Fiscal Policy, Congestion, and the Dual Nature of Public Goods*

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Abstract

We examine the impact of fiscal policy on macroeconomic performance when public goods play a dual role by simultaneously providing both productive *and* utility services to the private sector. When these services are subject to congestion, a consumption tax is distortionary, generating a dynamic adjustment that contrasts an income tax. The design of optimal fiscal policy demonstrates the possibilities for using both income- and consumption-based fiscal instruments as opposed to relying on the income tax alone. In correcting for congestion, an income tax-consumption subsidy combination is the preferred policy when factor-substitutability in production is limited. On the other hand, an increase in the elasticity of substitution in production raises the efficacy of a consumption tax as an alternative to the income tax. If the dual benefits of public goods are not internalized, it might lead to significant errors in evaluating the impact of public policies on welfare.

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1 Introduction

The role of the government in influencing private economic activity has been a long-standing subject of investigation amongst economists and policymakers. Public goods and their associated externalities provide a crucial channel through which spending and taxation policies of the government affect private resource allocation and social welfare. In this paper, we argue that most common public goods, such as infrastructure, education, health, and law and order, play a *dual* role in influencing private economic activity, by simultaneously affecting both private utility (welfare) *and* productivity. Based on this often overlooked premise, we derive a set of new results linking fiscal policy to an economy's structural characteristics and its macroeconomic performance.

Distinguishing public goods by strictly defined characteristics such as public *consumption* goods (welfare-enhancing) or public *investment* goods (productivity-enhancing) is a standard feature of intertemporal models of growth.[1] As a practical matter, however, it is difficult to rationalize this distinction and define public goods as purely consumption *or* investment goods. Indeed, in many cases, it may be more appropriate to conceptualize a composite public good that yields both utility and productivity benefits to the private sector. Based on this observation, we try to provide an answer to the following question: how does this "dual" nature of public goods affect the relationship between fiscal policy, growth, and welfare, especially in the presence of a common public-good externality such as congestion?

The following examples might help set this discussion in perspective. Consider economic infrastructure, which is, without exception, treated purely as a productivity-enhancing input in the production process. Roads and highways, apart from influencing productivity by facilitating the transportation of goods and services, might also be an important source of utility to consumers, who might get pleasure out of driving or taking road trips.[2] Similar examples can be offered for other aspects of infrastructure as well, such as power and water supply, transport and communication, etc. Education and healthcare are further examples of public goods whose dual role is often overlooked. Their productivity-enhancing roles are underlined by the economy's set of skills, knowledge-base, human capital, and a more productive work-force; see Barro (1991). But at the same time, it can be argued that altruistic parents derive satisfaction from sending their children to good schools, with the intention of enabling them to be better citizens in the future. Moreover, in developing countries that lack credit markets, investment in a child's education is often seen as

[1] One strand of literature, starting with Bailey (1971) and with later contributions by Aschauer (1988) and Barro (1989), highlights the welfare-enhancing properties of public goods by focusing on the substitutability between public and private consumption in the utility function. On the other hand, Gramlich (1994) reviews the empirical evidence that suggests that government investment expenditures may have large productivity effects on the economy. A second strand of research therefore focuses on the productivity-enhancing role of public investment goods, such as infrastructure; See Arrow and Kurz (1970) for an early analysis, and Barro (1990), Futagami et al. (1993), Baxter and King (1993), Glomm and Ravikumar (1994) for later contributions. Though Turnovsky and Fisher (1995) and Turnovsky (2004) study both public consumption and investment, they are modeled as individually distinct goods.

[2] The New York Times reported that about 87 percent of all vacation travelers in the U.S. (38 million people) used the country's interstate highway system for road trips during the 2006 Memorial Day weekend.

a means of providing social insurance for parents in their old age. Similarly, healthy parents may derive satisfaction from the knowledge that they can provide for their children better than others by working longer and harder. Further, an important objective of free basic healthcare systems, such as the public-sector National Health Scheme (NHS) in the UK, is to ensure that the state provides a safety net for the welfare of the poor, old and the infirm (Spending Review, 2004).[3]

The above argument holds for traditionally defined public consumption goods as well, such as law and order, national parks, defense, etc. While these goods might directly affect the utility consumers derive from them, they can also have significant productivity benefits (by providing security, protecting property rights, or reducing stress). The important point here is that different agents in the economy (e.g. consumers and firms) can derive different types of services (e.g. utility and productivity) from the accumulated stock of the *same* public good. In this context, it is appropriate to mention the work of Tanzi and Schuknecht (1997, 2000), who find that government provision of education, health, public pensions and social insurance has led to increases in the literacy and life-expectancy rates, and reductions in infant mortality rates and unemployment insecurity in the OECD countries over the 1913-1990 period, during which there was a fourfold increase in public spending as a proportion of GDP. In effect, they make the argument that traditionally defined public "capital" goods contribute as much to social welfare as do public "consumption" goods.

The objective of this paper, therefore, is to study the design and impact of fiscal policy on growth and welfare when (i) the economy-wide aggregate stock of a composite public good provides *both* consumption as well as productive services, and (ii) these services are subject to differential degrees of relative congestion.

The value-added of this paper lies both in its modeling and its results. In terms of modeling, two critical features distinguish the analytics from previous work. First, the "dual" nature of the composite public good we consider is manifested in two key relationships: (i) the interaction between the public good and private capital in production, through a constant elasticity of substitution (CES), and (ii) the interaction between the public good and the private consumption good in the utility function, through the relative weight assigned to the public good in utility. This "dual" relationship provides the government an extra margin to simultaneously target both private production and consumption through the design of fiscal policy.[4] Second, it is entirely plausible that different agents in the economy might be subject to different degrees of congestion, depending

[3] Education and healthcare represent substantial proportions of government spending in most developed countries. Public education spending in the UK, France, and the USA all exceed 5% of GDP, with substantial increases in such spending of late. Spending on health is even higher in these countries, with the UK spending 7.8% of GDP on its NHS and the US spending approximately 15% of GDP on healthcare expenditures (OECD, 2006).

[4] The possibility of a dual role played by public investment was first suggested by Arrow and Kurz (1970, chapter 1), though a formal treatment was not provided. In a recent but related contribution, Agenor (2005) develops a model where the government provides two distinct public goods, namely infrastructure and health services. Whereas infrastructure enters the production function, health services affect both production and utility. However, the analysis is restricted to a Cobb-Douglas specification as opposed to the more generalized CES structure we employ, and focuses mainly on the allocation of government spending between infrastructure and health, rather than on the design of fiscal policy to correct for differential degrees of congestion.

on the type of service they derive from the underlying public good. For example, power outages and shortages in water supply during peak "usage" seasons such as summer are common examples of congestion in many developing countries (World Bank, 1994). However, the disutility caused by a power outage for a household may be quite different from the loss in productivity suffered by a firm or worker. This aspect of the model further distinguishes itself from the existing literature, where the effects of congestion are restricted to either production *or* utility, depending on the type of public good (i.e., consumption or investment) being modeled.[5]

These innovations yield some new insights into how different instruments of fiscal policy might be used to correct congestion externalities and thereby affect an economy's equilibrium behavior. First, we show that when the utility services derived from the public good are subject to congestion, a consumption tax will be *distortionary*, affecting both the economy's dynamic adjustment and its equilibrium resource allocation. The dual nature of the public good plays an important role in this result by linking the marginal utility of consumption and its relative price to the marginal return on private capital. In general, a consumption tax will work in a way that is in sharp contrast to that of an income tax. Second, the impact of consumption and income taxes on economic welfare depends critically on the interaction between (i) the degree of substitutability between private capital and the public good in production, and (ii) the relative importance of the public good in the utility function. Our numerical experiments show that in economies with limited substitutability in production, a combination of an income tax and a consumption subsidy can yield higher welfare gains relative to using an income or a consumption tax alone. However, as the elasticity of substitution increases, the efficacy of the consumption tax relative to other fiscal instruments increases. In fact, in the limit, when there is perfect substitutability in production, replacing the income tax with a consumption tax yields the highest welfare gains. Third, we show that if the dual nature of the public goods is not taken into account, the fiscal authority might incorrectly estimate the impact of public policies on welfare. Finally, we demonstrate that in designing optimal fiscal policy to counter the effects of congestion, the government has the flexibility to use a mix of fiscal instruments rather than a single tax or subsidy alone.

It would be instructive at this point to highlight the contribution of our results relative to the existing literature. In the context of endogenous growth, the appeal of a consumption tax has stemmed mainly from the finding that it is non-distortionary, thereby providing an important policy tool for the government to finance its expenditures without affecting private economic decisions.[6] However, in intertemporal models, the only condition under which a consumption tax is

[5] Congestion is often used as a classic example of rivalry associated with public goods, and its effects on growth, welfare and the design of optimal fiscal policy have been studied by several authors, including Edwards (1990), Barro and Sala-i-Martin (1992), Fisher and Turnovsky (1998), and Eicher and Turnovsky (2000).

[6] The consumption tax has a long history in economics, dating back to Hobbes (1651) and Mill (1895), with Fisher (1937) and Kaldor (1955) providing the early contributions in the 20th century; see Atkinson and Stiglitz (1980) for a review of the early literature and Gentry and Hubbard (1997) for a discussion on the distributional effects of consumption taxes. More recently, the consumption tax has also occupied a significant place in the political debate on tax reform in the United States. See, for example, the 2003 United States Economic Report of the President

distortionary is when the work-leisure choice is endogenous; see Milesi-Ferretti and Roubini (1998) and Turnovsky (2000) for some recent examples. Our results on the distortions introduced by a consumption tax are very distinct from the existing literature as they do not depend on the assumption of an endogenous work-leisure choice, but rather on the dual nature of public goods and the presence of congestion in the utility services derived from them. In that sense, we extend the literature by highlighting a new mechanism through which a consumption tax might impact growth and welfare.

Another important contribution of this paper relates to the design of fiscal policy in correcting for congestion externalities. Most of the existing literature relies on the income tax as the sole corrective fiscal instrument for congestion, with the consumption tax playing the role of a non-distortionary lump-sum tax, used to balance the government's budget; see Barro and Sala-i-Martin (1992) and Turnovsky (1996). By contrast, our analysis assigns an important role to *consumption*-based fiscal instruments as a *complement* to the income tax in correcting for different sources of congestion. This refinement is only possible when one acknowledges the dual nature of a public good and the differential congestion externalities its usage generates. More importantly, we demonstrate that most of the standard results in the literature on congestion and optimal fiscal policy can be conveniently derived as special cases of our more general model. Our framework thus represents both a refinement and a generalization of the existing analyses on this issue.

