Benefits of Communications Infrastructure Capital in U.S. Economy

M. Ishaq Nadiri*
and
Banani Nandi*

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M. Ishaq Nadiri
Department of Economics
New York University
New York, NY 10003
USA
m.ishaq.nadiri@nyu.edu

Banani Nandi #
AT&T Shannon Laboratories
180 Park Avenue, Rm # 30
Florham Park, NJ 07932
USA
ban@homer.att.com

Responsible for all correspondence

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Abstract:

In this paper we empirically estimate the contribution of the communications infrastructure to the growth of output and productivity at the dis-aggregate industry and at the aggregate economy levels. The estimated value of the marginal benefits, or the shadow price of the communications infrastructure capital, is positive in each of 34 industries representing the major industrial sectors of the U.S. economy. This effect captures network externality benefits and can be interpreted as each industry's willingness to pay for communications infrastructure capital services over and above their direct payments for communications services. These results suggest that an increase in communications infrastructure capital services reduces cost in all the industries and, as a consequence, that of the entire economy. The relatively high value of estimated total marginal benefits for the aggregate economy indicates a high social rate of return to the investments in communications infrastructure.

Key Words: communications, infrastructure, network externality, marginal benefits, productivity.

JEL Code: D2, D24, L00, L86, L96, O47

I. INTRODUCTION

The term 'infrastructure' generally describes large social overhead capital such as roads, bridges, sewer facilities, electricity generation and distribution, and communication networks. The general characteristics of these types of infrastructure capital are such that the development and upgrading of these infrastructure systems requires large amounts of long-term investment and they generate network externality benefits as the number of users connected to the infrastructure network increases.[1] These infrastructure systems can be owned either by the public or by the private sector. Since investments in infrastructure systems are highly risky, public financing is more common than private financing. Therefore, the existing econometric studies in this area focus primarily on publicly owned infrastructure systems.[2] However, it is important to evaluate the contributions of various types of infrastructure capital to growth of output and productivity irrespective of whether they are publicly or privately owned. In this paper, we are interested in measuring the contribution of the communications infrastructure to the growth of output and the growth of productivity.

In the U.S., a significant portion of the infrastructure system is, in fact, privately owned. The information infrastructure is one of them. The technology that a society uses to produce, process, store and communicate information in various forms (such as voice, data, and images) is known as the

[1] Networks, communications and infrastructure networks exhibit positive consumption and production externalities. A positive consumption externality (or network externality) signifies the fact that the value of a unit of the good (which is part of the network) increases with the number of units sold. In the case of telephone networks, this kind of externality effect could appear due to an increase in penetration rate or an increase in the number of telephones per capita so that more and more individuals access and use the network. The former type of expansion takes place mostly in developing countries, whereas the later case of expansion is more common in developed countries where universal telephone service has existed for many years.

[2] Numerous studies (Aschauer, 1989a, 1989b, 1990; Munnell, 1990a, 1990b, 1992; Tatom, 1991; Brendt and Hansson, 1992; Holz-Eakin, 1994; Nadiri and Mamuneas, 1994, 1996; Morrisson and Schwartz, 1994, 1996) have measured the contribution of publicly funded infrastructure capital on economic growth. In general, the results show a positive contribution, but the magnitudes and degree of significance of the contribution vary among the studies.

information technology. It is the information infrastructure network that makes possible the delivery of services using this technology. In a broader sense, the information infrastructure encompasses the transmission media, including telephone lines, cable television lines, and satellites and antennas, together with routers and other devices that control the transmission path. It also includes the software that is used to send, receive and manage the signals that are transmitted. Since, in recent years, the world has experienced an explosive growth in information technology and its applications, it is extremely important for public policy to evaluate the contribution of the information infrastructure capital to economic growth and technological advancement.

