Productive government expenditures and long-run growth

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Abstract

The purpose of this paper is to review some of the recent developments in endogenous growth models. Specifically, our focus is on the growth effects of productive government spending in dynamic general equilibrium models. We use a simple overlapping generations model as our basic framework and illustrate the role of taxes and spending. We then examine several related issues: nonrivalry in publicly provided goods, existence and uniqueness of competitive equilibrium, endogenous public policy, ways of financing public expenditures, composition of publicly provided goods and services, and private alternatives. Finally, we review some empirical results related to output elasticity of public capital and educational expenditures.

Key words: Endogenous growth; Infrastructure; Public education; Government spending

JEL classification: O10; E62

1. Introduction

What are the factors that determine a country's rate of economic growth in the long run? Ever since Adam Smith's publication of 'The Wealth of Nations' in 1776, economists have been trying to answer this question. The growth models of the 1960s assigned a significant role to private investment in physical capital. Long-run growth in these models was entirely due to growth in technological knowledge, which was exogenous to the models. Models of the 1980s and 1990s generate long-run growth endogenously from the actions of individuals in the economy (see Romer, 1986; Lucas, 1988).

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Recently, economists have begun to study the influence of government spending on consumption-savings decisions in models which allow the possibility of persistent growth. The recent developments have significant policy implications since government expenditures in dynamic general equilibrium models may influence long-run growth rates and welfare.

There are roughly four classes of long-run growth models with government involvement. We can think of the government as collecting distortionary taxes and distributing the revenue lump-sum; we can think of the government as collecting lump-sum taxes and distributing the tax revenue in a distortionary fashion; in the Ramsey problem the government finances a fixed stream of government expenditure with distortionary taxes; finally, we can think of the government as collecting distortionary taxes, using the tax revenue to acquire and distribute a resource in a distortionary fashion. The last case is the focus of this paper.

While there are many different ways in which a government can distribute revenue, we concentrate on two particular types of government expenditure. First, we consider government expenditures which enter as inputs in the production function for final output. Here we can think of the public provision of infrastructure such as roads, airports, harbors, or public sector R&D. Next, government expenditures which enhance investment technologies are considered. Government expenditures on education are a prototypical example. We do not consider government expenditures which enhance utility and potentially distort labor-leisure choices.

In Section 2, we lay out a simple dynamic model and characterize its equilibrium. In Section 3, we examine several related issues: nonrivalry in publicly provided goods, existence and uniqueness of competitive equilibrium, endogenizing policy through majority voting, ways of financing public expenditures, composition of publicly provided goods and services, and private alternatives to public provision.

In Section 4, we briefly review the empirical literature. We begin with a description of empirical results related to output elasticity of public capital. Then we describe the evidence on public expenditures on education. We close the section with evidence from growth regressions. Section 5 contains concluding remarks.

2. Theoretical framework

The basic framework we employ is a version of the Diamond (1965) model of capital accumulation. We present a simple model in which government

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1 See Stern (1991) for an overview of the role of public policy in economic development.
expenditures enter the production function for final output. Some of the early models of capital accumulation in which public capital is a factor of production include Shell (1967) and Arrow and Kurz (1970). More recently, Barro (1990) and Glomm and Ravikumar (1994a) present models where government spending is a productive input.

2.1. A simple model

Consider an overlapping generations model where individuals live for two periods. Each generation consists of a continuum of agents. The size of each generation is normalized to unity. Every individual born at \( t = 0, 1, 2, \ldots \) has identical preferences represented by

\[
\ln c^j_t + \beta \ln c^{j+1}_t, \quad \beta \in (0, 1),
\]

where \( c^j_t \) is time \( j \) consumption of an individual born in period \( t \).

Members of the initial old generation are each endowed with \( k_0 \) units of physical capital. Individuals in subsequent generations are endowed with one unit of leisure in their youth and \( h_t \) units of human capital. Human capital is accumulated according to the production function

\[
h_t = H(h_{t-1}, E_{t-1}), \quad (1)
\]

where \( E_{t-1} \) is public expenditures on education in period \( t - 1 \).\(^2\) We will describe the properties of \( H \) later. We will take \( h_0 \) to be an initial condition.

Each firm produces output \( y_t \) at time \( t \) according to the technology,

\[
y_t = AG_t^\alpha k_t^\theta (n_t h_t)^{1-\alpha}, \quad A > 0, \quad \alpha, \theta \in (0, 1), \quad t = 0, 1, \ldots,
\]

where \( k_t \) is the amount of capital rented by the firm, \( n_t h_t \) is the amount of skill-weighted or effective labor input, and \( G_t \) is aggregate stock of public capital available to all firms at time \( t \). The public factor is a common external input to each firm's production function, that is \( G_t \) is a pure public good. (Note that there may be scale effects in this economy since public capital is nonrival, i.e., normalizing the generation size to one is not innocuous.)

