Is All Government Capital Productive?

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The early 1970s witnessed dramatic change in per-capita output and labor-productivity growth rates in the United States. These growth rates averaged 2.2 percent and 2.0 percent, respectively, for the 1950–1969 period compared to 1.3 percent and 0.8 percent for the 1970–1989 period. Aschauer (1989) advances the idea that an important explanatory factor in this productivity slowdown is the government's stock of capital. Estimating a production function that relates private sector output to private sector labor and capital and to total government capital for the aggregate U.S. economy (1949–1985), Aschauer finds the output elasticity of government capital to be 0.39.[1] That is, for every 1 percent change in government capital, output responds by 0.39 percent. This productivity coefficient, coupled with the sharp fall in the average growth rate of government capital from 4.1 percent for 1950–1970 to 1.6 percent for 1971–1985, constitutes the evidence underlying Aschauer's view.[2]

The Aschauer (1989) study is innovative and important. His evidence suggests that government capital plays a significant role in economic growth. His findings are, however, surprising and somewhat unconvincing. The evidence is surprising because the output elasticity of government capital is relatively high and because government capital contains many different types of stocks (e.g., museums, hospitals, airports, prisons, seawalls, and wildlife preservation

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[1] See Aschauer (1989), Table 1, equation (1.1). Also, more exactly, Aschauer (1989) estimates a generalized, constant-returns-to-scale, Cobb-Douglas production function. The estimation method is least-squares and applies to the functional relationship in level form. The measure of total government capital is the net, consolidated-government, nonmilitary, nonresidential stock.

[2] These numbers are from Aschauer (1989), Table 7.

facilities), some of which are highly unlikely to make a direct productive contribution to output.[3] Aschauer's evidence is unconvincing not only because it fails to distinguish the growth rate of the productive component of government capital from the growth rate of total government capital, but also because the output elasticity of government capital may be inflated from reverse-causation bias.[4] That is, the productivity-coefficient estimate may be capturing the effect of output on government investment spending and hence on government capital instead of the effect of government capital on output. Output could affect government investment spending because government investment decisions possibly depend on output performance—higher output can lead to more tax revenue to finance such investment.

Aschauer's (1989) work raises many questions. What is unique to government capital that could be so productive? Which components of government capital play a role in production? What is the nature of the production channel through which they exercise this role? Do these channels differ across components? What are the magnitudes of the associated productivity coefficients, controlling for possible reverse causation? How do these magnitudes explain output and labor-productivity growth rates in the post-World War II United States? Finally, are the real returns to investing in productive government capital components high?

This article addresses these questions. The answers provide guidance for government investment policies by elucidating how components of government capital influence output production and by quantifying their effects on economic growth. Lucas (1987) underscores the importance of these questions by showing that changes in economic growth as small as 1 percentage point can have huge social welfare effects.

The article proceeds as follows. Section 1 describes the components of total government capital and considers their possible production roles. The resulting analysis suggests that only government-owned, privately operated capital (GOPO), government enterprise capital (ENTP), and government highway capital (HGWY) directly contribute to private production. GOPO's and ENTP's contribution to private production stems from the measurement of private sector output. One possible way that GOPO and ENTP enter the production function is through the same channel as most private sector capital; i.e., GOPO and ENTP perfectly substitute for private sector capital.[5] To capture this effect, the present study retains standard production function theory but changes the

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[3] The figure 0.39 is large relative to 0.30, the output elasticity of private capital found in other studies (see Lucas [1990]).

[4] Aschauer's use of the total stock, rather than the productive component, of government capital also may affect the estimate in unknown ways.

[5] "Most private sector capital" here means total private (business) sector capital less its transportation-vehicle component.

standard measure of capital by adding private capital, GOPO, and ENTP together. HGWY affects production because of transportation services. In particular, HGWY and the transportation-vehicle component of private (business) sector capital together yield services that facilitate the transportation of both final and intermediate goods and, in turn, help produce final delivered output. Capturing this idea, Section 2 extends standard production function theory so as to model transportation services and distinguish them from those of the other factors of production—labor and the augmented stock of private capital mentioned above.

Section 2 also embeds the production theory in a general equilibrium model of the economy that allows derivation of mathematical statements of private firms' investment and capital-utilization decision rules. These rules are useful in the estimation exercise, undertaken here, by bringing more information to bear on the parameter values of the production function. Section 3 outlines the data and method for estimating the production function and firms' decision rules. For this method, Generalized-Method-of-Moments, the possible reverse-causation phenomenon does not distort the coefficient estimates.

The highlights of the empirical findings of Section 4 pertain to the productivity coefficient of highway capital. The point estimate is 0.16; it is statistically significant but imprecise. For example, a 95 percent confidence interval around this point estimate implies that the true productivity coefficient could be as much as 0.32 or as little as 0.001. Using the point estimate 0.16, highway capital reduced output growth by 0.1 percent during the 1970–1989 period. These results support, but strongly moderate, Aschauer's (1989) claim that government capital is an important explanatory factor in the productivity slowdown. Section 5 concludes with thoughts on the policy implications of the empirical findings.

1. COMPONENTS OF GOVERNMENT CAPITAL

This section describes the components of total government capital, listing the main types of capital goods in each component and summarizing some quantitative features. The key quantitative features include the components' average shares in total government capital (see Table 1) and the characteristics of the component shares' trends. The sample period is 1950–1989. The appendix provides further detail on all data underlying this discussion and indicates data sources and measurement caveats. Also, this section considers the possible production role for each component.

Highway Capital (HGWY)

HGWY includes highways, streets, bridges, tunnels, overpasses, viaducts, and association lighting and erosion control structures. It is the largest component of government capital, with an average share of 0.36. From 1965 to 1989, this share exhibits a downward trend.

Table 1 Component Average Shares in Total Government Capital

Component	Share
Highway Capital	0.361
Government Enterprise Capital	0.248
Educational and Hospital Capital	0.190
Fire and Natural Resource Stocks	0.081
Equipment Capital	0.048
Administrative, Judicial, Police, and Research and Development Stocks	0.040
Government-Owned Privately Operated Capital	0.032
Total	1.000

Notes: (1) The entries are average annual shares over the period 1950–1989.
(2) See the appendix for data definitions, caveats, and the reason that equipment capital is a separate component in this table.

HGWY influences output production in the private sector through the provision of transportation services. HGWY and the stock of private (business) sector transportation vehicles are necessary stocks for the transportation of both intermediate and final goods. The flow of transportation services from these stocks directly contributes to the production of final delivered goods.

The ratio of HGWY to private sector output is small but not insignificant; its average value is 0.18.[6] This ratio trends down from 1975 to 1989.

Government Enterprise Capital (ENTP)

Government enterprises include various credit and insurance corporations (e.g., Commodity Credit Corporation, FDIC, and FSLIC); the U.S. Post Office; gas and electric utilities; water and sewerage utilities; public transit agencies; airport and maritime terminal operators; and miscellaneous service-producing agencies (e.g., agencies that administer lotteries, parking, highway tolls, and housing and urban renewal). Their capital consists of office buildings, electrical transmission facilities, gas structures, parking structures, sewer systems, water supply facilities, public transit stations (bus, streetcar, subway, and rail), railroad structures, airport facilities, maritime buildings, harbors, amusement structures,

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[6] Compare it to the average value of the private capital to private output ratio of about one (see Table 5).

and associated equipment.[7,8] This component is the second-largest component of government capital; on average, its share in government capital is 0.25. For the period 1968–1989, this share shows an upward trend.