There are a number of recent studies, which examine the contribution of the general information infrastructure capital to output and productivity growth of various industries (Loveman, 1994; Wildman, 1992; and Gera et al., 1998). Generally, the evidence does not clearly support a strong impact of the infrastructure on productivity growth (see Khan, 1993). Part of the explanation for this finding may be that service industries are heavy investors in information technology. Since the measurement of output in the service industries is often problematic, it is likely that substantial productivity gain due to the information infrastructure will remain unmeasured. A number of studies specifically measure the contribution of the information technology equipment to the performance of the overall economy (Bresnahan, 1986; Jorgenson and Stiroh, 1995, 1999; Morrison, 1997). These studies suggest some interesting findings but they do not cover the potential benefits of the entire communications infrastructure network to all the U.S. sectors and industries. Similarly, a number of researchers have investigated the relationship between the telecommunications infrastructure capital, a major component of communications network capital and economic growth (Bebee and Gilling, 1976; Hardy, 1980; Cronin et al., 1991, 1993; Dhalakia and Harlam, 1994). Most of these studies are based on statistical analyses or simple regression analysis and do not consider fully the effects of telecommunication infrastructure capital on the structure of the production at the industry and aggregate economy levels. Further these studies do not address the issue of the social rate of return on the telecommunication investment and the externalities of the telecommunication network.

In this study we focus on the contribution of the communication infrastructure capital stock on the growth of output and productivity for 34 industries representing different sectors of the US economy. We formulate a cost model that incorporates publicly funded infrastructure capital as well as communication infrastructure capital together with industry-specific output and input levels. Our model is estimated for each industry using time series data for the period 1950-1991. From these estimates for each industry we calculate the contribution of the two types of infrastructure capital to growth of output and productivity. The aggregate economy results are obtained by aggregating the individual industry level estimates.

Since our focus in this paper is on evaluating the contribution of the communication infrastructure capital, we shall not discuss the effects of the publicly funded infrastructure capital. We specifically calculate the marginal benefits of the communication infrastructure capital for each industry and for the "aggregate" economy. We also calculate the social rate of return (exclusive of the payments received by the communications industry by selling its services to other industries) to investment in communication infrastructure capital using the analytical framework of our model.

The remainder of this paper is organized into four sections. Section II introduces the theoretical model and the econometric model to be estimated. In Section III, we present data description and the estimation results. The primary data are a cross-section, time series of prices and quantities of output and inputs for 35 industry sectors for the period 1950-1991. Data construction methodology and sources are presented in the data appendix. Section IV presents our measurement of the cost elasticities of the communications infrastructure capital for each industry. Estimates of the marginal benefits of a change in the level of total communications infrastructure capital for each industry and the aggregate economy are also shown in this section. The conclusion and summary of our results are presented in the last section.

II. ECONOMETRIC MODEL SPECIFICATION

We assume that the two infrastructure capital stocks are exogenously available to private firms, and the services generated by these capital stocks facilitate private sector production. For publicly funded infrastructure capital, the government either provides them ‘free’ or charges a small user fee. The sources of funding for this type of capital are taxes and long term government debt, which eventually will be paid by future taxes. Therefore, in the industry production function the services of this type of infrastructure capital are treated as “unpaid” factors of production.

For privately financed infrastructure capital such as the communication infrastructure capital, the source of finance is the communication firms themselves, and they recoup their expenses by charging their customers for the services rendered. That is, each industry incurs some expenses for telecommunication services. These expenses are included as part of the material cost. However, in addition, each industry in the private sector receives the externality benefits in terms of added efficiency gains from the expansion and modernization of the total communications infrastructure network for which they do not pay any direct fees. Expansion and modernization of the communications infrastructure increases the ability of managers to communicate efficiently and rapidly over increased distances and helps in the coordination of the activities of interdependent economic units which foster productivity increase. Investment in the communications infrastructure also facilitates economic growth by increasing the size and efficiency of the network, which in turn enhances the transfer of information and knowledge to all the participants, thereby increasing the quality and number of economic activities. As noted, this externality effect is in addition to the benefits of communication services that firms pay for. Therefore, similar to services provided by public infrastructure capital, the privately funded communications infrastructure capital can also be treated as an unpaid input in the private industry production process.

To incorporate the effects of these two types of infrastructure capital on production and cost structure, we need to modify the traditional cost function. We can write the cost function of each industry as:

$$C = C\,(q, Y, S_1, S_2, T) \qquad (1)$$

where q denotes the vector of input prices for inputs labor (L), private capital (K) and material (M), Y denotes output quantity, T is an index of time representing disembodied technical change, S_1 the flow of services from private sector communications infrastructure capital and S_2 the flow of services from public infrastructure capital. The cost function (C) implicitly contains the assumption that the demand for private inputs fully adjusts to their cost-minimizing levels within one period. There are no market prices for the externality effects of the infrastructure capitals, S_1 and S_2. However, one can determine the shadow price or willingness-to-pay of S_1 and S_2, that is, the savings in private production cost associated with them. The shadow values are the measure of the potential cost savings from a decline in variable cost.

