How should the government allocate its tax revenues between productivity-enhancing and utility-enhancing public goods?

by

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Abstract: We present a fairly standard general equilibrium model of endogenous growth with productive and non-productive public goods and servives. The former enhance private productivity and the latter private utility. We solve for Ramsey second-best optimal policy (where policy is summarized by the paths of the income tax rate and the allocation of the collected tax revenues between productivity-enhancing and utility-enhancing public expenditures). We show that the properties and implications of second-best optimal policy (a) differ from the benchmark case of the social planner's first-best allocation (b) depend crucially on whether public goods and services are subject to congestion.

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1. Introduction

Public expenditures on goods and services are traditionally classified as productive and non-productive. The former, known as productivity-enhancing, include expenditure on infrastructure, the law, education and training, etc. The latter, known as utility-enhancing, include expenditure on national defense, national parks, various social programs, etc. Although in practice what is productive or non-productive is unclear, this classification has been very common in the theoretical literature (see e.g. Turnovsky, 1995).[1]

A natural question to ask is what is the optimal allocation of government scarce resources (tax revenues) between the above two categories of public expenditures. This is the main goal of this paper. It studies Ramsey second-best optimal policy (where policy is summarized by the paths of the income tax rate and the allocation of the collected tax revenues between productivity-enhancing and utility-enhancing public goods) in a fairly standard general equilibrium model of endogenous growth. By Ramsey second-best optimal policy, we mean that the paths of (non-lump sum) policy instruments are chosen by a benevolent government that takes into account the competitive decentralized equilibrium, where the latter includes the optimal reaction of private agents to the policy instruments.

We show that solving for second-best optimal policy produces very different normaltive results from the benchmark case of the social planner's first-best allocation, which is usually studied in the literature. We also show that the properties and implications of second-best optimal policy depend crucially on whether productivity-enhancing public goods and services are subject to congestion.

Congestion is a form of rivalry of public goods. It means that, for a given quantity of aggregate public goods and services, the quantity available to an individual declines as other individuals use the facilities. Examples of productivity-enhancing public goods and services with congestion include highways, police and fire services, courts, public schools, etc. Actually, much of the literature on the role of public

[1] See also Glomm and Ravikumar (1994), Turnovsky and Fischer (1995), Turnovsky (1996), Fischer and Turnovsky (1998), Eicher and Turnovsky (2000), Baier and Glomm (2001), Park and Philippopoulos (2003, 2004), Chatterjee and Ghosh (2007) and many others. On the other hand, see e.g. Kneller et al. (1999) for a practical classification of government expenditures.

investment/capital in endogenous growth has assumed that such productivity-enhancing public goods and services are subject to congestion.[2]

We use a model that is a straighforward extension of the tractable growth model introduced by Barro (1990). This is a commonly used model in the related literature (see Section 5 for comparision with the literature). We distinguish between productivity-enhancing public goods and services (denoted as PE and included as an externality in private production function) and utility-enhancing public goods and services (denoted as UE and included as a direct external argument in private utility function). We study two specifications of this model. In the first, PE is subject to congestion, while UE is not. In the second, neither PE nor UE are congested. Note that although we study these two polar cases, our results hold in all cases in which all public goods and services are subject to congestion, but PE is congested to a higher degree than UE. Within this model, government expenitures on PE and UE are financed by income tax revenues. Subject to the competitive decentralized equilibrium, the government chooses its tax policy (the path of the income tax rate) and revenue allocation policy (the path of the allocation of the collected tax revenues between PE and UE).

Our results are as follows. We study the long run where the economy can grow at a constant balanced growth rate. We also find it interesting to focus on how this long-run equilibrium is affected by a preference parameter that measures how much the representative citizen values public consumption (UE) relative to private consumption. In all cases, the more the citizen values UE, the higher the required tax rate and the higher eventually the provision of UE as a share of private capital. This is as expected. What is interesting is that the provision of PE as a share of private capital should also increase. Thus, UE and PE should move in the same direction meaning that higher public consumption cannot be sustained without higher public infrastructure. All these effects are monotonic and independent of congestion.

What is more interesting is the way the government allocates its tax revenues and the resulting balanced growth rate. This crucially depends on congestion. Consider first the popular case in which PE is congested by private activity, while UE is not. In all

[2] See e.g. Barro and Sala-i-Martin (1992, 1995, p. 158), Glomm and Ravikumar (1994), Turnovsky (1995, 1996), Fischer and Turnovsky (1998), Eicher and Turnovsky (2000), Ott and Turnovsky (2005) and Chatterjee and Ghosh (2007).

numerical solutions, the effect of the preference parameter on the allocation decision and the resulting balanced growth rate is not monotonic: above a critical value of the preference parameter (which coincides with the empirically plausible region), the more the citizen values UE, the more tax revenues the government should allocate to PE vis-à-vis UE, and the higher is the balanced growth rate. This is different from the traditional recipe. Only below the critical value of the preference parameter (which however looks empirically implausible), we get the traditional recipe; namely, the more the citizen values UE, the more tax revenues the government should allocate to them vis-à-vis PE, and the lower is the balanced growth rate. When PE is not congested by private activity, results are monotonic and obey the traditional recipe.

The intuition behind the non-monotonicity result for the policy allocation decision and the balanced growth rate is as follows. The nature of second-best optimal policy arises out of the tension between two goals. First, the government wishes to tax-spend in the most efficient way. Second, the government wishes to correct for externalities; in the presence of congestion of PE, when private agents decide to accumulate capital and the economy grows, this leads to a reduction in the supply of PE relative to private capital, and hence policy is needed to internalize this externality (see also Barro and Sala-i-Martin, 1995, p. 159). Policy decisions will therefore reflect these two policy goals.

When PE is not subject to congestion problems, or when there are congestion problems but the citizen values UE (unrealistically) a lot, it is the first policy goal that dominates. Thus, as the citizen values UE more, the government finds it optimal not only to tax more but also to allocate a larger fraction of its tax revenue to UE. Not surprisingly, all this is bad for growth. But when PE is subject to congestion problems and we are in the empirically plausible parameter region, it is the second policy goal that dominates. To correct for congestion externalities and restore PE at its desired ratio, the government finds it optimal to allocate more tax revenues to PE. This turns out to be good for growth and tax bases. Larger tax bases allow the provision of more public goods and services including UE. Hence, the more the citizen values UE, the more tax revenues the government finds it optimal to allocate to PE rather than to UE. This is good for growth, tax bases and UE itself. Loosely speaking, growth-promoting policies and large tax bases are needed to afford the provision of utility-enhancing public goods and services.

The above refer to second-best optimal policy. In sharp contrast, in the social planner's solution, the planner finds it optimal to first hit a relatively high growth rate independently of preferences over various non-productive uses, and in turn to make the allocation choices among the latter. The degree of allocation among non-productive uses depends simply on how much the society values one vis-à-vis the others. For instance, if the citizens value public consumption goods and services more than private consumption, the planner increases the resources allocated to the former and decrease the resources allocated to the latter. All social planner results are monotonic. Note that, in our model economy, this first-best allocation cannot be implemented by the government of the decentralized economy (recall e.g. the classic Tinbergen target-policy problem). Thus, as is generally recognized (see e.g. Atkinson and Stiglitz, 1980, p. 14), the first-best optimum may be unattainable and can serve as a reference case only.

Therefore, the properties of optimal fiscal (tax-spending) policy depend crucially on whether: (i) We are in a static or growing economy. (ii) A first-best allocation is not attainable so that the government has to design a second-best policy problem. (iii) Public goods are impure, where impureness takes here the form of congestion or equivalently rivalry; in particular, on whether different public goods are subject to different degrees of congestion.

The rest of the paper is as follows. Section 2 presents a model with congestion, its competitive equilibrium and solves for Ramsey second-best optimal policy. Section 3 solves the associated social planner's problem. Section 4 studies what drives our results. Section 5 compares our work with the literature. Section 6 concludes.

2. A growth model with public goods and second-best optimal policy

2. 1 Informal description of the model

The model is similar to that in e.g. Barro (1990), Barro and Sala-i-Martin (1992 and 1995, chapter 4) and Turnovsky (1995, chapter 13). Consider a closed economy populated by a representative agent and a government. The representative agent consumes and saves in the form of capital. She derives utility from private consumption and UE. Output is produced by using private inputs and PE, where is latter is subject to congestion (the assumption of congested PE is relaxed in Section 4 below). The supply of labor is fixed inelastically at one. The government imposes a distorting tax on the representative agent's income to finance the increase in UE and PE.