The measure of private sector production in the national income accounts includes the output of government enterprises (see Department of Commerce [1988]).[9] The underlying national income accounting rationale is that the output of enterprises is very similar to the output of private firms (one can, for example, compare electricity or postal services across the two). This measurement, combined with the fact that government enterprises use their capital stocks to produce their output, implies that enterprise capital directly contributes to the production of private sector output. Given that outputs are similar across enterprises and private firms, presumably so too are the associated production techniques/methods, suggesting that the production functions of enterprises and private firms should be treated the same. It follows that the aggregate production function relates the private sector product measure to the sum of private and enterprise capital. That is, private and enterprise capital are perfect substitutes for one another in the production process.

Government-Owned, Privately Operated Capital (GOPO)

GOPO includes research and development facilities, atomic energy facilities, nuclear weapon factories, arsenals, shipyards, and associated equipment. It is the smallest component, with an average share of only 0.03. This share trends downward from 1955 to 1989. During the two world wars, GOPO was quantitatively significant (see Braun and McGrattan [1993]).

GOPO directly enters the production process of private sector output. Since GOPO contains capital goods similar to privately owned capital goods, one possible way of capturing its productive contribution is to treat it as a perfect substitute for private capital in the production function.

The ratio of ENTP and GOPO to private sector output is small but not negligible, with an average value of 0.14. This ratio does not exhibit a noticeable trend over the sample period.

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[7] The term *harbors* refers to harbors, piers, canals, docks, and dredging and drainage equipment.

[8] Harbors and some airport facilities (primarily those on national parks and Indian reservations) included in this component are not owned (or operated) by enterprises. They are owned and operated by state and local government and by federal government, respectively. These are included here because they cooperate with, in the case of harbors, or are very similar to, in the case of federal airports, some of the enterprise capital stocks. Since both stocks are small, their inclusion/exclusion is not of quantitative importance. See the appendix for more detail.

[9] It does not include the output of the rest of government. The rest of government is referred to as "general government" in Department of Commerce (1988).

Educational and Hospital Capital (EDHS)

This component consists of primary, secondary, and university-level educational buildings, associated buildings (laboratories, libraries, student unions, and dormitories), and equipment; stocks that serve an educational purpose (e.g., public libraries, museums, art galleries, observatories, archives, and botanical and zoological gardens); and health care and institutional facilities (e.g., hospitals, clinics, and infirmaries). Its average share in government capital is 0.19. This share evolves like an inverted “v,” trending upwards to peak in 1975 and trending downwards thereafter.

Without doubt, EDHS influences output production by promoting the knowledge and well-being of labor input. But, if the measure of labor input accounts for both labor input’s quantity, in terms of the number of manhours, and labor input’s quality, in terms of, for example, each worker’s educational level and age, then it is difficult to see why EDHS should have a separate productive effect. This study uses a labor input measure that incorporates many quality adjustments; therefore, EDHS is not included as a direct factor of production in the quantitative analysis.

Administrative, Judicial, Police, and Research and Development Stocks (ADMN)

Office buildings, customs houses, courthouses, prisons, police buildings, research and development facilities, and associated equipment comprise this category. Its share, averaging only 0.04, sharply trends up from 1963 to 1989.

Could ADMN affect production? It could since it is linked to the setting of rules and regulations governing the conduct of business and to research and development that affects technology. For rules, regulations, and technology determine the amount of output that can be produced from any given quantity of inputs (see Hansen and Prescott [1993]). But linkages such as these are subtle and indirect.

Fire and Natural Resource Stocks (NATR)

NATR consists of structures on government land that are intended for water, land and animal protection (e.g., reservoirs, irrigation facilities, seawalls, erosion control systems, fish hatcheries, and wildlife preservation facilities), housing for forest rangers and national park employees, fire buildings, and associated equipment.[10] As a share of government capital, it averages 0.08 and shows a downward trend during 1953–1989.

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[10] This component includes housing for forest rangers and national park employees even though the total government capital stock under review is classified as nonresidential by the Department of Commerce.

Some of the capital goods in NATR contribute to the output production process. Specifically, stocks such as fire buildings, fire equipment, reservoirs, and seawalls mitigate or prevent the destruction of other capital stocks that are directly employed in production, for example, private capital stocks. But, the productive role of these government stocks, while valuable, is merely supportive. Therefore, they do not qualify for the present analysis as a direct factor of production.

The foregoing considerations suggest that only HGWY, ENTP, and GOPO directly contribute to private production. Accordingly, they are the only capital components entering the quantitative part of this study's investigation. The channels of their contribution, suggested above, require an extension of standard production function theory to allow an explicit role for HGWY and an expanded measure of private capital to include ENTP and GOPO. The upshot of this for the quantitative questions motivating the study is that they will pertain to HGWY only. That is, those quantitative questions will not apply to ENTP and GOPO since their effects cannot be separated from that of private capital.[11,12]

2. THE MODEL ECONOMY

The model economy presented here provides a mathematical framework to address the quantitative questions raised above. The model specifies economic agents' objectives and constraints, including the production function, the market structure, and the stochastic exogenous processes. From it firms' investment and capital-utilization decision rules can be derived, which are useful for estimating the parameters of the production function.

Consider an economy with a large number of identical firms and households and a government. Since all firms and all households are identical, one can focus on the behavior of any one representative firm and any one representative

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[11] Aschauer (1989) undertakes one estimation differing from that described in the beginning of the article by breaking the total government capital stock into separate components. These components are more comprehensive than those considered in this article. All of them are included in his estimation. See Aschauer (1989), Table 6, for further details.

[12] Other studies estimating production functions involving government capital for the United States include Munnell (1990a, 1990b), Garcia-Mila and McGuire (1992), Hulten and Schwab (1991), Holtz-Eakin (1992), Tatom (1992), Fernald (1992), and Lynde and Richmond (1993). In most cases the stock of government capital is measured by a total (or comprehensive) capital stock. Garcia-Mila and McGuire (1992) and Fernald (1992) use the highway component of government capital. Their production function specifications differ from that of this article. See footnote 17 for more detail. Also, Garcia-Mila and McGuire (1992) and Fernald (1992) use state and industrial-level data, respectively, in contrast to the aggregate economy-level data employed here.

household.[13] Therefore, most quantity variables will be expressed in per-capita terms. The goods and factor markets in which firms, households, and the government interact are competitive, with all agents viewing prices as beyond their control; i.e., the agents are price takers. There are three stochastic, exogenous variables in the economy: technology, energy prices, and government investment spending. In the following discussion, unless otherwise indicated, most variables are current-period variables; variables with a prime ($'$) attached are next-period variables. The notation is explained in Table 2.