We can define the marginal benefits of the two types of infrastructure capital for each industry. For the communication infrastructure capital, S_1, the shadow price is given by

$$U_{S_1} = -\partial C / \partial S_1 \qquad (2)$$

which shows that an increase in this infrastructure capital results in the savings of U_{S_1} monetary units of total production cost. This cost reduction benefit can be defined as the marginal benefit of communications infrastructure capital. For public infrastructure capital, the shadow price is given by

$$U_{S_2} = -\partial C / \partial S_2 . \qquad (3)$$

That is, one additional unit of public infrastructure capital results in the savings of U_{S_2} monetary units of total private production cost. The aggregate marginal benefit derived from the communications infrastructure is obtained by summing the marginal benefits of all industries and is defined as $SMBS_1$. Similar estimates of the aggregate marginal benefits derived from the public infrastructure capital are defined as $SMBS_2$.

To implement this model empirically, we employ a translog cost function of the following form for each industry:

$$\begin{aligned}
\ln(C / p_M) = {} & \alpha_0 + \alpha_L \ln \tilde{p}_L + \alpha_K \ln \tilde{p}_K + \alpha_Y \ln Y + \alpha_G \ln(S_1^{\theta} \cdot S_2^{1-\theta}) + \alpha_T T \\
& + 1/2\{\alpha_{LL} \ln \tilde{p}_L{}^2 + \alpha_{KK} \ln \tilde{p}_K{}^2 + \alpha_{YY} \ln Y^2 + \alpha_{GG} \ln(S_1^{\theta} \cdot S_2^{1-\theta})^2 + \alpha_{TT} T^2\} \\
& + \alpha_{TL} \ln \tilde{p}_L \ln Y + \alpha_{YK} \ln \tilde{p}_K \ln Y + \alpha_{YG} \ln Y \ln(S_1^{\theta} \cdot S_2^{1-\theta}) + \alpha_{TT} \ln Y \cdot T \\
& + \alpha_{LK} \ln \tilde{p}_L \ln \tilde{p}_K + \alpha_{LG} \ln \tilde{p}_L \ln(S_1^{\theta} \cdot S_2^{1-\theta}) + \alpha_{LT} \ln \tilde{p}_L \cdot T \\
& + \alpha_{GT} \ln(S_1^{\theta} \cdot S_2^{1-\theta}) \cdot T
\end{aligned} \qquad (4)$$

where C is the total cost and P_M, P_L and P_K are the prices of materials, labor and private capital, respectively. $\tilde{P}_L(P_L / P_M)$ and $\tilde{P}_K(P_K / P_M)$ are the relative prices of labor and capital. The production cost is given by $C = P_L L + P_M M + P_K K$, where $P_K = P_I(r + \delta - \dot{P}_I / P_I)$, and where P_I denotes the acquisition price of capital, r is the interest rate, δ is the rate of depreciation and

$(\dot{P}_I / P_I)$ is the price change of capital goods. Y is the level of output. S_1 and S_2 are the service flows of the communications infrastructure capital and public infrastructure capital respectively. T is an index of technical change.

An industry utilization rate, u, is used to capture the utilization of both public and communications infrastructure capital, i.e., $S_1 = (\overline{S}_1 \times u)$ and $S_2 = (\overline{S}_2 \times u)$ as flow variables where $\overline{S}_1$ and $\overline{S}_2$ are the stock of communication and publicly funded infrastructure capital respectively. That is, the stocks of both types of infrastructure capital are adjusted by the same utilization rate to obtain the necessary services rendered. In principle, each input, including the communications capital stock, should be adjusted by input specific utilization rates. However, data limitations preclude such an option.

