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Should mobile capital pay for public infrastructure investment?

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Abstract The paper contributes to the discussion of fiscal competition with infrastructure goods. We explicitly focus on the costs of providing public infrastructure capital that appear in the public budget as investment. Thus we analyse the problem in a dynamic framework. Public infrastructure is considered as a marginal product complement to private capital. A central result of the model is that the fact that public capital is a complement to private capital, so that an increase in the supply of public capital *ceteris paribus* improves the marginal productivity of private capital, cannot be used as an argument to support a source tax. The so-called indirect productivity effect on private capital induced by public inputs does not justify the taxation of mobile capital. Rather, the efficiency of a source tax on mobile capital income depends on the question of whether or not the public input generates a factor rent to private capital.

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1 Introduction

A standard argument in the theory of fiscal competition is that small open economies should not levy a source tax on international mobile capital, because capital will always be able to shift the tax burden to immobile factors (Wildasin 2000; Sinn 1997). However, it is still debatable whether a capital income tax is a proper instrument to finance productive public infrastructure. An essential contribution to the discussion of fiscal competition with infrastructure goods was made by Zodrow and Mieszkowski (1986), who oppose that a source-based capital tax is an efficient instrument to finance public inputs.[1] A contrasting view is taken by Oates and Schwab (1991, 1988). They posit that a source tax on mobile capital can be interpreted as a benefit tax and thus justified as a price for public inputs. Any attempts to attract new business investment by lowering taxes below the cost of providing productive public goods will neither increase income nor create jobs in the community. Gerber and Hewitt (1987) attempt a synthesis of the two perspectives by categorizing the infrastructure goods according to their rivalry features. They distinguish between publicly provided private inputs and the "creation of atmosphere" type of public capital, as first described by Meade (1952), and conclude that a source tax is a proper instrument to finance publicly provided private inputs. Richter (1994) and Matsumoto (2000) discuss a fiscal competition model with so-called firm-augmenting public capital, where the costs of providing public inputs are assumed to rise with the number of firms in the jurisdiction. In this framework, a capital tax can be justified to avoid overly high profit taxes. A survey of different types of public inputs is given by Feehan (1989). Sinn (2003, 1997) considers infrastructure goods that lower the costs of using private capital. In his model, the government sets a source tax equal to the marginal congestion externality of private capital (Sinn 2003, p. 34).

Although most theoretical work in the area of infrastructure competition deals with the welfare implications of alternative ways of financing public capital, none of these studies examine government as an investing agent. In this paper we focus on the costs of providing and improving the public capital stock that appears in the public budget as investment. Thus the problem must be analyzed in a dynamic framework.[2] The policy question discussed in this paper is whether public infrastructure investment expenditures should be financed by mobile capital according to the benefit-taxation principle. We take the perspective of a small open economy that competes for mobile capital. Public infrastructure is considered as a marginal product complement to private capital. This means that public

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[1] Zodrow and Mieszkowski (1986) argue that a source-based capital tax leads to an underprovision of public inputs even if the resulting tax income is used by the government to finance local public inputs. Thus, a jurisdictional government would prefer to tax its residents by a non-distorting lump sum tax. Noiset (1995) shows that in the framework of Zodrow and Mieszkowski, a tax on capital can under certain conditions also lead to an overprovison of public inputs. Matsumoto (1998) shows that Noiset's result of potential overprovision depends on the exogenity of the number of firms in the Zodrow-Miezskowski model.

[2] Several previous studies have examined interesting aspects of intertemporal fiscal competition, e.g. Wildasin (2003b), Huizinga and Nielsen (1997).

infrastructure influences the private factor productivity positively and can thus be used by the government in order to accommodate mobile capital (Pfähler et al. 1997). A central result of the model outlined in this paper is that the efficiency of a capital income tax depends not only on the rivalry features of public capital but also on the question of whether or not public capital generates a factor rent to private capital.

The paper is organized as follows. Section 2 reviews alternative specifications of public inputs which are based on the degree of homogeneity of the production function. Section 3 presents a dynamic model of a small open economy where private capital formation and saving decisions are influenced by a source-based tax, a flat rate wage tax and the supply of productive infrastructure. The markets for goods and inputs are perfectly competitive and both goods and private capital are perfectly mobile across borders. Section 4 is devoted to the question of how governments design an optimal investment and financing policy. According to the neoclassical approach, the public decision-maker seeks to promote social welfare, while acting as a price-taker in the capital market and not engaging in strategic interaction in response to the policies of neighbouring jurisdictions.[3] In Sect. 5 the analysis explicitly indicates how the opportunity costs of public investments depend on the financing instruments used. Section 6 highlights in detail the incidence of a source tax in the steady state. It is then followed by some conclusions in Sect. 7