\(^2\)One way of interpreting the sequence of human capital endowments is as follows. Suppose that each individual lives for three periods and the first period of life is the learning period. For concreteness think of learning as formal schooling. During the learning period, individuals accumulate human capital according to the learning technology (1) by inelastically allocating their time endowment to learning. Think of \( h_{t-1} \) as the stock of human capital of the corresponding parent and \( E_{t-1} \) as the quality of public schools.
Income is taxed at a uniform rate $\tau$ in order to finance the public investment in infrastructure and public expenditures on education. The constraints faced by a representative young agent of generation $t$ are

$$c_t^i + s_t^i \leq (1 - \tau)w_i h_t,$$

$$c_{t+1}^i \leq (1 + (1 - \tau)r_{t+1})s_t^i,$$  \hspace{1cm} (2)

$$(c_t^i, c_{t+1}^i) \geq 0,$$

where $s_t^i$ is the individual's savings. Each individual takes the wage rate, $w_i$, the real interest rate, $r_{t+1}$, and the tax rate, $\tau$, as given. Clearly, one unit of labor is inelastically supplied by each young individual and no old individual wishes to save. The young agent's problem is to maximize utility subject to the constraints (2).

The firm's problem is static. Each firm hires capital and effective labor to

$$\max AG_t^G k_t^G (n_t h_t)^{1-\alpha} - w_t n_t h_t - q_t k_t,$$

where $q_t$ is the rental rate on capital. The technology exhibits constant returns to private factors so that the profits are zero in equilibrium.

We assume that private capital depreciates at the rate $\delta_k$ and public capital depreciates at the rate $\delta_G$. The accumulation of public capital is described by

$$G_{t+1} = I_t^G + (1 - \delta_G)G_t,$$

where $I_t^G$ is the public investment in period $t$. We also assume that the government's budget is balanced.

Given the initial $k_0, h_0$, and $G_0$, an equilibrium for our economy is a sequence of allocations $\{n_t, k_t, h_t, y_t, c_t^i, c_{t+1}^i\}_{t=0}^\infty$, and prices $\{w_t, r_t, q_t\}_{t=0}^\infty$ such that

(i) given $w_t$ and $r_{t+1}$, the allocation $(c_t^i, c_{t+1}^i)$ solves the generation $t$ young agent's problem,

(ii) given $w_t$ and $q_t$, the allocation $(y_t, k_t, n_t)$ maximizes the representative firm's profits subject to the production technology,

(iii) $k_{t+1} = s_t^i$, $n_t = 1$,

(iv) $r_t = q_t - \delta_k$,

(v) $I_t^G + E_t = \tau(w_t h_t + r_t k_t)$, and

(vi) $G_{t+1} = I_t^G + (1 - \delta_G)G_t$ and $h_t$ evolves according to (1).
The first four conditions are standard. The fifth condition is our balanced budget assumption and the sixth describes the evolution of public capital and human capital. (Each member of the initial old generation consumes all his wealth.)

2.2. Investment in infrastructure

To study the effect of infrastructure investment on long run growth, consider the following version of the above model: \( H(h, E) = 1, E_t = 0 \) for all \( t \), i.e., human capital endowments remain the same in each period and the tax revenues are used only to finance public investment in infrastructure. Long-run growth in this model depends on the returns to the augmentable factors, public capital, \( G \), and private capital, \( k \).

Optimization by the representative young agent of generation \( t \) yields

\[ s_t^* = \beta(1 - \tau)w_t/(1 + \beta). \]

Profit maximization by firms yield

\[ w_t = (1 - \alpha)AG_t^0k_t^x \quad \text{and} \quad q_t = \alpha AG_t^0k_t^{x-1}. \]

Thus, in equilibrium,

\[ k_{t+1} = \beta(1 - \tau)(1 - \alpha)AG_t^0k_t^x/(1 + \beta). \]

Suppose, for simplicity, \( \delta_G = 1 \) and \( \delta_k = 0 \). Then,

\[ G_{t+1} = \tau AG_t^0k_t^x, \]

and hence,

\[ G_{t+1}/k_{t+1} = (1 + \beta)\tau/\{\beta(1 - \alpha)(1 - \tau)\}. \]

We will assume that \( \alpha + \theta = 1 \) and focus on the balanced growth path. It is easy to see that consumption, private capital, output, and public capital will all grow at the same rate. The growth rate of private capital is given by

\[ \gamma = \ln k_{t+1} - \ln k_t = \ln \beta \theta/(1 + \beta) + \ln A + \ln(1 - \tau) + \theta \ln (G_t/k_t) \]

\[ = (1 - \theta)\ln \beta \theta/(1 + \beta) + \ln A + (1 - \theta) \ln(1 - \tau) + \theta \ln \tau. \]

The growth rate is concave in \( \tau \) and the growth-maximizing tax rate is \( \tau = \theta \), the output elasticity of public capital. In this framework, income tax not only affects
the private incentives but also enhances investment in public capital which leads to higher future output.

The dynamics are straightforward: the economy settles on the constant growth path in the initial period. Furthermore, the model delivers predictions similar to those in the endogenous growth literature (see, for instance, Jones and Manuelli, 1990; Rebelo, 1991). If the technology and preference parameters vary across countries, then the long-run growth rates across countries will typically be different. If the underlying parameters were the same across countries, there could still be persistent differences in per capita income levels purely due to differences in initial conditions.