Using Shephard's Lemma, we can obtain the cost share of labor, material and capital as the logarithmic derivative of the cost function with respect to the corresponding input price. That is,

$$S_i = P_i X_i / C = \partial \ln(C / P_M) / \partial \ln P_i \qquad i = L, M, K$$

More explicitly, the share equations for L and K derived from the cost equation (4) take the form:

$$S_L = \alpha_L + \alpha_{LL} \ln \tilde{P}_L + \alpha_{LK} \ln \tilde{P}_K + \alpha_{YL} \ln Y + \alpha_{LG} \ln(S_1^{\theta} S_2^{1-\theta}) + \alpha_{LT} \cdot T$$

$$S_K = \alpha_K + \alpha_{LK} \ln \tilde{P}_L + \alpha_{KK} \ln \tilde{P}_K + \alpha_{YK} \ln Y + \alpha_{KG} \ln(S_1^{\theta} S_2^{1-\theta}) + \alpha_{KT} \cdot T$$

(5)

where S_L and S_K are the cost shares of labor and capital. The share of the material inputs used for normalization is determined by $S_m = 1 - \sum_{i \neq m} S_i \quad i = L, K$. Input shares in each publicly and privately financed infrastructure capital industry not only depend on relative prices of inputs and technical change, but they also depend on the levels of public infrastructure capital and privately financed communications infrastructure capital.

III. DATA AND ESTIMATION RESULTS

The model described in the previous section is estimated using data for 35 two-digit industries of the US economy for the period 1950-1991. The industry coverage is derived from a detailed 80-industry classification that Jorgenson, Gallop and Fraumeni (1987) have carefully aggregated into 35 industries and sectors. Data for the value of gross output and costs of labor, capital services and intermediate inputs, as well as their price indices for all industries, are from Jorgenson, Gallop and Fraumeni.[3] To capture the effect of the communications infrastructure capital on production cost, we use the net capital stock of the communications industry. These data are obtained from the *Fixed Reproducible Tangible Wealth in the United States, 1925-91*, a publication of the U.S. Department of Commerce. For publicly funded infrastructure capital, annual data on total nonresidential net government physical capital stock is measured as the sum of federal, state and local net capital stock of structure and equipment excluding military. Federal structures include industrial, educational, hospital and other buildings, highways constructions and other structures. State and local structures include educational, hospital and other buildings, highways and streets, construction and development, and other structures. These data are obtained from the Bureau of Economic Analysis (BEA). The data on capacity utilization rates for manufacturing industries are obtained from Klein

[3] For a description of data construction, see Jorgenson, Gallop, and Fraumeni (1987), and Jorgenson (1990) and the brief discussion in data appendix.

and Summer (1966) and from the Wharton Economic Forecasting Association's report (1992). The detailed description of the data construction is available in the data appendix.

Implementation of the model includes estimating the parameters of the total cost function (4) and the parameters of the system of factor share equations (5) representing the factor demands. Since we use the communications sector capital stock as a measure of exogenously given communications infrastructure capital in each industry's production function, we exclude the cost function and input share equations of the communications industry from the estimation. Therefore, we estimate these equations using the pooled time series and cross section data for the remaining 34 industries.

In Table 1, we present the parameter estimates. The estimated model satisfies all the required regularity conditions of being non-decreasing in output, linearly homogeneous in input prices, and concave in factor prices. The results indicate that the model is well-estimated, and the parameter estimates are statistically significant. We introduced industry-specific dummy variables into our model to capture the difference in cost structure among different industries. Coefficients of the industry-specific dummy variables (not shown in Table 1) are also statistically significant. This suggests that the cost structure varies across industries. The correlation coefficients between the actual and predicted values are high, and the standard error of each equation is small.

IV. CONTRIBUTION OF COMMUNICATIONS CAPITAL

IV. 1. Industry elasticity and marginal benefits

One of the most important properties obtained from the estimated cost function from the perspective of this study is the effect of communications capital stock on productivity and the cost structure of each industry. In order to estimate the direct productivity effect of the communications infrastructure capital at the industry level, we estimate the cost elasticity (η_{CS1}) with respect to communications infrastructure capital S_1 for each industry using the estimates of model parameters. It is defined as $(\partial C/\partial S_1) S_1/C$ where $\partial C/\partial S_1$ is given by equation (2). These elasticities are shown in column 3 of Table 2. They show that an increase in communication capital stock reduces the cost in all manufacturing, as well as non-manufacturing, industries.[4] The magnitude of the cost elasticity (η_{CS1}) with respect to the communications infrastructure capital varies among industries ranging from -0.0084 to -0.0125.