2 Public investment and production technology

Our first focus is the time-invariant production technologies used in the jurisdiction. There are different factors of production: labour L_t, private capital K_t and three kinds of public capital $G_{i,t}$ (for i = P, K, L) which are used by private firms to produce one homogeneous good Y_t at time t. The price of Y_t is normalized to unity. The labour supply grows at an exogenous rate n, thus $L_{t+1} = (1 + n)L_t$. Capital is simply non-consumed output. The production function

$$A(G_{P,t})F(K_t, G_{K,t}, L_t, G_{L,t}) = Y_t \tag{1}$$

exhibits positive diminishing marginal products with respect to each input, for all factors $L_t, K_t, G_{i,t} > 0$ and the Inada conditions hold. All factors are complements in the sense that the second-order cross derivations of $A(G_{P,t}) F(K_t, G_{K,t}, L_t, G_{L,t})$ are positive. The underlying production function for the private goods has increasing returns of scale in all inputs, but $F(K_t, G_{K,t}, L_t, G_{L,t})$ is linear homogeneous in private capital, labour and all kinds of publicly provided private inputs. A further property of the production technology is that it faces diminishing returns to the accumulation of private and public capital together. Thus the production function specifies decreasing returns for fixed L. The public capital yields only production benefits, so

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[3] The question whether governments interact atomistically or like oligopolists is broadly discussed in the literature of fiscal competition (Wildasin 2003a). When the number of regions becomes small, strategic interaction between local governments plays an important role. Nevertheless, the aspect of strategic behaviour of the government is not considered in our model.

that households are not immediate beneficiaries of public capital.[4] In theoretical discussions, public inputs are mainly distinguished as follows (Feehan 1989; Arrow and Kurz 1970):

- **The "creation of atmosphere type" of public capital** ($G_{P,t}$): This type of public input was first discussed by Meade (1952) and Kaizuka (1965) and applied to a fiscal competition framework by Zodrow and Mieszkowski (1986) and Matsumoto (1998).[5] It exhibits no congestion externalities. The public capital stock $G_{P,t}$ determines the total factor productivity $A(G_{P,t})$. The marginal effect of this specific kind of public infrastructure capital on total factor productivity is $\partial A(G_{P,t})/\partial G_{P,t}$. Therefore total factor productivity is not considered to be exogenous but can be produced by the supply of $G_{P,t}$. In the discussion of a new start for the so-called "Lisbon Strategy", the European Commission (2005) describes the public investments that a modern, knowledge-economy needs to adapt in the face of changing economic and social conditions. One of these public inputs is an effective regulation that has a significant positive impact on the framework conditions for economic growth and productivity. A second category of such public inputs is increased and improved public investment in R&D. According to the European Commission (2005), public support for young and innovative companies in particular can improve total factor productivity. The quoted public inputs excellently describe what is meant by $G_{P,t}$.

- **The publicly provided private input** ($G_{K,t}$ and $G_{L,t}$): The empirical literature on local public expenditure shows that many publicly provided inputs have roughly the same amount of rivalry as private goods (Gramlich 1994; Reiter and Weichenrieder 1997; Büttner et al. 2004). Government provides such private inputs because exclusion is either not possible or prohibitively expensive and a market solution thus unsatisfactory. Since the private production function exhibits constant returns in K_t, L_t, $G_{L,t}$, and $G_{K,t}$, the output Y_t can be decomposed into the imputed shares of private capital, government capital and labour. According to Euler's theorem

$$Y_t = \underbrace{\left[\frac{\partial Y_t}{\partial K_t}K_t + \frac{\partial Y_t}{\partial G_{K,t}}G_{K,t}\right]}_{\textit{aggregate capital income}} + \underbrace{\left[\frac{\partial Y_t}{\partial L_t}L_t + \frac{\partial Y_t}{\partial G_{L,t}}G_{L,t}\right]}_{\textit{aggregate wage income}}$$

holds, so that national income is not exhausted if private inputs were paid their partial marginal product. We assume that private capital and labour have some way to appropriate the benefits of certain public inputs and convert them into private factor income. Thus, the income share of the publicly provided private capital is

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[4] Wilson and Gordon (2003) discuss a model where households shift into or out of the jurisdiction in response to increases or decreases of local tax rate and public consumption services. They assume, however, that residents directly control tax rates whereas the government only controls expenditure.

[5] This kind of public input is often referred to "factor-augmenting" because the benefits of the public input accrue not to firms as profits but to the factor owners (see McMillan 1979). Note, that the creation of atmosphere type of public capital induces only indirect productivity effects to capital and labour.

distributed to private capital and labour, and both private factors are paid more than their partial marginal product (Gramlich 1994).[6] We distinguish a publicly provided private input that is bound on labour ($G_{L,t}$) and another one that is bound on private capital ($G_{K,t}$). These publicly provided inputs can only be used by firms by employing private factors. An example of investments that increase $G_{L,t}$ and improve labour income is public expenditure in education. According to the OECD (2005) resources for education in OECD countries depend heavily on the allocation of public budgets. Public funding today provides for most spending by educational institutions, with over 90% of primary and secondary expenditure coming from this source. Better-educated adults earn more on average. However, investment in education brings both individual and collective rewards. With respect to $G_{K,t}$ we think of public investment in a modern transportation and energy infrastructure. The European Commission (2005) argues that this kind of public investment in particular has a positive impact on private sector investment and enterprise decisions by improving the economic attractiveness of locations. The described example shows that public ownership of capital does not generate rents that directly enter the public budget, but generates factor rents. As long as public inputs are free of charge they can be interpreted as "unpaid factors".

