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**Capital Tax Competition and  
Dynamic Optimal Taxation**

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# Capital Tax Competition and Dynamic Optimal Taxation

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## Abstract

I analyze international tax competition in a framework of dynamic optimal taxation for strategically competing governments. The global capital stock is determined endogenously as in a neo-classical growth model. With perfect commitment and a complete tax system (where all factors of production can be taxed), governments set their capital taxes so that the net return is equal to the social marginal product of capital. Capital accumulation thus follows the modified golden rule. This is independent of relative country size, capital taxes in other countries, and the degree of capital mobility. In contrast, with an exogenous capital stock returns on capital are pure rents and a government's ability to capture them is limited through capital flight, triggering a race to the bottom. With an endogenous capital stock, capital is an intermediate good and taxes on it are not used to raise revenues, but to implement the optimal capital stock. Even in a non-cooperative game it is thus not individually rational for governments to engage in tax competition. I provide a general proof that if the modified golden rule holds in a closed economy, then it also does in an open economy.

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*Keywords:* Tax Competition, Open Economy, Capital Taxes, Capital Mobility, Ramsey Taxation, Optimal Dynamic Taxation

## 1 Introduction

In the past two decades, the mobility of capital has greatly increased as flows of foreign direct investment have reached unprecedented heights. In the European Union, for example, the ongoing

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integration process has created conditions of almost perfect capital mobility, as Mendoza and Tesar (2005) argue. This has led to concerns about tax competition, i.e. that governments lower their capital taxes in order to attract capital from other jurisdictions and as a consequence, taxes on labor income would have to rise or government spending to be reduced. There are communiques by the OECD and the European Commission on “harmful tax competition,” see OECD (1998) and EU (1997). This does not have to be confined to the country-level: Burstein and Rolnick (1994) argue that harmful tax competition is taking place between states within the United States.

In this paper I analyze the implications of dynamic optimal taxation for tax competition. The question is, how should non-cooperative governments optimally set their fiscal policy when the capital stock is determined by optimal savings decisions and it is mobile across jurisdictions? I find that with perfect commitment, governments set their long-run capital taxes in order to achieve the “modified golden rule” capital-labor ratio and not to raise revenues.<sup>1</sup> This is independent of taxes in other countries; in other words, governments will optimally not engage in tax competition. However, it does not imply that capital taxes are zero. The main assumption driving the results is the existence of a tax system which allows the government to tax all factors of production independently, i.e. in the baseline case to allow separate labor and capital taxes (lump-sum taxes are of course excluded).

The results are quite robust to other assumptions, often found in the tax-competition literature: for instance, the number of countries, productive infrastructure spending, a public consumption good, asymmetries between countries, increasing returns to scale, and whether governments are benevolent or self-interested.

This contrasts starkly with the traditional results when the global capital stock is exogenously determined, which are summarized well in the Mirrlees Review:

This literature has focused on the international spillover effects which national tax policies can have, and which are not accounted for when governments choose their tax policies solely with the purpose of maximizing national welfare. For example, if one country lowers its source-based corporate income tax, it may attract corporate investment from abroad, thereby reducing foreign national income and foreign tax revenues. When this spillover effect is not accounted for by individual governments, there is a presumption that corporate tax rates will be set too low from a global perspective (Adam, Besley, Blundell, Bond, Chote, Gammie, Johnson, Myles, and Poterba (2010)).

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<sup>1</sup>From here on, when I refer to the results of this paper, I do not always repeat that it concerns long-run policy. I explain below why I focus on the long-run.

What explains this discrepancy and why should governments not lower their capital taxes when the capital stock is internationally mobile? After all, the government of a large economy can use its tax rates to influence the world interest rate and directly tax foreign capital invested at home.

Under the same assumptions as for the model with endogenous capital, I investigate optimal taxes on a mobile factor that is in fixed global supply. I find that optimal tax rates for this factor are equal to one in a closed economy and zero in a small open economy, with large open economies ranking in-between. For a fixed global capital stock, the supply in a closed economy is perfectly inelastic, so a tax on it is non-distortionary.<sup>2</sup> In a large open economy, capital moves abroad in response to taxes, but the government still has market power to influence the equilibrium rate of return and uses it to capture (part of) the rents accruing to that factor. As the relative size of an economy decreases, capital taxes will lead to higher outflows of capital and optimal rates will hence be lower. Since capital taxes are globally non-distortionary, this tax competition is inefficient and tax harmonization is desirable.

When the capital stock is endogenous through households' optimal savings, on the other hand, capital is an intermediate good. From society's perspective, capital is produced from current output, is used as an input in future production, and does not convey any direct utility. Governments therefore do not find it optimal to engage in an uncooperative game of trying to obtain the largest share possible of rents from capital, as there are no rents to capital. Countries' individually optimal capital taxes are thus efficient from a global perspective.

For a large class of models, it is optimal in a closed economy to implement the modified golden rule in the long run (which may imply positive, negative, or zero taxes). This means that social and private returns to capital are equalized. If the economy were open and capital flowed freely, would the government want to attract capital from abroad by lowering its tax rates? No, since lowering taxes would imply higher private returns, which would thus be larger than the social returns. The government would then spend tax revenues to attract capital from foreign investors, whose returns would be larger than what the incoming capital would contribute to society – that cannot be optimal. I show that in general, if the modified golden rule holds in a closed economy, then it also does in an open economy.