The timing is as follows. First, the government chooses its policy. In turn, the representative agent makes her decisions. We assume a commitment technology on the part of the government so that it chooses policy once-and-for-all by solving a Ramsey-type problem. We assume continuous time, infinite horizons and perfect foresight.

In practice, public goods and services (productive and non-productive) are not a flow. They are a combination of public capital, a stock, and new expenditure on the part of government, a flow. Thus, another goal of this paper is to study how (Ramsey second-best) optimal policy depends on whether public goods and services are part stock and part flow variables. Obviously, we get the popular case, in which UE is regarded as a flow variable and PE as a stock variable, as a special case.

2.2 *The representative private agent*

The representative private agent maximizes intertemporal utility:

$$\int_0^\infty u(C,N)e^{-\rho t}dt \tag{1}$$

where C is private consumption, N is the stock of utility-enhancing public goods and services (UE) and $\rho > 0$ is the rate of time preference. The utility function $u(.)$ is increasing and concave. For simplicity, we use an additively separable function:

$$u(C,N) = \nu \log C + (1-\nu)\log N \tag{2}$$

where the parameter $0 < \nu < 1$ measures how much the agent values private consumption relative to UE.

The flow budget constraint of the private agent is:

$$C + I = (1-\tau)Y \tag{3a}$$

where I is private investment, Y is output produced and $0 \le \tau < 1$ is the income tax rate. Private investment follows:

$$\dot{K} = -\delta^k K + I \tag{3b}$$

where K is the stock of private capital and $0 \le \delta^k \le 1$ is the depreciation rate of private capital. The initial stock $K(0)$ is given. A dot over a variable denotes its time derivative.

Following e.g. Barro and Sala-i-Martin (1992, p. 650, and 1995, p. 158) and Turnovsky (1995, p. 416), output (Y) is produced according to the production function:

$$Y = A\left(\frac{K_g}{K}\right)^{\beta} K \tag{4}$$

where K_g is the stock of productive public capital, the initial stock $K_g(0)$ is given, $A > 0$ and $\beta \ge 0$. The idea in (4) is that productive public capital, K_g, acts as a positive externality subject to congestion, where the latter is measured by economy-wide private capital, K (our results do not change if we use Y for congestion) . The optimizing private agent chooses the paths of C and K by taking the paths of $\left(\frac{K_g}{K}\right)$, N and τ as given. Thus, this production function is AK at private level and increasing returns to scale at social level.[3]

The representative agent acts competitively by choosing the paths of C and K, while taking policy and aggregate variables as given. The first-order conditions include (3a)-(3b) and the Euler equation:

[3] For different, richer forms of congestion functions, see e.g. Turnovsky (1995, chapter 13), Fischer and Turnovsky (1998), Ott and Turnovsky (2005) and Chatterjee and Ghosh (2007). In these models, the productive services derived by each individual from a given amount of public goods depend upon the usage of its individual capital stock relative to aggregate usage.

$$\dot{C} = C\left[(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \rho\right] \tag{5}$$

2.3 *Public goods*

The stock of productivity-enhancing public goods and services (PE) evolves according to:

$$\dot{K}_g = -\delta^g K_g + G \tag{6a}$$

where the parameter $0 \leq \delta^g \leq 1$ is the depreciation rate of productive public capital and G is public investment. If $\delta^g = 1$, PE becomes a flow variable.

Similarly, the stock of utility-enhancing public goods and services (UE) evolves according to:

$$\dot{N} = -\delta^n N + E \tag{6b}$$

where the parameter $0 \leq \delta^n \leq 1$ is the depreciation rate of non-productive public capital and E is public consumption. If $\delta^n = 1$, UE becomes a flow variable.

2.4 *Government budget constraint*

On the revenue side, the government taxes the representative agent's output at a rate $0 \leq \tau < 1$. On the expenditure side, it spends G on productive and E on non-productive activities. Assuming a balanced budget within each period:

$$G + E = \tau Y \tag{7a}$$

where, at each instant, only two out of the three policy instruments (τ, G, E) can be set independently.

Equivalently, it is convenient for what follows to rewrite (7a) as:

$$G = b\tau Y \tag{7b}$$

$$E = (1-b)\tau Y \tag{7c}$$

where $0 \leq b \leq 1$ is the fraction of tax revenue used to finance PE and $0 \leq 1-b \leq 1$ is the fraction that finances UE. Thus, at each instant, policy can be summarized by τ and b.

2.5 Decentralized competitive equilibrium

In a Decentralized Competitive Equilibrium (DCE), (i) the representative agent maximizes utility (ii) all constraints are satisfied (iii) all markets clear. This holds for any feasible policy, where the latter is summarized by the paths of the two independent policy instruments, $0 \leq \tau < 1$ and $0 \leq b \leq 1$.

Combining (1)-(7), it is straightforward to show that a DCE is given by:

$$\frac{\dot{C}}{C} = (1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \rho \tag{8a}$$

$$\frac{\dot{K}}{K} = (1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \frac{C}{K} \tag{8b}$$

$$\frac{\dot{N}}{N} = -\delta^n + (1-b)\tau A\left(\frac{K_g}{K}\right)^{\beta} \frac{K}{N} \tag{8c}$$

$$\frac{\dot{K}_g}{K_g} = -\delta^g + b\tau A\left(\frac{K_g}{K}\right)^{\beta} \frac{K}{K_g} \tag{8d}$$

which is a four-equation system in the paths of C, K, K_g, N. This is given the paths of τ and b.

2.6 Second-best optimal policy

We now endogenize policy as summarized by the paths of the income tax rate, $0 \leq \tau < 1$, and the allocation of tax revenues between the two types of public goods, $0 \leq b \leq 1$. The government chooses the paths of τ and b to maximize the representative agent's utility

(1) subject to the DCE in (8a)-(8d). In doing so, the government will try to control for externalities and raise funds optimally to finance its activities. The current-value Hamiltonian, H, of this second-best problem is:

$$
\begin{aligned}
H = {} & \nu \log C + (1-\nu)\log N + \lambda_c C\left[(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \rho\right] + \lambda_k\left[(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} K - \delta^k K - C\right] + \\
& + \lambda_n\left[-\delta^n N + (1-b)\tau A\left(\frac{K_g}{K}\right)^{\beta} K\right] + \lambda_g\left[-\delta^g K_g + b\tau A\left(\frac{K_g}{K}\right)^{\beta} K\right]
\end{aligned}
\tag{9}
$$

where λ_c, λ_k, λ_n and λ_g are dynamic multipliers associated with (8a), (8b), (8c) and (8d) respectively.

The first-order conditions include the constraints (8a)-(8d) and the optimality conditions with respect to τ, b, C, K, N and K_g:[4]

$$\lambda_c C + \lambda_k K = \lambda_n K \tag{10a}$$

$$\lambda_n = \lambda_g \tag{10b}$$

$$\dot{\lambda}_c = -\frac{\nu}{C} - \lambda_c\left[(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \rho\right] + \lambda_k + \rho\lambda_c \tag{10c}$$

$$
\begin{aligned}
\dot{\lambda}_k = {} & \beta(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} K^{-1}\lambda_c C - (1-\beta)(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta}\lambda_k + \delta^k\lambda_k - (1-\beta)(1-b)\tau A\left(\frac{K_g}{K}\right)^{\beta}\lambda_n + \\
& - (1-\beta)b\tau A\left(\frac{K_g}{K}\right)^{\beta}\lambda_g + \rho\lambda_k
\end{aligned}
\tag{10d}
$$

$$\dot{\lambda}_n = -\frac{(1-\nu)}{N} + \delta^n\lambda_n + \rho\lambda_n \tag{10e}$$

[4] The transversality condition that guarantees utility is bounded is also satisfied. With a log-linear utility function, this only requires $\rho > 0$ (details are available upon request).

$$\dot{\lambda}_g = -\beta(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} K_g^{-1}\lambda_c C - \beta(1-\tau)A\left(\frac{K_g}{K}\right)^{\beta-1}\lambda_k - \beta(1-b)\tau A\left(\frac{K_g}{K}\right)^{\beta-1}\lambda_n + \delta^g\lambda_g + \\ -\beta b\tau A\left(\frac{K_g}{K}\right)^{\beta-1}\lambda_g + \rho\lambda_g \tag{10f}$$

Thus, (10a)-(10f), jointly with the constraints (8a)-(8d), constitute a ten-equation system in the paths of $\tau, b, C, K, N, K_g, \lambda_c, \lambda_k, \lambda_n, \lambda_g$. This is a general equilibrium with second-best optimal policy.