2.3. Public expenditures on education

Here we study a version of our model where the only government expenditures are on education. Suppose that the learning technology is

\[ H(h, E) = Bh^\mu E^{1-\mu}, \quad B > 0, \quad \mu \in (0,1). \]

Furthermore, set \( \theta = 0 \) and \( I_t^e = 0 \) for all \( t \). In this model, long-run growth is the consequence of both physical and human capital being augmentable.

Utility maximization by the representative young agent of generation \( t \) yields

\[ s_t^e = \beta(1 - \tau)\omega_t h_t/(1 + \beta). \]

Profit maximizations by firms yield

\[ \omega_t h_t = (1 - \alpha) Ak_t^\theta h_t^{1-\alpha} \quad \text{and} \quad q_t k_t = \alpha Ak_t^\theta h_t^{1-\alpha}. \]

In equilibrium,

\[ k_{t+1} = \beta(1 - \tau)(1 - \alpha) Ak_t^\theta h_t^{1-\alpha}/(1 + \beta). \]

Again assuming that \( \delta_k = 0 \), public expenditure on education is

\[ E_t = \tau Ak_t^\theta h_t^{1-\alpha}. \]

\textsuperscript{3}It may seem odd that we get sustained growth under constant returns in a model with finite lifetimes, whereas Boldrin (1992a) and Jones and Manuelli (1992) do not. The reason is that, in our model, there is a dynamic externality between generations.
and hence,
\[ h_{t+1} = Bh_t^\mu (A k_t^\alpha h_t^{1-\alpha})^{1-\mu}. \]

Thus, the ratio of human capital to physical capital evolves according to

\[ \frac{h_{t+1}}{k_{t+1}} = \frac{B \tau^{1-\mu} (1 + \beta)}{\beta (1 - \tau) (1 - \alpha) A^\mu} \left( \frac{h_t}{k_t} \right)^{\alpha \mu}. \]

Clearly, this ratio converges monotonically to a unique steady state, \( x^* \), given by

\[ \ln x^* = \frac{1}{1 - \alpha \mu} \ln \left( \frac{B (1 + \beta)}{\beta (1 - \alpha) A^\mu} \right) + \frac{1 - \mu}{1 - \alpha \mu} \ln \tau - \frac{1}{1 - \alpha \mu} \ln (1 - \tau). \]

As before, consumption, physical capital, human capital, output, and public expenditures on education will all grow at the same rate. The long-run growth rate is given by

\[ \gamma = \ln \left( \beta (1 - \alpha) A/(1 + \beta) \right) + \ln (1 - \tau) + (1 - \alpha) \ln x^*. \]

Substituting for \( \ln x^* \), it is easy to see that the growth-maximizing tax rate is \( 1 - \alpha \), which is the output elasticity of human capital. Here the disincentives due to a higher tax rate are balanced against the benefits of public expenditures on human capital investment.

The dynamics in this economy look similar to the Diamond (1965) model. However, the economy does not converge to a steady state level but to a sustained growth path. Again, the model's predictions are similar to the endogenous growth literature.

3. Related issues

In this section, we examine some issues related to productive government spending. For most of the discussion below we will concentrate on investment in infrastructure although some of the issues raised are common to both types of government spending.

3.1. Congestion

A substantial part of public capital such as roads and highways, airports, harbors, etc. are clearly not pure public goods (see Stiglitz, 1988, Fig. 5.2, p. 124). Roads and highways, for example, are subject to congestion and individuals can
be excluded at some cost from using a given road. To allow for this possibility, assume that the public capital stock is nonexclusive but only partially nonrival and let the production function be

\[ y_t = A \theta t^{\phi} k_t^{1-\alpha}, \quad G_t = G_t/\{K_t L_t\}, \quad \rho, \phi \geq 0, \]

where \( G_t \) and \( K_t \) are the aggregate stocks of infrastructure and private capital, respectively, and \( L_t \) is the aggregate labor input at time \( t \). The parameters \( \rho \) and \( \phi \) are indicators of the degree of nonrivalry. According to the above specification, large amounts of aggregate private inputs imply a low contribution from the public capital stock to each firm. Again, normalizing the population size hides the scale effects of the impure public good. (Note that if both \( \rho \) and \( \phi \) are equal to zero, then infrastructure is a pure public good.) In this model, income tax, through its disincentive for private capital accumulation, also yields the benefit of reducing congestion.

To obtain long-run growth here, we have to assume \( \alpha + (1 - \rho) \theta = 1 \). To ensure that the marginal product of private capital is positive in equilibrium, we need another condition: \( \alpha + \rho \theta > 0 \). In an infinitely-lived representative agent framework, Glomm and Ravikumar (1994a) show that, if \( \rho + \phi \) equals one, the growth rate is independent of the size of the population. If \( \rho + \phi \) is less than (greater than) one, then the growth rate is increasing (decreasing) with the population size. The intuition behind this result is as follows. Suppose that \( \rho = \phi = 0 \) so that infrastructure is completely nonrival. In this case, public investments in infrastructure increase linearly with the population size. Thus, the services flowing from infrastructure to each firm are increasing with the population size since there are no congestion externalities. However, when \( \rho \) and \( \phi \) are positive, the congestion externalities have a negative effect on the service flow from infrastructure. For small congestion effects, the long-run growth rate is an increasing function of the population size. For sufficiently large \( \rho \) and \( \phi \), the congestion effects dominate and the growth rate decreases with the population size.