Using the industry marginal cost estimates, we calculate the marginal benefits derived

[4] For detail results see Nadiri and Nandi (1998).

from the communication infrastructure capital in each industry. They are calculated as the magnitude of cost reduction experienced by an individual industry as a result of an increase in the infrastructure capital services. The formula for measuring the marginal benefits derived from communications capital is defined (see equation 2) for each industry as follows:

$$MB\,(P, Y, u, T, S_{1,} S_2) = -\,\partial C(P, Y, u, T, S_2, S_1)/\partial\, S_1$$

Column 4 of Table 2 reports the average marginal benefit (MB) of the communications capital in real terms (i.e., in terms of material prices) for each industry over the sample period. These marginal benefits indicate how much each industry is willing to pay for an additional unit of the communications infrastructure capital services, exclusive of the direct payments each industry makes for communication services. These estimates measure the network externality benefits of the communications infrastructure capital in each industry.

All the marginal benefits estimates are positive, indicating that the shadow value of the communications infrastructure capital service is positive in all industries. However, the magnitudes[5] of these benefits vary considerably among the industries. Low rates of marginal benefits are observed in Metal Mining (industry code 2), Coal Mining (industry code 3), Nonmetallic Mining (industry code 5) and some industries like Furniture and Fixture (industry code 12), Leather Products (industry code 18) and Miscellaneous Manufacturing (industry code 27). The magnitudes of marginal benefits are high for the service sectors. The top two among them are Trade (industry code 32), and Finance, Insurance and Real Estates (industry code 33). The relatively high values of MB in the service industries reflect the high

[5] The small magnitudes of these benefits are partly due to the relatively large size of communications infrastructure capital stock corresponding to total costs in each industry (see Nadiri and Mamuneas, 1994, for more explanation.

information intensities of these industries.

IV. 2. The aggregate contribution of communications infrastructure capital

An increase in the communications infrastructure capital raises the production efficiency of all industries and thereby increases productivity at the national level.

The contributions of the communications infrastructure capital at the economy level are estimated by aggregating the industry level estimates. The average cost elasticity, social marginal benefits and the net rate of return to communications infrastructure capital is shown in Table 3.

Table 3: Aggregate Cost Elasticity and Rates of Return to Communications Infrastructure Capital, 1987

η_{CS1}	$SMBS_1$	$NBRS_1$
-0.0136	0.328	0.224

Table 3 shows that the aggregate elasticity of cost with respect to communications infrastructure (η_{CS1}) for the year 1987 is –0.0136 and is obtained by summing the corresponding industry elasticities. This suggests that a 1% increase in the communication capital will reduce costs by slightly more than 0.013%. The magnitude of this elasticity is trended over time, suggesting that the productivity gain derived from the communications infrastructure capital has been increasing in recent years.

The net rate of return to the communications infrastructure capital is calculated using the expression

$$NRRS_1 = \sum_f \left(\frac{¶C_f}{¶S_1}\right) / P_{S1} - d$$

where $\sum_f \partial C_f / \partial S_1$ is the sum of marginal benefits of all industries, P_{S1} is the acquisition price and δ is the depreciation rate of the communications infrastructure capital. Applying this formula, we estimate the net rate of return. Table 3 above shows the values of the sum of marginal benefits of all industries ($SMBS_1$) and $NRRS_1$ for the year 1987. The value of $SMBS_1$ is about 0.328 and the net rate of return in 1987 is approximately 0.224. This suggests an impressive social rate of return to the communications infrastructure investment. The total rate of return, consisting of returns received by the communication firms on their investment and the social rate of return on communication infrastructure network, is even more impressive.

In Figure 1, we display the time series plots of $SMBS_1$ and S_1, where the $SMBS_1$ curve represents the sum of the marginal benefits of all industries in the private sector industries and the S_1 curve represents total communications infrastructure capital over the entire study period. They are both indexed as 1.00 in 1950. We observe four turning points where the aggregate marginal benefit curve $SMBS_1$ changes its slope significantly, indicating acceleration in the marginal contribution of the communications infrastructure. These turning points[6] are: the beginning of 1970s, the mid-1970s, the early 1980s, and around 1985, which is just after AT&T's divestiture. However, during the entire period the growth rate of communications capital stock (S_1) seems to be constant. Therefore, the observed acceleration in social marginal benefit of S_1 could be due to either better utilization of existing infrastructure or to the advancement in the quality of the communications infrastructure. The

[6] We ran very simple regression using dummy variables for various time intervals to identify the different turning points in the time series values of $SMBS_1$ and S_1 and results support few turning points for $SMBS_1$ but not for S_1.

advancement in quality of communication capital is evident from the history of the advancement of telecommunica-tions technology and its commercial applications in the postwar period.[7]

V. CONCLUSION

The analysis in this paper suggests a strong relationship between the growth of communications infrastructure capital and the growth of output and productivity. This relationship is evident in the estimated results at the industry level as well as at the aggregate economy level. The study also measures the externality effects of the communications infrastructure. The producer's surplus, derived from the growth of this infrastructure capital, is positive for all industries. The relatively high value of total marginal benefits, with respect to communications capital, indicates a high social return on the communications infrastructure investments.