2.7 Stationary second-best general equilibrium

Since the model allows for long-term growth, we need to transform the variables to make them stationary. We define $c \equiv \frac{C}{K}$, $n \equiv \frac{N}{K}$, $k_g \equiv \frac{K_g}{K}$, $\Lambda_c \equiv \lambda_c C$, $\Lambda_k \equiv \lambda_k K$, $\Lambda_n \equiv \lambda_n N$ and $\Lambda_g \equiv \lambda_g K_g$. Thus, c, n and k_g are the ratios of consumption to-, non productive public capital to- and productive public capital-to-private capital respectively, whereas Λ_c, Λ_k, Λ_n and Λ_g measure respectively the social value of consumption, private capital, non-productive public capital and productive public capital. It is straightforward to show that the dynamics of (8a)-(8d) and (10a)-(10f) are equivalent to the dynamics of (11a)-(11i) below:

$$\dot{c} = c^2 - \rho c \tag{11a}$$

$$\dot{n} = -\delta^n n + (1-b)\tau A k_g^{\beta} - (1-\tau)A k_g^{\beta} n + cn + \delta^k n \tag{11b}$$

$$\dot{k}_g = -\delta^g k_g + b\tau A k_g^{\beta} - (1-\tau)A k_g^{1+\beta} + c k_g + \delta^k k_g \tag{11c}$$

$$\dot{\Lambda}_c = -\nu + \rho\Lambda_c + \Lambda_k c \tag{11d}$$

$$\dot{\Lambda}_k = \beta(1-\tau)A k_g^{\beta}\Lambda_c + \beta(1-\tau)A k_g^{\beta}\Lambda_k - (1-\beta)(1-b)\tau A k_g^{\beta}\frac{\Lambda_n}{n} - (1-\beta)b\tau A k_g^{\beta-1}\Lambda_g + (\rho - c)\Lambda_k \tag{11e}$$

$$\dot{\Lambda}_n = -(1-\nu) + \rho\Lambda_n + (1-b)\tau A k_g^{\beta}\frac{\Lambda_n}{n} \tag{11f}$$

$$\dot{\Lambda}_g = -\beta(1-\tau)Ak_g^{\beta}\Lambda_c - \beta(1-\tau)Ak_g^{\beta}\Lambda_k - \beta(1-b)\tau Ak_g^{\beta}\frac{\Lambda_n}{n} + (1-\beta)b\tau Ak_g^{\beta-1}\Lambda_g + \rho\Lambda_g \tag{11g}$$

$$\Lambda_c + \Lambda_k = \frac{\Lambda_n}{n} \tag{11h}$$

$$\Lambda_n k_g = \Lambda_g n \tag{11i}$$

where (11a)-(11i) constitute a nine-equation system in the paths of τ, b, c, n, k_g, Λ_c, Λ_k, Λ_n, Λ_g. This is a stationary general equilibrium with second-best optimal policy. We next study the long run of this economy.[5]

2.8 Long-run second-best general equilibrium

In the long run, $\frac{\dot{\tau}}{\tau} = \frac{\dot{b}}{b} = \frac{\dot{c}}{c} = \frac{\dot{n}}{n} = \frac{\dot{k}_k}{k_g} = \frac{\dot{\Lambda}_c}{\Lambda_c} = \frac{\dot{\Lambda}_k}{\Lambda_k} = \frac{\dot{\Lambda}_n}{\Lambda_n} = \frac{\dot{\Lambda}_g}{\Lambda_g} \equiv 0$ in (11a)-(11i). Let denote the resulting long-run values of $\tau, b, c, n, k_g, \Lambda_c, \Lambda_k, \Lambda_n, \Lambda_g$ as $\tilde{\tau}, \tilde{b}, \tilde{c}, \tilde{n}, \tilde{k}_g, \tilde{\Lambda}_c, \tilde{\Lambda}_k, \tilde{\Lambda}_n, \tilde{\Lambda}_g$. In this long run, all components of national income grow at the same non-negative balanced growth rate, denoted as $\tilde{\gamma}$, and policy instruments do not change. We thus have in the long run (see Appendix A for details):

$$\tilde{c} = \rho \tag{12a}$$

$$\tilde{n} = \frac{(1-\tilde{b})\tilde{\tau}A\tilde{k}_g^{\beta}}{(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k - \rho} \tag{12b}$$

$$\tilde{k}_g = \frac{\tilde{b}\,\tilde{\tau}A\tilde{k}_g^{\beta}}{(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^g - \delta^k - \rho} \tag{12c}$$

$$\tilde{\Lambda}_c = \tilde{\Lambda}_k = \frac{\nu}{2\rho} \tag{12d}$$

$$\tilde{\Lambda}_n = \frac{1-\nu}{(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k} \tag{12e}$$

[5] In this paper, we focus on the long run ignoring transitional dynamics.

$$\tilde{\Lambda}_g = \frac{(1-\nu)[(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k - \rho]}{\rho[(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k]} \tag{12f}$$

$$\nu(1-\tilde{b})\tilde{\tau}[(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k]A\tilde{k}_g^{\beta} = \rho(1-\nu)[(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k - \rho] \tag{12g}$$

$$\rho\tilde{k}_g = (1-\tilde{b})\tilde{\tau}A\tilde{k}_g^{\beta} \tag{12h}$$

We solve the non-linear long-run system (12a)-(12h) numerically. We start by using the following baseline parameter values: $\beta = 0.30$ (where $\beta \geq 0$ is the productivity of public capital in the production function), $A = 1$ (where $A > 0$ is total factor productivity in the production function), $\delta^k = \delta^n = \delta^g = 0.06$ (where $\delta^k, \delta^n, \delta^g > 0$ are the depreciation rates of private capital, non-productive public capital and productive public capital respectively), $\rho = 0.04$ (where $\rho > 0$ is the rate of time preference). Qualitative results will be robust to the parameter values chosen, except otherwise stated.

Table 1a reports the long-run solution for varying values of the parameter ν in a wide range, $0.1 \leq \nu \leq 0.9$. We focus on ν because this is an interesting parameter in our setup; it measures how much the representative citizen values her own private consumption vis-à-vis public consumption, UE (see equation (2) above). We also report the resulting equilibrium values of the balanced growth rate, $\tilde{\gamma}$, as well as the government resources earmarked for PE and UE as shares of output, $\tilde{G}/\tilde{Y}$ and $\tilde{E}/\tilde{Y}$.

Table 1a here

Inspection of the results in Table 1a implies the following: (a) The solution is well defined.[6] For instance, $0 < \tilde{\tau} < 1$, $0 < \tilde{b} \leq 1$, $\tilde{c} > 0$, $\tilde{n} > 0$, $\tilde{k}_g > 0$, $\tilde{\Lambda}_c > 0$, $\tilde{\Lambda}_k > 0$, $\tilde{\Lambda}_n > 0$, $\tilde{\Lambda}_g > 0$. Also the balanced growth rate - along which all national income

[6] Throughout the paper, except otherwise stated: (i) For the parameter values used, there is only one well-defined solution, whose properties we discuss. For instance, solutions that imply a shrinking economy in the long run (i.e. negative balanced growth rate) are not meaningful and hence are not reported. (ii) The growth rates below are too high. This is not important and is due to the chosen value of aggregate productivity (A).

quantities grow at the same constant rate - is positive, $\tilde{\gamma} > 0$. (b) As ν falls (i.e. as we care more about UE relative to private consumption), it is optimal to tax more ($\tilde{\tau}$ rises monotonically). (c) The relationship between ν and the fraction of tax revenue allocated to PE relative to UE ($\tilde{b}$) is not monotonic. Specifically, in the region $0.7 \leq \nu < 0.9$, as ν falls, $\tilde{b}$ rises; in the region $0.1 < \nu < 0.7$, as ν falls, $\tilde{b}$ falls. (d) The balanced growth rate, $\tilde{\gamma}$, behaves like $\tilde{b}$, i.e. its behavior is non-monotonic. (e) Both $\tilde{E}/\tilde{Y}$ and $\tilde{G}/\tilde{Y}$, and their associated stocks $\tilde{n}$ and $\tilde{k}_g$, all increase monotonically as ν falls.

In other words, there is a critical value of ν, denoted as ν^*, above which the more the citizen values UE, the more tax revenues the government should allocate to PE relative to UE (i.e. for $\nu \geq \nu^*$, $\frac{\partial \tilde{b}}{\partial \nu} < 0$). This policy allocation effect more than offsets the adverse effect from higher tax rates ($\frac{\partial \tilde{\tau}}{\partial \nu} < 0$), so that the balanced growth rate rises in this region (i.e. for $\nu \geq \nu^*$, $\frac{\partial \tilde{\gamma}}{\partial \nu} < 0$). By contrast, in the region $0 < \nu < \nu^*$, we have $\frac{\partial \tilde{b}}{\partial \nu} > 0$. That is, in this region, we get the conventional policy recipe: the more the citizen values UE, the more tax revenues the government should allocate to them relative to PE. Now the allocation effect works in the same direction with the adverse effect from higher tax rates ($\frac{\partial \tilde{\tau}}{\partial \nu} < 0$), so that the balanced growth rate falls (i.e. for $0 < \nu < \nu^*$, $\frac{\partial \tilde{\gamma}}{\partial \nu} > 0$).