Futagami and Mino (1993) consider a model in which two types of government capital enter the production function for final output. One type of the government capital is a pure public good. It enters the production function exactly like the public good in Section 2.1. The second type of government capital is rival. Letting \( g_R \) denote the stock of this rival capital, \( \lambda(g_R/K) \) are the services flowing to each firm from the rival capital when the aggregate capital stock is \( K \). The function \( \lambda \) exhibits a threshold:

\[
\lambda(g_R/K) = \begin{cases} 
\hat{\lambda} & \text{if } 0 \leq g_R/K < \mu, \\
\hat{\lambda} & \text{if } \mu \leq g_R/K,
\end{cases}
\]
where $0 < \lambda < \bar{z}$. The government splits the total government capital stock proportionally between the two types of capital. Households in this model live forever and maximize the discounted sum of utility. Absent the threshold this is the same as the Barro (1990) model. Futagami and Mino find that there might be two balanced growth equilibria depending on the income tax rate which is used to finance investment in government capital. These two balanced growth equilibria correspond to the cases where $g_R / K$ exceeds or falls short of the threshold $\mu$. When dual balanced growth paths exist, Futagami and Mino show that the dynamic behavior of the economy becomes quite complex.

In Cazzavillan (1993a), public capital is a factor of production and enhances household's utility. The per period utility function in his model is $c_t^\phi G_t^\psi$. In the balanced growth equilibrium, the growth rate is nonmonotonic in the tax rate as in Barro (1990). Furthermore, when $\psi + \phi < 1$, the growth rate increases monotonically to the balanced growth rate; when $\psi + \phi > 1$, the equilibrium growth rate may exhibit a stable cycle of period 2.

### 3.2. Some technical issues

In the model described in Section 2, the agents' lifetimes are finite so that long-run growth does not give rise to existence problems similar to the ones encountered in the infinitely-lived representative agent settings. In Glomm and Ravikumar (1994a), we present a discrete time infinitely-lived representative agent model in which government expenditures enter the production function for final output. The representative household's problem is to choose $\{c_t, k_{t+1}\}_{t=0}^\infty$ to

$$\max \sum_{t=0}^\infty \beta^t \ln(c_t),$$

subject to

$$\sum_{t=0}^\infty p_t(c_t + k_{t+1}) = \sum_{t=0}^\infty \{p_t(1 - \tau_t)(w_t + r_t k_t) + z_t\},$$

$$c_t, k_{t+1} \geq 0, \quad t = 0, 1, \ldots,$$

given $k_0$, $\{p_t, w_t, r_t, z_t, \tau_t\}_{t=0}^\infty$,

where $p_t$ is the price of consumption/investment good at time $t$, $w_t$ is the wage rate, $r_t$ is the rental rate on capital, $\tau_t$ is the tax rate, and $z_t$ is the household's share of the profits.

To obtain existence and uniqueness of competitive equilibrium, we formulate an artificial planning problem using two features of the model: (i) there is no
borrowing and lending in equilibrium and (ii) the production function is homogeneous of degree one so that profits are zero in each period. Thus, the public sector part of the aggregate production function can be treated just like exogenous technological progress. Furthermore, the competitive equilibrium allocations can be characterized using Euler equations and transversality condition.

Establishing existence and uniqueness of optimal public investment is much more difficult. In Atkinson and Stiglitz (1980), the government chooses tax rates to maximize an indirect utility function; they refer to this as the dual approach. Lucas (1990), on the other hand, uses the primal approach where the marginal conditions to the households' problem are part of the government's constraints and the government chooses the households' allocations directly. Glomm and Ravikumar (1993) provide an existence theorem for an optimal tax rate sequence assuming that the government has access to a commitment technology. They use the dual approach and fail to provide uniqueness or characterize the optimal policy. Conditions under which the optimal public policy is unique remain elusive since apart from continuity and monotonicity in the state variable little is known about the private policy rules as functions of the public policy.

3.3. Endogenous policy

To endogenize the public policy, a frequently used strategy is to consider a benevolent government which maximizes the utility of the representative household. The government is a Stackelberg leader that takes the private decision rules as given when deriving the public policies. Instead of the fiction of a benevolent government suppose that the households vote on the sequence of tax rates. In a simple democracy, the equilibrium sequence of tax rates would be the one most preferred by a majority. The collective choice problem obviously does not have any conflicts in a model where all households are identical.

Alesina and Rodrik (1990) consider an economy where households are differentiated according to the initial endowment of capital. They obtain the private decision rules first and then determine the equilibrium tax rate using majority voting. They show that the tax rate, inequality, and the growth rate are all constant over time. Mohtadi and Roe (1991) endogenize public investment as a lobbying equilibrium. All agents allocate resources to influence the government. The relative size of these allocations determines the equilibrium tax rate.