I focus on the long-term results with perfect commitment for two reasons: First, the Ramsey

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<sup>2</sup>Even if the global capital supply is not perfectly inelastic, it remains optimal to tax capital for revenue purposes in a large open economy.

approach assumes rational expectations from time zero on and future (expected) taxes affect savings today. Savings at time zero, however, are not influenced by taxes at that time. This is a modeling inconsistency, as expectations for taxes in the short-run are not modeled and there is hence no reaction from agents to violations of these expectations. If it is possible to dupe agents and impose lump-sum taxes on capital at time zero, though, then the government should attempt to do so at other time periods, too, but that violates of course rational expectations.<sup>3</sup> This is the famous time-inconsistency problem first pointed out by Kydland and Prescott (1977). As argued for a similar problem in monetary policy by Woodford (1999), I thus focus on the long-run results. This can be either a steady state or any non-degenerate long-run average, so results do not rely on the assumption that the former exists. Second, I focus on perfect commitment: Governments might be able to credibly commit to future policy, since one could view it as a repeated game where reputation effects would induce the government to refrain from expropriatory capital taxation. Furthermore, the results in this paper can be interpreted as what a government ought to do if it could commit, it serves as a benchmark, as Kydland and Prescott (1980) argue.

Whether capital tax competition is happening or not has not been decisively answered empirically. The theoretical literature mostly supports the view that it is harmful, but to my knowledge all papers find that governments should optimally set their taxes differently when capital is mobile. This paper shows that being in an open economy with international capital flows does not change how capital is optimally taxed. It suggests that capital tax competition is an issue only insofar as the tax system is incomplete. It thus contributes to the policy debate on optimal capital taxation.<sup>4</sup> Moreover, it suggests that tax competition over capital is not as much of a threat as feared. If lack of commitment is an issue, then tax competition due to the international mobility of capital may even be welfare-enhancing.

The remainder of the paper is organized as follows: the next section discusses the related literature and how it compares to the results of this paper. Section 3 contains an example economy and section 4 investigates taxes on a mobile factor in exogenous supply. Section 5 shows the importance of a complete tax system, whereas section 6 discusses the robustness of the result

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<sup>3</sup>As (Diamond and Saez, 2011, p.179) put it, “taxing initial wealth as much as the available tax tools allow [...] strains the relevance of the assumption that the government is committed to a policy that this taxation of wealth will not be repeated.” As a sidenote, the results in this paper do not rely on the infinite-dynasty assumption, as section 7 encompasses overlapping generations.

<sup>4</sup>(Mankiw, Weinzierl, and Yagan, 2009, p.167) for example argue that “in the modern economy [...] the increasing globalization of capital markets [...] can lead to highly elastic responses of capital flows to tax changes,” which is probably true, but it does not invalidate arguments in favor of positive capital taxes.

to different modeling assumptions. Section 7 generalizes the previous results. The final section concludes.

## 2 Related Literature

Most of the early academic papers, such as Zodrow and Mieszkowski (1986) and Wilson (1986), stressed the negative effects of capital tax competition. The vast literature that followed led to many different conclusions (“Bane or Boon?”), see for an overview Wilson and Wildasin (2004) or Nicodème (2006) and Zodrow (2009). A common feature is the simplifying assumption of an exogenously given capital stock. While some papers endogenize it, through some transformation from an endowment, taxes on capital in all of these papers are taxes on the endowment.<sup>5</sup> In this paper, capital is an intermediate good and thus does not contain an endowment component.<sup>6</sup> Section 4 shows in detail how the same model generates completely different predictions for these two types of capital. I believe it highlights the importance of how capital accumulation is modeled, as it also changes the welfare implications. If capital is an endowment, it is efficient to tax its returns fully; when governments play a non-cooperative game of sharing the rents from this endowment, some rents from capital remain (inefficiently) untaxed. If capital is an intermediate good, then taxing capital does not tax any endowment; each government aims to implement the efficient capital allocation, independent of foreign policy.

Chamley (1986) and Judd (1985) showed how long-run capital taxes are optimally zero in a closed economy, whereas Aiyagari (1995) and Erosa and Gervais (2002) for instance provided model economies with non-zero capital taxes. What these papers have in common is that there is no distortion for capital in the long-run, i.e. the modified golden rule holds.<sup>7</sup> It fails when the tax system is incomplete, that is when one of the factors of production cannot be taxed independently, see Correia (1996b) and Chari and Kehoe (1999).

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<sup>5</sup>Sorensen (2004) endogenizes the capital stock in an atemporal model by assuming that some given wealth can be transformed into capital, but the wealth cannot be taxed. Eggert (2000) features endogenous capital, in a two-period model where the initial endowment and first-period consumption cannot be taxed. In both cases, capital taxes indirectly tax the otherwise untaxable endowment.

<sup>6</sup>Again, this is for capital in the long-run, as the accumulation of capital and the formation of expectations until time zero are not explicitly modeled.

<sup>7</sup>In a related paper, Gross (2013a), I show in detail the link between capital’s intermediate good aspect and the optimality of the modified golden rule and how the latter holds for a very large class of models.