The rest of the paper is organized as follows. Section 2 develops the analytical framework using a composite public good. Section 3 characterizes resource allocation in a centrally planned economy, which yields the benchmark first-best optimum. Section 4 derives the macroeconomic equilibrium in a decentralized economy and discusses the design of optimal fiscal policy. In Section 5, we conduct a numerical analysis of the model and its dynamic properties, with a particular emphasis on welfare. Section 6 concludes the paper.

2 Analytical Framework

We consider a closed economy populated by N infinitely lived representative agents, each of whom maximizes intertemporal utility from the consumption from a private good C, and the services derived from the accumulated stock of a composite public good:

$$U \equiv U\left(C, K_g^s\right) = \int_0^{\infty} \frac{1}{\gamma}\left[C\left(K_g^s\right)^{\theta}\right]^{\gamma} e^{-\beta t} dt, \quad -\infty < \gamma \leq 1,\ 0 \leq \theta \leq 1,\ \gamma(1+\theta) < 1 \qquad (1)$$

In the utility function (1), K_g^s represents the services derived from the aggregate economy-wide stock of the public good, K_g, and θ denotes the weight attached to these services in the utility function, relative to the private consumption good . The available stock of the public good is

(Chapter 5, pp. 175-212) for a discussion on the pros and cons of a consumption-based tax system relative to an income-based system.

non-excludable, but the services derived from it by an individual agent or consumer may be subject to rivalry, in the form of congestion. In other words, the "utility" benefits derived by the agent from the composite public good depend on the usage of its own private capital (K), relative to the aggregate economy-wide usage ($\bar{K}$):

$$K_g^s = K_g \left(\frac{K}{\bar{K}}\right)^{1-\sigma_c}, \quad 0 \leq \sigma_c \leq 1 \tag{2}$$

where σ_c parameterizes the degree of relative congestion associated with the utility benefits derived from the public good.

The public good, apart from generating utility benefits for the representative agent, is also available for productive purposes. Each agent produces a private good, whose output is given by Y, using a CES technology, with its individual stock of private capital and the economy-wide stock of the public good serving as factors of production. However, the productive services derived from the public good may also be subject to congestion, in a manner similar to (2):

$$Y = A\left[\alpha K^{-\rho} + (1-\alpha)\left\{K_g\left(\frac{K}{\bar{K}}\right)^{1-\sigma_y}\right\}^{-\rho}\right]^{-\frac{1}{\rho}}, \quad 0 < \alpha < 1, \;\; -1 < \rho < \infty, \;\; 0 \leq \sigma_y \leq 1 \tag{3}$$

where σ_y measures the degree of relative congestion associated with the productive benefits derived from the composite public good.[7] The intertemporal elasticity of substitution between private capital and the public good is given by $s = 1/(1+\rho)$.[8] The parameterization of θ in (1) provides a convenient tool by which the role of the public good in influencing economic activity can be defined. For example, when $\theta > 0$, the public good plays a *dual* role in the economy, by providing both productive and utility services. On the other hand, when $\theta = 0$, the public good is just a productive input with no direct utility benefits. This case corresponds to the standard public capital-growth model found in the literature, as in Futagami et al. (1993).

The accumulation of private capital and the public good is enabled by corresponding flows of new investment, given by:

$$\dot{K} = I \tag{4a}$$

$$\dot{K}_g = G \tag{4b}$$

where the I is the flow of private investment, and G represents the flow of expenditures on the

[7] In our specification, when $\sigma_i = 1$ ($i = c, y$), there is no congestion associated with the public good. In that case, the public good is a non-rival good available equally to all agents. On the other hand, $\sigma_i = 0$ represents a situation of proportional congestion, where congestion grows with the size of the economy. The case where $0 < \sigma_i < 1$ represents partial congestion. It is also plausible that the degrees of relative congestion in the utility and production functions are distinct, i.e., $\sigma_c \neq \sigma_y$.

[8] Assuming flexibility in the production structure by adopting a CES technology is useful for analyzing the efficacy of fiscal policy shocks as the degree of factor substitutability changes. When $s = 1$ ($\rho = 0$), we obtain the familiar Cobb-Douglas specification. On the other hand, as $s \to 0$ ($\rho \to \infty$), (3) converges to the fixed proportions production function, and when $s \to \infty$ ($\rho \to -1$), there is perfect substitutability between private capital and the public good.

public good, which may be undertaken either by a social planner or a government. Finally, the economy's aggregate resource constraint is given by

$$Y = C + \dot{K} + \dot{K}_g \tag{5}$$

The analytical description of the model will proceed sequentially, in the following manner. First, we will describe the allocation problem in a centrally planned economy. Given this "first-best" benchmark equilibrium, we will then derive the equlibrium in a decentralized economy. This sequential analysis will enable us to characterize the design of optimal fiscal policy in the decentralized economy. The crucial behavioral difference between the centrally planned economy and the decentralized one lies in the way the congestion externalities are internalized. In the centralized economy, the social planner recognizes the relationship between the stocks of individual and aggregate private capital, $\bar{K} = NK$, *ex-ante*. However, in the decentralized economy, the representative agent fails to internalize this relationship, although it holds *ex-post*, in equilibrium. As a result, the resource allocation problem in the decentralized economy is subject to the various sources of congestion described in (2) and (3), and consequently is sub-optimal. Optimal fiscal policy in the decentralized economy would then entail deriving the appropriate tax and expenditure rates for the government that would enable a replication of the equilibrium in a centrally planned economy.

3 A Centrally Planned Economy

Since the social planner in a centrally planned economy internalizes the effects of congestion ex-ante, we set $\bar{K} = NK$ and normalize $N = 1$. The planner's utility and production functions take the form

$$U = \int_0^\infty \frac{1}{\gamma}\left(CK_g^\theta\right)^\gamma e^{-\beta t} dt \tag{1a}$$

$$Y = A\left[\alpha K^{-\rho} + (1-\alpha) K_g^{-\rho}\right]^{-\frac{1}{\rho}} \tag{3a}$$

It is also convenient to begin with the assumption that the social planner allocates a fixed fraction, g, of output to investment in the public good, to sustain an equilibrium characterized by endogenous growth. We will, of course, relax this assumption in a subsequent section to characterize optimal public investment, i.e., when g is chosen optimally by the planner.

$$\dot{K}_g = G = gY, \quad 0 < g < 1 \tag{6}$$

The planner makes the resource allocation decision for the representative agent by choosing consumption and the accumulation of private capital and the public good by maximizing (1a) subject to (5) and (6), while taking note of (3a) and (4a). The equilibrium relationships will be described in terms of the following stationary variables: $z = K_g/K$, the ratio of the stock of the public good to private capital, $c = C/K$, the ratio of private consumption to private capital, and $y = Y/K$, the output-private capital ratio. Under the assumption that g is arbitrarily fixed, the optimality conditions are given by

$$C^{\gamma-1}K_g^{\theta\gamma} = \lambda \tag{7a}$$

$$\alpha A^{-\rho}\left[(1-g)+qg\right]y^{1+\rho} = \beta - \frac{\dot{\lambda}}{\lambda} \tag{7b}$$

$$\frac{(1-\alpha)A^{-\rho}\left[(1-g)+qg\right]\left(\frac{y}{z}\right)^{1+\rho} + \theta\left(\frac{c}{z}\right)}{q} + \frac{\dot{q}}{q} = \beta - \frac{\dot{\lambda}}{\lambda} \tag{7c}$$

where λ is the shadow price of private capital, q is the shadow price of the public good relative to that of private capital, and $y = A[\alpha + (1-\alpha)z^{-\rho}]^{-1/\rho}$.

The optimality conditions (7a)-(7c) can be interpreted as follows. Equation (7a) equates the marginal utility of consumption to the shadow price of private capital, while (7b) equates the rate of return on private investment to the corresponding return on consumption. The return on private investment is adjusted for two factors: the complementarity of private capital and the public good in production implies that an increase in private investment must also increase the stock of the public good, given a fixed g. Further, the return on private investment is also offset by the resource cost of allocating a fixed fraction of output to investment in the public good. An analogous interpretation holds for (7c), which equates the return on public investment to that on consumption. Since the public good plays a dual role in this economy, both as a consumption and an investment good, its social return is derived from two sources: (i) the return from production, given by the first term on the left-hand side of (7c), and (ii) the return from utility, given by the second term, $\theta(c/z)$, which measures the marginal rate of substitution between the private consumption good and the stock of the public good. Additionally, the last term on the left-hand side of (7c) describes the capital gains emanating from the rate of change in its real price q (given that private capital is treated as the numeraire good).

Using (5), (6), (7a), and (7b), we can derive the equilibrium growth rates for private capital, the public good, and consumption:

$$\psi_k = \frac{\dot{K}}{K} = A(1-g)\left[\alpha + (1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} - c \tag{8a}$$

$$\psi_g = \frac{\dot{K}_g}{K_g} = gA\left[(1-\alpha) + \alpha z^{\rho}\right]^{-\frac{1}{\rho}} \tag{8b}$$

$$\psi_c = \frac{\dot{C}}{C} = \frac{\alpha A^{-\rho}\left[(1-g)+qg\right]y^{1+\rho} + \theta\gamma g\,(y/z) - \beta}{1-\gamma} \tag{8c}$$

Note that the growth rate of consumption in (8c) depends not only on the marginal return on private capital, but also on the marginal utility return derived from the consumption of the public good, as long as $\theta > 0$.