In Glomm and Ravikumar (1993), we show that this trick can be used for a wide class of preferences and technologies in the one-sector growth model. In an economy where the government collects taxes only on capital income Becker (1985) also obtains the competitive equilibrium by solving an artificial planning problem. In Becker's artificial planning problem the discount factor is adjusted to reflect the capital income tax rate. His analysis is restricted to constant tax rates. See also Kehoe, Levine, and Romer (1992).
Again the equilibrium share of output allocated to public investment is constant and the economy grows at a constant rate. Glomm and Ravikumar (1992) and Boldrin (1992b) present overlapping generations models where public expenditures on education affects capital accumulation. They endogenize the public expenditures on education through majority voting. Glomm and Ravikumar (1992) set $\theta = \alpha = 0$ and $I_t^p = 0$ for all $t$ and thus focus exclusively on human capital accumulation. Individuals derive no utility from consumption when young, learn while young, and supply labor inelastically when old. Only the old in each time period are allowed to vote. Absent a bequest motive the old would vote unanimously for a zero tax rate. One way to circumvent such a result is to posit the utility function

$$\ln c_{t+1} + \ln E_{t+1},$$

where $\ln E_{t+1}$ is the utility derived from quality of education provided to one's children. In such a model the tax rate is constant over time at 50 percent and the equilibrium law of motion for human capital becomes

$$h_{t+1} = B(\frac{1}{2} A)^{1-\mu} h_t,$$

so that the economy exhibits constant growth. In Boldrin (1992b) the production function is

$$y_t = k_t^\alpha h_t^{-\beta}. $$

The learning technology is given by

$$h_{t+1} = (1 + n)^{-1}(e + E_t)^\gamma h_t,$$

where $e > 0$ and $n > 0$ is the rate of population growth. The utility function is as in Section 2.1. Consumer behavior in his model is exactly the same as in the model in Section 2.1, that is we have

$$c_t = (1 + \beta)^{-1}(1 - \tau_t)w_t h_t,$$

$$s_t = \beta(1 + \beta)^{-1}(1 - \tau_t)w_t h_t,$$

$$c_{t+1} = \beta(1 + \beta)^{-1}(1 - \tau_t)w_t (1 - \tau_{t+1}) q_{t+1}. $$

Both the old and young are allowed to vote. If there is positive population growth, there are always more young than old agents in each period. Therefore the young voters are decisive. Substituting the private decision rules back into the utility function and remaximizing with respect to the tax rate $\tau_t$, assuming
that the future tax rate $\tau_{t+1}$ is a fixed number, Boldrin shows that the equilibrium tax rate is given by

$$\tau_t^* = \frac{\gamma \beta (1 - \alpha)}{\gamma \beta (1 - \alpha) + 1 + \alpha \beta} - \frac{\varepsilon (1 + \alpha \beta)}{\alpha y_t} \{\gamma \beta (1 - \alpha) + 1 + \alpha \beta\},$$

provided that $y_t$ is sufficiently high. For low values of $y_t$ the equilibrium tax rate is zero. But when the equilibrium tax rate is zero, the law of motion for human capital is

$$h_{t+1} = (1 + n)^{-1} \varepsilon h_t,$$

so that human capital shrinks to zero when $\varepsilon < 1$. Persistent growth is only possible when $y_0$ is sufficiently large.

What exactly is the source of this poverty trap? If the parameter $\varepsilon$ in the learning technology is positive, a poor individual will not find it worthwhile to vote for positive taxes. Having zero funding for public education causes human capital to shrink only if the $\varepsilon$ parameter in the learning technology is below $(1 + n)^{1/\gamma}$. Notice however that this model is capable of generating a poverty trap even if $\varepsilon = 0$. For the sake of illustration assume that tax rates are exogenous and constant over time, which is easy to establish since all Cobb–Douglas, then we have

$$h_{t+1} = \tau(k/h)^{\alpha}(h_t)^{1+\gamma}.$$

If $\tau(k/h)^{\alpha} < 1$, then this difference equation yields a poverty trap as well. The reason for the poverty trap here are the increasing returns to scale in the learning technology $(1 + \gamma > 1)$.

One nice result which rests on the assumption of increasing returns to scale is that the equilibrium fraction of national income allocated to public education, which in this model is $\tau_t$, is increasing over time. This seems to be consistent with the observation that rich countries spend a larger share of national income on public education than poor countries. Furthermore, in the U.S., the share of national income going to public education has increased steadily during the 20th century.

In models with heterogeneity, the majority voting equilibrium typically depends upon the skewness of the income/wealth distribution. For instance, when the median is far below the mean, there is a large transfer of resources from the rich to the poor. In turn, the distortionary (in-kind) transfers have implications for growth. Thus, a short-run growth–inequality tradeoff may emerge depending upon the equilibrium capital accumulation equation. However, if the economy exhibits convergence in the long run, then the initial income/wealth inequality
has no implications for long-run growth. [See Glomm and Ravikumar (1994b) for such a model.]