Notice that in most related applied studies, $0 \leq (1-\nu) \leq 0.3$ (see e.g. Malley et al., 2007, pp. 1067-8, who also provide references). Thus, the conventional policy recipe can hold for values of ν that are too low relative to those commonly used in the literature. This means that if we focus on the commonly used parameter region, it is the striking new policy recipe that holds rather than the conventional one. It should be also reported that the conventional recipe holds for relatively low values of β, and in particular $0 \leq \beta \leq 0.2$, where recall that β is the productivity of public capital in the private production function. This makes sense since the role of public capital must be high enough to affect the policy choices.

Let us discuss these results. The more the citizen values public consumption, the more resources are eventually allocated to them (i.e. as ν falls, both $\tilde{E}/\tilde{Y}$ and $\tilde{n}$ rise). This is natural to happen. But, at the same time and in the whole range of parameter values, the stronger the preference over public consumption, the higher should also be the public investment-to-output ratio and the public capital-to-private capital ratio (i.e. as ν falls, $\tilde{G}/\tilde{Y}$ and $\tilde{k}_g$ rise monotonically). This implies that higher provision of public consumption should go along with higher provision of public infrastructure, and this is achieved by the right tax and spending policy decisions on the part of the Ramsey government. Note that the property that $\tilde{G}/\tilde{Y}$ should increase as ν falls is due to the effort of the government to correct for externalities by keeping $\tilde{k}_g$ at its desired ratio (as we shall see below, $\tilde{G}/\tilde{Y}$ is independent of ν in the absence of congestion problems and thus externalities to be internalized by the government).

What is more striking is the optimal allocation policy decision and the resulting balanced growth rate. In the empirically plausible region, the more the citizen values UE, the more tax revenues the government should allocate to PE vis-à-vis UE, and the higher is the balanced growth rate. Only below the critical value of the preference parameter (which however looks empirically implausible), we get the traditional recipe, namely, the more the citizen values UE, the more tax revenues the government should allocate to them vis-à-vis PE, and the lower is the balanced growth rate. As we show below, the non-monotonicity result for b and the striking policy recipe in the empirically plausible region depend on the presence of congestion and so their interpretation is delayed for below.

Although the exact role of congestion is made clear below, here we can discuss a general policy lesson emerging from our results. In a growing economy, the government realizes that it needs large tax bases to finance the provision of public consumption goods and services. It thus makes its allocation decision (b) so as to boost economic growth and enlarge the tax base. Having achieved this, it can afford to raise the tax rates to finance non-productive public spending. In other words, non-growing societies cannot afford the provision of public consumption goods and services. Actually, our results show that the more "socialist" a society is, in the sense that it values public consumption goods and services, the more growth-promoting policies it should choose, here in the form of giving priority to public investment. Only when there are "unrealistically" strong preferences over public consumption, it is optimal to follow the conventional policy recipe; namely, not only to tax more but also to allocate more tax revenues to public consumption.

2.9 Some popular special cases

We finally report what happens in two popular cases derived as special cases of our model. In Table 1b, we use the same parameter values as in Table 1a, except that now we set $\delta^n = 1$. In other words, public consumption services become a flow variable. In Table 1c, we set $\delta^n = \delta^g = 1$. In other words, both public consumption services and public productive services are now flow variables.

Tables 1b and 1c here

The qualitative results are as above. The results in Table 1b remain as in Table 1a. Thus, it does not matter whether public consumption goods and services are a stock or a flow variable. The same is true in Table 1c, where both public goods are treated as flow variables. Specifically, in the region $0.8 \le \nu < 0.9$, as ν falls, $\tilde{b}$ and $\tilde{\gamma}$ rise; in the region $0.6 \le \nu < 0.8$, as ν falls, $\tilde{b}$ and $\tilde{\gamma}$ fall. Therefore, although the critical value of of ν, ν^*, and the other quantitative results change, whether public goods are a stock or a flow variable does not alter the main policy lessons.

3. Social planner's solution

This section solves for the benchmark case of a first-best allocation (FBA). Now a social planner directly chooses the paths of C, K, K_g, N, G and E (respectively, private consumption, private capital, productive public capital, non-productive public capital, resources assigned to infrastructure and resources assigned to public consumption) to maximize (1a)-(1b) subject to:

$$\dot{K} = AK_g{}^{\beta} K^{1-\beta} - \delta^k K - C - G - E \tag{13a}$$

$$\dot{K}_g = -\delta^g K_g + G \tag{13b}$$

$$\dot{N} = -\delta^n N + E \tag{13c}$$

where (13a) is the economy's resource constraint and (13b)-(13c) are the motions of productive and non-productive public capital respectively.

3.1 Solution of the social planner's problem

The current-value Hamiltonian, H, of this first-best problem is:

$$\begin{aligned} H \equiv \nu \log C + (1-\nu)\log N + \lambda_k [AK_g{}^{\beta} K^{1-\beta} - \delta^k K - C - G - E] + \lambda_g [-\delta^g K_g + G] + \\ + \lambda_n [-\delta^n N + E] \end{aligned} \tag{14}$$

where λ_k, λ_g and λ_n are new dynamic multipliers associated with (13a), (13b) and (13c).

Deriving the first-order conditions with respect to $C, G, E, \lambda_k, K, \lambda_g, K_g, \lambda_n, N$, and using the stationary auxiliary variables $c \equiv \frac{C}{K}$, $k_g \equiv \frac{K_g}{K}$ $n \equiv \frac{N}{K}$, $g \equiv \frac{G}{K}$ and $e \equiv \frac{E}{K}$, we have:

$$\frac{\dot{c}}{c} = -\beta A k_g^{\beta} - \rho + c + g + e \tag{15a}$$

$$\frac{\dot{n}}{n} = -\delta^n + en^{-1} - Ak_g^{\beta} + \delta^k + c + g + e \tag{15b}$$

$$\frac{\dot{k}_g}{k_g} = -\delta^g + gk_g^{-1} - Ak_g^{\beta} + \delta^k + c + g + e \tag{15c}$$

$$\beta Ak_g^{\beta-1} - (1-\alpha)k_g^{\beta} = \delta^g - \delta^k \tag{15d}$$

$$\frac{c}{n} = \frac{\nu[(1-\beta)Ak_g^{\beta} + \delta^n - \delta^k]}{(1-\nu)} \tag{15e}$$

where (15a)-(15e) constitute a system of five equations in the paths of c, n, k_g, g and e. Note that in turn the resulting consumption growth rate is:

$$\frac{\dot{C}}{C} = (1-\beta)Ak_g^{\beta} - \delta^k - \rho \tag{15f}$$

This is a stationary first-best allocation (FBA). We next study this economy in the long run.

3.2 *Long run first-best allocation*

In the long run, $\frac{\dot{c}}{c} = \frac{\dot{n}}{n} = \frac{\dot{k}_g}{k_g} = \frac{\dot{g}}{g} = \frac{\dot{e}}{e} \equiv 0$ in (15a)-(15e). Let denote the resulting long-run values of c, n, k_g, g, e as $\bar{c}, \bar{n}, \bar{k}_g, \bar{g}, \bar{e}$. Thus, variables with bars denote long-run values in a first-best allocation. The long-run solution of (15a)-(15e) and some analytical comparative static properties of this solution are presented in Appendix B. Here, to make our results directly comparable to those in the previous section, we present numerical results. The parameter values used are the same as above. We also report the resulting solutions of $\frac{\bar{G}}{\bar{Y}}$, $\frac{\bar{E}}{\bar{Y}}$ and $\bar{\gamma}$, as we did in Section 2. Tables 2a-2c correspond to Tables 1a-1c in the previous section, the only difference is that we now solve for FBA.