3 The private sector

In the private sector, private capital has two costs to the firm: the rental price r_t and a source-based tax on capital revenue, where $\theta_{K,t}$ denotes the capital tax rate. Firms invest capital up to the point where the marginal revenue of private investment equals the costs. Since firms are free to invest and produce domestically or abroad, net of tax return of capital is the same everywhere $r_t = r^*$. The supply of capital is completely price elastic. The marginal revenue of private capital

$$\frac{r^*}{1 - \theta_{K,t}} = \frac{\partial Y_t}{\partial K_t} + \frac{\partial Y_t}{\partial G_{K,t}} \frac{G_{K,t}}{K_t} \tag{2}$$

is the sum of the partial product of private capital $\partial Y_t / \partial K_t$ plus the output share of public capital appropriated by private capital $(\partial Y_t / \partial G_{K,t})(G_{K,t}/K_t)$.[7] Thus the aggregate domestic output

$$Y_t = r^* K_t + W_t + \left(\frac{\partial Y_t}{\partial K_t} K_t + \frac{\partial Y_t}{\partial G_{K,t}} G_{K,t} \right) \theta_{K,t}$$

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[6] In the literature we also find "firm-augmenting" public inputs that are congestible among firms and "semi-public input" congestible within industries. Since we argue in a one-sector model, semi-public inputs are not considered. Firm-augmenting public inputs are unpaid factors that generate a rent, which can be absorbed by firms as a profit. In a fiscal competition framework, firm-augmenting public inputs that generate profits are discussed by Richter (1994) and Matsumoto (2000).

[7] This assumption is also found by Oates and Schwab (1991, p. 130) and Gerber and Hewitt (1987, p. 456).

can be decomposed in an income share that goes to the mobile factor r^*K_t, the gross wage income W_t that goes to the immobile private households and the source tax revenue received by the government.

Since we assumed that all factors are marginal product complements, the second-order cross derivations of Y_t are positive. Therefore all three kinds of public capital have a so-called indirect productivity effect on private capital in the sense that an increase in the supply of $G_{i,t}$ raises the partial productivity of private capital. However, only $G_{K,t}$ that is distributed among firms in proportion to each firm's capital stock generates a rent to private capital. Equation 2 shows that *ceteris paribus*, an inflow of a marginal unit of private capital lowers the rent appropriated by each unit of private capital invested in the jurisdiction and thus creates a negative externality to private capital. This reminds us of congestion externalities as modelled by Sinn (2003, 1997). However in our model the source tax is not justified by externalities. What should in fact be the bad side of lowering a rent that goes to the mobile factor? As will be shown, the potential problem of a marginal capital inflow is the induced marginal effect to capital income that may exceed its partial output effect if the source tax is chosen on an inefficient level.

The household sector is designed according to the overlapping-generations model. An individual born at time t supplies a fixed amount of labour and pays a proportional tax rate $\theta_{L,t}$ on per capita wage income $w_t = W_t/L_t$. Since labour is supplied inelastically, the wage tax can be considered as equivalent to a lump sum tax. From the perspective of the private agents, the fiscal parameters $G_{i,t}$, $\theta_{K,t}$, and $\theta_{L,t}$ are exogenous. Each young person consumes $\bar{c}_t^y$ of the net income and saves the remainder $s_t = (1 - \theta_{L,t})w_t - \bar{c}_t^y$. In the second period of his life the individual consumes $\bar{c}_{t+1}^o$ that equals all his wealth, both interest and principal $\bar{c}_{t+1}^o = s_t(1 + r^*)$. Like firms, private households have access to the world capital market so r^* is the time-invariant return on private saving. Domestic and foreign claims on capital are assumed to be perfect substitutes as stores of value. No residence-based tax on capital income is levied. The decision problem for young people is to maximize the lifetime log utility function $u(\bar{c}_t^y, \bar{c}_{t+1}^o) = \ln \bar{c}_t^y + \vartheta \ln \bar{c}_{t+1}^o$, with $0 < \vartheta < 1$, subject to the budget constraint $\bar{c}_t^y = (1 - \theta_{L,t})w_t - \bar{c}_{t+1}^o/(1 + r^*)$. The parameter ϑ denotes the subjective discount factor. The assumption of a log utility function leads to a constant ratio of individual optimal consumption in the first and second period of lifetime, which simplifies the following analyses. The optimal consumption of somebody born in t when in old age is $c_{t+1}^o = \vartheta(1 + r^*)c_t^y$. The lifetime budget constraint of the private household is thus given by

$$0 = (1 - \theta_{L,t})w_t - (1 + \vartheta)c_t^y \qquad (3)$$

The indirect utility function, that expresses the maximum utility achievable by the private household at a given interest rate r^* and wage income is given by