3.1 Macroeconomic Equilibrium

The core dynamics of the centrally planned economy can be expressed by the evolution of the stationary variables z, c, and q and can be expressed using (8a)-(8c), and by equating (7b) and (7c):

$$\frac{\dot{z}}{z} = gA\left[(1-\alpha) + \alpha z^{\rho}\right]^{-\frac{1}{\rho}} - A(1-g)\left[\alpha + (1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} + c \tag{9a}$$

$$\frac{\dot{c}}{c} = \frac{\alpha A^{-\rho}\left[(1-g) + qg\right]y^{1+\rho} + \theta\gamma g\,(y/z) - \beta}{1-\gamma} - A(1-g)\left[\alpha + (1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} + c \tag{9b}$$

$$\frac{\dot{q}}{q} = A^{-\rho}\left[(1-g) + qg\right]\left[\alpha - (1-\alpha)\frac{z}{q}^{-(1+\rho)}\right]y^{1+\rho} - \frac{\theta}{q}\left(\frac{c}{z}\right) \tag{9c}$$

The steady-state equilibrium is attained when $\dot{z} = \dot{c} = \dot{q} = 0$, and is characterized by sustained balanced growth and a constant relative price of the public good:

$$gA\left[(1-\alpha) + \alpha\tilde{z}^{\rho}\right]^{-\frac{1}{\rho}} = A(1-g)\left[\alpha + (1-\alpha)\tilde{z}^{-\rho}\right]^{-\frac{1}{\rho}} - c \tag{10a}$$

$$\frac{\alpha A^{-\rho}\left[(1-g) + \tilde{q}g\right]\tilde{y}^{1+\rho} + \theta\gamma g\,(\tilde{y}/\tilde{z}) - \beta}{1-\gamma} = A(1-g)\left[\alpha + (1-\tilde{\alpha})z^{-\rho}\right]^{-\frac{1}{\rho}} - \tilde{c} \tag{10b}$$

$$A^{-\rho}\left[(1-g) + \tilde{q}g\right]\left[\alpha\tilde{q} - (1-\alpha)\tilde{z}^{-(1+\rho)}\right]\tilde{y}^{1+\rho} = \theta\left(\frac{\tilde{c}}{\tilde{z}}\right) \tag{10c}$$

Equations (10a)-(10c) can be solved to yield the steady-state values of $\tilde{z}$, $\tilde{c}$, and $\tilde{q}$, given a fixed g. The dynamic behavior of the equilibrium system (9) can be expressed in a linearized form around the steady state ($\tilde{z}$, $\tilde{c}$, $\tilde{q}$):

$$\underline{\dot{X}} = \Delta\left(\underline{X} - \underline{\tilde{X}}\right) \tag{11}$$

where $\underline{X}' = (z, c, q)$, $\underline{\tilde{X}}' = (\tilde{z}, \tilde{c}, \tilde{q})$, and Δ represents the 3x3 coefficient matrix of the linearized system. It can be demonstrated that the linearized dynamic system (11) is characterized by one stable (negative) and two unstable (positive) eigenvalues, which thereby generates saddle-point behavior.

3.2 Optimal Public Expenditure

The centrally planned economic system described in section 3.1 was based on the assumption that the social planner allocates an arbitrarily fixed fraction of output to expenditure on the public good. However, it is plausible that the planner makes an optimal choice with respect to g to attain the first-best resource allocation. In that case, the optimization problem is independent of the constraint in (6). Consequently, the optimal share of public expenditure in output, say $g = \hat{g}$, is derived endogenously from equilibrium.

Performing this optimization, we find that

$$\hat{q} = 1 \tag{12}$$

In other words, in choosing the optimal quantity of public expenditure, the planner must ensure that the shadow prices of private capital and the public good are equalized along the transition path. Substituting (12) in (10b) and (10c), while taking note of (10a), we can re-write the steady-state conditions as follows ("ˆ" denotes the steady-state value of a variable when g is set optimally):

$$\hat{g}A\left[(1-\alpha)+\alpha\hat{z}^{\rho}\right]^{-\frac{1}{\rho}} = A(1-\hat{g})\left[\alpha+(1-\alpha)\hat{z}^{-\rho}\right]^{-\frac{1}{\rho}} - \hat{c} \tag{13a}$$

$$\frac{\alpha A^{-\rho}\hat{y}^{1+\rho}+\theta\gamma\hat{g}\left(\hat{y}/\hat{z}\right)-\beta}{1-\gamma} = A(1-\hat{g})\left[\alpha+(1-\alpha)\hat{z}^{-\rho}\right]^{-\frac{1}{\rho}} - \hat{c} \tag{13b}$$

$$A^{-\rho}\left[\alpha-(1-\alpha)\hat{z}^{-(1+\rho)}\right]\hat{y}^{1+\rho} = \theta\left(\frac{\hat{c}}{\hat{z}}\right) \tag{13c}$$

Given (12), we can solve (13a)-(13c) for the optimal steady-state values of $\hat{z}$, $\hat{c}$, and $\hat{g}$.

An interesting point to note here is that (12) implies that $\dot{q} = 0$ at all points of time. Therefore, the core dynamics are independent of the (unitary) real shadow price of the public good. Substituting (12) into (9b) and noting (9a), we see that when g is set at its optimal level, the dynamics are reduced to a second-order system and can be expressed solely in terms of z and c:

$$\frac{\dot{z}}{z} = \hat{g}A\left[(1-\alpha)+\alpha z^{\rho}\right]^{-\frac{1}{\rho}} - A(1-\hat{g})\left[\alpha+(1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} + c \tag{14a}$$

$$\frac{\dot{c}}{c} = \frac{\alpha A^{-\rho}y^{1+\rho}+\theta\gamma\hat{g}\left(y/z\right)-\beta}{1-\gamma} - A(1-\hat{g})\left[\alpha+(1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} + c \tag{14b}$$

When the planner optimally allocates output to investment in the public good, the resource costs appearing in (7b) and (7c) are no longer relevant. However, in evaluating the marginal costs and benefits of the private and public expenditure decisions, the planner must consider the fact that allocating an extra unit of output to the public good provides not only a productivity return, but also a utility return. This aspect of the model represents a significant departure from earlier work regarding the optimality of public investment in endogenous growth models. For example, Turnovsky (1997) finds that when g is chosen optimally, the economy is *always* on a balanced growth path and devoid of transitional dynamics. However, we see from (13) and (14), that once the social planner chooses the optimal allocation of g, the stationary variables z and c are not constant, but evolve gradually along the transition path, while the social planner ensures that the shadow prices of private capital and the public good are always equalized. The key point here is that since the social return from the public good is derived both from utility and production, the corresponding investment in private capital must track this return along the transition path for (12) to hold. As a result, z and c must adjust accordingly at each point of time, until the steady-state equilibrium is attained.

It is easy to demonstrate that the relative weight of public capital in the utility function (θ) plays a crucial role in this result. To see this, assume that $\theta = 0$ in (10). Given that $\hat{q} = 1$, it is immediately evident from (10c) that

$$\hat{z} = \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{1+\rho}}$$

This implies that $\dot{z} = 0$ at all points of time. Consequently, from (10b), it turns out that $\dot{c} = 0$ must also hold if the transversality conditions are to be satisfied. Therefore, in the special case where $\theta = 0$, the economy is always on its balanced growth path and there is no dynamic adjustment. This is essentially the result obtained in Turnovsky (1997). We can then conclude that the utility function (1) represents a general specification, from which earlier results in the literature can be derived as special cases, depending on the magnitude of θ.

4 A Decentralized Economy

We now consider the case of a decentralized economy where the government plays a passive role, while the representative agent makes its own resource allocation decisions. There are two crucial behavioral differences between this regime and the centrally planned economy described in section 3. First, the government now provides the entire stock of the public good using the financial and policy instruments at its disposal, while the representative agent takes this stock as exogenously given in making its private allocation decisions. Second, the representative agent does not internalize the effects of the two sources of congestion externality, σ_c and σ_y. The utility function for the representative agent in this regime is therefore given by

$$U = \int_0^\infty \frac{1}{\gamma}\left[CK_g^\theta\left(\frac{K}{\bar{K}}\right)^{\theta(1-\sigma_c)}\right]^\gamma e^{-\beta t}dt \tag{1c}$$

while the production function is given by (3):

$$Y = A\left[\alpha K^{-\rho} + (1-\alpha)\left\{K_g\left(\frac{K}{\bar{K}}\right)^{1-\sigma_y}\right\}^{-\rho}\right]^{-\frac{1}{\rho}} \tag{3}$$

The agent accumulates wealth in the form of private capital and holdings of government bonds, and is subject to the following accumulation constraint

$$\dot{K} + \dot{B} = (1-\tau_y)(Y + rB) - (1+\tau_c)C - T \tag{15}$$

where r is the interest earnings on government bonds, τ_y is the income tax rate, τ_c is the consumption tax rate, and T is a lump-sum tax. Taking the stock of K_g as given, the agent chooses its flow of consumption, private investment, and holdings of government bonds to maximize (1c), subject to the flow budget constraint (15) and the accumulation rule (4a), while taking note of (3). It is important to note here that in performing its optimization, the representative agent fails to internalize the relationship $\bar{K} = NK$, although it will hold in equilibrium. As before, we will express the equilibrium in terms of the stationary variables z and c, and normalize $N = 1$, without loss of generality. Since the agent does not make an allocation decision with respect to the public good, q is not relevant in this regime.

The optimality conditions for the above maximization problem are

$$C^{\gamma-1} K_g^{\theta\gamma} = \lambda(1+\tau_c) \tag{16a}$$

$$(1-\tau_y)A^{-\rho}[\alpha + (1-\alpha)(1-\sigma_y)z^{-\rho}]y^{1+\rho} + \theta(1-\sigma_c)(1+\tau_c)c = \beta - \frac{\dot{\lambda}}{\lambda} \tag{16b}$$

$$\beta - \frac{\dot{\lambda}}{\lambda} = (1-\tau_y)r \tag{16c}$$

The interpretation of the optimality conditions (16a)-(16b) is analogous to that of the centrally planned economy, except that in (16b), the rate of return on private capital is subject to the sources of congestion in production and utility. The presence of congestion raises the total market return on private capital when K increases, by increasing the productive and utility services derived from the stock of the public good. The last term on the left-hand side of (16b), $\theta(1-\sigma_c)(1+\tau_c)c$, represents the marginal rate of substitution between consumption and private capital generated by congestion in the utility function. In other words, it reflects the price of consumption relative to private capital. This is the crucial channel through which a consumption tax affects the agent's resource allocation decisions along the equilibrium path. Equation (16c) equates the rate of return on consumption to the return on government bond holdings, and represents the no-arbitrage condition that equalizes the returns from consumption, private capital, and government bonds.

The government provides the necessary expenditure for the provision of the public good, which accumulates according to

$$\dot{K}_g = G = gY, \quad 0 < g < 1 \tag{17}$$

where g represents the fraction of output allocated by the government to the accumulation of the public good. This investment is financed by tax revenues and issuing government debt:

$$\dot{B} = r(1-\tau_y)B + G - (\tau_y Y + \tau_c C + T) \tag{18}$$

Equation (18) states to the extent that interest payments on debt and expenditure on the public good exceed tax revenues, the government will finance the resulting deficit by issuing debt. Combining (18) with (15) yields the aggregate resource constraint for the economy, given by (5).