3.4. Financing public investment

Most models of long-run growth which incorporate productive government spending justify governmental provision of core infrastructure, police protection, or R&D by appealing to the public goods nature of these goods and services. Typically, these are only local public goods. Even public sector agricultural research concerning high yielding varieties may only be suitable to specific geographic conditions. If the public good is local and not global the question of which level of government should finance the public good becomes relevant. For instance, in the U.S., funding for public education comes in roughly equal parts from state and local sources; federal funding for education plays a minor role. [See Benabou (1992) for a model that studies federalism in education and the impact on growth.] To provide satisfactory answers in a dynamic general equilibrium framework, migration between jurisdictions induced by different levels of the public good has to be considered. To this end, static models of local public finance (e.g., Epple and Romer, 1991) may be useful.

When goods and services provided by the government are not pure public goods, one needs to justify why governmental provision of such goods and services is desirable. One can easily imagine models in which roads and highways are provided by local monopolists. If these monopolists are allowed to charge prices above marginal costs and earn supranormal profits, large inefficiencies may result. Efficient provision of these local public goods may then call for governmental regulation. On the other hand, governmental regulation may be subject to a supervision technology such as the one used by Lucas (1978) in his study of the size distribution of firms. The details of such a model have not been worked out.

In Section 2, the form of taxation is very simple: there is only one tax rate on both labor and capital income which is collected at a uniform rate. An example of dynamic models that allow for different types of taxes is Jones, Manuelli, and Rossi (1993); they allow labor and capital to be taxed at different rates in a model where government spending enters an investment technology. To what extent optimal public expenditures depend on the types of taxes used and on the uniformity of tax rates is an open question. For instance, in models with heterogeneity it may be desirable to allow the tax rates to vary according to income or wealth.

3.5. Composition of government spending

Typically, long-run growth models with productive government spending lump several goods and services, such as roads and highways, law and order,
sewer systems, harbors, public sector R&D, together into one category called public capital. Is a reduced form such as the one in Section 2 appropriate for all publicly provided goods? While increasing the stock of transportation may well enhance the productivity of private factors, increasing police protection seems to operate in a fundamentally different manner. Without police protection, a large level of stealing may prevail. Although stealing is purely redistributive in a given period, expectations of future stealing lowers rates of returns to investment. Equilibrium dynamics in such an economy may be drastically different from those of the simple model of Section 2. Moreover, the implications of shifting resources from one type of productive government expenditure to another are largely unexplored.

Similarly, public spending on education include expenditures on teachers, administrators, school buildings, computers and other equipments, lunches, and books. A disaggregated model may help clarify whether composition of government spending has implications for growth.

3.6. Private alternatives

In Section 2, we abstracted away from any private provision of investment in infrastructure or educational expenditures. In most countries, these services are also available through the private sector. Education, for instance, is provided through public schools as well as private schools. To the extent that formal schooling is a significant component of human capital investment, the institutions for schooling may be important for growth and vice versa.

If we consider a simple model where the quality of public schools depends on per capita tax revenues and households pay taxes only if they send their children to public schools, it is easy to see no one would choose public education. The richest household can do better on its own and hence will not use the public schools. Once the richest household opts out of the public education system the second richest household has exactly the same incentives to opt out and the whole system unravels. In the U.S., all parents pay taxes used for public education but they can opt out of public schools. In such a case, the size of public education relative to private education has implications for evolution of income. An alternative institution to examine is one where the tax revenues are not spent directly on public schools but distributed as education vouchers.

\(^5\)Stiglitz (1974) was among the first to study such an institution.
4. Empirical evidence

4.1 Public capital

In this section we briefly review some empirical evidence concerning the impact of the public capital stock on aggregate output. Most empirical studies we review here aim to find estimates of the aggregate production function

\[ Y = \alpha G^q K^s L^\beta, \]

where \( Y \), \( G \), \( K \), and \( L \) are aggregate output, public capital, private capital, and labor, respectively. Econometric techniques and data sets used vary widely.

Among the first to estimate the impact of public infrastructure on output in an aggregate production function framework was Ratner (1983) who used annual data for the U.S. from 1949 to 1973 and found an estimated elasticity of output with respect to public capital (net nonmilitary stock of government owned equipment and structures) of 0.06. Aschauer (1989) produced a widely cited estimate of 0 of 0.39, using annual data for the U.S. from 1949 to 1985. Moreover, Aschauer includes a measure of capacity utilization in his regressions. Holtz-Eakin (1988) and Munnell (1990a) obtained estimates of similar magnitudes (see also Garcia-Mila and McGuire, 1992). Ford and Poret (1991) use an estimation technique similar to Aschauer's using data from ten industrialized countries. They find positive and significant effects of various definitions of public capital on total factor productivity growth.

The size of Aschauer's estimates met with disbelief. The productivity of public capital was simply not believed to be larger than the productivity of the private capital stock (which is roughly 0.36). Moreover, Aschauer's econometric techniques were criticized on several grounds such as (i) the endogeneity of public capital, (ii) nonstationarity of the time series, and (iii) missing price variables such as energy prices.