The representative firm maximizes profit:

$$\Pi = y - wl - r_v(vu_v) - r_k(ku_k) - p(e_v + e_k). \tag{1}$$

Profit is the difference between the revenue from the sale of output and the cost of labor, capital services, and energy. Output is the numeraire, so its price is normalized at one. All factor prices are relative prices. Notice that the utilization rate of a given amount of any one capital stock determines the flow of capital services. Interpret a utilization rate as the number of hours worked per period and/or the intensity of work per hour of the capital stock. The firm's choice variables are $y, l, v, k, u_v, u_k, e_v$, and e_k and are subject to the following technical constraints. The production function

$$y = (zl)^{\theta 1}(ku_k)^{\theta 2}s^{\theta 3}, \quad 0 < \theta_i < 1 \quad (i = 1, 2, 3) \qquad \theta_1 + \theta_2 + \theta_3 = 1 \tag{2}$$

states that output positively depends on technology, labor, services from capital (k), and transportation services.[14] Transportation services directly contribute to output production by facilitating the transportation of both final and intermediate goods associated with the production process.[15] Transportation services are an increasing function of the services from vehicles and the effective highway stock:

$$s = (vu_v)\bar{g}^{\psi}, \psi > 0. \tag{3}$$

The effective highway stock is defined as the aggregate highway stock adjusted for, or divided by, its aggregate usage:

$$\bar{g} = \frac{G}{(VU_v)}, \tag{4}$$

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[13] In this model economy, no distinction is drawn between a private firm and a government enterprise. An implicit assumption, therefore, is that enterprises are profit maximizers.

[14] Placing the exponent parameter, θ_1, on z is for algebraic convenience only. With this specification, the steady-state growth rate of the economy is given by the growth rate of z rather than that of z/θ_1 (see King, Plosser, and Rebelo [1988]).

[15] Although intermediate goods underlie this production process, they do not enter the production function (2), since implicitly it is derived by averaging across all firms' production functions for all goods (final and intermediate). Intermediate-good output of one firm cancels with the intermediate-good input of another. Alternatively expressed, (2) is the value-added production function for the economy.

Table 2 Notation

Π = per-capita profit
y = per-capita output
w = wage rate for labor
l = per-capita labor hours
v = per-capita stock of private transportation vehicles, in place at the beginning of the period
k = per-capita stock of other private capital, in place at the beginning of the period
$r_v(r_k)$ = rental rate for capital services from $v(k)$
$u_v(u_k)$ = utilization rate of $v(k)$
p = exogenous energy price
$e_v(e_k)$ = per-capita energy use required for the utilization of $v(k)$
z = exogenous technology
s = per-capita transportation services
θ_i $(i = 1, 2, 3)$ = parameters
$\overline{g}$ = per-capita effective stock of government highway capital
G = aggregate stock of government highway capital, in place at the beginning of the period
V = aggregate stock of private transportation vehicles, in place at the beginning of the period
U_v = economy-wide average value of u_v
ω_i $(i = 1, 2, 3, 4)$ = parameters
g = per-capita stock of government highway capital, in place at the beginning of the period
E_t = expectations operator conditioned on information available in time period t
β = subjective discount factor
c = per-capita consumption
γ = a parameter
t = time period t
log = natural logarithm
τ = the tax rate on income from capital services due to v and k
n = per-capita lump-sum transfer payment from government
$i_v(i_k)$ = per-capita private gross investment in $v'(k')$
x = per-capita lump sum tax paid to government
$\delta_v, \delta_k, \delta_g$ = depreciation rates of $v, k,$ and g
$\underline{i_g}$ = per-capita exogenous government gross investment in g'
$\overline{z}$ = mean gross growth rate of z
ϵ = innovation/disturbance term
E = unconditional expectations operator

where VU_v measures the aggregate usage. So, equations (3) and (4) capture the notion that there is congestion of aggregate highway capital. That is, the higher the total use of vehicles in the economy (VU_v), the lower the contribution of aggregate highways (G) to each firm's transportation services (s). For this reason, $\overline{g}$ is referred to as the effective highway stock: it is the highway stock effectively contributing to transportation services. Since $\bar{g}$ depends on the aggregate stocks, G and V, and the economy-wide average utilization rate, U_v, each of which is beyond the representative firm's control, it follows that $\bar{g}$ is exogenous to the firm. Barro and Sala-i-Martin (1992) and Glomm and Ravikumar (1992) model congestion of public goods in a similar fashion to that modeled here.[16]

The remaining technical constraints are the energy relationships:

$$\frac{e_v}{v} = \omega_1(u_v)^{\omega 2}, \omega_i > 0 \ (i = 1, 2) \tag{5}$$

and

$$\frac{e_k}{k} = \omega_3(u_k)^{\omega 4}, \omega_i > 0 \ (i = 3, 4). \tag{6}$$

These equations specify that energy is essential for the utilization of capital, k and v, with an increase in utilization increasing energy use per unit of capital at an increasing rate. These specifications follow those in Finn (1993). Their presence here serves the purpose of forming cost margins for utilization decisions and of explicitly according a role to energy in the production process. Finn (1993) shows that the latter is important when addressing questions involving productivity.

Equations (2), (3), (5), and (6) together show that output exhibits constant returns to scale in l, k, v, e_k, and e_v. Therefore, this production structure is consistent with the assumed competitive market structure.

The assumption of identical firms implies that in equilibrium the economy's per-capita amount of V is the same as each firm's choice variable v. Furthermore, U_v coincides with u_v. Noting these equilibrium results and dividing G and V on the right-hand side of (4) by the population size leads to:

$$\bar{g} = \frac{g}{(vu_v)}. \tag{7}$$

Substitute (7) into (3), and the result into (2) to obtain:

$$s = (vu_v)^{(1-\psi)} g^{\psi} \tag{8}$$

and

$$y = (zl)^{\theta 1}(ku_k)^{\theta 2}(vu_v)^{\theta 3(1-\psi)} g^{\theta 3 \psi}. \tag{9}$$

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[16] In Barro and Sala-i-Martin (1992), a total government spending flow entering the production function is subject to congestion. The government spending flow is divided by the economy's aggregate private capital stock. In Glomm and Ravikumar (1992), an aggregate stock of government capital entering the production function is congested. The government capital stock is divided by a Cobb-Douglas function of the economy's aggregate amounts of private labor and capital. See Glomm and Ravikumar (1992) for references to other, earlier studies advancing the congestion idea.

Equation (8) shows that s satisfies constant returns to scale in v and g, while equation (9) specifies y as a constant-returns-to-scale function of l, k, v, and g. To this list one may add e_k and e_v, by noting (5) and (6). These constant-returns-to-scale features are important. They imply that the production function is consistent with steady-state or balanced growth. Therefore, in the absence of temporary innovations to the exogenous variables, output, all three capital stocks, and energy use will grow at the constant rate of technology growth. (See the technical appendix of King, Plosser, and Rebelo [1988] for an explanation.) This result is important because steady-state growth is a characteristic of many developed market economies (see King, Plosser, and Rebelo [1988]).[17]

The exponents in (9) are the output elasticities or productivity coefficients of the corresponding factors of production. Of particular interest is $\theta_3\psi$, the productivity coefficient of highway capital. Equation (9) differs from standard production functions by distinguishing vu_v from ku_k and by including g. These differences stem from the objective of explicitly accounting for the role of highway capital in production.