Tables 2a-2c here

Inspection of numerical results, again for varying values of ν, reveals the following: (a) The solution is well defined. For instance, $\bar{c}>0$, $\bar{n}>0$, $\bar{k}_g>0$, $\bar{g}>0$, $\bar{e}>0$, $\frac{\overline{G}}{\overline{Y}}>0$, $\frac{\overline{E}}{\overline{Y}}>0$ and $\bar{\gamma}\geq 0$. (b) The positive balanced growth rate ($\bar{\gamma}>0$) is independent of ν. This differs from the second-best equilibrium above, where the balanced growth rate was dependent upon ν (compare Tables 1 and 2). (c) Not only the growth rate, but also all variables associated with the production side of the economy are independent of ν (see the flat values of $\bar{k}_g, \bar{g}$ and $\frac{\overline{G}}{\overline{Y}}$). This differs from the second-best equilibrium, where the same variables decreased with ν. (d) The social resources earmarked for non-productive uses do depend on ν. Specifically, $\bar{c}$ increases, while $\bar{e}$ and $\frac{\overline{E}}{\overline{Y}}$ decrease, with ν. (e) The balanced growth rate is higher than that in a second-best equilibrium (compare the long-run values of γ in Tables 1 and 2).

Therefore, in our model economy, the social planner finds it optimal to first hit a relatively high growth rate independently of preferences over alternative non-productive goods and services, and in turn to make the allocation choice among the latter. Thus, we get a form of dichotomy. Having achieved an efficient use of productive factors, the planner allocates social resources to various consumption uses by following the conventional recipe: the more the citizen values public consumption relative to private consumption, the more social resources the planner allocates to the former relative to the latter.

We finally check whether the government in the decentralized economy could choose its policy instruments so as to implement the first-best allocation. In other words, whether it is possible to choose τ, b so as the long-run DCE solution from equations (8a-d)[7] coincides with the long-run solution of the social planner reported in Appendix B. It is straightforward to see that, in our model economy, this is not possible. This happens because here (in addition to the classic Tinbergen target-policy problem which states that the number of independent policy instruments should not be less than the number

[7] Strictly speaking, it is the stationary long-run DCE as summarized by equations (12a), (12b) and (12c). We then compare the long-run solution of these three equations to the long-run first-best solution reported in Appendix B. It is not possible to find values of τ, b that make these two solutions equal.

of policy targets), the second-best equilibrium has the property $\tilde{c} = \rho$ (see (12a) above), where ρ is the exogenous rate of time preference. This means that the government does not have the freedom to affect the consumption-to-capital ratio.[8]

4. What drives our results?

To understand the logic of our results and test their robustness, we have experimented with several model specifications.[9] The key determinant of our non-monotonicity result for b and the new striking policy recipe in the second-best case (see Tables 1a-c) is the presence of congestion in PE, or more generally the assumption that the degree of congestion of PE is higher than the degree of congestion of UE.

To show this, in this section we study the model of section 2 but now there are no congestion problems. Specifically, the only difference from the model in section 2 is that now the private production function changes from (4) to:

$$Y = AK^{1-\beta} K_g^{\beta} \tag{16}$$

where private agents take K_g as given. This is another popular function introduced by Barro (1990) and then used by e.g. Barro and Sala-i-Martin (1995, p. 153), Futagami et al. (1993), Park and Philippopoulos (2003, 2004) and many others. It is important to point out that our modelling has several advantages. For instance, both models corresponding to (4) and (16): (i) have the same social planner's solution; (ii) differ only because now there is no congestion (iii) allow for a well-defined stationary solution.

The new DCE is given by:

$$\frac{\dot{C}}{C} = (1-\tau)\alpha A K^{-\beta} K_g^{\beta} - \delta^k - \rho \tag{17a}$$

[8] In other economies, the first-best solution can be attained (see e.g. Turnovsky, 1995, chapter 13).

[9] Like different production and utility functions, elastic labor supply and congestion. In all model specifications we have solved, the key determinant of our results is congestion.

$$\frac{\dot{K}}{K} = (1-\tau)AK^{-\beta}K_g^{\beta} - \delta^k - \frac{C}{K} \tag{17b}$$

$$\frac{\dot{N}}{N} = -\delta^n + (1-b)\tau AK^{1-\beta}K_g^{\beta}\frac{1}{N} \tag{17c}$$

$$\frac{\dot{K}_g}{K_g} = -\delta^g + b\tau AK^{1-\beta}K_g^{-(1-\beta)} \tag{17d}$$

We endogenize policy as in subsection 2.6 above. Thus, the government chooses the paths of τ and b to maximize (1)-(2) subject to the new DCE in (17a-d). Working exactly as in section 2 and using the same transformations, we end up with the following stationary long-run second-best general equilibrium (see Appendix C for details), which is the analogue of (12a-h):

$$\tilde{c} = (1-\alpha)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \rho \tag{18a}$$

$$\tilde{n} = \frac{(1-\tilde{b})\tilde{\tau}A\tilde{k}_g^{\beta}}{(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k - \rho} \tag{18b}$$

$$\tilde{k}_g = \frac{\tilde{b}\,\tilde{\tau}A\tilde{k}_g^{\beta}}{(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^g - \delta^k - \rho} \tag{18c}$$

$$\tilde{\Lambda}_c = \frac{\nu\beta(1-\tilde{\tau})[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k](1-\tilde{b})\tilde{\tau}A^2\tilde{k}_g^{2\beta-1} + (1-\nu)[\rho + \delta^k - \delta^n - (1-\beta)A\tilde{k}_g^{\beta}][\rho - (1-\tilde{b})\tilde{\tau}A\tilde{k}_g^{-\alpha}]\tilde{c}}{\rho[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k](1-\tilde{b})\tilde{\tau}\beta(1-\tilde{\tau})A^2\tilde{k}_g^{2\beta-1}} \tag{18d}$$

$$\tilde{\Lambda}_k = \frac{(1-\nu)[\rho + \delta^k - \delta^n - (1-\beta)A\tilde{k}_g^{\beta}][(1-\tilde{b})\tilde{\tau})A\tilde{k}_g^{-\alpha} - \rho]}{[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k](1-\tilde{b})\tilde{\tau}\beta(1-\tilde{\tau})A^2\tilde{k}_g^{2\beta-1}} \tag{18e}$$

$$\tilde{\Lambda}_n = \frac{1-\nu}{(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k} \tag{18f}$$

$$\tilde{\Lambda}_g = \frac{(1-\nu)[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \rho - \delta^k]}{[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta} + \delta^n - \delta^k](1-\tilde{b})\tilde{\tau}A\tilde{k}_g^{-\alpha}} \tag{18g}$$

$$(1-\nu)[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta}+\delta^n-\delta^k-\rho][(\rho\tilde{k}_g^{1-\beta}-(1-\tilde{b})\tilde{\tau}A)((1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta}-\rho)+\rho(1-\tilde{\tau})A]= \\ =\nu(1-\beta)(1-\tilde{\tau})[(1-\beta)(1-\tilde{\tau})A\tilde{k}_g^{\beta}+\delta^n-\delta^k](1-\tilde{b})\tilde{\tau}A^2\tilde{k}_g^{\beta} \quad (18h)$$

$$\rho\tilde{k}_g^{1-\beta}=A[\beta-\tilde{b}\,\tilde{\tau}] \quad (18i)$$

This is a nine-equation system in the long-run values of τ, b, c, n, k_g, Λ_c, Λ_k, Λ_n, Λ_g (denoted again as $\tilde{\tau},\tilde{b},\tilde{c},\tilde{n},\tilde{k}_g,\tilde{\Lambda}_c,\tilde{\Lambda}_k,\tilde{\Lambda}_n,\tilde{\Lambda}_g$). We solve this non-linear system numerically by using the same parameter values as in Section 2. Results are reported in Tables 3a-c, which are the analogues of Tables 1a-c above.

Table 3a-3c here

The solution is again well defined. Comparison of Table 3a and Table 1a reveals that now we get the conventional policy recipe for all values of ν. That is, the more the citizen values public consumption (i.e. as ν falls), the higher the tax rate, the smaller the allocation of tax revenues to public production relative to public consumption, and hence the lower the growth rate. Also, as ν falls, $\tilde{E}/\tilde{Y}$, $\tilde{n}$ and $\tilde{k}_g$ all increase, while $\tilde{G}/\tilde{Y}$ remains the same (see above for interpretation of these results). All these effects are monotonic. Table 3b (where public consumption is a flow variable) and Table 3c (where both public consumption and production are flow variables) deliver the same messages.

Therefore, congestion of PE is important to our non-monotonicity result for b and the new striking policy recipe in the second-best case. In the presence of congestion effects on PE that are not internalized by the private agent, the latter's decision to expand its capital and output reduces public productive services as a share of private capital or output. To correct for this market failure, the Ramsey government allocates additional resources (i.e. tax revenues) to public productive services. This implies a higher b which turns out to be good for growth and tax bases. The latter allows the finance of all public services including non-productive ones (UE).