$$v(w_t, \theta_{L,t}, r^*, \vartheta) = \left\{ \ln \frac{1}{(1 + \vartheta)} + \vartheta \ln \frac{\vartheta(1 + r^*)}{(1 + \vartheta)} \right\} + (1 + \vartheta)\ln(W_t - \phi_{L,t}/L_t).$$

$$(4)$$

4 The welfare maximizing tax and investment strategy of an autonomous jurisdiction

The government's total tax revenue is the sum of the capital tax revenue $\phi_{K,t} = (Y_t - W_t)\theta_{K,t}$ and the wage tax revenue $\phi_{L,t} = W_t\,\theta_{L,t}$. Both tax rates $\theta_{L,t}$ and $\theta_{K,t}$ are allowed to be time-variant. Public investment is $\sum_{i=P,K,L} G_{i,t+1} - (1 - \chi_i)G_{i,t}$ and χ_i denotes the appropriate depreciation rate. Public consumption is neglected in the model. The budget constraint of the public sector is thus given by

$$\sum_{i=P,K,L} \left[G_{i,t+1} - (1 - \chi_i)G_{i,t} \right] - \phi_{L,t} - \phi_{K,t} = 0. \tag{5}$$

We assume that the government has the objective to maximize the utility $v(w_t, \phi_{L,t}, r^*, \vartheta)$ of its residents and discounts the utility of future generations at rate $\lambda > 0$. The government maximizes a social welfare function of the form $\Psi = \sum_{t=1}^{T=\infty} (1 + \lambda)^{1-t} v(w_t, \phi_{L,t}, r^*, \vartheta)$ over an infinite optimization horizon[8] subject to the private constraint (2) and the public budget constraint (5). Furthermore, additional constraints hold that $G_{i,1}$ are given. Accordingly, the Lagrangian expression is

$$Z\left(\phi_{K,t}, \phi_{L,t}, G_{i,t+1}, K_{t+1}\right) = \Psi + \sum_{t=1}^{T} \mu_t \left[\phi_{L,t} + \phi_{K,t} - \sum_{i=P,K,L} G_{i,t+1} + (1 - \chi_i)G_{i,t} \right]$$
$$+ \sum_{t=1}^{T} \rho_t \left[Y_t\left(G_{i,t}, K_t\right) - W_t\left(G_{i,t}, K_t\right) - \phi_{K,t} - r^* K_t \right]$$

where the Lagrange multipliers μ_t and ρ_t are functions of the time t. The control variables of the government are the capital tax revenue $\phi_{K,t} = (Y_t - W_t)\theta_{K,t}$, the wage tax revenue $\phi_{L,t} = W_t\,\theta_{L,t}$ and the three kinds of public capital $G_{i,t}$ (for i = P, K, L). From the first-order conditions of the optimization problem – presented in the Appendix – we deduce the shadow price in utility terms of tax revenue μ_t that depends on the underlying tax instrument:

$$\mu_t \le (1 + \lambda)^{1-t}(1 + \vartheta) \left\{ \frac{1}{(W_t - \phi_{L,t})} \right\} \quad \phi_{L,t} \ge 0; \quad \phi_{L,t} \frac{\partial Z}{\partial \phi_{L,t}} = 0 \tag{7}$$

$$\mu_t \le (1 + \lambda)^{1-t}(1 + \vartheta) \frac{1}{(W_t - \phi_{L,t})} \frac{\left\{ \frac{\partial W_t}{\partial K_t} \right\}}{\left[r^* - \frac{\partial(Y_t - W_t)}{\partial K_t} \right]} \quad \phi_{K,t} \ge 0; \quad \phi_{K,t} \frac{\partial Z}{\partial \phi_{K,t}} = 0 \tag{8}$$

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[8] If the government has the same time horizon as the private household, then T = 1. In this case the government does not engage in public investment at all. The reason is that public investment undertaken in period t affects only wage income earned in later periods, whereas the tax burden of financing this public investment occurs in period t.

From (1) and (2) we know $r_t{}^* = (Y_t - W_t - \phi_{K,t})/K_t$. The public decision-maker uses the tax instrument that causes fewer utility losses for the private sector. Thus a source-based tax on capital revenue $\phi_{K,t} \geq 0$ is chosen only if the first term of condition (8) is binding. In this case the shadow price of a capital tax is smaller than or equal to the shadow price of a wage tax. To meet this requirement

$$\phi_{K,t} = \theta_{K,t}(Y_t - W_t) \leq \left[(Y_t - W_t) - \frac{\partial Y_t}{\partial K_t} K_t \right]$$

must hold. Using Eq. 2 it can be shown that the amount of taxes contributed by private capital never exceeds the share of public capital income that is appropriated by private capital $(\partial Y_t/\partial G_{K,t}) G_{K,t}$. Given an interior solution the optimal source tax rate is

$$\theta_{K,t}^* = \frac{\frac{\partial Y_t}{\partial G_{K,t}} G_{K,t}}{(Y_t - W_t)}. \tag{9}$$