4.1 Macroeconomic Equilibrium

The equilibrium dynamics in the decentralized economy can be expressed by

$$\frac{\dot{z}}{z} = gA\left[(1-\alpha)+\alpha z^{\rho}\right]^{-\frac{1}{\rho}} - A(1-g)\left[\alpha+(1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}} + c \tag{19a}$$

$$\begin{aligned}\frac{\dot{c}}{c} &= \frac{(1-\tau_y)A^{-\rho}\left[\alpha+(1-\alpha)(1-\sigma_y)z^{-\rho}\right]y^{1+\rho}+\theta\left[(1-\sigma_c)(1+\tau_c)c+\gamma g\left(y/z\right)\right]-\beta}{1-\gamma} \\ &\quad -A(1-g)\left[\alpha+(1-\alpha)z^{-\rho}\right]^{-\frac{1}{\rho}}+c\end{aligned} \tag{19b}$$

The steady-state equilibrium is attained when $\dot{z} = \dot{c} = 0$ and is characterized by sustained balanced growth:

$$gA\left[(1-\alpha)+\alpha\tilde{z}^{\rho}\right]^{-\frac{1}{\rho}} = A(1-g)\left[\alpha+(1-\alpha)\tilde{z}^{-\rho}\right]^{-\frac{1}{\rho}} - \tilde{c} \tag{20a}$$

$$\begin{aligned}&\frac{(1-\tau_y)A^{-\rho}\left[\alpha+(1-\alpha)(1-\sigma_y)\tilde{z}^{-\rho}\right]\tilde{y}^{1+\rho}+\theta\left[(1-\sigma_c)(1+\tau_c)\tilde{c}+\gamma g\left(\tilde{y}/\tilde{z}\right)\right]-\beta}{1-\gamma} \\ &= A(1-g)\left[\alpha+(1-\alpha)\tilde{z}^{-\rho}\right]^{-\frac{1}{\rho}}-\tilde{c}\end{aligned} \tag{20b}$$

Equations (20a) and (20b) can be solved for the steady-state values of $\tilde{z}$ and $\tilde{c}$. The dynamic evolution of the economy and the steady-state equilibrium are independent of the shadow price of the public good, q. This happens because the representative agent treats the government-provided stock of the public good as exogenous to its private decisions. As a result, the agent does not internalize the effect of its private investment decisions on the evolution of the public good.

4.1.1 Income versus Consumption Taxes in the Presence of Congestion

The macroeconomic equilibrium for the decentralized economy, described in (19) and (20), provides some new insights on the interaction between private resource allocation decisions and the government's fiscal instruments. One interesting result to emerge from this analysis is that the consumption tax, τ_c, can be *distortionary*, affecting both the dynamic evolution and the steady-state equilibrium of the economy. This is a significant result, since our framework does not assume an endogenous labor-leisure choice which, in the literature, is crucial for a distortionary consumption tax. However, for the consumption tax to have distortionary effects in our framework, two conditions must be simultaneously satisfied: (i) the public good provides utility services ($\theta > 0$) as well as productive services, and (ii) the utility services derived from the public good are subject to congestion ($0 < \sigma_c < 1$). As discussed in the introduction, both these conditions are very plausible in the context of most public goods. Intuitively, in the presence of congestion in utility, a change in the consumption tax rate will increase the marginal rate of substitution between private consumption and private capital through the utility services derived from the public good, which in turn affects the market return from private capital, given by (16b). We view this as a new result in the public goods-growth literature, since previous studies have shown that in the absence of an endogenous work-leisure choice, a consumption tax is similar to a lump-sum tax. Therefore, the dual nature of the composite public good and congestion generated by its utility services provide an alternative transmission mechanism for the consumption tax in affecting private economic decisions.

The steady-state equilibrium described in (20a) and (20b) also throws some light on the way an income and a consumption tax might impact the economy in the presence of congestion externalities. Since both the utility and productive services from the public good are congested by private usage, the market return on private capital in a decentralized economy is above its socially optimal level, given by (7b). Therefore, the steady-state equilibrium is characterized by "too much" private investment and "too little" private consumption, relative to the social optimum. In this scenario, the goal of public policy would be to reduce the market return on private capital. From (16b) and (20), it is clear that an increase in income tax will help alleviate congestion by reducing the after-tax marginal return on private capital. On the other hand, an increase in the consumption tax works exactly in the opposite direction, by *increasing* the after-tax return on capital. This happens because, in the presence of congestion in utility services, a consumption tax will increase the relative price of consumption, and lower that of private capital; see (16b). However, the impact of these tax rates on intertemporal welfare will depend crucially on the private allocation of resources between consumption and private investment. This allocation in turn will depend on (i) the elasticity of substitution in production, and (ii) the relative importance of the public good in the utility function. These insights give us an important basis for comparing the dynamic effects of the two competing fiscal instruments, i.e., the income and consumption tax rates, which we will consider subsequently in section 5 by undertaking a numerical analysis of the model.

4.2 Optimal Fiscal Policy

Given that income and consumption taxes impact the economy in very different ways, it is instructive to ask, what tax and expenditure rates in the decentralized economy will replicate the first-best equilibrium attained by the social planner? Let these choices be represented by the vector $\underline{\Lambda}' = (\hat{g}, \hat{\tau}_y, \hat{\tau}_c)$. Then, by definition, $\underline{\Lambda}$ is a description of optimal fiscal policy in the decentralized economy.

To determine these optimal choices, we will compare the equilibrium outcome in the decentralized and centrally planned economies. Since our focus is on the two distortionary tax rates, we will assume that g is set optimally at $\hat{g}$, given by the solution to (13), and is appropriately financed by some combination of non-distortionary lump-sum taxes and government debt. Given $\hat{g}$, a comparison of (13b) and (20b) yields the following optimal relationship between the income and consumption tax rates:

$$\tau_y = \frac{A^{-\rho}(1-\alpha)(1-\sigma_y)(y/z)^{\rho} + \theta(1-\sigma_c)(1+\tau_c)(c/y)}{A^{-\rho}[\alpha + (1-\alpha)(1-\sigma_y)z^{-\rho}]y^{\rho}} \tag{21}$$

From (21), we see that in the presence of congestion in both production and utility, only *one* tax rate can be chosen independently to attain the first-best equilibrium. This implies that the government has a choice in the "mix" between the income and consumption tax rates: if one is set arbitrarily, the other automatically adjusts to satisfy (21) and enable the first-best resource allocation. But the crucial question is, what kind of a policy "mix" must the government choose? Given the dependency of the two tax rates on one another, a unique combination of τ_y and τ_c is unattainable. However, a unique feature of (21) is that even if one individual tax instrument is at its non-optimal level, the government can adjust the other appropriately to attain the social optimum.

To see this flexibility in designing optimal fiscal policy, note that the income and consumption tax rates are positively related to each other in the optimal relationship given by (21). A useful benchmark, then, is to derive the tax on income, say $\hat{\tau}_y$, when $\tau_c = 0$. Given this benchmark rate, we can evaluate the role of the consumption-based tax when the actual income tax rate, τ_y, differs from its benchmark rate, $\hat{\tau}_y$. When consumption taxes are absent, i.e., $\tau_c = 0$, the appropriate tax on income is given by

$$\hat{\tau}_y = \frac{A^{-\rho}(1-\alpha)(1-\sigma_y)(y/z)^{\rho} + \theta(1-\sigma_c)(c/y)}{A^{-\rho}[\alpha + (1-\alpha)(1-\sigma_y)z^{-\rho}]y^{\rho}} > 0 \tag{22}$$

Therefore, the income tax rate required to attain the first-best optimum must correct for *both* sources of externalities, σ_y and σ_c, and take into account the impact of the public good on utility, θ. In other words, the optimal income tax reduces the rate of return on private capital to its social return by targeting the effect of its usage on both productivity and utility. Even if the production externality is absent, i.e., $\sigma_y = 1$, but the consumption externality is present, i.e., $0 < \sigma_c < 1$, the optimal income tax must be positive, to correct the distortions in utility caused by private investment. Also, note that when public capital provides direct utility benefits ($\theta > 0$), the optimal income tax rate is higher than those derived in the previous literature, namely Barro (1990), Futagami et al. (1993), and Turnovsky (1997).

Now suppose that the actual income tax rate is different from its benchmark rate derived in (22). The government has a choice to use the consumption tax to correct for this deviation, and yet attain the first-best optimum without affecting the income tax rate. To see this, subtract (22) from (21):

$$\tau_c = \frac{A^{-\rho}[\alpha + (1-\alpha)(1-\sigma_y)z^{-\rho}]y^{\rho}}{\theta(1-\sigma_c)(c/y)}(\tau_y - \hat{\tau}_y)$$

Therefore, when $\tau_y > \hat{\tau}_y$, the government must introduce a positive consumption tax ($\tau_c > 0$) to attain the first-best equilibrium, without changing the income tax rate. On the other hand, if $\tau_y < \hat{\tau}_y$, a consumption subsidy ($\tau_c < 0$) is the appropriate corrective fiscal instrument. In the case where $\tau_y = \hat{\tau}_y$ as in (22), the consumption tax must be zero ($\tau_c = 0$). The intuition behind this result can be explained as follows. When the income tax rate is above its benchmark rate given in (22), the private return on capital falls below its socially optimal return. In this case, a positive tax on consumption helps offset this deviation by raising the private return to capital relative to consumption. Conversely, if the income tax rate is below its benchmark rate, then the private return on capital exceeds its social return and a consumption subsidy corrects this deviation by lowering the private return on capital relative to consumption.

Of course, when there is no congestion in utility ($\sigma_c = 1$) or when the public good is purely a productive input ($\theta = 0$), this margin of adjustment is non-existent and the consumption tax has no bearing on the equilibrium allocation. In this case, the optimal tax on income is the only corrective fiscal instrument and is similar to that obtained in the public-capital growth literature[9]:

$$\hat{\tau}_y = \frac{(1-\alpha)(1-\sigma_y)}{[\alpha z^{\rho} + (1-\alpha)(1-\sigma_y)]}$$

Our discussion of optimal fiscal policy can be evaluated by relating it to the corresponding literature on congestion, taxation, and growth. A useful benchmark in this literature is a paper by Turnovsky (1996). In that paper, a consumption tax is non-distortionary and works like a lump-sum tax, and must be reduced to zero as the degree of congestion increases, while the income tax emerges as the sole policy instrument when there is proportional congestion. When there is no congestion in production, the optimal income tax rate is zero and government expenditure must be financed by the *non-distortionary* consumption tax. Our results can be viewed both as a refinement and a generalization of these results. First, we show that under certain very plausible conditions, the consumption tax is distortionary, both in transition as well as in steady-state. Second, we show that a consumption-based fiscal instrument (in the form of a tax or subsidy) can be used jointly with an income tax to correct for different sources of congestion in an economy. Third, when there is no congestion in production ($\sigma_y = 1$), the income tax rate must still be positive, with or without a consumption tax or subsidy, to correct for distortions in utility. Finally, when there is no congestion in utility ($\sigma_c = 1$), the consumption tax is non-distortionary and our results are comparable to those in Turnovsky (1996) as well as most of the literature.