Hulten and Schwab (1991) use first differencing to take account of common trends in the data and find public capital to be statistically insignificant. Eberts (1986) estimates the direct effect of the public capital stock on manufacturing output within SMSAs and finds an estimate of 0 of 0.03, which is significantly different from zero. Munnell (1990b) uses data for the contiguous 48 states in the U.S. for 1970 to 1986 and finds a public capital elasticity of about 0.1. If public capital is taken to be only highways and streets, she finds an elasticity of 0.06, and when public capital is taken to be water and sewer systems, the elasticity is 0.12. Running regressions for the four regions in the U.S. yields estimates ranging from 0.07 for the Northeast to 0.36 for the South. Duffy-Deon and Eberts (1989) using data on 28 SMSAs for 1980 to 1984 and employing...
two-stage least squares estimation find a public capital elasticity of 0.08 (see also Eberts, 1990).

Holtz-Eakin (1992) attempts to reconcile the vastly different estimates. By running OLS regressions he obtains estimates of $\theta$ as large as 0.2, which is in line with the estimates obtained by Munnell (1990b) and Costa et al. (1987). After controlling for unobserved, state specific effects, Holtz-Eakin finds 'essentially no role for public capital at the margin' (p. 2). Cazzavillan (1993b) uses a panel data set for 12 European countries from 1957 to 1987 and finds, even after inclusion of a fixed effect, a public capital elasticity of 0.25. Fay (1993) concentrates on one particular type of public capital, namely electrical generating capacity. Her data set covers 95 countries for 5 five-year periods from 1960–1985. Her two-stage least squares estimates after inclusion of measures of capacity utilization and fixed effects yields a public capital elasticity estimate of 0.2. Canning and Fay (1993) obtain similar results for transportation networks using similar estimation techniques.

Time series estimates of the public capital elasticity still turn out to be large. Lynde and Richmond (1993a) account for nonstationarity in the data, and use value added data which enables them to incorporate intermediate goods (e.g., oil) prices in their estimation. Their estimate of $\theta$ is 0.2 and changes in the public capital–labor ratio can explain 40 percent of the productivity slowdown in the U.S. since 1973. Lynde and Richmond (1993b) perform similar estimation for U.K. data and find similar results.

In quarterly Australian data for the period 1960 to 1992, Otto and Voss (1994) find that the inputs and the output are cointegrated. Their (consistent) estimate of the output elasticity of public capital turns out to be 0.20. Their impulse response functions reveal that (i) a positive shock to public capital induces a positive lagged effect on private capital and (ii) public capital shows no response to innovations in private output and private employment, thus providing some evidence that causality flows public capital to private production. Christodoulakis (1993) estimates how output of large-scale manufacturing in Greece between 1964 and 1990 depends upon the stock of public capital in transport, communications and electricity. His estimates are roughly comparable to Aschauer's estimate. He finds that public capital Granger causes output and that there is no reverse causation.

Ai and Cassou (1993) estimate public capital in a neoclassical growth model and use GMM to estimate Euler equations. Their estimate of $\theta$ is 0.2. Finn (1994) uses GMM to estimate a model of productive highway capital which is publicly provided, subject to congestion and a complementary input to private transportation capital. The productivity coefficient of highway capital is estimated to be 0.16. De Frutos and Pereira (1993) estimate a VARMA model which allows feedback between output, labor, private capital, and public capital. They use annual data for the U.S. economy from 1950 to 1989. Their impulse response functions show that, in the short run, the growth of output and private capital
are relatively unresponsive to changes in the public capital stock. However, a permanent shock of 1 percent to the public capital stock induces a 7.4 percent increase in output after 10 years and after 200 years, induces an increase in private capital of 55.5 percent. These large long-run effects stem from the influence of public capital on output and from the feedback from output to public capital. According to de Frutos and Pereira, running cross-section regressions to find short-term effects of public capital on output may be missing most of the role of public capital.

Another group of papers aim to assess the impact of public capital on output by estimating (industry) cost functions. Nadiri and Mamuneas (1991) estimate the effect of two types of public capital separately on the cost function of 12 U.S. manufacturing industries. The two types of public capital are the fixed non-residential government net capital stock at all levels of government and the government stock of R&D capital. For both types of public capital, Nadiri and Mamuneas find significant productive effects. Shah (1992) estimates cost functions for 26 Mexican industries between 1970 and 1987 as functions of the public capital stock in electricity, communications, and transportation. His estimated elasticity is 0.05.

What conclusions, if any, can be drawn from the studies cited above? The Aschauer estimate of the public capital elasticity of 0.39 appears too large. The studies that found insignificant effects of public capital on output, seem to concentrate on short-run effects of public capital. As de Frutos and Pereira point out, finding small short-run effects does not imply that public capital has no (long-run permanent) effect on output. Evidence produced by Binswanger, Khandker, and Rosenzweig (1993) also can be used to argue that the productive effects of public capital do not show up in the short run but only in the long run: for 85 districts in India between 1960 and 1981 the agricultural output elasticity with respect to road investment is about 0.2. Some of the effects of improved roads on output is lagged and indirect: Improved roads induce commercial bank expansion, commercial bank expansions accelerates private agricultural investment which increases output.