Correia (1996a) shows that the Chamley-Judd result of zero optimal taxes in steady-state also holds in a small open economy. In Gross (2013b), I extend the analysis to large open economies. I find that for territorial and hybrid tax systems, long-run capital taxes are zero for a closed and any open economy. This does not hold for residential taxes, however, as the latter do not allow governments to tax all factors of production. Notably, capital invested by foreigners in the home economy cannot be taxed with residential taxes only.<sup>8</sup>

Mendoza and Tesar (2005) quantify the consequences of tax competition in steady state and on the transition path. However, in order to be able to do a computational implementation, they restrict governments to use time-invariant taxes.<sup>9</sup> In a standard closed-economy model, it is optimal to tax the initial capital stock (as it is akin to lump-sum taxation of rents) while setting long-run capital taxes to zero (since capital that is created after time zero is a pure intermediate good). Thus, when the tax rate has to be constant over time, there is a trade-off between optimal capital taxes in the short-run and in the long-run.<sup>10</sup> Mendoza and Tesar (2005) find that there is very little downward pressure on capital taxes when governments cannot adjust consumption taxes; however, when they do, steady-state capital taxes fall below zero in their calibration. The reason is that an unexpected increase in the consumption tax at time zero acts like a tax on the initial capital stock, so capital taxes can be set to a low level to obtain a higher capital stock in the long-run, which is unaffected by consumption taxes.<sup>11</sup> In comparison, I allow taxes to be different over time, so that long-run results are not influenced by the surprise taxation of the initial capital stock, and I provide analytical results.

To avoid time-consistency issues, Klein, Quadrini, and Rios-Rull (2005) use a model in which the government can only commit imperfectly to future taxes and re-optimizes every period, and solve recursively for the equilibrium outcome.<sup>12</sup> In time-consistent models, it is the inability to credibly commit to capital taxes in the future (and to therefore determine them) that creates

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<sup>8</sup>Lejour and Verbon (1998) compare the steady-state welfare implications of source-based and residential taxes in an endogenous savings model, but do not allow for any tax instruments besides capital taxes.

<sup>9</sup>This restriction seems difficult to circumvent – otherwise each government’s strategy is an infinite sequence for each control variable and best responses are hence hard to compute.

<sup>10</sup>Similarly, when the tax rate on capital is restricted (say to be less than or equal to one), taxes on capital beyond period zero can be used to tax the initial capital stock. Agents would like to decrease their capital holdings, as the returns are low, but consuming more drives down the marginal utility. If agents had seen these high capital taxes coming, they would have consumed more before and thus reduced the capital stock at time zero.

<sup>11</sup>Wildasin (2003) looks at a small open economy and also relies on the “surprise factor” for taxes.

<sup>12</sup>Ha and Sibert (1997) also analyze optimal taxes in a time-consistent setting, albeit in an overlapping-generations framework. They find that capital-exporters should subsidize capital and importers should tax it. However, similar to a problem pointed out by Lansing (1999) in an infinite-horizon setting, due to log-utility, savings are independent of capital taxes.

tax competition. The initial capital stock is taken as given by each subsequent government, so it attempts to capture the rents associated with it. The mobility of capital in an open economy impedes it in fully taxing these perceived rents.

In the absence of commitment, tax competition drives down steady-state capital tax rates to the efficient level, since the ability to tax the perceived rents is limited by capital flight. Correspondingly, Quadrini (2005) shows that capital taxes are lower when capital is mobile in a time-consistent framework, but that it represents a welfare improvement.

Empirically, it is not clear whether tax competition takes place or not, i.e. that countries compete over scarce capital by lowering corporate tax rates. Depending on how tax rates are measured, they appear to decline over time (and with increasing capital mobility) or to stay constant, for effective and revenue-based rates respectively, according to Backus, Henriksen, and Storesletten (2008). Devereux, Lockwood, and Redoano (2008) show how the relaxation of capital controls can explain the drop in statutory and marginal effective rates, but do not address revenue-based rates. Chirinko and Wilson (2009) obtain the result that tax rates of states in the US depend negatively on the rates in other states. Brueckner and Saavedra (2001) on the other hand estimate a positive strategic interaction for local property taxes. Mendoza and Tesar (2005) find a similar relationship for corporate tax rates of the big European countries and the US. Krogstrup (2004) uses panel data and argues that the corporate tax burden has fallen by one fifth in the European Union from 1980-2001, being directly attributable to fiercer tax competition. Stewart and Webb (2006), however, see no evidence of a race to the bottom, arguing that former findings to the contrary are the result of methodological flaws. Whether governments compete strategically for capital through taxes or not, it is relatively well-documented that tax rates matter for individual firms' investment decisions (de Mooij and Ederveen, 2003).

### **3 An Example Economy**

In this section I present a simple model illustrating the connection between optimal dynamic taxation and tax competition. In later sections I show how the assumptions can be relaxed and the results generalized. There are two countries with one representative agent living in each. A fixed measure of monopolistically competitive firms produce output in each country from labor and capital. The latter is rented from globally acting, perfectly competitive investment firms. They collect

individuals' savings and invest them in government bonds and capital in both countries. Capital is perfectly mobile, while labor is immobile. The government in each country aims to maximize the home agent's utility and disposes of capital and labor taxes to finance a stream of exogenous expenditures; it may also issue government bonds. Capital taxes are paid according to the territorial principle, i.e. they are paid where the capital is employed. The two governments engage in a one-shot game with each other, announcing a sequence of taxes and bond issues at time zero, to which agents and firms then react.