Our results have important policy implications. The evidence of a significant contribution of communications infrastructure to growth of output and products in our study suggests that through regulation, tax and subsidy, government should encourage investments on new and improved communications infrastructure and more efficient use of the existing infrastructure. Our study also shows that marginal benefits derived from the communications infrastructure varies across industries and may influence the growth pattern of different industries accordingly. This phenomenon may

[7] From the 1940s, major investment took place to add and improve transmission capacity. After the mid-'70s, a digital system has been significant. In the mid-'70s, digital transmissions were available for long distance transportation which increased network capacity significantly. An advanced switching system (4ESS) was also installed during that time. In 1979, fiber optic routes were included in the Bell system. Deployment of fiber optic cable technology has progressed rapidly since 1983-84.

suggest the need for an industry specific fiscal policy. Thus, our study results can help the government to undertake appropriate policy decisions to build optimum communications infrastructure.[8]

The communications infrastructure capital may also affect consumer decisions and lead to a greater demand for various products of different industries. This can generate an externality effect on the demand side of the product of an industry and can further enhance the output expansion effect due to communications infrastructure capital. Future research in this area will allow us a more complete evaluation of the importance of communications infrastructure to the aggregate economy.

The most interesting future research in this area would be to develop a more general model to fully include the demand and supply side phenomena of the investments in communications infrastructure capital. Since the communications infrastructure capital is privately financed, a more complete analysis would incorporate the link between the investments in communications infrastructure and the demand for communications services by business and residential users. For this analysis, a general equilibrium framework is required, which is beyond the scope of this paper.

Table 1: Parameter Estimates of Cost Function
(Sample Period: 1950-1991, 34 industries[*])

[8] David Salant and Glen Woroh (1991) developed a model which addresses the regulatory problem of encouraging regulated firms to undertake long-term investment projects in a strategic setting. They examined the circumstances under which the regulated firm would agree to engage in a socially optimum investment strategy.
[*] The coefficients of the industry-specific dummy variables are not reported.

Parameters	Coefficients	Standard Errors
α_G	-0.0646	0.0566
α_Y	0.9325	0.0852
α_0	0.6693	0.3558
α_T	0.0153	0.9081E-02
α_{LL}	0.1165	0.6050E-02
α_{KK}	0.0715	0.1282E-02
α_{TT}	0.3687E-04	0.1328E-02
α_{YY}	-0.0119	0.8159E-02
α_{YL}	-0.0476	0.5806E-02
α_{YK}	-0.0721	0.4246E-02
α_{YT}	0.1198E-02	0.6235E-02
α_{LK}	-0.0396	0.1579E-02
α_{LT}	-0.1670E-02	0.2564E-02
α_{KT}	0.2604E-02	0.1899E-02
α_{YG}	0.8175E-02	0.0138
α_{LG}	0.0112	0.5732E-02
α_{KG}	0.0164	0.4407E-02
α_{GT}	-0.3046E-02	0.1193E-02
θ	0.10145	0.000248

Equation	Standard Error	R^2	D-W
Total Cost	0.0344	0.9991	1.6235
Labor-Share	0.0107	0.9901	1.9787
Private Capital-Share	0.8699E-02	0.9920	1.8854

Table 2: Cost Function Elasticities (η_{CS1}) and Marginal Benefits (MB) Averages: 1950-1991