Thus the optimal public policy is to tax away the rents appropriated by the private capital so that the corresponding tax revenue equals exactly the share of public capital income $(\partial Y_t/\partial G_{K,t})G_{K,t}$. This result is suggestive of Sandmo (1972), who defines an optimal tax to finance a firm-augmenting public input as a direct charge on firms. In Sandmo (1972), the firm-augmenting public input can be interpreted as an unpaid factor that generates an excess profit to private firms. Since $G_{K,t}$ represents an unpaid factor that generates a factor rent to private capital, $\phi_{K,t}{}^*$ is a direct charge on private capital for the supply of $G_{K,t}$. However, as shown in Kellermann (2006) the revenue of this benefit tax is not cost equivalent in the sense that the tax revenue $\phi_{K,t}{}^* = (Y_t - W_t) \theta_{K,t}{}^*$ covers exactly the public expense caused by the optimal provision of $G_{K,t}$.

That rents earned by mobile factors provides an efficient and thus highly desirable means of raising tax revenue is certainly not a surprisingly result. Zodrow (2006) quotes several arguments supporting source-based capital income taxes on account of rents. What in a way may surprise, is that according to Eq. 9 neither the supply of public capital from the creation of atmosphere type $G_{P,t}$ nor the supply of $G_{L,t}$ justifies a source tax on capital. The fact that $G_{P,t}$ and $G_{L,t}$ are complements to private capital, so that an increase in the supply of both kinds of public capital *ceteris paribus* improves the marginal productivity of private capital, cannot be used as an argument to support a source tax. If the output elasticity of $G_{K,t}$ is assumed to be zero, so that public capital generates no rents to private capital, then $\theta_{K,t}{}^* = 0$ despite the beneficial impact of $G_{P,t}$ and $G_{L,t}$ that goes to private capital.

In this respect, the optimal tax rule given by Eq. 9 deviates from the result derived by Feehan and Matsumoto (2000). By examining the case of a creation of atmosphere type of public capital,[9] they argue that each of the private factors should be taxed proportional to the change in this factor's marginal productivity due to a

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[9] Feehan and Matsumoto (2000) use the expression factor-augmenting public input.

marginal change in the public input. However, Feehan and Matsumoto (2000) do not consider the case of a small open economy that competes for mobile capital but argue in a static world where domestic factors are fixed in supply. Thus the problem of capital flight is neglected. Compared with this, in our model capital flight is a major concern of the welfare maximizing government. If the output elasticity of $G_{K,t}$ is assumed to be zero, a source tax rate $\theta_{K,t} > 0$ leads to inefficient low private investment. Condition (2) shows that in this case the partial marginal output of private capital exceeds the world interest rate $\partial Y_t/\partial K_t > r^*$. The income share of the immobile factors, i.e. labour income and tax revenue, can thus be improved by further capital inflows. The world interest rate r^* can be interpreted as the opportunity costs of private capital to the small open economy. In other words, a reduction of the source tax raises wage income by more than the induced loss of tax revenue, so that private households prefer a wage tax to a source tax. The only exception occurs if the partial marginal productivity of $\partial Y_t/\partial K_t < r^*$. In this case the output elasticity of $G_{K,t}$ is positive and the mobile private capital appropriates a factor rent, that according to (9) justifies a source tax.

Note that for $\theta_{K,t} = \theta_{K,t}^*$ the private marginal rate of time preference $[(\partial u/\partial c_1^y)/(\partial u/\partial c_{1+1}^0)-1]$ as well as the partial productivity of private capital equalizes the marked interest rate r^*. On that score in the private sector, the source tax rate $\theta_{K,t}^*$ makes a first best solution possible. According to the so-called "second-best shadow pricing approaches", discussed in the theory of optimal taxation, we would expect that in this case the government should also use r^* as a social discount rate (Sandmo and Drèze 1971; Marchand and Pestieau 1984). However, from the optimization problem (6) and condition (3) we receive the optimal investment path of the jurisdictional government as

$$\frac{\partial Y_{t+1}}{\partial G_{i,t+1}} = (1 + \lambda)(1 + n)\frac{c_{t+1}^y}{c_t^y} - (1 - \chi_i). \tag{10}$$

Condition (10) can be interpreted as a modified golden rule of government investment (Barro and Sala-i-Martin 1995). It states that decreasing lifetime consumption for the individuals working in period t leads to a decrease of their utility $L_t \frac{\partial u}{\partial c_t^y} = L_t \frac{(1+\vartheta)}{c_t^y}$ but makes an increase in the utility of the individuals working in period t+1 possible through public capital accumulation. According to the optimality condition, this utility increase discounted to t using the social discount rate $\lambda > 0$ must equal the initial utility decrease. Condition (10) shows that the rate of return on government capital does not unconditionally equal the marginal product of private capital, which according to (2) and (9) equals r^*. Rather, it would appear that r^* (and with that the private rate of time preference) exceeds the marginal social rate of time preference.[10]

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[10] Marglin (1963) discusses some reasons why there should be a difference between the way we view saving versus consumption decisions collectively and the way we view these decisions individually. Nevertheless, the assumption that the private rate of time preference differs from the social one is not decisive for our results. Marglin (1963) discusses some reasons why there should be a difference between the way we view saving versus consumption decisions collectively and the way we view these decisions individually. Nevertheless, the assumption that the private rate of time preference differs from the social one is not decisive for our results.