We also report that the first-best allocation is again not attainable. Specifically, it is not possible to find values of τ, b that make the second-best solution in (18a-c) equal to the first-best solution.

We close by adding two things. First, our result (namely, that congestion matters) resembles the result of Jones (1995) and Young (1998) who show that greater and greater quantities of resources have to be devoted to inoovative activities in order to sustain a given growth rate. Our result is similar in the sense that, when there are congestion problems so that the share of public goods falls as the private economy expands, the Ramsey government needs to devote more tax revenues to finance public goods and keep them to their desired ratio. And this can be achieved by large tax bases and growth-enhancing policies. Therefore, our congestion effect works like the scale effect in these papers.

Second, Economides and Philippopoulos (2007) have derived similar policy results in a growth model with renewable natural resources. In their model, natural resources are a utility-enhancing public good which is depleted by private economic activity (this is a form of congestion) but it can also be maintained by public cleanup policy. They show that, in the presence of this form of congestion, the main results of Section 2 above hold. Namely, the more the citizen values the environment, the more growth-enhancing policies a Ramsey government should choose. Actually, their results are stronger in the sense that, as ν falls, not only the allocation of tax revenues to PE relative to cleanup policy increases, but also the income tax rate falls. In other words, the desirability of growth becomes stronger. All these effects are monotonic.

5. Relationship to the literature

Turnovsky (1995, chapter 13) models both types of public goods and also allows for congestion. Eicher and Turnovsky (2000), Fischer and Turnovsky (1998) and Turnovsky (1996) study growth models with a single public good (i.e. either productivity- or utility-enhancing) allowing for congestion. Chatterjee and Ghosh (2007) also allow for congestion and their single public capital provides both productive and utility services.

But all these papers study the social planner's problem, or solve for policies that can replicate the first-best allocation resulting from that problem.

Barro and Sala-i-Martin (1992) and Glomm and Ravikumar (1994) develop growth models with congestion of public productive services treating them either as a flow or a stock variable. These papers do study second-best policy but (since they have a single public good) do not study the allocation issue (namely, how a Ramsey government should allocate the collected tax revenues to different public goods). Park and Philippopoulos (2003, 2004) have both types of public goods and study second-best allocation policies but, since they do not have congestion effects, they get the conventional policy recipe only. Baier and Glomm (2001) present a rich model with various types of public expenditures, but they do not have congestion, solve for growth maximizing policies and do not choose all government expenditure shares optimally. Futagami et al. (1993) extend Barro's (1990) model by treating productivity-enhancing public goods as a stock variable without congestion. Our present paper is close in spirit to Economides and Philippopoulos (2007); however, as said above, that paper studies a specific form of congestion effects that is found in environmental models only.

In sum, our work differs from the literature in that at the same time: (a) we study Ramsey second-best optimal policy in a general equilibrium model of growth augmented with the two main categories of public goods and services; (b) we allow for congestion effects and show their key role in policy recipes. Note that in doing so, we also nest some important models in the literature on dynamic optimal public finance.

Finally, it is worth adding that Ott and Turnovsky (2005) study the role of excludability of public goods, which means that individuals can have access to them only if they pay a user fee. Recall that rivalry and excludability are the key features of impure public goods.

6. Conclusions

In this paper, we set up a dynamic general equilibrium model of endogenous growth in which productive and non-productive public goods were financed by distorting taxes, and policy decisions were made by a Ramsey-type government that solved a second-best optimal policy problem. We focused on the allocation of the collected tax revenues between productive and non-productive public goods, and provided some new results in the case of rival (public goods under congestion) public goods.

APPENDIX

A. Second-best equilibrium with congestion

Inspection of (11a) reveals that this is an equation in c only. Actually, since c is a jump variable, this equation implies $c = \rho$ (or $C = \rho K$) along the whole optimal path including the long run. But then the first two dynamic constraints to the government's optimization problem coincide, namely $\frac{\dot{C}}{C} = \frac{\dot{K}}{K} = (1-\tau)A\left(\frac{K_g}{K}\right)^{\beta} - \delta^k - \rho$. This implies $\Lambda_c = \Lambda_k$ (or $\Lambda_c \equiv \lambda_c C = \lambda_k K \equiv \Lambda_k$) along the whole optimal path. This property, jointly with (11d) in the long run, gives (12d). Then, the rest of equations in (12) follow by simple substitutions if we set dotted variables to zero. Specifically, (12c), (12g) and (12h) constitute a three-equation system in $\tilde{\tau}$, $\tilde{b}$ and $\tilde{k}_g$ only. Once we solve for $\tilde{\tau}$, $\tilde{b}$ and $\tilde{k}_g$, we can go back to (12b), (12e) and (12f) and get closed-form solutions for $\tilde{n}$, $\tilde{\Lambda}_n$ and $\tilde{\Lambda}_g$ respectively. Note that the property $\Lambda_c = \Lambda_k$ is a feature of the AK model at private level. See below in Appendix C for $\Lambda_c \neq \Lambda_k$.

B. First-best allocation

Inspection of (15d) reveals that this is an atemporal non-linear equation in k_g only. Hence, k_g is constant along the optimal path. In turn, equations (15a), (15b) and (15c) in the long-run give:

$$\bar{c} + \bar{g} + \bar{e} = \beta A\bar{k}_g^{\beta} + s(1-\beta)A\bar{k}_g^{\beta} + \rho \qquad \text{(B.1)}$$

$$\bar{c} + \bar{g} + \bar{e} = A\bar{k}_g^{\beta} + sA\bar{k}_g^{\beta}\bar{n}^{-1} - \bar{e}\bar{n}^{-1} + \delta^n - \delta^k \qquad \text{(B.2)}$$

$$\bar{c} + \bar{g} + \bar{e} = A\bar{k}_g^{\beta} - \bar{g}\bar{k}_g^{-1} + \delta^g - \delta^k \qquad \text{(B.3)}$$

Equations (B.1) and (B.3) together imply:

$$\bar{g} = \bar{k}_g\left[(1-s)(1-\beta)A\bar{k}_g^{\beta} + \delta^g - \delta^k - \rho\right] \qquad \text{(B.4)}$$

Given the solution for $\bar{k}_g$ from (15d), (B.4) is an equation in $\bar{g}$ only.

Combining equations (15e), (B.1) and (B.2), we get:

$$\overline{n} = \frac{\beta(1-s)A\overline{k}_g^{\beta} + \rho - \overline{g}}{\frac{\nu}{(1-\nu)}\left[(1-\beta)(1-s)A\overline{k}_g^{\beta} + \delta^n - \delta^k\right] + (1-\beta)A\overline{k}_g^{\beta} + \delta^n - \delta^k - s(1-\beta)A\overline{k}_g^{\beta} - \rho} \tag{B.5}$$

$$\overline{e} = sAk_g^{\beta} + \left[(1-\beta)A\overline{k}_g^{\beta} + +\delta^n - \delta^k - s(1-\beta)Ak_g^{\beta} - \rho\right]\overline{n} \tag{B.6}$$

Given the solutions for $\overline{k}_g$ and $\overline{g}$ from (15d) and (B.4), (B.5) is an equation in $\overline{n}$ only. Once, we solve for $\overline{n}$, (B.6) gives $\overline{e}$, Finally, given $\overline{k}_g$, $\overline{g}$ and $\overline{e}$ from (15d), (B.4) and (B.6), (B.1) gives $\overline{c}$. As said in the text, we solve (15d), (B.4), (B.5), (B.6) and (B.1) numerically for $\overline{k}_g, \overline{g}, \overline{n}, \overline{e}$ and $\overline{c}$ respectively.

Finally, notice from (15d) that $\overline{k}_g$ is independent of ν. This implies that the first-best growth rate and $\overline{g}$, given by (15e) and (B.4) respectively, are also independent of ν. (B.5) implies $\frac{\partial \overline{n}}{\partial \nu} < 0$. Given that, (B.6) and (B.1) imply $\frac{\partial \overline{e}}{\partial \nu} < 0$ and $\frac{\partial \overline{c}}{\partial \nu} > 0$ respectively.