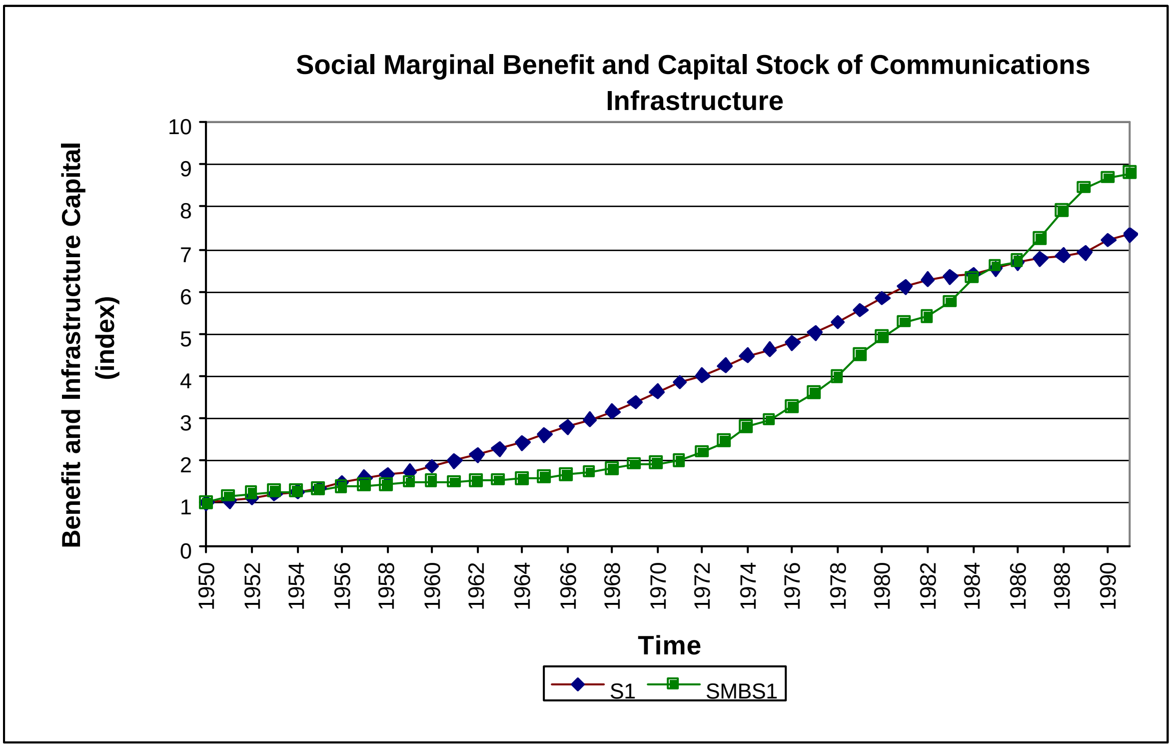
Industry Code	Industry Title	η_{CS1}	MB

1	Agriculture, Forestry and Fisheries	-0.0107	0.0070
2	Metal Mining	-0.0118	0.0003
3	Coal Mining	-0.0110	0.0007
4	Crude Petroleum and Natural Gas	-0.0096	0.0028
5	Nonmetallic Mineral Mining	-0.0121	0.0004
6	Construction	-0.0094	0.0119
7	Food and Kindred Products	-0.0103	0.0086
8	Tobacco Manufactures	-0.0122	0.0006
9	Textile Mill products	-0.0114	0.0022
10	Apparel and Other Textile Products	-0.0111	0.0021
11	Lumber and Wood Products	-0.0125	0.0021
12	Furniture and Fixtures	-0.0117	0.0010
13	Paper and Allied Products	-0.0106	0.0027
14	Printing and Publishing	-0.0105	0.0029
15	Chemicals and Allied Products	-0.0102	0.0045
16	Petroleum Refining	-0.0093	0.0036
17	Rubber and Plastic Products	-0.0105	0.0028

Table 2: Cost Function Elasticities (η_{CS1}) and Marginal Benefits (MB) (continued)
Averages: 1950-1991

Industry Code	Industry Title	η_{CS1}	MB
18	Leather and Leather products	-0.0118	0.0005
19	Stone, Clay and Glass Products	-0.0105	0.0016
20	Primary Metals	-0.0084	0.0042
21	Fabricated Metal Products	-0.0103	0.0030
22	Machinery, Except Electrical	-0.0087	0.0047
23	Electrical Machinery	-0.0099	0.0038
24	Motor Vehicles	-0.0097	0.0046
25	Other Transportation Equipment	-0.0105	0.0034
26	Instruments	-0.0090	0.0019
27	Miscellaneous Manufacturing	-0.0116	0.0010
28	Transportation and Warehousing	-0.0101	0.0067
29	Communication	0.0000	0.0000
30	Electric Utilities	-0.0107	0.0033
31	Gas Utilities	-0.0101	0.0019
32	Trade	-0.0081	0.0184
33	Finance, Insurance, and Real Estate	-0.0089	0.0140
34	Other Services	-0.0088	0.0203
35	Government Enterprises	-0.0110	0.0023

Figure - 1



Social Marginal Benefit and Capital Stock of Communications Infrastructure
Benefit and Infrastructure Capital (index)
10
9
8
7
6
5
4
3
2
1
0
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
Time
S1
SMBS1

APPENDIX

Detail construction of the data

This section gives details of how the data for different variables were constructed and adjusted before being used in the estimation.