5 Fiscal Policy and Transitional Dynamics: A Numerical Analysis

We begin our analysis of the framework laid out in sections 3 and 4 with a numerical characterization of both the centrally planned and decentralized economies. In particular, we are interested in (i) analyzing the role played by the relative importance of the public good in utility (θ) in the propagation of fiscal policy shocks (g, τ_y, and τ_c), and (ii) comparing the dynamic effects of an increase in the consumption tax rate with an equivalent increase in the tax on capital income. Finally, we would also like to examine the sensitivity of the effects of the various fiscal policy

[9] For an example with the Cobb-Douglas specification, see Turnovsky (1997).

shocks on welfare with respect to (i) the elasticity of substitution in production, (ii) the congestion parameters, and (iii) the relative importance of the public good in the utility function.

5.1 Equilibrium in a Centrally Planned Economy

Our starting point is the steady-state equilibrium in the centrally planned economy, which will serve as a useful benchmark. The following Table describes the choices of the structural and policy parameters we use to calibrate this benchmark economy:

Preference Parameters:	$\gamma = -1.5$, $\beta = 0.04$, $\theta \in [0,\, 0.3]$
Production Parameters:	$A = 0.4$, $\alpha = 0.8$, $s \in [0.25,\, \infty)$

The preference parameters β and γ are chosen to yield an intertemporal elasticity of substitution in consumption of 0.4, which is consistent with Ogaki and Reinhart (1998). Since there is no known estimate of θ, the relative weight of the public good in the utility function, we consider a range between 0 and 0.3, where $\theta = 0$ corresponds to the standard public capital-growth framework where the public good is only a productive input, and $\theta = 0.3$ corresponds to the estimate of the ratio of public consumption to private consumption, used by Turnovsky (2004).[10] The output elasticity of private capital is set at 0.8, which is reasonable if we consider private capital to be an amalgam of physical and human capital, as in Romer (1986). This of course implies that the corresponding output elasticity for the public good is 0.2, which is consistent with the empirical evidence reviewed by Gramlich (1994). Finally, we are not aware of any empirical estimate for the elasticity of substitution between private capital and public goods in production ($s = 1/(1+\rho)$), and therefore choose a range between 0.25, indicating limited substitutability between K and K_g, and infinity, indicating perfect factor substitutability. The case where $s = 1$ ($\rho = 0$) represents the familiar Cobb-Douglas technology, and will serve as a useful benchmark.

Table 1 characterizes the steady-state equilibrium in a centrally planned economy, for different values of θ. When $\theta = 0$, the equilibrium outcome corresponds to the literature which treats the public good purely as a productive input. Therefore, considering the outcomes when $\theta > 0$ provides a useful insight into its role in resource allocation. For example, when $\theta = 0$, the optimal ratio of the public good to private capital ($\hat{z}$) is 0.25, while the corresponding value for the consumption-capital ratio ($\hat{c}$) is about 0.2. Optimal public expenditure ($\hat{g}$) is about 6.7 percent of aggregate output. The consumption-output and capital-output ratios are 0.67 and 3.30, respectively, while the steady state is characterized by a balanced growth rate of 8.1 percent.[11] As θ increases,

[10] It should be noted here that Turnovsky (2004) treats the public good in the utility function as a pure consumption good, with no productive effects, as does most of the literature, where public consumption and investment goods are clearly distinguishable. Moreover, treatments of public consumption goods typically consider a flow of services, whereas in our case it is the accumulated stock that is relevant.

[11] The calibration of the model is purely for illustrative purposes, rather than approximating a real economy, though some of the equilibrium quantities, like the consumption-output and capital-output ratios, lie in their corresponding empirically estimated ranges. The introduction of depreciation rates and adjustment cost functions for private and public investment would enable the calibration of a real economy such as the U.S., as in Turnovsky (2004). However, the central results of our analysis would remain qualitatively unaffected by these changes.

the utility return from public expenditure increases, thereby augmenting its total return, causing the central planner to allocate a larger fraction of output to the public good relative to private investment. This is reflected by an increase in the equilibrium levels of $\hat{z}$ and $\hat{g}$. A larger stock of the public good, being complementary to private consumption, facilitates the consumption of the private good, leading to an increase in $\hat{c}$. The consumption-output and capital-output ratios are lower for higher values of θ, indicating that the higher $\hat{g}$ expands output proportionately larger than consumption and private capital. As θ increases, the fraction of output allocated to public spending also increases, but is eventually subject to diminishing returns. Therefore, the equilibrium growth rate is lower for large values of θ relative to the case when it is small (e.g. $\theta = 0$).

Table 2 illustrates the optimal rates of public expenditure as a fraction of output in the centrally planned economy, for variations in both θ and the elasticity of substitution, s. As in Table 1, we see that for any given s, an increase in θ above zero will lead the planner to allocate a higher fraction of output to investment in the public good. On the other hand, for any given θ, an increase in the elasticity of substitution, s, will lower the equilibrium allocation of $\hat{g}$. This happens because a larger s increases the return on private capital relative to the public good, leading the planner to allocate fewer resources to the public good and more to private capital on the margin. Another interesting feature of Table 2 is the relationship between the rate of optimal public expenditure, the relative weight of the public good in utility, and its output elasticity. For example, in the flow model of Barro (1990), the optimal (welfare-maximizing) rate of public investment is given by, say, $g^* = 1-\alpha = 0.2$ (since $\alpha = 0.8$ in our calibration), i.e., by setting the rate of public investment equal to its output elasticity. However, Turnovsky (1997) shows that when public investment is treated as a stock variable rather than a flow, $g^* < 1 - \alpha$. In Table 2, this corresponds to the case where $\theta = 0$, and let us denote this rate by $\hat{g}_{\theta=0}$. Our numerical results show that when the *dual* benefits of the public good are internalized by the planner ($\theta > 0$), the optimal rate of public expenditure, say, $\hat{g}_{\theta>0}$, is still lower than $(1 - \alpha)$, but is higher than $\hat{g}_{\theta=0}$, i.e., $\hat{g}_{\theta=0} < \hat{g}_{\theta>0} < g^* = 1 - \alpha$. For example, when $s = 1$, and $\theta = 0$, $\hat{g}_{\theta=0} = 0.0668$. But when $\theta = 0.3$, $\hat{g}_{\theta>0} = 0.1149$. Therefore, internalizing the dual nature of the public good generates an optimal expenditure rate that is less than Barro (1990) but larger than Turnovsky (1997).

5.2 Equilibrium in a Decentralized Economy

Table 3 characterizes the benchmark equilibrium and long-run effects of fiscal policy shocks in a decentralized economy under the Cobb-Douglas specification ($s = 1$). Since it is difficult to conceptualize a decentralized economy without any congestion, we consider the case of partial congestion, with $\sigma_y = \sigma_c = 0.5$ serving as a benchmark specification, while θ is set at 0.3 in the utility function.[12] The pre-shock fiscal policy parameters are set arbitrarily at $g = 0.1$, $\tau_y = 0.1$,

[12] Even though we set the two congestion parameters to be equal, we will consider the sensitivity of the results to their variation in Table 4B.

and $\tau_c = 0$.[13]

In the benchmark equilibrium, the ratio of the public good to private capital is approximately 0.38, while the consumption-capital ratio is about 0.21. The representative agent devotes about 63 percent of output to consumption, while the capital-output ratio is 3.04. Finally, these allocations lead to a long-run balanced growth rate of about 8.74 percent.

5.2.1 Long-run Effects of Fiscal Policy Shocks

The panels of Table 3 report the long-run impact of five fiscal policy shocks on the equilibrium resource allocation in the decentralized economy:[14] (i) an increase in g, the share of output claimed by the government for public good provision, from its pre-shock level of 0.1 to 0.2, (ii) an increase in the income tax rate, τ_y, from 0.1 to 0.2, (iii) an increase in the consumption tax rate, τ_c, from 0 to 0.1, (iv) a mix of an income tax increase and a consumption subsidy, where τ_y increases from 0.1 to 0.2, while τ_c is reduced from 0 to -0.1 (representing a 10 percent subsidy to consumption), and (v) replacing the income tax rate with a consumption tax, where τ_y is reduced from its benchmark rate of 0.1 to 0, while τ_c is increased from 0 to 0.1.

I. *An increase in public investment (g):* A higher share of output claimed by the government for public spending, which is financed by an appropriate adjustment in government debt or lump-sum taxes, leads to a higher flow of investment in the public good, thereby increasing its long-run stock relative to private capital (z). The higher stock of the public good increases the long-run productivity of private capital, thereby encouraging an increase in private investment. This leads to a substitution away from private consumption towards private investment, leading to a long-run decline in the consumption-capital ratio (c). As the flow of output increases due to the shift towards investment, private consumption also increases. However, given the higher stocks of the private capital and the public good, output increases more than in proportion to both consumption and private capital, leading to declines in their respective proportions in total output. The investment boom also increases the long-run equilibrium growth rate and welfare. For example, the long-run growth rate increases from 8.74 to approximately 10 percent, while welfare increases by about 2.27 percent. The increase in welfare can be attributed to two factors: (a) an indirect effect, operating through the investment channel which, by increasing the flow of output, generates a higher flow of consumption, and (b) a direct effect, since the increase in the stock of the public good lowers congestion and leads to an increase in the proportion of utility services derived from its stock.

[13] Both g and τ_y represent fractions of aggregate output and are set at 10 percent each. However, the consumption tax rate, τ_c, is set at 0 to make it comparable to much of the existing growth literature, where it mainly works as a non-distortionary lump-sum tax. Since in our model τ_c is distortionary, the effects of its variation from zero will provide a useful insight into its role in equilibrium resource allocation.

[14] Note that the changes in the growth rate and welfare are expressed as percentages. Long-run welfare is measured by numerically evaluating the integral $W = \int_0^\infty \frac{(C(t)K_g(t)^\theta)^\gamma}{\gamma} e^{-\beta t} dt$, when $C(t)$ and $K_g(t)$ are on their respective equilibrium paths.

II. *An increase in the income tax rate* (τ_y) : The higher tax on private income lowers the after-tax return on private capital. This leads the agent to substitute away from private investment towards consumption. As a result, the stock of private capital falls and, with a fixed g, leads to a long-run increase in z and c. Consequently, the capital-output ratio falls and the consumption-output ratio increases. The increase in z reduces the average product of the public good and, combined with the lower return from private capital, reduces the long-run growth rate. The higher income tax rate also has a positive impact on welfare, which can be attributed to two reinforcing factors: (a) the substitution towards consumption, and (b) the smaller stock of private capital, which in turn generates higher services from the public good in the utility function by reducing congestion.