5 Restriction to a wage tax or a source tax

What happens if the government is restricted to one or the other tax instrument for whatever reason? First we consider the case where only a wage tax is imposed, so that the optimal investment path of the jurisdictional government is given by:

$$
\frac{\partial Y_{t+1}}{\partial G_{i,t+1}} = \left[(1+\lambda)(1+n)\frac{c^y_{t+1}}{c^y_t} - (1-\chi_i) \right]
$$
$$
+ \left[\frac{\partial Y_{t+1}}{\partial G_{K,t+1}} G_{K,t+1} \right] \frac{\dfrac{\partial \left[\frac{\partial Y_{t+1}}{\partial K_{t+1}} K_{t+1} + \frac{\partial Y_{t+1}}{\partial G_{K,t+1}} G_{K,t+1} \right]}{\partial G_{i,t+1}}}{\dfrac{\partial W_{t+1}}{\partial K_{t+1}} K_{t+1} + \frac{\partial Y_{t+1}}{\partial G_{K,t+1}} G_{K,t+1}}
\tag{11}
$$

This optimality condition equals (10) only if the output share of public inputs appropriated by mobile capital $[\partial Y_{t+1}/\partial G_{K,t+1}]G_{K,t+1}$ is zero, so that the second part of the RHS of Eq. 11 disappears. In this case $\theta_{K,t}^* = 0$ holds and condition (9) is not violated by the restriction, but it is efficient to finance all public investments by a wage tax.

Equation (11) shows that the opportunity costs of all three kinds of public inputs include the excess burden incurred by a non-optimal tax policy. Although the wage tax itself can be interpreted as a non-disturbing lump sum tax, it is not the appropriate tax instrument to confiscate the private capital's factor rent. Thus the restriction to a wage tax leads to the problem of an inefficiently high inflow of private capital. Equation (2) shows that for $\theta_{K,t} = 0$ the marginal output effect of private capital, i.e. its partial productivity is lower than the marginal revenue of private capital r*. Excluding the source tax, it becomes impossible to reach the optimum described by Eq. 9. Furthermore, investment in $G_{K,t}$ now has to be financed by a wage tax, which again lowers the available income of the private households. Assuming constant output elasticities α, β and ε_i (i = L,K,P) with respect to labour, private capital and all three kinds of public capital, (11) reduces to

$$
\frac{\partial Y_{t+1}}{\partial G_{i,t+1}} = \left[(1+\lambda)(1+n)\frac{c^y_{t+1}}{c^y_t} - (1-\chi_i) \right] \frac{(\alpha + \varepsilon_L)\beta + \varepsilon_K}{(\alpha + \varepsilon_L)(\beta + \varepsilon_K)}
\tag{11'}
$$

Equation (11') shows that the opportunity costs rise unequivocally with respect to all public factors and are the same for $G_{P,t+1}$, $G_{L,t+1}$ and $G_{K,t+1}$. Only for $\varepsilon_K = 0$ Eq. (11') equals Eq. (10).

If the government is restricted to a source tax, the opportunity costs of public investment become

$$\frac{\partial Y_{t+1}}{\partial G_{i,t+1}} = \left((1+\lambda)(1+n)\frac{c^y_{t+1}}{c^y_t} \frac{\left[\frac{\partial W_t}{\partial K_t}\right]\left[r^* - \frac{\partial(Y_{t+1}-W_{t+1})}{\partial K_{t+1}}\right]}{\left[\frac{\partial W_{t+1}}{\partial K_{t+1}}\right]\left[r^* - \frac{\partial(Y_t-W_t)}{\partial K_t}\right]} - (1-\chi_i) \right)$$
$$- \left\{ \left[\frac{\partial Y_{t+1}}{\partial G_{K,t+1}} G_{K,t+1}\right] - \sum_{i=P,K,L}\left[G_{i,t+2} - (1-\chi_i)G_{i,t+1}\right] \right\} \frac{\left[\frac{\partial W_{t+1}}{\partial G_{i,t+1}}\right]}{\left[\frac{\partial W_{t+1}}{\partial K_{t+1}}K_{t+1}\right]}. \tag{12}$$

Under the arbitrary assumption that total public net investment $\sum_{i=P,K,L}\left[G_{i,t+1} - (1-\chi_i)G_{i,t}\right]$ equals the factor rent $\frac{\partial Y_{t+1}}{\partial G_{K,t+1}}G_{K,t+1}$, the restriction on a source tax is not binding. In this case the second term of the RHS of Eq. (12) vanishes and since $r^* = \partial Y_t/\partial K_t$ the whole expression (12) reduces to (10). In all other cases, the restriction on a source tax is binding and the opportunity costs of public capital adjust. If we again assume constant output elasticities in the long run, public opportunity costs are given by

$$\frac{\partial Y}{\partial G_i} = [(1+\lambda)(1+n) - (1-\chi_i)]\left(\frac{\beta}{\beta + \varepsilon_K - \left(\sum_{i=P,K,L}[(n+\chi_i)G_i]/Y\right)} \right). \tag{12'}$$

For public net investment $\sum_{i=P,K,L}[(n+\chi_i)G_i]$ exceed the income share $\varepsilon_K Y$ that, according to Eq. (9), equals the optimal source tax revenue, the restriction $\theta_{L,t} = 0$ raises the opportunity costs of all three public inputs. Therefore the government invests less than it would without this restriction.