### 3.1 The Representative Agent

Let there be a measure one of agents in the home country and a measure  $\chi$  abroad. All agents take prices and taxes as given and maximize lifetime utility:

$$\sum_{t=0}^{\infty} \beta^t u(c_t, l_t). \quad (1)$$

$u(c_t, l_t)$  is a utility function that is strictly increasing and strictly concave in consumption  $c_t$  and leisure  $l_t$  (all terms here are in per-capita terms, which is equal to the aggregate for the home country, since the home population size is unitized).<sup>13</sup>  $\beta \in (0, 1)$  is the discount factor, which is common across countries (otherwise a steady state or stable long-run average would not exist); all other parameters, including those of production can be different. The household divides up its total unitized time between labor  $n_t$  and leisure. The per-period budget constraint is:

$$c_t = (1 - \tau_t^n)w_t n_t + (1 + R_t)a_t - a_{t+1}. \quad (2)$$

$w_t$  is the domestic wage,  $\tau_t^n$  are labor taxes,  $a_t$  are asset holdings, and  $R_t$  is the international net rate of return. Initial asset holdings  $a_0 > 0$  are exogenously given.

Utility maximization implies the familiar labor-leisure trade-off and an Euler equation concerning the trade-off between consumption today versus tomorrow (subscripts denote derivatives, e.g.

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<sup>13</sup>To ensure an interior solution, also assume that the marginal utility of consumption (leisure) goes to infinity as consumption (leisure) goes to zero and that the marginal utility of leisure goes to zero as leisure goes to one.

$u_c(t) = \partial u(c_t, n_t) / \partial c_t$ :

$$u_l(t) = u_c(t)(1 - \tau_t^n)w_t \quad (3)$$

$$u_c(t) = \beta u_c(t+1)R_{t+1} \quad (4)$$

Equations (2), (3), and (4) characterize the household behavior together with no-Ponzi conditions (which I leave out for notational convenience).

### 3.2 Firms and Production

There is a continuum of identical firms of measure one, indexed by  $m$ . Each firm produces a differentiable intermediate good  $y_m$ . Assume that the final good  $Y$ , which is used for consumption and investment, is assembled from intermediate inputs  $y_m$ , which are bought for a price  $p_m$ , by a representative final goods producer in a competitive market according to the standard CES production function

$$Y = \left( \int_m y_m^\rho \right)^{1/\rho}, \quad 0 < \rho < 1. \quad (5)$$

The inverse demand function for each intermediate goods producer is hence  $p_m = y_m^{\rho-1} Y^{1-\rho}$ . Output is produced according to a Cobb-Douglas production function

$$f(k_m, n_m) = Z k_m^\alpha n_m^{1-\alpha}, \quad (6)$$

where  $Z$  is the firm's productivity,  $k_m$  is the firm's capital, and  $n_m$  the amount of labor it hires. Capital depreciation is set to zero for notational simplicity, but could be easily incorporated without changing results. Each monopolistically competitive firm aims to maximize total dividends,  $r_m k_m$ , where  $r_m$  is the dividend per unit of capital:

$$\begin{aligned} \max_{n_m, y_m, p_m} \quad & r_m k_m & (7) \\ \text{s.t.} \quad & y_m p_m - w n_m \geq r_m k_m \\ & p_m = y_m^{\rho-1} Y^{1-\rho} \\ & y_m \leq f(k_m, n_m). \end{aligned}$$

Since firms' dividends are strictly concave in capital, each firm will receive the same amount of capital (which is also equal to the total in the economy,  $K$ ). As all firms are the same and there is measure one of them,  $y_m = Y$ , otherwise  $Y = (\int_i y_i^\rho)^{1/\rho}$  would be violated. This also implies that the price of the intermediate good has to be equal to the price of the final good:  $p_m = 1$ , otherwise the final goods producer would make a loss. The wage and rate of return on capital are thus determined by

$$w = \rho(1 - \alpha)f(K, n)/n \quad (8)$$

$$r = (1 - \rho(1 - \alpha))f(K, n)/K. \quad (9)$$

### 3.3 Investors

Investors allocate savings from agents into firm capital and government bonds to maximize their profits (which are zero in equilibrium due to perfect competition). Let  $\hat{r}$  denote the net return on government bonds.<sup>14</sup> Capital returns are taxed at source in each country. The representative investor's profit maximization problem is

$$\max_{K, K^*, b, b^*} r(1 - \tau^k)K + r^*(1 - \tau^{*k})K^* + b\tilde{r} + b^*\tilde{r}^* - (a + \chi a^*)R \quad (10)$$

$$\text{s.t. } a + \chi a^* = K + K^* + b + b^*. \quad (11)$$

The first-order conditions are the common no-arbitrage conditions. The net returns on each asset have to be equal to each other and the international rate of return:

$$R = r(1 - \tau^k) \quad (12)$$

$$= r^*(1 - \tau^{*k}) \quad (13)$$

$$= \hat{r} \quad (14)$$

$$= \hat{r}^*. \quad (15)$$

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<sup>14</sup>No-arbitrage requires that returns on government bonds have to be equal to dividends from firms. It therefore does not matter whether bond returns are taxed or not.