The representative household maximizes its expected, discounted lifetime utility:

$$\underset{0}{\mathrm{E}} \sum_{t=0}^{\infty} \beta^t[\log c_t + \gamma \log(1 - l_t)], 0 < \beta < 1, \gamma > 0. \tag{10}$$

Here, utility in any one period positively depends on consumption and leisure. The time endowment in each period is normalized at one. As part of its maximizing behavior, the household engages in market activities that involve purchasing consumption and investment goods from and selling labor and capital services to the firm. The household pays taxes to and receives transfer payments from the government. Therefore, its choice variables in any one period are c, i_v, i_k, and l and are subject to the following budget and technical constraints. Total income must equal total spending:

$$wl + (1 - \tau)[r_v v u_v + r_k k u_k] + n = c + i_v + i_k + x. \tag{11}$$

The sum of wage and after-tax capital income and transfer payments constitutes total income. Total spending is the sum of consumption, investment, and lump-sum taxes. The reason for the presence of taxes and transfers is

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[17] The production function specifications of Garcia-Mila and McGuire (1992) and Fernald (1992) differ from equation (9). Garcia-Mila and McGuire specify a production function of private structures, private equipment, labor, the highway stock, and government educational spending. Fernald's specification comes closer to that of the current study. He specifies a production function in which, like here, highway capital and private business sector vehicle capital affect production through transportation services. His specification assumes increasing returns to scale to labor, private capital, and highway capital. By contrast, here the specification assumes constant returns to scale to all of the inputs, making the production theory consistent with the balanced-growth facts.

explained below. Also, for any one type of capital good, its one-period future value depends on the current undepreciated quantity of and investment in that capital good:

$$v' = (1 - \delta_v)v + i_v \tag{12}$$

and

$$k' = (1 - \delta_k)k + i_k. \tag{13}$$

Ensuring internal consistency of the model economy requires a description of the behavior of government. This behavior is kept as simple as possible given the existence of highway capital and distortional taxation. More exactly, highway capital evolves over time according to a technical constraint analogous to those of the household capital stocks:

$$g' = (1 - \delta_g)g + i_g. \tag{14}$$

Government investment spending is exogenous and must be balanced each period by lump-sum tax revenue:

$$i_g = x. \tag{15}$$

Government revenue from distortional capital-income taxation is rebated each period through lump-sum transfers:

$$n = \tau[r_v v u_v + r_k k u_k]. \tag{16}$$

The above description of government behavior is the simplest possible one given the internal consistency requirement, since the government's budget is balanced each period and government investment spending is both exogenous and independent of distortional-taxation effects on the household. (See Aschauer and Greenwood [1985], Baxter and King [1993], and Dotsey and Mao [1993] for analyses of more realistic fiscal policy.) But, the description is adequate for addressing the quantitative questions of this study. In particular, an explanation of government investment, which could involve the reverse-causation phenomenon, would have no effect on the production function or firms' investment and capital-utilization decision rules that are to be used in the econometric investigation below.[18] However, because distortional capital-income taxation does influence the decision rules and is quantitatively important for the behavior of private capital, such taxation is included in this model economy (see Greenwood and Huffman [1991] and Finn [1993] for some supporting evidence).

Regarding the stochastic, exogenous shock structure, i.e., the z, p, and i_g processes, only that pertaining to z needs detailed description here. The z process is a logarithmic random walk with drift:

$$\log\ z' = \log\ z + \log\ \bar{z} + \epsilon'. \tag{17}$$

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[18] The econometric investigation will take account of the real world possibility of reverse causation.

Assume that the innovation, ϵ, is identically and independently distributed through time with zero mean. Suppose the p process is stationary. The i_g process is assumed to have a trend component, due to z, and a stationarity component. These assumptions ensure that there is only one source of growth in the economy, technology growth. Furthermore, i_g will grow at that rate along the steady-state growth path.

The competitive equilibrium of the economy obtains when the representative firm and household solve their maximization problems and the government satisfies its constraints. Of the equations implicitly defining this competitive equilibrium, only the production function, (9), the technology process, (17), and the following four equations are used in the estimation exercise. The intertemporal efficiency conditions:

$$1 = \beta E_t \left\{ \frac{c_t}{c_{t+1}} \left[(1-\tau)\theta_2 \frac{y_{t+1}}{k_{t+1}} + 1 - \delta_k - p_{t+1}\omega_1 (u_{kt+1})^{\omega_2} \right] \right\} \tag{18}$$

and

$$1 = \beta E_t \left\{ \frac{c_t}{c_{t+1}} \left[(1-\tau)\theta_3 \frac{y_{t+1}}{v_{t+1}} + 1 - \delta_v - p_{t+1}\omega_3 (u_{vt+1})^{\omega_4} \right] \right\} \tag{19}$$

govern the firm's investment decisions in k_{t+1} and v_{t+1}, respectively. The firm sets the marginal cost of investing an additional unit at time t equal to the time t expected discounted marginal benefit of the return from that investment at time $t+1$. For example, in equation (18), the marginal cost is the foregone marginal utility of consumption at time t, or $1/c_t$. The marginal benefit is the product, at time $t+1$, of the marginal utility of consumption, or $1/c_{t+1}$, and a term including the after-tax marginal product of k less its depreciation and marginal energy costs. So, the marginal benefit is:

$$(1/c_{t+1}) \left\{ \left[(1-\tau)\theta_2 \frac{y_{t+1}}{k_{t+1}} + 1 - \delta_k - p_{t+1}\omega_1 (u_{kt+1})^{\omega_2} \right] \right\}.$$

The intratemporal efficiency conditions

$$\omega_1 \omega_2 (u_{kt})^{\omega_2} p_t = (1-\tau)\theta_2 y_t / k_t \tag{20}$$

and

$$\omega_3 \omega_4 (u_{vt})^{\omega_4} p_t = (1-\tau)\theta_3 y_t / v_t \tag{21}$$

determine the firm's capital-utilization decisions, u_{kt} and u_{vt}, respectively. They equate, at time t, the marginal benefits and costs of increasing utilization rates. In equation (20), for example, the marginal benefit is the after-tax marginal product of u_{kt}, or $(1-\tau)\theta_2 y_t / u_{kt}$. The marginal cost is the marginal energy cost of u_{kt}, or $\omega_1 \omega_2 (u_{kt})^{\omega 2-1} p_t k_t$.

Notice that any corresponding pair of intertemporal and intratemporal efficiency conditions includes the productivity coefficient of the relevant capital stock (e.g., equations [18] and [20] each include θ_2, the productivity coefficient of k_t). This is the reason for including these equations in the estimation exercise. That is, these equations bring more information to bear on the values of the parameters of the production function.[19]

Also, the estimation exercise includes one of the model's balanced-growth restrictions, mentioned earlier:

$$E \log (y_{t+1}/y_t) = \log \ \bar{z}, \tag{22}$$

which states that the mean growth rate of output coincides with that of technology.

3. THE ESTIMATION METHOD AND DATA MEASURES

The estimation method is Generalized-Method-of-Moments (GMM) due to Hansen (1982) and Hansen and Singleton (1982). Those studies explain the method and show how the GMM estimator is consistent and asymptotically normal. Ogaki (1992, 1993) also explains GMM and provides practical guidance on its implementation.