C. Second-best equilibrium without congestion

The government chooses the paths of τ and b to maximize (1) subject to (17a)-(17d). The current-value Hamiltonian, H, is:

$$\begin{aligned} H = {} & \nu \log C + (1-\nu)\log N + \lambda_c C[(1-\tau)AK_g^{\beta}K^{-\beta} - \delta^k - \rho] + \lambda_k[(1-\tau)AK_g^{\beta}K^{1-\beta} - \delta^k K - C] + \\ & + \lambda_n[-\delta^n N + (1-b)\tau AK_g^{\beta}K^{1-\beta}] + \lambda_g[-\delta^g K_g + b\tau AK_g^{\beta}K^{1-\beta}] \end{aligned} \tag{C.1}$$

where λ_c, λ_k, λ_n and λ_g are dynamic multipliers associated with (17a), (17b), (17c) and (17d) respectively. The first-order conditions include (17a)-(17d) and the optimality conditions with respect to τ, b, C, K, N and K_g:

$$\alpha\lambda_c C + \lambda_k K = \lambda_n K \tag{C.2a}$$

$$\lambda_n = \lambda_g \tag{C.2b}$$

$$\dot{\lambda}_c = -\frac{\nu}{C} - \lambda_c[(1-\tau)AK_g^{\beta}K^{-\beta} - \delta^k - \rho] + \lambda_k + \rho\lambda_c \tag{C.2c}$$

$$\begin{aligned} \dot{\lambda}_k = {} & \beta(1-\beta)(1-\tau)AK_g^{\beta}K^{-\beta-1}\lambda_c C - (1-\beta)(1-\tau)AK_g^{\beta}K^{-\beta}\lambda_k + \delta^k\lambda_k - (1-\beta)(1-b)\tau AK_g^{\beta}K^{-\beta}\lambda_n + \\ & - (1-\beta)b\tau AK_g^{\beta}K^{-\beta}\lambda_g + \rho\lambda_k \end{aligned} \tag{C.2d}$$

$$\dot{\lambda}_n = -\frac{(1-\nu)}{N} + \delta^n \lambda_n + \rho\lambda_n \tag{C.2e}$$

$$\begin{aligned}\dot{\lambda}_g = &-\beta(1-\beta)(1-\tau)AK_g^{\beta-1}K^{-\beta}\lambda_c C - \beta(1-\tau)AK_g^{\beta-1}K^{1-\beta}\lambda_k - \beta(1-b)\tau AK_g^{\beta-1}K^{1-\beta}\lambda_n + \delta^g\lambda_g + \\ &-\beta b\tau AK_g^{\beta-1}K^{1-\beta}\lambda_g + \rho\lambda_g\end{aligned} \tag{C.2f}$$

We define $c \equiv \frac{C}{K}$, $n \equiv \frac{N}{K}$, $k_g \equiv \frac{K_g}{K}$, $\Lambda_c \equiv \lambda_c C$, $\Lambda_k \equiv \lambda_k K$, $\Lambda_n \equiv \lambda_n N$ and $\Lambda_g \equiv \lambda_g K_g$. It is straightforward to show that the dynamics of (17a)-(17d) and (C.2a)-(C.2f) are equivalent to the dynamics of (C.3a)-(C.3i) below:

$$\dot{c} = c^2 - [\beta(1-\tau)Ak_g^{\beta} + \rho]c \tag{C.3a}$$

$$\dot{n} = -\delta^n n + (1-b)\tau Ak_g^{\beta} - (1-\tau)Ak_g^{\beta} n + cn + \delta^k n \tag{C.3b}$$

$$\dot{k}_g = -\delta^g k_g + b\tau Ak_g^{\beta} - (1-\tau)Ak_g^{1+\beta} + ck_g + \delta^k k_g \tag{C.3c}$$

$$\dot{\Lambda}_c = -\nu + \rho\Lambda_c + \Lambda_k c \tag{C.3d}$$

$$\dot{\Lambda}_k = \beta(1-\beta)(1-\tau)Ak_g^{\beta}\Lambda_c + \beta(1-\tau)Ak_g^{\beta}\Lambda_k - (1-\beta)(1-b)\tau Ak_g^{\beta}\frac{\Lambda_n}{n} - (1-\beta)b\tau Ak_g^{\beta-1}\Lambda_g + (\rho-c)\Lambda_k \tag{C.3e}$$

$$\dot{\Lambda}_n = -(1-\nu) + \rho\Lambda_n + (1-b)\tau Ak_g^{\beta}\frac{\Lambda_n}{n} \tag{C.3f}$$

$$\dot{\Lambda}_g = -\beta(1-\beta)(1-\tau)Ak_g^{\beta}\Lambda_c - \beta(1-\tau)Ak_g^{\beta}\Lambda_k - \beta(1-b)\tau Ak_g^{\beta}\frac{\Lambda_n}{n} + (1-\beta)b\tau Ak_g^{\beta-1}\Lambda_g + \rho\Lambda_g \tag{C.3g}$$

$$\alpha\Lambda_c + \Lambda_k = \frac{\Lambda_n}{n} \tag{C.3h}$$

$$\Lambda_n k_g = \Lambda_g n \tag{C.3i}$$

In the long run, $\frac{\dot{\tau}}{\tau} = \frac{\dot{b}}{b} = \frac{\dot{c}}{c} = \frac{\dot{n}}{n} = \frac{\dot{k}_k}{k_g} = \frac{\dot{\Lambda}_c}{\Lambda_c} = \frac{\dot{\Lambda}_k}{\Lambda_k} = \frac{\dot{\Lambda}_n}{\Lambda_n} = \frac{\dot{\Lambda}_g}{\Lambda_g} \equiv 0$ in (C.3a)-(C.3i). This gives equations (18a-i) in the text.

Table 1a

Effect of ν on long-run second-best equilibrium with congestion

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.880	0.816	0.04	1.652	7.347	1.25	1.25	4.130	18.369	0.718	0.161	0.117
0.2	0.778	0.876	0.04	0.494	3.505	2.50	2.50	2.473	17.526	0.681	0.096	0.223
0.3	0.677	0.900	0.04	0.231	2.101	3.75	3.75	1.737	15.762	0.610	0.067	0.302
0.4	0.578	0.913	0.04	0.129	1.370	5.00	5.00	1.294	13.705	0.528	0.049	0.363
0.5	0.479	0.921	0.04	0.078	0.921	6.25	6.25	0.984	11.515	0.441	0.037	0.407
0.6	0.381	0.925	0.04	0.049	0.616	7.50	7.50	0.747	9.252	0.352	0.028	0.435
0.7	0.284	0.926	0.04	0.031	0.396	8.75	8.75	0.552	6.947	0.263	0.020	0.442
0.8	0.187	0.923	0.04	0.019	0.230	10.00	10.00	0.382	4.617	0.173	0.014	0.423
0.9	0.092	0.912	0.04	0.009	0.101	11.25	11.25	0.218	2.281	0.083	0.008	0.356

Notes: $A = 1$, $\beta = 0.30$, $\delta^k = 0.06$, $\delta^g = 0.06$, $\delta^n = 0.06$ and $\rho = 0.04$.

Table 1b

Effect of ν on long-run second-best equilibrium with congestion when $\delta^n = 1$

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.896	0.797	0.04	0.316	8.683	1.25	1.25	0.791	21.708	0.715	0.181	0.097
0.2	0.794	0.870	0.04	0.128	3.871	2.50	2.50	0.640	19.359	0.691	0.103	0.208
0.3	0.693	0.897	0.04	0.070	2.263	3.75	3.75	0.525	16.794	0.622	0.070	0.291
0.4	0.593	0.912	0.04	0.042	1.457	5.00	5.00	0.429	14.570	0.540	0.052	0.355
0.5	0.492	0.920	0.04	0.027	0.972	6.25	6.25	0.346	12.153	0.453	0.039	0.402
0.6	0.393	0.924	0.04	0.018	0.648	7.50	7.50	0.271	9.728	0.363	0.029	0.432
0.7	0.294	0.926	0.04	0.011	0.417	8.75	8.75	0.202	7.297	0.272	0.021	0.442
0.8	0.195	0.923	0.04	0.006	0.243	10.00	10.00	0.136	4.863	0.180	0.014	0.426
0.9	0.097	0.913	0.04	0.003	0.107	11.25	11.25	0.071	2.428	0.089	0.008	0.362

Notes: $A = 1$, $\beta = 0.30$, $\delta^k = 0.06$, $\delta^g = 0.06$, $\delta^n = 1$ and $\rho = 0.04$.

Table 1c

Effect of ν on long-run second-best equilibrium with congestion when $\delta^n = \delta^g = 1$

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1												
0.2												
0.3												
0.4												
0.5												
0.6	0.849	0.9620	0.04	0.025	0.641	7.50	7.50	0.377	9.622	0.817	0.032	0.020
0.7	0.720	0.9640	0.04	0.015	0.413	8.75	8.75	0.267	7.232	0.694	0.025	0.080
0.8	0.566	0.9653	0.04	0.008	0.241	10.00	10.00	0.173	4.826	0.546	0.019	0.113
0.9	0.374	0.9650	0.04	0.003	0.107	11.25	11.25	0.087	2.412	0.361	0.013	0.104

Notes: $A=1$, $\beta=0.50$, $\delta^k=0.06$, $\delta^g=1$, $\delta^n=1$ and $\rho=0.04$. For $0<\nu<0.6$, solutions are ill defined.