III. *An increase in the consumption tax rate* (τ_c) : In the presence of congestion in utility $(0 \leq \sigma_c < 1)$ and with $\theta > 0$, the introduction of a consumption tax is distortionary in a manner opposite to an income tax. The higher consumption tax affects the marginal rate of substitution between private consumption and the services derived from the public good, by increasing the relative price of consumption. From (16b), we see that this raises the after-tax return on private capital, as the substitution from consumption towards savings increases the stock of private capital and consequently the services derived from the public good. As a result, z, c, and the consumption-output ratio decline in equilibrium. With a fixed g, the higher capital stock raises the capital-output ratio and the equilibrium growth rate. However, the higher consumption tax makes the economy worse off by reducing welfare. The welfare loss is due to (a) the fall in private consumption, and (b) the higher stock of private capital, which worsens the distortions created by congestion in the utility function by reducing the utility services derived from the stock of the public good.

In the absence of congestion in utility $(\sigma_c = 1)$, the consumption tax is non-distortionary and operates in a manner similar to a lump-sum tax. It must also be noted that the effects of a consumption tax increase are quite small, compared to those of an income tax. This happens because the consumption tax is tied to the flow of consumption, which in turn is a fraction of output. Therefore, the magnitude of, say, a 10 percent tax on consumption is much smaller to an equivalent tax on income, as a proportion of aggregate output. Further, from (16b), we see that the increase in the rate of return on private capital caused by a higher consumption tax is proportional to the term $\theta(1 - \sigma_c)c$, which is also quite small in magnitude.

IV. *An increase in the income tax rate combined with a consumption subsidy* $(d\tau_y > 0, d\tau_c < 0)$: Since in the presence of congestion in the utility function, a consumption tax increase makes the economy worse off, it would be easy to show that a consumption subsidy would have a positive welfare impact on the economy, by drawing resources away from capital into consumption, which in turn would help alleviate the distortions from congestion. In this sense, a consumption subsidy might reinforce the effect of an income tax increase, and it would be instructive to compare the effects of such a policy "mix" with the effects of raising the income tax alone. Such a combination does indeed have a larger impact on the economy's resource allocation relative to an increase in the income tax alone, including the positive impact on long-run welfare. This happens because the income tax and the consumption subsidy target the two sources of congestion more efficiently than a single fiscal instrument. The income tax, by reducing the stock of capital, reduces congestion in the production function, while the consumption subsidy, by lowering the relative price of consumption, draws more resources away from private capital, increasing the services derived from the public good in the utility function. Moreover, a tax-subsidy policy mix also enables the government to use the income tax revenues to finance the consumption subsidy. A policy implication that emerges from this discussion is that when the government is faced with congestion associated with the public good in the utility function, a mix of income tax and consumption subsidy might be more effective at reducing distortions than using an income tax (or a consumption subsidy) alone.

V. *Replacing the income tax rate with a consumption tax:* The cut in the income tax rate (to zero) and the introduction of a positive consumption tax raises the after-tax return on private capital, both by reducing the after-tax marginal product of private capital and by raising the relative price of private consumption. This leads to a large increase in private investment and, consequently, the stock of private capital. As a result, both z and c decline, while the capital-output ratio rises. The substitution away from consumption (due to the positive consumption tax) and the private investment boom (due to the removal of the income tax) leads to a decline in the consumption-output ratio and an increase in the long-run growth rate. However, such a policy is socially undesirable, as the increase in private capital worsens the distortions associated with the congestion externalities. In fact, the long-run welfare loss of -1.07 percent is the worst among all the policy shocks considered in this section.

5.2.2 Transitional Dynamics

Figures 1 and 2 illustrate the dynamic response of the decentralized economy to fiscal policy shocks (i)-(iii). In each figure, we have set $s = 1$ (Cobb-Douglas), with $\sigma_y = \sigma_c = 0.5$. Since we have already outlined the basic intuition behind the long-run effects of policy changes, our discussion here can be brief.

Figure 1 depicts the transitional response of the economy to an increase in the rate of public expenditure, g. The higher flow of public spending leads to an accumulation of the public good relative to private capital, thereby raising z over time to its higher steady-state level. The implied increase in the long-run productivity of private capital and consequently the lower marginal utility of consumption leads to a substitution away from consumption on impact of the shock. As a result, both the consumption-capital ratio and the consumption-output ratio fall instantaneously. The growth rate of the public good jumps up on impact, over-shooting its higher long-run equilibrium. Thereafter, as the public good is accumulated, its average product, y/z, declines and its growth rate slows down until it reaches the new steady-state equilibrium. The growth rate of private capital falls instantaneously due to crowding out following the increase in g. However, the increase in z over time raises the average productivity of private capital, thereby increasing its growth rate in transition to a new and higher equilibrium. The growth rate of consumption also declines on impact, but increases thereafter as private capital and the public good are accumulated and the flow of output is increased. However, the transitional growth rate of consumption exceeds that of private capital since the higher stock of the public good increases the flow of utility services to the private agent, in the proportion $\gamma\theta g(y/z)$; see (19b). The consumption-capital ratio therefore rises in transition, although it converges to a lower equilibrium value in the new steady state. Further, the rate of growth of output exceeds that of consumption and private capital, leading to continuous declines of the consumption-output and capital-output ratios to their lower after-shock equilibrium levels.

Figure 2 compares the dynamic responses generated by an income tax increase (panel A) and a consumption tax increase (panel B). It is immediately evident that the two responses are mirror images of each other, implying that in the presence of congestion, the two tax rates have opposite impacts on the adjustment of equilibrium variables. An increase in τ_y leads to a substitution away from private capital by reducing its after-tax rate of return. With a fixed g, this implies that z increases over time as the stock of private capital falls relative to the public good. On the other hand, a higher τ_c, by increasing the return on private capital relative to consumption, leads to an increase in private capital accumulation, thereby reducing z in transition. The higher income tax will cause an immediate substitution in favor of private consumption, leading to an instantaneous upward jump in c. Exactly the opposite happens for the consumption tax increase, as the agent substitutes away from consumption towards private investment. Consequently, the consumption-output ratio jumps up for an income tax increase, but jumps down for a consumption tax increase. The dynamic responses of the growth rates of private and the public good, as well as consumption, also are in sharp contrast to each other for the two tax shocks. For an income tax increase, the growth rates of private capital and consumption jump down on impact. The downward jump of the consumption growth rate reflects the permanent reduction in the after-tax return on private capital. The growth rate of the public good does not respond instantaneously, since g is fixed and the average product of the public good is tied down by the initial stocks of private capital and the public good. However, the increase in z in transition lowers the average product of the public good as well as its growth rate in transition. The lower stock of private capital increases its average product, which increases its growth rate after the initial downward jump. The lower stock of private capital helps reduce congestion and increases the return on consumption by enhancing the utility services derived from the public good. As a result, consumption grows faster than capital in transition, leading to an increase in c to its higher long-run equilibrium. As is evident from panel B of Figure 2, the corresponding responses for a consumption tax increase are exactly the opposite, both qualitatively and intuitively.

5.3 Welfare Analysis

Tables 4A and 4B report the impact of fiscal policy shocks (considered in Table 3) on long-run welfare and their sensitivity to the critical structural parameters of the model, namely θ, s, σ_y and σ_c. Table 4A examines the welfare responses of the five policy shocks to variations in the elasticity of substitution in production, s, and the relative weight of the public good in utility, θ. Table 4B reports analogous results for variations in the congestion parameters, σ_y and σ_c.

The welfare changes reported in Table 4A are based on a range of s between 0.25 and infinity, and a range of θ between 0 and 0.3. We control for congestion by setting $\sigma_y = \sigma_c = 0.5$, as in Table 3. Both s and θ have a crucial impact not only on the welfare effects of fiscal policy shocks, but also on their relative rankings.

I. *An increase in public investment:* The relative importance of the public good in utility (θ) plays a crucial role in the welfare impact of an increase in public expenditure. For example, when $s = 1$ (Cobb-Douglas case) and $\theta = 0$, an increase in public spending leads to a welfare *loss* of 6.14 percent. However, when $\theta = 0.3$, the same increase in public investment leads to a welfare *gain* of 2.27 percent. Therefore, if the relative importance of the public good in utility is not taken into account, the fiscal authority might grossly underestimate the impact of public expenditures on welfare. The intuition behind this result can be explained as follows. When $\theta = 0$, the underlying public good only yields direct productivity benefits (as in the literature). Higher spending leads to a large stock of the public good in the long run, which not only crowds out private investment and consumption, but is also subject to diminishing returns. Consequently, this leads to a long-run loss in welfare. But when $\theta = 0.3$, the increase in public spending has an additional impact on welfare by (i) increasing the utility return from consumption, and (ii) raising the return to private capital by affecting the marginal rate of substitution between private consumption and capital, through the term $\theta(1 - \sigma_c)c$; see (16b). Indeed, in this case it more than offsets the effect of diminishing returns in production.

In general, for any given θ, an increase in s lowers the welfare impact of an increase in public spending. This happens because the larger is s, the higher is the return from private investment relative to a given level of public investment. Therefore, as s increases, higher public spending causes the agent to allocate more resources to private investment by substituting away from consumption, which has an adverse effect on welfare. However, as θ increases, the negative effects of a larger s are partially alleviated and, in some cases, more than offset as the higher public expenditure impacts welfare and private consumption as well.

II. *An increase in the income tax rate*: An increase in the income tax rate lowers the return to private capital and leads to a reallocation towards consumption. However, its impact on welfare depends on its interaction with s and θ and the congestion externalities. For any given θ, an increase in s lowers the positive impact on an income tax increase in the presence of congestion.

For example, when $\theta = 0.1$ and $s = 1$, an income tax increase leads to a small welfare gain of 0.21 percent. However, when $s = 1.25$, the same tax increase leads to a welfare loss of 0.42 percent. From Table 4A we note that for low values of s (for $s \leq 1$), an income tax increase has a positive impact on welfare, implying a reduction in congestion. But when $s > 1$, the impact of the tax shock on welfare is negative, implying a worsening of congestion. This happens because an increase in s, by increasing the relative return on private capital, lowers the impact of the tax on its return and causes a smaller substitution towards consumption, which worsens congestion and ultimately, welfare. On the other hand, an increase in θ increases the welfare gains from the tax increase for $s \leq 1$, and lowers the losses for $s > 1$. In other words, $\theta > 0$ enhances the effectiveness of an income tax in the presence of congestion, because the smaller long-run stock of private capital (following the tax increase) enables a larger flow of services from the public good in the utility function by reducing congestion.