Here, GMM is used to estimate the parameters of equations (9) and (18) through (22). There are two reasons it is particularly appropriate for this task. First, GMM is an instrumental-variables procedure and so avoids the possible reverse-causation bias noted at the beginning of the article.[20] Second, it is applicable to equations that are nonlinear in both parameters and variables.

In the remainder of this section, some key features and requirements of the estimation method are outlined with reference to the estimation equations of this study. Also, the data are briefly described.

The application of GMM requires that each equation include only stationary variables. Equations (18) through (22) already satisfy this requirement. Their variables are growth rates of consumption and output, output-capital ratios, utilization rates, and the relative price of energy, all of which are stationary.

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[19] This approach is similar in spirit to using the factor profit-share equations, derived from a profit function, in estimating production function parameters. Lynde and Richmond (1993) take this related approach.

[20] Aschauer (1989) obtains least-squares estimates of the production function expressed in a form that is not a cointegrating relationship in the sense of Engle and Granger (1987). Because of Aschauer's method, the possible two-way interaction between output and government capital, described at the beginning of the article, may affect his estimates. See Engle and Granger (1987) for further discussion of these econometric concepts.

By taking first differences of the logarithm of equation (9), it may be transformed into a stationary form, in which all of its variables are growth rates:

$$\hat{y}_{t+1} = \theta_1[\hat{z}_{t+1} + \hat{l}_{t+1}] + \theta_2[\hat{k}_{t+1} + \hat{u}_{kt+1}] \\ + \theta_3(1-\psi)[\hat{v}_{t+1} + \hat{u}_{vt+1}] + \theta_3\psi[\hat{g}_{t+1}], \qquad (9')$$

where ˆ denotes the percentage rate of change. Using equation (17) to eliminate the unobservable $\hat{z}_{t+1}$ from equation $(9')$ and noting the constant-returns-to-scale restriction $\theta_1 = 1 - \theta_2 - \theta_3$ gives the estimation form of the production function

$$\hat{y}_{t+1} = (1-\theta_2-\theta_3)\hat{l}_{t+1} + \theta_2(\hat{k}_{t+1} + \hat{u}_{kt+1}) \\ + \theta_3(1-\psi)(\hat{v}_{t+1} + \hat{u}_{vt+1}) + \theta_3\psi\hat{g}_{t+1} \\ + (1-\theta_2-\theta_3)\ \log\bar{z} + \bar{\epsilon}_{t+1}, \qquad (9'')$$

where $\bar{\epsilon}_{t+1} = (1-\theta_2-\theta_3)\epsilon_{t+1}$.

Next, each equation is used to generate or specify, as the case may be, a disturbance term. For equations (18) and (19), the disturbances are one-period expectational/forecast errors. The disturbances for equations (20) and (21) take the form of combinations of any omitted variables. In the case of equation (22), the deviation of output growth from its mean is the disturbance. For equation $(9'')$, $\bar{\epsilon}_{t+1}$ is the disturbance term.

GMM requires that the instrumental variables for any one equation belong to an information set of variables that are independent of the equation disturbance. Also, the instrumental variables must be stationary. There is no requirement that the instruments be econometrically exogenous. That is, candidate instruments, appropriately dated and transformed to satisfy the information set and stationarity requirements, include endogenous variables such as output and consumption growth. Also, instruments may include a constant term.

The instrumental variables and the corresponding disturbance terms are used to create a set of orthogonality conditions.[21] These conditions form the basis of GMM's criterion function, denoted by J here for convenience. The GMM estimator of the vector of parameters, b, is the parameter vector that minimizes the criterion function.

Recalling equation $(9'')$, if reverse causation is present in the data, $\hat{g}_{t+1}$ will be correlated with $\hat{y}_{t+1}$ and hence with $\bar{\epsilon}_{t+1}$. But, this possibility will not invalidate the orthogonality conditions used in the GMM procedure. It follows that possible reverse causation will not distort or bias the GMM estimates of the parameters in equation $(9'')$.

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[21] No instrumental variables are chosen for equation (22) because it is already in the form of an orthogonality condition.

When the number of orthogonality conditions equals (exceeds) the number of parameters, the estimation system is exact (overidentified). In the case of an overidentified system, Hansen (1982) shows that the minimized value of J, multiplied by sample size, is asymptotically distributed as a Chi-square whose degrees of freedom equal the number of overidentifying restrictions. This Chi-square, therefore, provides a measure of the model's fit.

Ogaki (1992) shows that one way of testing coefficient restrictions (such as constant returns to scale) is based on the test statistic:

$$T[J(b^r) - J(b^u)], \tag{23}$$

where $b^r(b^u)$ is the GMM estimator imposing (relaxing) the coefficient restrictions and T is the sample size. This test statistic is asymptotically distributed as a Chi-square whose degrees of freedom equal the number of coefficient restrictions. Ogaki (1992) also describes various methods for correcting for serial correlation when using GMM.[22]

Some of the parameters entering into the estimation equations are not estimated in this article. They are β, τ, δ_k, and δ_v. Since they do not appear in the production function, these parameters are not central to the current exercise. Also, the existing literature provides guidance to their values, in the cases of β and τ, or to a simple method of obtaining them, in the cases of δ_k and δ_v. Therefore, β and τ are set equal to the values used in many other studies (see Finn [1993] for references), while δ_k and δ_v are set equal to the U.S. sample average depreciation rates implied by equations (12) and (13) (see Greenwood and Hercowitz [1991] for an example). The resultant values are the following: $\beta = 0.96$, $\tau = 0.35$, $\delta_k = 0.08$, and $\delta_v = 0.17$.

The data are annual, real, per-capita data for the United States during the period 1950–1989. Full details of these data, their sources, and caveats with respect to the capital-stock measures are presented in the appendix. Since there are no exact empirical counterparts for u_k and u_v, the total-industry total-private-capital utilization rate, denoted by u, proxies for both. Once estimates of the production function parameters are obtained, they are used in equation (9) to solve for a data measure of technology, z. This series is then used for one purpose in Section 4.

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[22] The present article undertakes a diagnostic test for first-order serial correlation. It is a t-test and is described as follows. First, obtain the equation residuals, for each equation, using the GMM point-coefficient estimates reported in Table 3. Second, conduct an Ordinary-Least-Squares regression of the equation residuals on their one-period lagged values and a constant. The t-test pertains to the regressor's coefficient in this regression equation.

4. EMPIRICAL FINDINGS

This section discusses the empirical findings reported in Tables 3–7.