### 3.4 The Government

The benevolent government finances an exogenous stream of unproductive expenditures  $\{g_t\}_{t=0}^{\infty}$  via proportional source-based taxes on capital and labor income. Taxes are finite and smaller than one. Initial government debt  $b_0$  is exogenously given.<sup>15</sup> I assume that the initial debt level and the stream of expenditures are sufficiently small, so that it is possible for the government to finance it from labor taxes alone; i.e. the government is not constrained by the Laffer curve on taxes. The government's per-period budget constraint can be written as

$$g_t + b_t(1 + \hat{r}_t) = \tau_t^k r_t K_t + \tau_t^n w_t n_t + b_{t+1}. \quad (16)$$

### 3.5 Optimal Policy

Governments announce their policies simultaneously at time zero for the infinite future. Households and firms then react optimally to the announced policies. Using the households' and firms' optimality conditions as constraints allows the government to directly choose all of the households' and firms' decisions as control variables. For a sequence of net wages and rates of return which are greater than zero and finite, the household's two first-order conditions and the budget constraint uniquely characterize the household's decisions for any position of  $a_0$ .<sup>16</sup>

While domestic and foreign households react to domestic government policy as outlined above, the other government is a strategic actor. The foreign policy, consisting of capital and labor taxes and bond issues abroad, is thus taken as given. For any belief of foreign policy, the home government can then determine its best-response. This is a generalized game where the equilibrium is feasible, but off-equilibrium behavior is generally not (that is, the worldwide resource constraint will hold only in equilibrium). Later on, I also provide an alternative specification, in which off-equilibrium

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<sup>15</sup>This indirectly pins down the initial global capital stock, too, since  $a_0 + \chi a_0^* = K_0 + K_0^* + b_0 + b_0^*$ .

<sup>16</sup>Assets are finite since the return on capital approaches zero as assets tend to infinity. Given the nature of the production function (or for any standard production function which follows the Inada conditions), the equations determining wages and rates of return hold. For capital taxes which are smaller than one and finite, the no-arbitrage conditions will always hold (since  $r$  and  $r^*$  are strictly decreasing in capital and the marginal product of capital in each country tends to infinity as the capital stock tends to zero). The conditions for government bonds are only non-binding if bond holdings are zero, in which case they are redundant anyway.

behavior is feasible due to adjusting labor taxes.<sup>17</sup> The domestic government's Lagrangian is

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t) \\
& + \psi_t [\tau_t^k r_t K_t + \tau_t^n w_t n_t + b_{t+1} - (1 + R_t)b_t - g_t] \\
& + \theta_t [(1 - \tau_t^n)w_t n_t + (1 + R_t)a_t - a_{t+1} - c_t] \\
& + \mu_t [(1 - \tau_t^n)w_t u_c(t) - u_l(t)] \\
& + \zeta_{t|t>0} [(1 + R_t)u_c(t) - u_c(t-1)/\beta] \\
& + \theta_t^* [(1 - \tau_t^{n*})w_t^* n_t^* + (1 + R_t)a_t^* - a_{t+1}^* - c_t^*] \\
& + \mu_t^* [(1 - \tau_t^{n*})w_t^* u_c^*(t) - u_l^*(t)] \\
& + \zeta_{t|t>0}^* [(1 + R_t)u_c^*(t) - u_c^*(t-1)/\beta] \\
& + \gamma_t [r_t(1 - \tau_t^k) - R_t] \\
& + \gamma_t^* [r_t^*(1 - \tau_t^{k*}) - R_t] \\
& + \omega_t [a_t + \chi a_t^* - (K_t + K_t^* + b_t + b_t^*)]\},
\end{aligned} \tag{17}$$

where  $w$  and  $r$  are functions of  $K$  and  $n$  as described in equations (8) and (9) and  $l_t = 1 - n_t$  (and similarly for abroad). I have substituted in for the equilibrium prices of governments bonds. The set of control variables is then

$$X = \{c_t, c_t^*, n_t, n_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*, b_{t+1}, \tau_t^k, \tau_t^n, R_t\}_{t=0}^{\infty}. \tag{18}$$

**Definition 1** (Optimal Response Function). *An optimal response function is a sequence of capital taxes  $\{\tau_t^k\}_{t=0}^{\infty}$ , labor taxes  $\{\tau_t^n\}_{t=0}^{\infty}$ , and bond issues  $\{b_t\}_{t=1}^{\infty}$  for any belief of foreign policy  $\{\tau_t^{k*}, \tau_t^{n*}, b_{t+1}^*, I_{t+1}^*\}_{t=0}^{\infty}$  maximizing the agent's discounted lifetime utility such that the government budget constraint holds every period. The resulting allocations are such that*

1. *agents at home and abroad choose consumption, labor supply, and asset holdings to maximize their utility subject to their budget constraint, taking prices and taxes as given;*
2. *firms at home and abroad choose output prices, output, and labor to maximize dividends, taking capital, input prices, and demand functions as given;*

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<sup>17</sup>A more detailed discussion of the equilibrium concepts can be found in Gross (2013b).

3. investors choose bond and capital holdings at home and abroad to maximize profits, taking prices and taxes as given.

A strategy specifies the action taken at each information node of a game; since it is a one-shot game, a strategy corresponds to choosing a policy.