III. *An increase in the consumption tax rate*: When $\theta = 0$, the consumption tax is non-distortionary and has no impact on long-run welfare or on resource allocation. However, when $\theta > 0$ (along with $0 < \sigma_c < 1$), a consumption tax does lead to changes in welfare levels. However, these changes are sensitive to s and in general are opposite to those of an income tax shock. The introduction of a consumption tax is generally welfare reducing, since it increases the return to capital relative to consumption, thereby worsening congestion. However, for large values of s, a consumption tax can actually improve welfare. For example, when $\theta = 0.3$ and $s = 1$, the introduction of a consumption tax reduces long-run welfare by 0.08 percent. However, as $s \rightarrow \infty$, the consumption tax increases welfare by 0.1 percent. The intuition behind this result can be understood by focusing on the impact of s on the allocation between private consumption and capital. When s is small, a given increase in τ_c leads to a large substitution in favor of capital in order to maintain the no-arbitrage condition in (16b). This worsens welfare by increasing congestion. On the other hand, as s increases, the required substitution towards private capital declines, which lowers the welfare losses.

IV. *An increase in the income tax rate combined with a consumption subsidy*: The mix of an income tax increase with a consumption subsidy reinforces the effects of raising the income tax alone, since the subsidy also lowers the return on private capital relative to consumption. Therefore, when $\theta > 0$ and for $s \leq 1$, this policy mix yields higher welfare gains than the use of an income tax alone. Consequently, for $s > 1$, the welfare losses from this mix are also larger than those from an income tax. As in the case of an income tax increase, the welfare impact of this policy mix is enhanced as θ increases.

V. *Replacing the income tax rate with a consumption tax:* For a finite value of s, replacing the income tax with a consumption tax is welfare-deteriorating, irrespective of the magnitude of θ. This happens because reducing the income tax raises the after-tax return to private capital and, in the presence of congestion, that has an adverse effect on welfare. Further, when $\theta > 0$ and $\sigma_c \neq 1$, the consumption tax reinforces the increase in the after-tax return on capital, thereby increasing the magnitude of the welfare losses. However, as $s \to \infty$, the negative effect on welfare is reversed, as the large return to private capital (due to perfect substitutability in production) permits the agent to reduce its stock of capital and thereby reduce the effects of congestion in equilibrium as well.

Ranking Tax Policies: The array of welfare gains and losses in Table 4A permits a convenient means of ranking the underlying fiscal policy shocks in terms of their impact on economic welfare. For the purposes of comparison, we focus on the four taxation policies described above (II-V). The following patterns emerge from Table 4A:

(i) When $\theta = 0$ and $s \leq 1$, increasing the income tax is the most preferred policy. However, for $s > 1$, replacing the income tax with a consumption tax is the preferred alternative, since τ_c is non-distortionary in this case.

(ii) When $\theta > 0$, an increase in the income tax rate alone is undesirable, irrespective of the magnitude of s. For $s \leq 1$, a mix of an income tax increase and a consumption subsidy is the most preferred policy choice. For $s > 1$, the introduction of a consumption tax (with the income tax remaining constant) dominates other tax policies. However, in the limit, as $s \to \infty$, replacing the income tax with the consumption tax emerges as the dominant alternative.

The above rankings provide some useful policy implications for economies experiencing congestion in both production and utility services. For instance, once the dual nature of the public good is recognized (i.e., $\theta > 0$), using the income tax as a sole corrective instrument in the presence of congestion is not desirable. It is the elasticity of substitution in production between the public good and private capital that determines the efficacy of an underlying tax policy. Economies that have limited substitutability in production might be better off with a mix of an income tax and a consumption subsidy. Economies with more flexible production structures might be better off by introducing a consumption tax while keeping income taxes unchanged. Finally, when there is perfect substitutability in production, the most preferred policy is to replace the income tax with a consumption tax.

The robustness of the above rankings to variations in the magnitude of the congestion externalities σ_y and σ_c are reported in Table 4B. Controlling for s and θ (by setting $s = 1$ and $\theta = 0.3$) yields the following observations:

(i) As long as congestion is present in both utility and production functions, i.e., $\sigma_c \neq 1$ and $\sigma_y \neq 1$, an income tax and consumption subsidy mix is the most preferred policy.

(ii) When $\sigma_c = 1$ and $\sigma_y \neq 1$, i.e., there is congestion only in the production function, an income tax is the preferred policy for high levels of congestion (eg. $\sigma_y = 0$) in production. However, as the congestion externality diminishes ($\sigma_y \to 1$), replacing the income tax with a consumption tax (which is non-distortionary, since $\sigma_c = 1$) emerges as the preferred alternative, a result consistent with the literature.

(iii) Finally, when there is no congestion in either utility or production, i.e., $\sigma_y = \sigma_c = 1$, replacing the income tax with a non-distortionary consumption tax is the best policy outcome.

6 Conclusions

This paper analyzes the impact of fiscal policy in a growing economy, where the accumulated stock of a composite public good generates dual services for the private sector, by being simultaneously welfare- *and* productivity-enhancing. We motivate this idea by discussing examples of common public goods such as infrastructure, education, health, law and order, etc. that can generate both productivity and utility benefits for a private consumer. Modeling for the differential effects of congestion in the utility and productive services derived from such public goods, we show that a consumption tax can be distortionary, with a transmission mechanism that is qualitatively opposite to that of an income tax. However, the impact of these taxes on welfare depends crucially on the elasticity of substitution in production and the relative importance of the public good in the utility function. We show that in economies with limited substitutability in production, a combination of an income tax and a consumption subsidy yields higher welfare gains than the use of an income or a consumption tax alone. However, as the elasticity of substitution increases, the efficacy of the consumption tax relative to other fiscal instruments increases. In fact, in the limit, when there is perfect substitutability in production, replacing the income tax with a consumption tax is the preferred policy. We also show that if the dual nature of public goods is not taken into account, the fiscal authority might incorrectly estimate the impact of public policies on welfare. Our discussion of optimal fiscal policy refines and generalizes the existing results in the literature by demonstrating the possibilities of using both income and consumption-based tax or subsidy policies as corrective instruments for congestion. The optimal fiscal policy rules we derive indicate greater flexibility in the choice of corrective policy instruments relative to the sole reliance on the income tax that is prevalent in the literature. The above findings indicate that the role played by a public good and the different externalities it generates for different agents in the economy are potentially important in evaluating the role of the government in a growing economy. Our results contribute to the fiscal policy-growth literature by highlighting a new channel through which consumption taxes or subsidies might impact an economy's equilibrium and welfare, even in the absence of an endogenous labor-leisure choice.

Given the recent policy shift in many developing countries towards market provision of many public goods such as power generation, water and sewerage, irrigation, highway construction, communications, etc., one fruitful extension of this framework might be to analyze the role of consumption and income taxes when a public good is privately provided. In that case, the consumption tax rate might be an important determinant of the market price of the public good, by affecting the marginal rate of substitution between private consumption and the privately provided public good. Another area of interest might be to examine the implications of consumption taxation in models with an endogenous labor-leisure choice, but in the presence of utility and productivity enhancing public goods. Therefore, we hope that our results will provide the foundations for future research in the complex domain of public goods and economic growth.

TABLE 1
Benchmark Equilibrium in the Centrally Planned Economy
The Cobb-Douglas Case ($s = 1$)

	$\hat{z}$	$\hat{c}$	$\hat{g}$	C/Y	K/Y	$\hat{\psi}(\%)$
$\theta = 0$	0.25	0.202	0.0668	0.67	3.30	8.10
$\theta = 0.1$	0.333	0.212	0.0848	0.66	3.04	8.18
$\theta = 0.3$	0.495	0.227	0.1149	0.653	2.88	8.07

TABLE 2
Optimal Public Investment in the Centrally Planned Economy
($\hat{g} = G/Y$)

	$\theta = 0$	$\theta = 0.1$	$\theta = 0.3$
$s = 0.25$	0.1343	0.1404	0.1511
$s = 1$	0.0668	0.0848	0.1149
$s \rightarrow \infty$	0.0003	0.0286	0.0766

TABLE 3

Equilibrium in a Decentralized Economy with Congestion: Long-run Effects of Fiscal Policy Shocks

Structural Parameters: $s = 1$, $\theta = 0.3$, $\sigma_y = \sigma_c = 0.5$

Base(Pre-shock) Policy Parameters: $g = 0.1$, $\tau_y = 0.1$, $\tau_c = 0$

	$\tilde{z}$	$\tilde{c}$	$\tilde{C}/Y$	$\tilde{K}/Y$	$\tilde{\psi}(\%)$	$d\tilde{W}(\%)$
Benchmark Equilibrium	**0.375**	**0.209**	**0.634**	**3.04**	**8.74**	–
I. Increase in public investment: $dg = +0.1$	0.752	0.202	0.534	2.65	10.05	2.27
II. Increase in income tax rate: $d\tau_y = +\ 0.1$	0.421	0.223	0.663	2.97	7.99	0.51
III. Introduce a consumption tax: $d\tau_c = +0.1$	0.372	0.201	0.631	3.05	8.82	-0.08
IV. Income tax increase with consumption subsidy: $d\tau_y = +0.1$ and $d\tau_c = -0.1$	0.427	0.225	0.666	2.96	7.91	0.54
V. Replace income tax with consumption tax: $d\tau_y = -0.1$ and $d\tau_c = +0.1$	0.337	0.194	0.603	3.11	9.55	-1.07

TABLE 4

Welfare Sensitivity of Fiscal Policy Shocks to Structural Parameters and Congestion

A. Welfare Sensitivity to the Elasticity of Substitution (s) and the Relative Importance of Public Capital in Utility (θ)
($\sigma_y = \sigma_c = 0.5$)

	$\theta = 0$					$\theta = 0.1$					$\theta = 0.3$				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
$s = 0.25$	18.74	6.33	0	6.33	-5.90	23.09	6.51	-0.33	6.85	-6.32	31.60	6.72	-1.00	7.80	-7.07
$s = 0.75$	-1.14	1.20	0	1.20	-1.61	1.99	1.34	-0.06	1.39	-1.73	7.97	1.57	-0.18	1.74	-1.96
$s = 1$	-6.14	0.04	0	0.04	-0.77	-3.25	0.21	-0.02	0.22	-0.87	2.27	0.51	-0.08	0.54	-1.07
$s = 1.25$	-9.28	-0.61	0	-0.61	-0.35	-6.50	-0.42	-0.001	-0.45	-0.43	-1.34	-0.09	-0.03	-0.14	-0.61
$s = 1.5$	-11.39	-1.01	0	-1.01	-0.11	-8.78	-0.81	0.01	-0.85	-0.19	-3.81	-0.46	0.004	-0.56	-0.35
$s \to \infty$	-21.80	-2.43	0	-2.43	0.57	-19.99	-2.22	0.04	-2.33	0.54	-16.58	-1.84	0.10	-2.12	0.46