At the outset note that there is evidence of first-order autocorrelation in the residuals of equations (18) through (21), providing evidence of missing dynamic elements from these equations.[23,24] This autocorrelation is taken into account in the estimation and selection of the instruments.[25]

Consider the GMM estimation results in Table 3 for equations (18) through (22) and ($9''$). These results obtain for the particular choice of instruments indicated there. The productivity coefficients, θ_2 and θ_3, are statistically significant at the 5 percent level and have small standard errors. Their values seem plausible in view of the U.S. average share of total private capital in output, 0.30, found in many studies (e.g., Lucas [1990]) and the relative magnitudes of k and v.[26] The coefficients of the energy relationships, the ω_i $(i = 1, 2, 3, 4)$, are generally insignificant and very imprecise, presumably because of the omitted dynamics from equations (20) and (21). But, it is important to note that ω_i $(i = 1, 2, 3, 4)$ do not, it turns out, interfere much with the estimation of θ_2 and θ_3. That is, the estimates of θ_2 and θ_3 are essentially determined by equations (18) and (19), with little influence stemming from the marginal energy-cost terms.[27] This point is important because θ_2 and θ_3, not the ω_i $(i = 1, 2, 3, 4)$, enter the production function estimation equation, ($9''$). Furthermore, given the plausibility of the θ_2 and θ_3 estimates, it leads to the judgment here that the omitted dynamics from equations (18) and (19) are not that serious, at least for the purpose of this study. The mean annual rate of output growth, $\log \bar{z}$, is statistically significant, precise, and reasonable. The productivity coefficient of the capital stock v, $\theta_3(1 - \psi)$, is insignificant and imprecisely determined. Highway capital's productivity coefficient, $\theta_3\psi$, is 0.16. It is significant but imprecise. Highlighting the latter, note that a 95 percent confidence interval

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[23] Autocorrelation was detected using the diagnostic test described in footnote 22.

[24] This finding may be related to the finding in Canova, Finn, and Pagan (1993) that the dynamic restrictions imposed by many real business cycle models are empirically rejected.

[25] The autocorrelation correction is the modified-Durbin method described in Ogaki (1992). First-order serial correlation in the residuals of equations (18) through (21) implies that the instruments for equations (18) through (21) must be lagged two periods relative to the dates of the variables appearing in those equations. The instruments for equation ($9''$) must be lagged only one period relative to the variables appearing in the equation, unless they are capital-stock growth rates. The latter need not (but can) be lagged because the dating of the stocks is such that they already are lagged one period relative to, say, output. (This makes the dating of the empirical stocks conform with that of the model's stocks.)

[26] The average values of k/y and v/y are 1.06 and 0.05, respectively.

[27] The evidence supporting this assertion is that similar estimation results for θ_2 and θ_3 obtain when the capital-utilization energy-cost margins are entirely ignored, i.e., when equations (20) and (21) and the terms involving utilization in equations (18) and (19) are dropped. The results for this experiment (for the same choice of instruments as in Table 3) are: $\theta_2 = 0.242(0.003)$, $\theta_3 = 0.018(0.001)$, $\psi = 8.533(3.602)$, $\log \bar{z} = 0.015(0.003)$, and $\chi^2_1 = 0.039(0.844)$.

Table 3 GMM Estimation Results

$\theta_2 = 0.267\ (0.015)$ $\omega_1 = 0.121\ (0.063)$ $\omega_2 = 10.769\ (6.773)$
$\theta_3 = 0.020\ (0.002)$ $\omega_3 = 0.179\ (0.108)$ $\omega_4 = 9.745\ (9.300)$
$\psi = 7.963\ (3.590)$
$\log\ \overline{z} = 0.015\ (0.004)$

$\theta_3\psi = 0.158\ (0.077)$ $\theta_3(1-\psi) = -0.138\ (0.075)$

$\chi^2_1 = 0.045\ (0.832)$

Instruments:
I(18) = {constant} I(20) = {constant, u_{t-2}} I(9′′) = {constant, $\hat{y}_{t-1}$}
I(19) = {constant} I(21) = {constant, u_{t-2}} I(22) = {constant}

Notes: (1) Coefficient standard errors are in parentheses.
(2) χ^2_1 denotes the Chi-squared statistic with one degree of freedom. Its probability value is in parentheses.
(3) I(x) denotes the instrument set for equation x.
(4) Equations (18) through (21) were estimated subject to correction for first-order serial correlation.

for $\theta_3\psi$ implies that the true value of $\theta_3\psi$ could be as high as 0.32 or as low as 0.001. The Chi-square measure of fit, χ^2_1, indicates that the model's overidentifying restrictions are not rejected at a high level of confidence.

These findings, especially regarding the productivity coefficients, are robust to a wide range of instrument sets.[28] Also, tests of the constant-returns-to-scale restrictions, i.e., $\theta_1 = 1 - \theta_2 - \theta_3$, and the constant-returns-to-scale restriction from the transportation-services equation, (8), are neither individually nor jointly rejected at high levels of confidence.

In short, the model specification finds a good deal of empirical support. The key finding is that highway capital is significantly productive, with a productivity coefficient of 0.16. However, the estimate is imprecise, which must be borne in mind when assessing the implications for growth and real returns to government investment.

Highway capital growth has implications for output and labor-productivity growth, working through its productivity coefficient. These implications are summarized in Tables 4 and 5. The contribution of highway capital growth $\hat{g}_t$ to output growth $\hat{y}_t$ is measured by $\theta_3\psi\hat{g}_t$. Regarding labor-productivity growth,

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[28] In checking robustness, the instrument set for any one equation always included a constant and possibly the appropriately lagged variables appearing in that equation. The total number of instruments was kept small, following Tauchen's (1986) advocacy of a small number of instruments for small samples. Only occasionally, when using some two-period lagged variables as instruments for equations (18) through (21) or lagged capital-stock growth rates as instruments for equation (9′′), the estimation algorithm failed to converge or sensitivity of the estimates was detected. This result stemmed from the absence of strong correlation of those instruments with the equation variables.

Table 4 Output Growth Accounting

			contribution of $\hat{g}_t$ (to $\hat{y}_t$) evaluated at		
			point estimate	upper estimate	lower estimate
	$\hat{y}_t$	$\hat{g}_t$	($\theta_3\psi = 0.158$)	($\theta_3\psi = 0.315$)	($\theta_3\psi = 0.001$)
1950–1969	0.022	0.030	0.005	0.009	0.00004
1970–1989	0.013	−0.005	−0.001	−0.002	−0.000008
1950–1989	0.018	0.013	0.002	0.004	0.00002

	contribution of $\hat{g}_t$ (to $\hat{y}_t$) relative to $\hat{y}_t$ evaluated at		
	point estimate	upper estimate	lower estimate
	($\theta_3\psi = 0.158$)	($\theta_3\psi = 0.315$)	($\theta_3\psi = 0.001$)
1950–1969	0.218	0.434	0.002
1970–1989	−0.064	−0.127	−0.001
1950–1989	0.115	0.229	0.001

Notes: (1) The entries are average annual growth rates of the indicated variables over the time period shown. These entries have been rounded.
(2) Upper (lower) estimate of $\theta_3\psi$ is the estimate at the upper (lower) bound of the 95 percent confidence region for $\theta_3\psi$.

Table 5 Labor Productivity Growth Accounting

			contribution of $(\hat{g}_t - \hat{l}_t)$ (to $[\hat{y}_t - \hat{l}_t]$) evaluated at		
			point estimate	upper estimate	lower estimate
	$(\hat{y}_t - \hat{l}_t)$	$(\hat{g}_t - \hat{l}_t)$	($\theta_3\psi = 0.158$)	($\theta_3\psi = 0.315$)	($\theta_3\psi = 0.001$)
1950–1969	0.020	0.028	0.005	0.009	0.00004
1970–1989	0.008	−0.010	−0.002	−0.003	−0.00001
1950–1989	0.014	0.010	0.002	0.003	0.00001

	contribution of $(\hat{g}_t - \hat{l}_t)$ (to $[\hat{y}_t - \hat{l}_t]$) relative to $(\hat{y}_t - \hat{l}_t)$ evaluated at		
	point estimate	upper estimate	lower estimate
	($\theta_3\psi = 0.158$)	($\theta_3\psi = 0.315$)	($\theta_3\psi = 0.001$)
1950–1969	0.222	0.443	0.002
1970–1989	−0.203	−0.405	−0.002
1950–1989	0.105	0.209	0.001

Notes: (1) The entries are average annual growth rates of the indicated variables over the time period shown. These entries have been rounded.
(2) Upper (lower) estimate of $\theta_3\psi$ is the estimate at the upper (lower) bound of the 95 percent confidence region for $\theta_3\psi$.