**Definition 2** (Tax Competition Equilibrium). *A tax competition equilibrium is a sequence of prices  $\{w_t, r_t, w_t^*, r_t^*, R_t\}_{t=0}^\infty$ , government policies  $\{\tau_t^n, \tau_t^{n^*}, \tau_t^k, \tau_t^{k^*}, b_{t+1}, b_{t+1}^*\}_{t=0}^\infty$ , and allocations  $\{c_t, c_t^*, n_t, n_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*\}_{t=0}^\infty$  such that each government's equilibrium policy is an optimal response function to the other government's equilibrium policy.*

If an equilibrium exists (more on alternative specifications later), it will satisfy the worldwide resource constraint. In an equilibrium, each country plays an optimal response to the other country's policy; thus, each country's government budget constraint has to hold. Moreover, the budget constraints of both households and the capital market equation (with Lagrange multiplier  $\omega$ ) also hold. Combining these equations and using the fact that  $wn + rK = F(K, n)$ , which is also equal to total output  $Y$ , yields the worldwide resource constraint:

$$f(K_t, n_t) + K_t - K_{t+1} - c_t - g_t + f^*(K_t^*, \chi n_t^*) + K_t^* - K_{t+1}^* - \chi c_t^* - g_t^* = 0. \quad (19)$$

### 3.6 Optimal Capital Taxes

The question this paper attempts to answer is if optimal capital taxes differ in an open economy compared to a closed economy when they are not already zero in the latter case. In the example economy considered so far, there is a reason to tax capital even in the long run: the private returns to capital are higher than its marginal product. so a capital tax corrects this. Capital taxes are therefore used to cream off economic profits:<sup>18</sup>

**Proposition 1** (Equal Capital Taxes in an Open and a Closed Economy). *The optimal steady-state capital taxes of the model outlined above are given by  $\tau^k = (1 - \rho)(1 - \alpha)/(1 - \rho(1 - \alpha))$ . This is independent of whether it is an open or a closed economy.*

<sup>18</sup>Also see Guo and Lansing (1999) for a discussion of limited competition and capital taxes in a closed economy. In Judd (2002), monopolistic competition leads to an optimal capital subsidy, not a tax (also see section 5, where a capital subsidy is optimal due to an incomplete tax system). The reason is that profits accrue to owners of the firm who are separate from capital owners. In that case, capital subsidies are necessary to move to the modified golden rule, as there is an underprovision of capital. Here, capital owners receive the profits, so there is an overprovision of capital compared to the first best, which is corrected by a positive capital tax.

**Proof.** Taking the first-order conditions with respect to capital, government bonds, and labor and capital taxes yields

$$K_t: \psi_t \tau_t^k r_t + \psi_t \tau_t^k K_t \frac{\partial r_t}{\partial K_t} + \psi_t \tau_t^n n_t \frac{\partial w_t}{\partial K_t} + \theta_t (1 - \tau_t^n) n_t \frac{\partial w_t}{\partial K_t} + \mu_t u_c(t) (1 - \tau_t^n) \frac{\partial w_t}{\partial K_t} + \gamma_t (1 - \tau_t^k) \frac{\partial r_t}{\partial K_t} = \omega_t, \quad (20)$$

$$a_{t|t>0}: \theta_t (1 + R_t) + \omega_t = \theta_{t-1} / \beta, \quad (21)$$

$$\tau_t^n: \psi_t n_t w_t = \theta_t n_t w_t + \mu_t u_c(t) w_t, \quad (22)$$

$$\tau_t^k: \psi_t K_t r_t = \gamma_t r_t. \quad (23)$$

Inserting equations (22) and (23) into (20) yields

$$\psi_t \tau_t^k r_t + \psi_t K_t \frac{\partial r_t}{\partial K_t} + \psi_t n_t \frac{\partial w_t}{\partial K_t} = \omega_t. \quad (24)$$

Furthermore, total production has to equal total factor remuneration  $F(\cdot) = Kr + nw$  (as potential profits accrue to capital owners who are also shareholders). Differentiating with respect to capital leads to  $f_K = K(\partial r)/(\partial K) + r + n(\partial w)/(\partial K)$  and equation (24) then becomes

$$\psi_t \tau_t^k r_t + \psi_t K_t (f_K(t) - r_t) = \omega_t. \quad (25)$$

If a steady state exists (more on how this can be relaxed later), then time subscripts can be dropped. Equation (21) together with the household's Euler equation ( $1/\beta = 1 + R$  in steady state) then implies that  $\omega = \theta/\beta - \theta(1 + R) = 0$ . Combining this with equation (25) yields

$$\psi \tau^k r = \psi (r - f_K(\cdot)) \quad (26)$$

$$\Leftrightarrow \tau^k = (r - f_K(\cdot))/r \quad (27)$$

$$\Leftrightarrow \tau^k = (1 - \rho)(1 - \alpha)/(1 - \rho(1 - \alpha)). \quad (28)$$

For a closed economy, the constraints of the foreign households and the no-arbitrage condition for foreign investment disappear, i.e. all constraints with an asterisk in (17). These constraints do not affect the relevant first-order conditions, though. Optimal capital taxes are thus the same in an open and a closed economy.  $\square$

It also becomes apparent that it is irrelevant what the specific nature of the production function is or the reason why capital is taxed in the first place. Equation (27) does not rely on any of these assumptions. It is optimal to equate the net private return of capital to its marginal product. In terms of allocations, it is optimal to equate the gross marginal product of capital to society's discount rate, i.e. to follow the modified golden rule:

$$1 + F_K(\cdot) = 1/\beta. \tag{29}$$

The modified golden rule is also the condition that holds in the first-best, when lump-sum taxes are available. It is therefore independent of any revenue considerations. This can also be seen from equation (27), which pins down the capital tax rate in terms of the relative difference between the private marginal product of capital  $r$  and the social marginal product  $f_k(\cdot)$ , independent of the value of government or private funds,  $\psi$  and  $\theta$ . The modified golden rule applies for any belief of foreign policy. Hence, capital income taxes are independent of policies in other countries, whether taxes abroad are chosen optimally or not. The derivation of the results presented so far does not rely on any equilibrium conditions in the game between governments.