6 Incidence of a source-based capital tax in the long run

The derived results can be illustrated by examining the functional distribution of income between mobile private capital and labour. For the sake of simplicity only $G_{K,t}$ is considered, whereas the two others types of public capital are neglected. The production function is specified in the form $Y_t = L_t^\alpha K_t^\beta G_{K,t}^{\varepsilon_K}$, where the constant output elasticity with respect to labour, private capital and public capital, $\alpha + \beta + \varepsilon_K = 1$ and $\alpha,\beta,\varepsilon_K > 0$. In the following, we focus on the steady state and neglect population growth, so that $n = 0$.[11]

Figure 1 shows the convex partial productivity curve of private capital $(\partial Y/\partial K) = \beta(Y/K)$ for given G_K and L. *Ceteris paribus*, an extension of public capital supply G_K improves the partial marginal productivity of private capital as a result of the indirect productivity effect and thus shifts the productivity curve upwards. However, this indirect productivity effect does not justify a source tax. We know that

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[11] Ni and Wang (1995) discuss the stability properties in a comparable system. They show that under the assumptions made the steady states are locally stable.
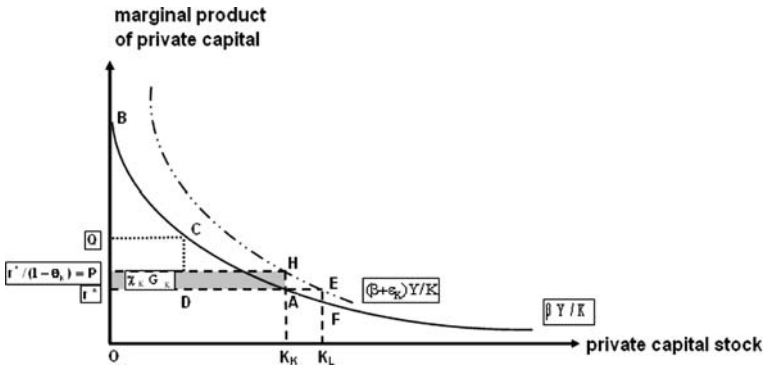
Fig. 1 Incidence of a source tax

the marginal revenue of private capital exceeds its partial marginal product if $\varepsilon_K > 0$. Therefore, a second pointed line is drawn in Fig. 1, which shows the marginal revenue of private capital given by $\frac{\partial Y}{\partial K} + \frac{\partial Y_L}{\partial G_K}\frac{G_K}{K} = (\beta + \varepsilon_K)\frac{Y}{K}$. Aggregate income is marked by the marginal productivity curve, but the distribution of the income between the two private factors depends on the pointed auxiliary curve.

When no source tax is levied, r* is the price of private capital and the market equilibrium is given by $K_L = (((\beta + \varepsilon_K)/r^*)L^\alpha G_K^{\varepsilon_K})^{1/1-\beta}$ since private capital revenue exceeds its partial marginal productivity. The corresponding total output $Y_L = \left(((\beta + \varepsilon_K)/r^*)^\beta L^\alpha G_K^{\varepsilon_K}\right)^{1/1-\beta}$, i.e. gross income of the factors employed in the small open economy, is represented by the area $0K_LFB$. Total income can be divided into aggregate wage income and aggregate capital income. Since capital income equals $K_L r^*$, it is shown by the area $0K_L Er^*$ and gross wage income $W_L = Y_L - K_L r^*$ is given by the residual (r*AB-AFE). The available income of the private household is given by $V_L = W_L - \phi_L$. In the long run, equilibrium public investment and thus the long run costs of providing G_K are given by $\phi_L = \chi_K G_K$, as represented in Fig. 1 by the areas r*DCQ. Using a wage tax as a financing instrument for public infrastructure the available wage income of the private household is represented by the area V_L = (r*AB-AFE- r*DCQ). If the wage tax is replaced by a source tax, user costs of private capital rise to $r^*/(1-\theta_K)$ and private capital is driven out of the small open economy. In the equilibrium, the capital stock shrinks from K_L to $K_K = \left((\beta/r^*)L_t^\alpha G_{K,t}^{\varepsilon_K}\right)^{1/1-\beta}$, for $\theta_K = \theta_K^* = \varepsilon_K/(1-\alpha)$. The change in the tax instrument further induces a decrease in aggregate income from Y_L to $Y_K = \left((\beta/r^*)^\beta L_t^\alpha G_{K,t}^{\varepsilon_K}\right)^{1/1-\beta}$, where Y_K is represented by the area $0K_KAB$. The source tax revenue $\phi_K = \chi_K G_K$ is given by the shaded areas r*AHP which