The primary sources of data for capital are from Jack Faucett Associates and the Bureau of Labor Statistics (BLS). The investment series for each industry was obtained from the *Annual Survey of Manufactures,* the *Census of Manufacturers,* and from various issues of *The Survey of Current Business*. Data for labor input have been obtained from *NIPA*, the *Census of Population* and the *Current Population Survey*. Data on gross output are from Jack Faucett Associates, BLS and the Bureau of Economic Analysis (BEA).

Labor and capital inputs were adjusted for quality changes. We construct the data on materials (or intermediate inputs) by subtracting value added from gross output.

Jorgenson and Fraumeni divide labor input into hours worked and average labor quality. NIPA provides hours worked by industry. Household survey data are used to desegregate total hours into hours worked by different types of workers classified by demographic variables such as sex, age, and education. Assuming that workers are paid proportionately to the value of their marginal products, Jorgenson and Fraumeni calculated labor input as a sum of hours worked by different workers, weighted by relative wage rates. Annual growth in the labor input for economy as a whole from 1947-1985 averaged 1.81 percent; hours grew an average 1.18 percent per year; and labor quality increased an average of 0.63 percent.

Jorgenson and Fraumeni also adjusted capital input stocks for quality changes by their relative efficiencies. For this quality adjustment, the rental sales of various types of capital are required.

Because the rental price is not directly observable, they obtain total payments to capital as property compensation, a residual after all other inputs have been paid (see Fernald, 1992). Using this data, they derive the implied rental rates for each type of capital based on knowledge of these stock and depreciation rates for each type, and tax parameters such as the corporate income tax and investment tax credits.

The construction of data on intermediate inputs of materials by industry is a difficult problem. The difficulty is mainly attributed to the poor quality of the underlying data. Intermediate inputs into any sector include inputs for all sectors. To obtain the proper measure of this industry-specific input, the desegregated intermediate inputs must be weighted by the industry's marginal products in order to calculate its own composite intermediate input. This requires consistent annual input-output tables in current and constant prices that are not available. BEA compiles comprehensive input-output tables only about every five years; the latest is for 1987. Jorgenson and Fraumeni, for these benchmark years, adjust the data to make them consistent over time and then aggregate to the 35-industry level. The benchmarks are then connected into shares of industry output and the shares are then interpolated from benchmark to benchmark. This gives an estimated input-output table for each year, which, in turn, allows for the creation of an appropriate price deflator for nominal payments to intermediary factors in each year.

To represent the communications infrastructure capital stock, we use net capital stock of communications industry. Data on the net capital stock of communications industry in constant dollars (1982 dollars for 1947-85) is obtained from the *Fixed Reproducible Tangible Wealth in the United States, 1925-1991* (a publication of the U.S. Department of Commerce), and interpolated up to 1991 based on information from time series. For publicly funded infrastructure capital, annual data on fixed nonresidential government capital stock (federal, state and local) have been obtained from 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, extending military at constant 1982 prices. "Federal structures" includes industrial, educational, hospital and other building, highway constructions, and other structures. "State and local structures" includes educational, hospital and other building, 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. The acquisition price of government capital is constructed as Tornquist index from the government's gross investment series on structures and equipment obtained from the same source.

We obtain data on capacity utilization rates for manufacturing industries during the period 1950 - 1966 from Klein and Summers (1966). We obtain this data for the period 1967 - 1991 from the Wharton Economic Forecasting Association's report (1992). Each series is linked using the capacity utilization rate of total manufacturing in 1967 obtained from Citibase. For non-manufacturing industries, we use average capacity utilization rates for all industries in the U.S. economy, obtained from the *Economic Report of the President* (1992). The capacity utilization series is normalized to equal 1 in 1987.

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