Declined? Productivity and Public Investment," *New England Economic Review*, Jan./Feb., 3-22.
- _____ (1990b), "How Does Public Infrastructure Affect Regional Economic Performance," *New England Economic Review*, Sep./Oct.
- Nadiri, I. M. and T. P. Mamuneas (1993), "The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries,"
- Nadiri, I. M. and M. Schankerman (1981a), "Technical Change, Returns to Scale

and Productivity Slowdown," *American Economic Review*, 71 (2), 314-19.
_____ (1981b), "The Structure of Production, Technological
Change, and the Rate of Growth of Total Factor Productivity in U.S. Bell
System," in *Productivity Measurement in Regulated Industries*, G. Cowing
and R.E. Stevenson (eds.), Academic Press, New York.

National Science Foundation (1988), *Research and Development in Industry 1987*,
Washington: Government Printing Office.

Tatom, J. A. (1991), "Public Capital and Private Sector Performance," *St. Louis
Federal Review*.

U.S. Department of Commerce (various issues), *Statistical Abstract of the United
States*, Washington, D.C.

U.S. Department of Commerce (1975), *Historical Statistics of the United States,
Colonial Times to 1970*, Washington, D.C.

The WEFA Group (1990), *Industrial Analysis Services Quarterly Review*, July.