$\hat{y}_t - \hat{l}_t$, the contribution of growth in the highway capital-to-labor ratio, $(\hat{g}_t - \hat{l}_t)$, is measured by $\theta_3\psi(\hat{g}_t - \hat{l}_t)$.

First, look at the output growth accounting. Using the point estimate $\theta_3\psi =$ 0.16, the contribution of $\hat{g}_t$ is always small but important. During the 1950–1969 period, it contributes 0.5 percent to the output growth rate of 2.2 percent, representing 22 percent of that rate. In the productivity slowdown period, 1970–1989, $\hat{g}_t$ has reduced the output growth rate of 1.3 percent by 0.1 percent, amounting to 6 percent of that output growth rate. Second, examine the labor-productivity growth accounting. At the point estimate $\theta_3\psi = 0.16$, the contribution of $(\hat{g}_t - \hat{l}_t)$ is again always small but not negligible. In the period 1950–1969, the contribution is 0.5 percent to the labor-productivity growth rate of 2.0 percent, which is 22 percent of labor-productivity growth. During the productivity slowdown, $(\hat{g}_t - \hat{l}_t)$ has reduced the labor-productivity growth rate of 0.8 percent by 0.2 percent, amounting to 20 percent of labor-productivity growth.

This accounting picture changes quite substantively when the upper and lower bound estimates, 0.32 and 0.001, of $\theta_3\psi$ are used. The contributions of $\hat{g}_t$ (or $\hat{g}_t - \hat{l}_t$) become much more important or negligible, as the case may be.

What is the real return to government investment in highway capital? How does it compare with the real returns to private investment in the private capital stocks, k and v? Table 6 summarizes the answers to these questions, pertaining to average annual real returns over the 1950–1989 period.

The real return to government investment is measured by the marginal product of g: $\theta_3\psi y/g$. The private marginal products of k and v, $\theta_2 y/k$ and $\theta_3 y/v$, give the real returns to private investment in those stocks.

Using the point productivity-coefficient estimates, the real returns from investments in k and v are 25 percent and 41 percent, respectively. These returns may seem high, but of course are consistent with the corresponding point-coefficient estimates and output-capital ratios. If they were compared to other returns (e.g., Treasury bill returns), it would be important to measure their net returns (net of taxes, depreciation, and marginal energy costs) and to note any differences in risk characteristics.

At the point estimate $\theta_3\psi = 0.16$, the real return to government investment of 87 percent is considerably higher than the above private real returns. The upper and lower bound estimates of $\theta_3\psi$ imply that the true real returns could be 174 percent or 0.8 percent, respectively.

Recall that three components of government capital, EDHS, ADMN, and NATR, do not enter the quantitative analysis. Section 1 suggests that influences on the production process could stem from EDHS if labor were inaccurately measured, and from ADMN because of its association with rules and regulations as well as with research and development. If these effects exist, then the technology measure, z, will embody them. In addition, if they are of quantitative importance, then a systematic correlation between the growth rates of technology and each of EDHS and ADMN will be evident. On the other hand, Section 1

Table 6 Average and Marginal Products

(y_t/k_t)	**marginal product of k_t evaluated at**		
0.942	**point estimate** ($\theta_2 = 0.267$)	**upper estimate** ($\theta_2 = 0.297$)	**lower estimate** ($\theta_2 = 0.236$)
	0.251	0.280	0.223
(y_t/v_t)	**marginal product of v_t evaluated at**		
20.360	**point estimate** ($\theta_3 = 0.020$)	**upper estimate** ($\theta_3 = 0.030$)	**lower estimate** ($\theta_3 = 0.010$)
	0.405	0.607	0.203
(y_t/g_t)	**marginal product of g_t evaluated at**		
5.507	**point estimate** ($\theta_3\psi = 0.158$)	**upper estimate** ($\theta_3\psi = 0.315$)	**lower estimate** ($\theta_3\psi = 0.001$)
	0.872	1.736	0.008

Notes: (1) The entries are annual averages of the indicated variables over the period 1950–1989.
(2) Upper (lower) estimates refer to the estimates of the relevant parameter at the upper (lower) bound of its 95 percent confidence region.

suggests that NATR, in and of itself, does not influence the production process, which implies that the technology measure, *z*, does not incorporate productivity effects stemming from NATR. Therefore, if there is no reason that the growth rates of NATR and *z* should be systematically linked together, then a significant correlation between the two will not be detected.

It is interesting, therefore, to compute these correlations. Table 7 reports the results. The only significant correlation is that involving NATR.[29,30] One possible interpretation of this correlation is that changes in *z*, by causing changes in output, affect changes in government investment in NATR. Or perhaps both *z* and NATR are jointly responding to movements in some other variable such as the weather. While it would be interesting to explore these interpretations further, note that the correlation between the growth rates of *z* and NATR is only marginally significant.

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[29] Significance is judged at the 5 percent level. The critical value for the one-sided t-test statistic, at the 5 percent significance level and with 40 degrees of freedom, is 1.68.

[30] Another government capital component, EQIP, was also omitted from the quantitative analysis. This variable is defined and explained in the appendix. The correlation between the growth rates of EQIP and technology is 0.357, with a t-statistic of 2.321. But, it is difficult to interpret this correlation since EQIP is a component that should be split across the EDHS, ADMN, and NATR categories.

Table 7 Correlations Between Growth Rates of Technology and Omitted Government Capital Stocks

Fire and Natural Resource Capital	0.288	(1.826)
Educational and Hospital Capital	0.248	(1.557)
Administrative, Judicial, Police, and Research and Development Capital	0.150	(0.924)

Notes: The entries (not in parentheses) are correlations between the growth rates of technology and the indicated capital stock over the period 1950–1989. The numbers to the right of these entries (in parentheses) are corresponding t-statistics.

5. CONCLUSION

The key empirical finding is that highway capital is significantly productive. The point estimate of its productivity coefficient is 0.16, meaning that for every 1 percent change in highway capital, output responds by 0.16 percent. But, there is much uncertainty surrounding this estimate. To highlight this uncertainty, consider that the true productivity coefficient could be as high as 0.32 or as low as 0.001. Further work achieving more precise estimation of the productive effect of highway capital would be worthwhile.

Using the productivity-coefficient estimate, 0.16, the implications for output growth accounting are as follows. During the 1950–1969 period, highway capital growth contributes 0.5 percent to the output growth of 2.2 percent, representing 22 percent of the output growth. In the productivity slowdown period, 1970–1989, highway capital growth has reduced the output growth of 1.3 percent by 0.1 percent, amounting to 6 percent of that output growth. These effects are small but significant. They imply that government investment in highway capital matters for output growth. However, the uncertainty surrounding the productivity-coefficient estimate of 0.16 must qualify this assessment of the magnitude of the contribution of highway capital growth to output growth. That contribution could be much larger or smaller than the numbers just mentioned suggest.