exactly equals r*DCQ.[12] However, the reduction of aggregate output shown by the area $K_K K_L FA$ is not borne by private households. By subtracting the gross capital income $K_K r^*$, represented by $OK_K Ar^*$ and the source tax revenue r^*AHP from the aggregate income Y_K, one derives the available wage income of the private households $W_K = V_K = (0K_K AB - 0K_K Ar^* - r^*AHP)$.[13] Compared to the case where a wage tax is levied, the available income V_K exceeds V_L by AFE.

7 Conclusions

The idea that even in conditions of fiscal competition mobile capital can be taxed according to the benefit principle to finance public infrastructure is widespread. Oates (1999) argues that if capital tax revenue is used by government to supply public infrastructure that improves the productivity of private capital, the tax-induced increase of the costs of capital in the jurisdiction will be compensated by an increase in the return of capital and thus counteract the capital outflow. However, the question remains whether the benefit of a capital inflow induced by infrastructure that is financed by a tax on immobile factors exceeds the benefit of a source tax.

Taking the perspective of a small, open and autonomous jurisdiction, it can be shown that the optimal financing instrument of public infrastructure depends on some technical properties of the publicly provided inputs. Public inputs of the "creation of atmosphere" type should not be financed by a source tax on mobile capital despite the fact that these inputs have an indirect productivity-enhancing effect on private capital. The same holds for publicly provided private inputs that are bound on labour. Public inputs, that evoke only indirect productivity effect on private capital, does not justify a source tax on the mobile factor. Actually, a source tax is an efficient financing instrument only for public capital that generates a factor rent on private capital. If such a factor rent occurs, it should be confiscated by the government through a source tax. If the government is, for whatever reason, restricted to a wage or a source tax, the supply of public capital can become suboptimal.

Appendix

This appendix presents some results derived in the text:

$$Z\big(\phi_{K,t}, \phi_{L,t}, G_{i,t+1}, K_{t+1}\big) = \Psi + \sum_{t=1}^{T} \mu_t \left[\phi_{L,t} + \phi_{K,t} - \sum_{i=P,K,L} G_{i,t+1} + (1 - \chi_i)G_{i,t} \right]$$
$$+ \sum_{t=1}^{T} \rho_t \big[Y_t(G_{i,t}, K_t) - W_t(G_{i,t}, K_t) - \phi_{K,t} - r^*K_t \big]$$

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[12] Note, that the source tax revenue $\chi_K G_K = \phi_K$ meets Eq. 9 only if $\lambda = 0$.

[13] $V_L = V_K \left[((\beta + \varepsilon_K)/\beta)^{\frac{\beta}{1-\beta}} - (\varepsilon_K/\alpha) \right]$ and $\left[((\beta + \varepsilon_K)/\beta)^{\frac{\beta}{1-\beta}} - (\varepsilon_K/\alpha) \right] < 1$

$$\frac{\partial Z}{\partial \phi_{L,t}} = \frac{\partial \Psi}{\partial \phi_{L,t}} + \mu_t \leq 0; \qquad\qquad \phi_{L,t} \geq 0; \phi_{L,t} \frac{\partial Z}{\partial \phi_{L,t}} = 0 \qquad (13)$$

$$\frac{\partial Z}{\partial \phi_{K,t}} = \mu_t - \rho_t \leq 0, \qquad\qquad \phi_{K,t} \geq 0; \phi_{K,t} \frac{\partial Z}{\partial \phi_{K,t}} = 0 \qquad (14)$$

$$\frac{\partial Z}{\partial K_{t+1}} = \frac{\partial \Psi}{\partial K_{t+1}} + \rho_{t+1} \left[\frac{\partial (Y_{t+1} - W_{t+1})}{\partial K_{t+1}} - r^* \right] = 0 \qquad (15)$$

$$\rho_{t+1} = - \frac{\left[\frac{\partial \Psi}{\partial K_{t+1}} \right]}{\left[\frac{\partial (Y_{t+1} - W_{t+1})}{\partial K_{t+1}} - r^* \right]}$$

$$\frac{\partial Z}{\partial G_{i,t+1}} = \frac{\partial \Psi}{\partial G_{i,t+1}} - \mu_t + \mu_{t+1}(1 - \chi_i) + \rho_{t+1} \left[\frac{\partial (Y_{t+1} - W_{t+1})}{\partial G_{i,t+1}} \right] = 0 \qquad (16)$$

Eliminating the Lagrange parameters and replacing $\phi_{K,t}^* = \theta_{K,t}^*(Y_t - W_t) = [\partial Y_t/\partial G_{K,t}]G_{K,t}$ according to (9) we receive the modified golden rule of public investment presented in (10).

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