4.2. Public expenditures on education

Here we discuss some empirical studies of the connection between economic growth, education, and public policy. We take as our starting point growth accounting exercises. Such exercises try to assess how much of the observed growth is due to various sources. [See Denison (1967) for an example of such a growth accounting exercise.] Education is responsible for as little as 0.8 percent of growth in Mexico between 1950 and 1964 and as much as 16.6 percent in Argentina between 1950 and 1962. In these growth accounting exercises an index of education is constructed which essentially is based on the
distribution of years of schooling. Other aspects of education such as the quality of education or the type of education are typically ignored.⁶

There is by now a large literature on the estimation of educational production functions.⁷ These studies are relevant to the extent that the influence of education on growth works through some measurable schooling output such as cognitive ability test scores. In this literature measures of educational outputs such as test scores, graduation rates, earnings are regressed on a variety of inputs. The inputs are typically divided into three groups: (i) private inputs over which the student has no control such as parental education levels, (ii) private inputs chosen by the student such as time and effort allocated to homework, and (iii) publicly provided/determined inputs such as the number of teachers per student, the quality of teachers, or length of the school term.

At least since the Coleman (1966) report the strength of family background as a determinant of schooling output has been recognized. For this review, we concentrate on the effect of publicly determined inputs on educational outputs. Card and Krueger (1992) study three measures of the quality of education in the U.S., teacher–student ratios, length of the school term, and teacher salary. They find that these measures of quality of education not only exert a significant influence on private choices such as time allocated to learning but also on wage rates.

Measures of school quality such as teacher–student ratios or teacher salary relative to per capita income exhibit very large variations across countries. For example, student–teacher ratios in primary schools vary from 81 in Mozambique in 1980 to 23 in Guinea-Bissau in the same year. Salaries of primary school teachers relative to per capita income vary from 1.3 in Uganda to 15.4 in Mauritania (see also Heyneman, 1984). To the extent that such measures of school quality do influence real wages, careful econometric work may well reveal that a large fraction of the variation in growth rates of real incomes across countries can be explained by variation in the school quality. Of course, such econometric work will have to take into consideration that school quality is endogenously determined.

4.3. Growth regressions

The literature on growth regressions tries to assess the influence of various public policies on economic growth. This typically involves regressing the (cross-country) growth rate on a variety of variables such as literacy rates, initial

⁶Krueger (1968) studied the influence of education on the level of income in a cross-section of countries. Her education measure also was years of schooling. Krueger found that roughly 50 percent of the variation in income can be explained by the variation in years of schooling.

⁷For a survey, see Hanushek (1986).
level of income, measures of political instability and civil liberty, domestic credit growth, investment share, and measures of public policy such as tax rates, money growth rates, public expenditures, and size of government (see Landau (1986) and Ram (1986) for early examples). The typical data set is the Summers and Heston data set or data from the World Bank.

Easterly and Rebelo (1993) find that (i) public transportation and communication investment is positively correlated with growth, (ii) aggregate measure of public investment is negatively correlated with growth, and (iii) educational investment is positively correlated with growth. There are a few problems with their results. First, they acknowledge that many of their fiscal policy variables are highly correlated with initial income levels, so attributing growth effects to fiscal policy is difficult. Second, they concede that they may not have found adequate instruments to deal with the endogeneity of fiscal policy variables. Third, Levine and Renelt (1993) conclude that "... very few economic variables are robustly correlated with cross-country growth rates. In particular, neither government capital formation nor government educational expenditures are robustly correlated with growth rates.'

Engen and Skinner (1993) correct for the potential endogeneity bias using the two stage instrumental variables technique. This correction reduces the coefficient on government spending to less than one-third of the OLS estimate and renders the coefficient insignificant from zero. Since their measure of government spending is highly aggregated, it leaves open the possibility that some types of government spending may be positively correlated with growth.

Kocherlakota and Yi (1994a,b) examine whether long-run growth is exogenous or endogenous by testing if innovations in public policy are associated with permanent changes in income levels. They use time series data for the U.S. and the U.K. and regress per capita income on public policy variables. Their results suggest that increasing public equipment capital and marginal tax rates simultaneously has a net positive effect on growth.

5. Conclusion

In this paper we have reviewed the literature on the influence of productive government expenditures on long-run growth. We have focused on two types of government expenditures, namely those that enter as inputs into the production function for final output, such as infrastructure, and those that enter as inputs in investment technologies such as expenditures on education.

Other types of government expenditures may well have large impacts on long-run growth as well. Public health expenditures, for example, may well increase life expectancy. Increased life expectancy in turn may have a significant impact on private capital accumulation decisions and hence on growth. In order to assess the impact of public health expenditures on long-run growth one
would like a dynamic general equilibrium model which has implications for life expectancies and mortality rates. In other words, mortality rates need to be determined endogenously as functions of own consumption and public health expenditures. Without such models a full understanding of the impact of productive government expenditures will remain elusive.

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