Tax coordination is not beneficial, since the optimal tax in each country is independent of other countries' taxes (again, as before I refer to the long-run). Tax harmonization, i.e. equalizing capital taxes across countries, can even be harmful in this context if countries' production parameters are different.

## 4 Tax Competition with a Fixed Factor

In this section, I show how each government finds it individually optimal to engage in tax competition for exogenous capital, i.e. to set capital taxes lower than in a closed economy. It is not important that this mobile factor is supplied perfectly inelastically (although the results are not as drastic – taxes will be smaller than one in a closed economy). The key is that the factor is not an intermediate good.

Let  $z$  be the domestic agent's per-capita endowment of exogenous capital and  $z^*$  for foreigners, while  $v_t$  is the amount used in domestic production and  $v_t^*$  abroad. Let  $F(K, n, v)$  be the aggregate domestic production function (ignoring the monopolistic competition aspect introduced earlier),

which satisfies the Inada conditions and constant returns to scale. With perfect competition, the factor remunerations are given by the marginal products. Call the price for a firm to rent one unit of exogenous capital  $s = F_v(K, n, v)$  and the (territorial) taxes on it  $\tau^v$ , while the return to households is  $S$ . Households can hide or freely dispose of their exogenous capital, so  $S \geq 0$ . Market clearing requires that  $z + \chi z^* = v_t + v_t^*$  and the no-arbitrage conditions are then  $S_t = s_t(1 - \tau_t^v) = s_t^*(1 - \tau_t^{v*})$ .<sup>19</sup> The Lagrangean can thus be written as

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \{ u(c_t, l_t) \\
& + \psi_t [\tau_t^k r_t K_t + \tau_t^v s_t v_t + \tau_t^n w_t n_t + b_{t+1} - (1 + R_t) b_t - g_t] \\
& + \theta_t [(1 - \tau_t^n) w_t n_t + S_t z + (1 + R_t) a_t - a_{t+1} - c_t] \\
& + \mu_t [(1 - \tau_t^n) w_t u_c(t) - u_l(t)] \\
& + \zeta_{t|t>0} [(1 + R_t) u_c(t) - u_c(t-1)/\beta] \\
& + \theta_t^* [(1 - \tau_t^{n*}) w_t^* n_t^* + S_t z^* + (1 + R_t) a_t^* - a_{t+1}^* - c_t^*] \\
& + \mu_t^* [(1 - \tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t)] \\
& + \zeta_{t|t>0}^* [(1 + R_t) u_c^*(t) - u_c^*(t-1)/\beta] \\
& + \gamma_t [r_t(1 - \tau_t^k) - R_t] \\
& + \gamma_t^* [r_t^*(1 - \tau_t^{k*}) - R_t] \\
& + \Gamma_t [s_t(1 - \tau_t^v) - S_t] \\
& + \Gamma_t^* [s_t^*(1 - \tau_t^{v*}) - S_t] \\
& + \omega_t [a_t + \chi a_t^* - (K_t + K_t^* + b_t + b_t^*)] \\
& + \Omega_t [z + \chi z^* - (v_t + v_t^*)] \},
\end{aligned} \tag{30}$$

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<sup>19</sup>For simplicity, I assume that it is never traded (agents are indifferent between trading it or not), so I do not need to find a price and can keep  $z$  and  $z^*$  constant.

Taking the first-order condition with respect to  $\tau_t^v$ ,  $S_t$ , and  $v_t$  yields<sup>20</sup>

$$\psi_t s_t v_t = \Gamma_t s_t \quad (31)$$

$$\theta_t z_t + \theta_t^* z^* = \Gamma_t + \Gamma_t^* \quad (32)$$

$$\psi_t \tau_t^v s_t = \Omega_t. \quad (33)$$

There are two inferences which can be made. First, for a small open economy the optimal tax on exogenous capital is zero. A small open economy is not affected by changes in the global exogenous capital stock, so  $\Omega_t = 0 \forall t$  and since the value of government funds and the marginal product of  $v$  are strictly positive,  $\tau_t^v = 0$ . Second, taxes on exogenous capital are as high as possible in a closed economy, since it amounts to lump-sum taxation. Formally, as long as distortionary taxes are needed, the value of government funds is higher than private funds, so  $\psi > \theta$ . Combining the first-order conditions (31) and (32) imply that  $\psi = \theta$ , as  $\theta_t^* = \Gamma_t^* = 0$  and  $v_t = z$  in a closed economy. Taxes on exogenous capital are therefore as high as possible, i.e.  $\tau_v^t = 1$ , given that these taxes are not high enough to finance government expenditures.<sup>21</sup>

A large open economy sets its optimal taxes in the interval  $(0, 1)$ , depending on its size compared to the rest of the world. A maximum tax of one would lead to a complete exodus of the factor, if taxes abroad are not equal to 1. If taxes abroad were equal to one, a tax of  $1 - \epsilon$  would attract all of the world's exogenous capital and improve welfare. It is also not optimal to set taxes below zero. The marginal product is then lower than the net rate of return. A country would pay more to foreign investors than it would gain in terms of higher production and valuable tax money would have to be spent on the subsidies. Therefore, taxes should be non-negative.