Table 2a

Effect of ν on long-run first-best equilibrium

ν	$\bar{c}$	$\bar{n}$	$\bar{k}_g$	$\bar{g}$	$\bar{e}$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.006	0.101	0.428	0.215	0.051	0.341	0.080	0.442
0.2	0.012	0.089	0.428	0.215	0.044	0.341	0.071	0.442
0.3	0.018	0.077	0.428	0.215	0.039	0.341	0.061	0.442
0.4	0.023	0.066	0.428	0.215	0.033	0.341	0.052	0.442
0.5	0.029	0.054	0.428	0.215	0.027	0.341	0.043	0.442
0.6	0.035	0.043	0.428	0.215	0.021	0.341	0.034	0.442
0.7	0.040	0.032	0.428	0.215	0.016	0.341	0.025	0.442
0.8	0.046	0.021	0.428	0.215	0.010	0.341	0.017	0.442
0.9	0.051	0.010	0.428	0.215	0.005	0.341	0.008	0.442

Notes: $A=1$, $\beta=0.30$, $\delta^k=0.06$, $\delta^g=0.06$, $\delta^n=0.06$ and $\rho=0.04$.

Table 2b

Effect of ν on long-run first-best equilibrium when $\delta^n=1$

ν	$\bar{c}$	$\bar{n}$	$\bar{k}_g$	$\bar{g}$	$\bar{e}$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.005	0.035	0.428	0.215	0.051	0.341	0.081	0.442
0.2	0.011	0.031	0.428	0.215	0.045	0.341	0.072	0.442
0.3	0.017	0.027	0.428	0.215	0.039	0.341	0.062	0.442
0.4	0.023	0.023	0.428	0.215	0.033	0.341	0.053	0.442
0.5	0.028	0.019	0.428	0.215	0.028	0.341	0.044	0.442
0.6	0.034	0.015	0.428	0.215	0.022	0.341	0.035	0.442
0.7	0.040	0.011	0.428	0.215	0.016	0.341	0.026	0.442
0.8	0.045	0.007	0.428	0.215	0.011	0.341	0.017	0.442
0.9	0.051	0.003	0.428	0.215	0.005	0.341	0.008	0.442

Notes: $A=1$, $\beta=0.30$, $\delta^k=0.06$, $\delta^g=0.06$, $\delta^n=1$ and $\rho=0.04$.

Table 2c

Effect of ν on long-run first-best equilibrium when $\delta^n = \delta^g = 1$

ν	$\bar{c}$	$\bar{n}$	$\bar{k}_g$	$\bar{g}$	$\bar{e}$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.004	0.038	0.187	0.208	0.042	0.456	0.093	0.116
0.2	0.009	0.033	0.187	0.208	0.037	0.456	0.082	0.116
0.3	0.014	0.029	0.187	0.208	0.032	0.456	0.071	0.116
0.4	0.019	0.025	0.187	0.208	0.028	0.456	0.061	0.116
0.5	0.024	0.020	0.187	0.208	0.023	0.456	0.051	0.116
0.6	0.028	0.016	0.187	0.208	0.018	0.456	0.040	0.116
0.7	0.033	0.012	0.187	0.208	0.013	0.456	0.030	0.116
0.8	0.038	0.008	0.187	0.208	0.009	0.456	0.020	0.116
0.9	0.042	0.004	0.187	0.208	0.004	0.456	0.010	0.116

Notes: $A = 1$, $\beta = 0.50$, $\delta^k = 0.06$, $\delta^g = 1$, $\delta^n = 1$ and $\rho = 0.04$.

Table 3a

Effect of ν on long-run second-best equilibrium without congestion

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.359	0.750	0.210	0.222	0.668	19.064	-3.149	2.264	6.820	0.271	0.089	0.297
0.2	0.347	0.776	0.212	0.189	0.657	18.684	-2.576	1.987	6.903	0.271	0.077	0.302
0.3	0.337	0.802	0.214	0.159	0.646	18.313	-2.016	1.719	6.984	0.271	0.066	0.307
0.4	0.326	0.828	0.216	0.131	0.636	17.948	-1.469	1.457	7.062	0.271	0.055	0.311
0.5	0.316	0.855	0.218	0.105	0.627	17.591	-0.933	1.202	7.139	0.271	0.045	0.315
0.6	0.307	0.883	0.219	0.081	0.618	17.240	-0.407	0.952	7.214	0.271	0.035	0.319
0.7	0.298	0.911	0.221	0.059	0.610	16.895	0.109	0.707	7.287	0.271	0.026	0.323
0.8	0.289	0.940	0.223	0.038	0.602	16.555	0.617	0.467	7.359	0.271	0.017	0.327
0.9	0.280	0.969	0.224	0.018	0.595	16.219	1.117	0.231	7.430	0.271	0.008	0.331

Notes: $A = 1$, $\beta = 0.30$, $\delta^k = 0.06$, $\delta^g = 0.06$, $\delta^n = 0.06$ and $\rho = 0.04$.

Table 3b

Effect of ν on long-run second-best equilibrium without congestion when $\delta^n = 1$

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.360	0.749	0.210	0.061	0.669	20.443	-3.414	0.673	7.298	0.270	0.090	0.297
0.2	0.349	0.773	0.212	0.053	0.658	19.888	-2.806	0.596	7.321	0.270	0.079	0.301
0.3	0.338	0.798	0.214	0.045	0.648	19.349	-2.212	0.519	7.344	0.270	0.068	0.306
0.4	0.328	0.824	0.216	0.038	0.638	18.822	-1.633	0.444	7.366	0.270	0.057	0.310
0.5	0.318	0.851	0.217	0.031	0.628	18.307	-1.066	0.368	7.389	0.270	0.047	0.315
0.6	0.308	0.878	0.219	0.024	0.620	17.804	-0.510	0.294	7.417	0.270	0.037	0.319
0.7	0.299	0.907	0.221	0.018	0.611	17.311	0.033	0.220	7.433	0.270	0.027	0.323
0.8	0.290	0.936	0.223	0.011	0.603	16.828	0.568	0.146	7.456	0.270	0.018	0.327
0.9	0.281	0.967	0.224	0.005	0.596	16.354	1.094	0.072	7.478	0.270	0.009	0.330

Notes: $A = 1$, $\beta = 0.30$, $\delta^k = 0.06$, $\delta^g = 0.06$, $\delta^n = 1$ and $\rho = 0.04$.

Table 3c

Effect of ν on long-run second-best equilibrium without congestion when $\delta^n = \delta^g = 1$

ν	$\tilde{\tau}$	$\tilde{b}$	$\tilde{c}$	$\tilde{n}$	$\tilde{k}_g$	$\tilde{\Lambda}_c$	$\tilde{\Lambda}_k$	$\tilde{\Lambda}_n$	$\tilde{\Lambda}_g$	$\tilde{G}/\tilde{Y}$	$\tilde{E}/\tilde{Y}$	$\tilde{\gamma}$
0.1	0.407	0.711	0.139	0.058	0.142	30.344	-8.004	0.768	1.891	0.289	0.117	0.131
0.2	0.391	0.739	0.141	0.049	0.141	29.235	-6.847	0.679	1.932	0.289	0.101	0.137
0.3	0.376	0.768	0.143	0.042	0.140	28.190	-5.753	0.592	1.970	0.289	0.087	0.142
0.4	0.362	0.798	0.145	0.035	0.140	17.199	-4.172	0.505	2.007	0.289	0.072	0.147
0.5	0.349	0.829	0.148	0.028	0.139	26.254	-3.171	0.419	2.042	0.289	0.059	0.152
0.6	0.336	0.861	0.149	0.022	0.138	25.349	-2.760	0.334	2.076	0.289	0.046	0.156
0.7	0.324	0.894	0.151	0.016	0.137	24.480	-1.838	0.249	2.108	0.289	0.034	0.160
0.8	0.312	0.928	0.153	0.010	0.137	23.642	-0.948	0.165	2.139	0.289	0.022	0.165
0.9	0.301	0.963	0.155	0.005	0.136	22.832	-0.085	0.082	2.170	0.289	0.011	0.169

Notes: $A = 1$, $\beta = 0.30$, $\delta^k = 0.06$, $\delta^g = 1$, $\delta^n = 1$ and $\rho = 0.04$.

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