Over the period 1950–1989 the real return to government investment in highway capital, when evaluated at the productivity coefficient 0.16, averages 87 percent per year. While, again, there is much uncertainty about this estimate, suppose for discussion purposes that it is reliable. The real return, 87 percent, is high. Compare it to, say, the real return to private investment in private capital that averages 25 percent per year over the same period. Does this imply that government investment in highway capital should be increased up to the point that ensures equality across the two returns? It is difficult to answer such a question about the optimal level of government investment. Much will depend on the financing of government investment. Suppose, for example, increases in government investment are financed by increases in the tax rates on labor and/or private capital income. Increases in these tax rates will work to reduce labor and private capital, thereby leading to output losses. On the other hand, the increase in government investment, by increasing government capital, will cause output to increase. The optimal level of government investment is that level which carefully balances these opposing output effects (see Glomm and Ravikumar [1992] for an analysis of these issues in a deterministic endogenous growth model). It is not clear that the optimal level occurs exactly at the point of equality between the real returns to private and government capital. Further complications arise if uncertainty is factored into the analysis. In the presence of uncertainty, real returns to investing in different assets are generally not equated, even in an expected sense, reflecting the differential roles that different assets play in hedging consumption risk (see Finn [1990]). Further exploration of optimal government investment that addresses the considerations just raised is an important task for future research.

APPENDIX: DATA SOURCES, DEFINITIONS, AND CAVEATS

The data sources are the following: (1) Citibase, (2) National Income and Wealth Division, Bureau of Economic Analysis, U.S. Department of Commerce, denoted by DC, (3) Federal Reserve Bulletin, denoted by FRB, and (4) Dale W. Jorgenson, Harvard University, denoted by DWJ. Unless otherwise indicated, the source is Citibase.

Population (thousands of persons): civilian non-institutional population aged 16 and over.

Output (billions of 1987 dollars): gross domestic product less gross government product.

Labor Hours (real index): aggregate domestic private quality-adjusted labor hours index, where the quality adjustment is based on a cross-classification by age, sex, education, class of worker, and occupation. The index is described in Jorgenson, Gallop, and Fraumeni (1987), Chap. 8. Source: DWJ.

Utilization Rate (real index): manufacturing sector utilization rate (1950–1953) and total industrial sector utilization rate for the remainder of the sample. Source: FRB.

Aggregate Price Deflator (1987=100): gross domestic product deflator.

Energy Price Index (1987=100): producer price index for fuels and related products (covering petroleum, natural gas, coal, and electricity).

Relative Price of Energy (1987=1): ratio of the energy price index to the aggregate price deflator.

Consumption (billions of 1987 dollars): personal consumer expenditures on nondurable goods plus services.

Private Transportation Vehicle Capital and Investment (billions of 1987 dollars): The capital is the net, end-of-period stock of transportation vehicles (automobiles, trucks, trailers, and buses) owned by the private (business) sector and government enterprises. The latter is proxied by taking one-tenth of enterprise equipment capital (see the discussion on caveats below, part [e], for an explanation). The investment is the corresponding gross investment. Source: DC.

Private Capital and Investment, excluding that pertaining to transportation vehicles (billions of 1987 dollars): The capital is a net, end-of-period stock consisting of nonresidential, fixed capital owned by the private (business) sector and government enterprises and that owned by general government but privately operated, plus federal government airport facilities, plus state and local government harbors. The terms *general government* and *harbors* are explained in footnotes 9 and 7, respectively. The latter two components of capital are proxied by three-quarters of the stocks in the DC “federal other structures” and “state and local conservation and development” categories (see the discussion on caveats, part [b], for more information). The investment series is the corresponding gross investment. Source: DC.

Total Government Capital (billions of 1987 dollars): government (federal, state, and local), net, end-of-period, fixed, nonresidential, nonmilitary capital. Source: DC.

Government Capital Components

In what follows, the mnemonics correspond to the paragraph titles in the text (pp. 55–58), except for EQIP, which denotes equipment capital. The components are defined with reference to the DC categories, the titles of which are in italics. Unless otherwise indicated, those categories are the sum of federal, state, and local government categories. Source: DC.

HGWY: *highways and streets.*

ENTP: government *enterprises* plus federal government airport facilities plus state and local government harbors. The latter two components of capital are approximated as described above.

GOPO: *government-owned and privately operated*.

EDHS: *educational and hospital buildings*.

NATR: federal *conservation and development* plus one-quarter of state and local *conservation and development* (i.e., the residual after measuring ENTP as described above).

ADMN: The structures component of total government capital less the structures components of ENTP and GOPO less HGWY, EDHS, and NATR (these last three components are entirely composed of structures).

EQIP: The equipment component of total government capital less the equipment components of ENTP and GOPO. Note that HGWY, EDHS, NATR, and ADMN do not have equipment components.

Some Caveats and Comments on the Capital-Stock Data

(a) The government *enterprises* category includes but does not isolate toll highways. *Highways and streets* also includes but does not isolate these. So there is unavoidable double-counting of toll highways. Because toll highways are a small part of government *enterprises* and *highways and streets,* this mismeasurement is probably not significant.

(b) Measures of federal government airport facilities and state and local government harbors are not published. Given the DC description of federal *other structures* and state and local *conservation and development,* it seems reasonable to get approximate measures of these variables by taking three-quarters of federal *other structures* and state and local *conservation and development,* respectively. Federal *other structures* are small relative to both total government capital and government *enterprises,* averaging 0.4 percent and 1.7 percent, respectively, over the sample period. Also, state and local *conservation and development* is small in relation to total government capital and government *enterprises,* averaging 1.2 percent and 5.1 percent, respectively, over the sample period. Therefore, any mismeasurement arising from the use of the indicated approximations in this article is not likely to be quantitatively significant.

(c) The fire capital-stock series described in the text on p. 58 is not separately available, nor is there useful information for forming an approximate measure. It is only because of the discussion in the text as opposed to the estimation task of the article, that the fire capital stock should be included in NATR and excluded from ADMN and EQIP, both of which, recall, are derived as residual series. But, this mismeasurement is probably immaterial since the fire capital stock is surely small.

(d) The only measures of equipment capital published by DC, relevant here, are the equipment components of total government capital, government *enterprises* and *government-owned and privately operated*. These components are used to form the EQIP series. No information is available for allocating EQIP among the EDHS, NATR, and ADMN components, which would have been interesting for the purpose of the discussion in the text.

(e) A measure of government enterprise vehicle capital is not available. Given the existence of the series on the equipment component of government *enterprises* and the fact that some enterprises undertake much transportation (public transit enterprises and the U.S. Post Office), it is desirable to get some proxy for enterprise vehicles. A proxy of one-tenth of the government *enterprises* equipment component seems reasonable in view of the list of government enterprises. Any mismeasurement arising from the use of this proxy in this study is not likely to be important since the equipment component of government *enterprises* is a small stock, averaging 0.8 percent of total government capital and 3.3 percent of government *enterprises* over the sample period.

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