B. Welfare Sensitivity to Congestion Parameters (σ_y and σ_c)
($s = 1$, $\theta = 0.3$)

	$\sigma_y = 0$					$\sigma_y = 0.5$					$\sigma_y = 1$				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
$\sigma_c = 0$	2.31	1.76	-0.35	2.03	-2.64	2.52	1.08	-0.26	1.26	-1.80	2.61	0.49	-0.16	0.56	-1.03
$\sigma_c = 0.5$	2.10	1.22	-0.14	1.31	-1.93	2.27	0.51	-0.08	0.54	-1.07	2.32	-0.13	-0.01	-0.17	-0.28
$\sigma_c = 1$	1.89	0.50	0	0.50	-1.18	2.02	-0.28	0	-0.28	-0.23	2.02	-0.98	0	-0.98	0.59

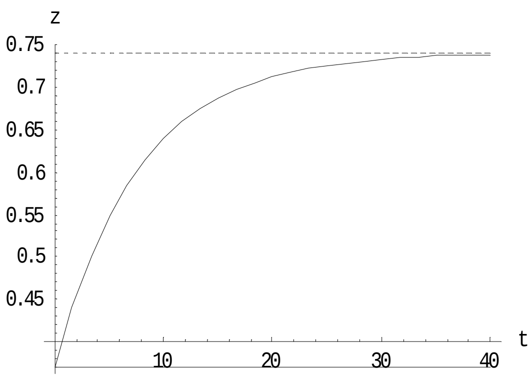
I. Increase in public investment: $dg = +0.1$
II. Increase in income tax rate: $d\tau_y = +0.1$
III. Introduce a consumption tax: $d\tau_c = +0.1$
IV. Income tax increase with consumption subsidy: $d\tau_y = +0.1$, $d\tau_c = -0.1$
V. Replace income tax with consumption tax: $d\tau_y = -0.1$, $d\tau_c = +0.1$

Note: Welfare gains are reported in percentages. The numbers in bold represent the largest (smallest) gains (losses) between the tax policies II-V.

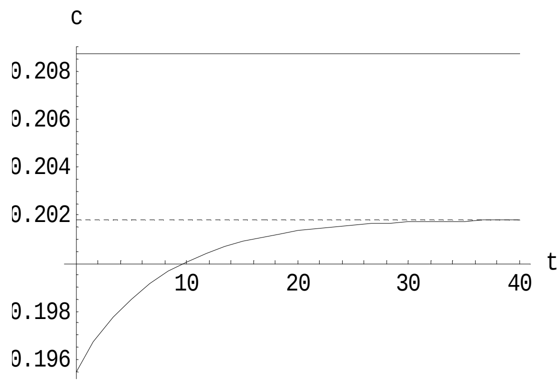
Figure 1. An Increase in Public Investment: Transitional Dynamics

$g = 0.1$ to 0.2; $\tau_y = 0.1$, $\tau_c = 0$

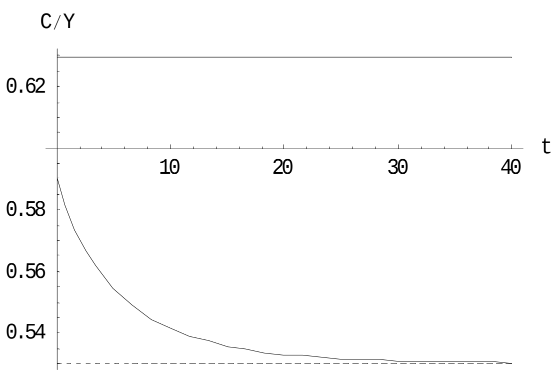
$\sigma_y = \sigma_c = 0.5$; $s = 1$



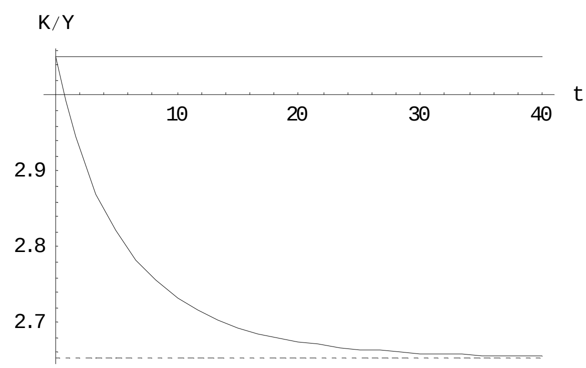
1a. Ratio of Public to Private Capital (z).



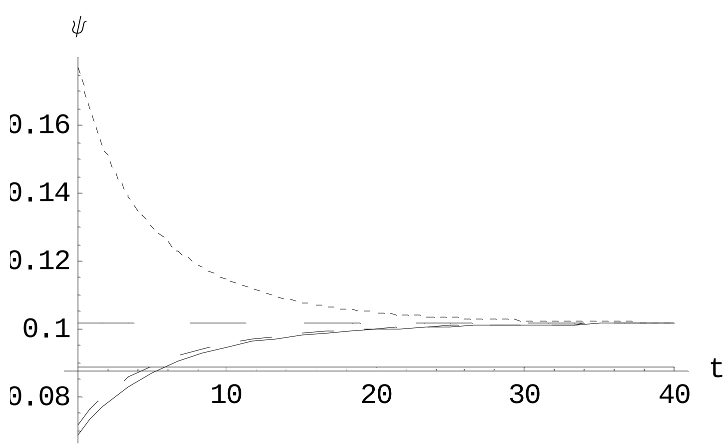
1b. Consumption-Private Capital Ratio (c)



1c. Consumption-Output Ratio (C/Y).



1d. Private Capital-Output Ratio (K/Y).



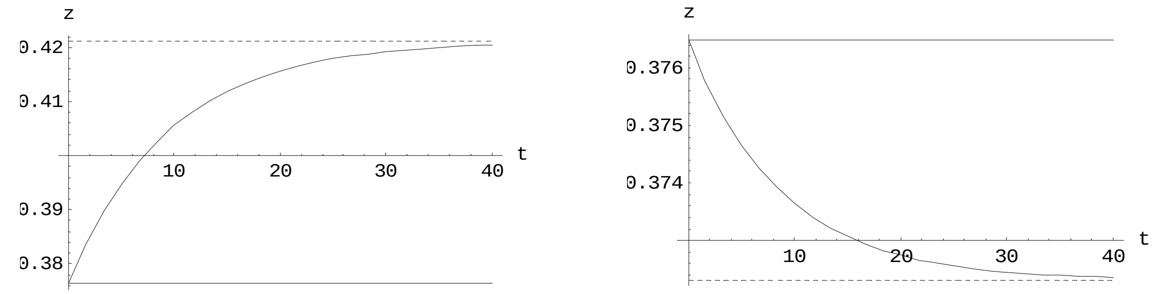
1e. Growth Paths of Private and Public Capital, and Consumption.

Figure 2. Income versus Consumption Tax: Transitional Dynamics

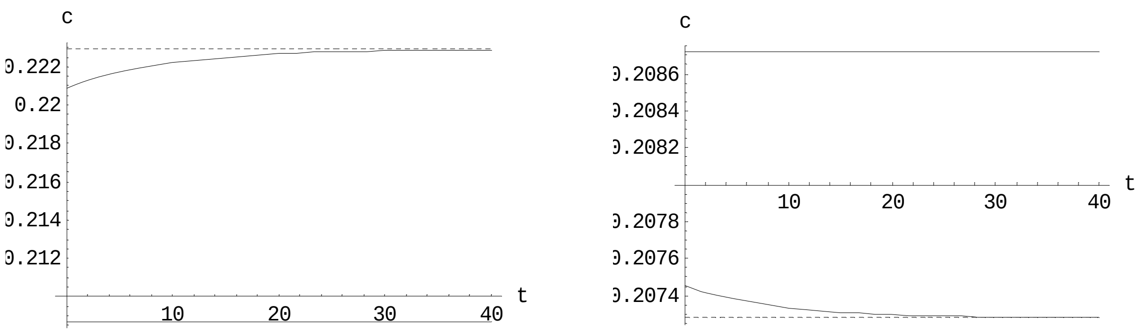
$\sigma_y = \sigma_c = 0.5;\ s = 1$

A. Income Tax Increase ($\tau_y = 0.1$ to 0.2)

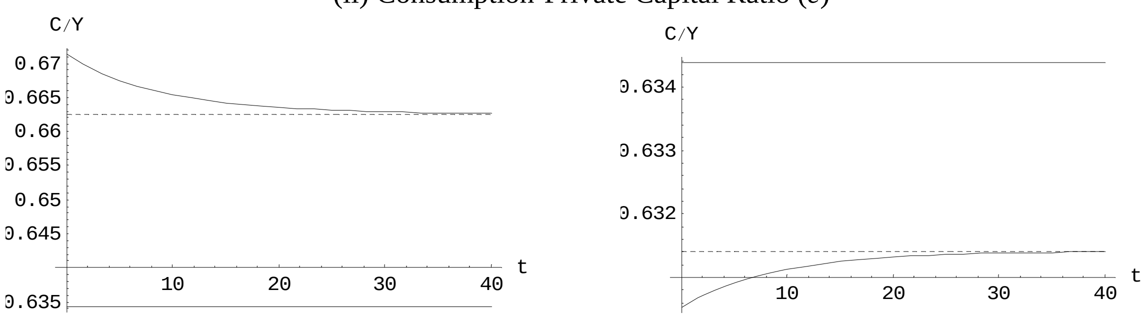
B. Consumption Tax Increase ($\tau_c = 0$ to 0.1)



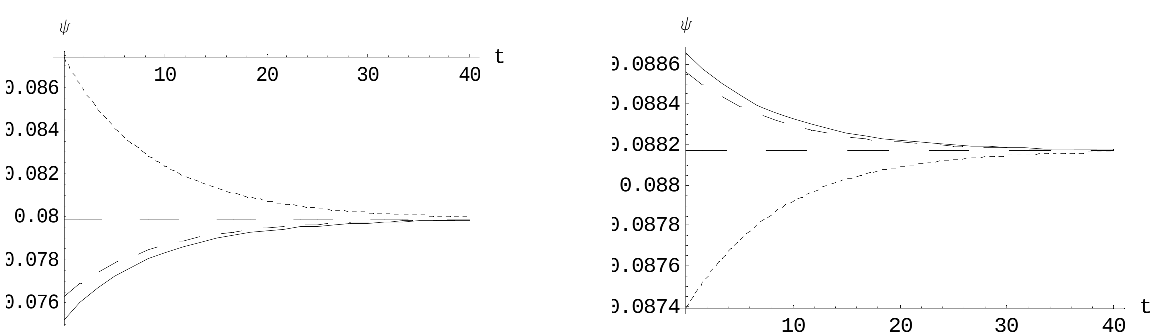
(i) Ratio of Public to Private Capital (z)



(ii) Consumption-Private Capital Ratio (c)



(iii) Consumption-Output Ratio (C/Y)



(iv) Growth Paths of Private and Public Capital, and Consumption

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