It stands to reason that a larger economy chooses higher taxes than a smaller economy – just as shown in static models. As outlined above, tax rates are non-negative, so the optimal rate described by equation (33) increases as  $\Omega$  increases.  $\Omega_t$  is equal to the derivative of foreign prices with respect to  $v_t^*$ , so it reflects the impact of the home economy on the rest of the world. The size of the home

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<sup>20</sup>When taking the derivative with respect to  $v_t$ , one can ignore its effects on prices, since there are constant returns to scale, the tax system is complete, and taxes are chosen optimally (i.e. these effects cancel out once the first-order conditions with respect to the different taxes are taken into account). This is not the case for  $v_t^*$ , since taxes abroad are not chosen by the home government.

<sup>21</sup>I generally omit in the whole paper the restriction that  $\tau \leq 1$  for any tax, which is never binding for labor and not binding for capital in the long run (also not in the short run for an open economy). For exogenous capital in a closed economy, this constraint is binding though and technically should be included – I have omitted it for notational convenience since it only applies for the limiting case of a closed economy.

economy is one, the size of the other country is  $\chi$ . Therefore, when  $1/\chi$  is large, a one unit change of  $v_t^*$  impacts prices abroad significantly, whereas if  $1/\chi$  is small, a one unit change of  $v_t^*$  will have almost no effect. For an economy that is very small compared to the rest of the world,  $\Omega$  is thus close to zero, so the tax will be in the vicinity of zero, too. For a very large economy, on the other hand, a shift of one unit of exogenous capital abroad will decrease its returns there massively, which means that it can use its market power to optimally set a higher tax rate than a smaller economy.

In this context, tax coordination can clearly be welfare increasing. For example, two symmetric countries could agree to set the tax to one minus  $\epsilon$ , thereby not creating any distortions on the factor allocation and generating tax revenues that would otherwise have been collected by distortionary taxes on labor income. Thus, the model with exogenous capital can replicate the findings in the conventional (static) tax competition literature. The ability to tax the pure rents of exogenous capital is severely limited in an open economy; in contrast, an intermediate good is not taxed for revenue purposes in the first place, hence the mobility of capital does not affect the optimal tax decision in this case.

## 5 An incomplete tax system

What happens if the tax system is incomplete? Correia (1996a,b) has shown that it is optimal to impose capital taxes when the tax system is incomplete, for a closed and a small open economy. Does this also occur in a large open economy and if so, how is it different from the capital taxes in the baseline configuration? As shown before, with a complete tax system, the government chooses the first-best capital-labor ratio, the modified golden rule, independent of other countries' tax choices. The capital taxes which implement this allocation are also independent of revenue requirements. With an incomplete tax system, the government deviates from the modified golden rule and levies capital taxes which depend on funding needs and other countries' policies.

Consider an economy as in the baseline setup, except that profits do not go to capital investors, but instead to the owners, i.e. the private agents in each country. Assume that the government cannot tax profits. The setup changes slightly: The interest rate and wages are equal to their

marginal revenue products and profits  $\pi$  are given by:<sup>22</sup>

$$w = \rho(1 - \alpha)f(K, n)/n \quad (34)$$

$$r = \rho\alpha f(K, n)/K \quad (35)$$

$$\pi = (1 - \rho)f(K, n). \quad (36)$$

These profits now enter the household's budget constraint, which becomes

$$c_t = (1 - \tau_t^n)w_t n_t + \pi_t + (1 + R_t)a_t - a_{t+1}. \quad (37)$$

The first-order conditions remain therefore unchanged, except that the derivative of the Lagrangean with respect to  $K_t$  contains the additional term  $\theta_t(\partial\pi_t)/(\partial K_t)$ . Combining these first-order conditions then results in a very similar equation to (24):

$$\psi_t \tau_t^k r_t + \psi_t K_t \frac{\partial r_t}{\partial K_t} + \psi_t n_t \frac{\partial w_t}{\partial K_t} + \theta_t \frac{\partial \pi_t}{\partial K_t} = \omega_t. \quad (38)$$

As before, in steady state  $\omega = 0$ .  $K(\partial r)/(\partial K) = -n(\partial w)/(\partial K)$  and  $(\partial\pi)/(\partial K) = (1 - \rho)f_K$ , so the optimal tax rate is given by

$$\tau_k = -\frac{1 - \rho}{\rho} \frac{\theta}{\psi}. \quad (39)$$

Three major differences as compared to the economy with a complete tax system emerge. First, the modified golden rule generally does not hold anymore (except when  $\rho = 1$ , i.e. there are no profits):  $1 + f_K[\rho + (1 - \rho)\theta/\psi] = 1/\beta$ . Second, capital taxes depend on the value of government funds. The modified golden rule can be implemented by subsidizing capital returns until  $r = f_K$  when the government can levy lump-sum taxes, i.e. in the first-best when the value of government resources  $\psi$  is equal to privately held resources  $\theta$ . The more distortionary taxes are, i.e. the smaller  $\theta/\psi$  is, the smaller the subsidy to capital and the larger the deviation from the modified golden rule. Third, the capital taxes are no longer independent of decisions abroad. This can be seen by taking the first-order condition with respect to  $R$  in steady state:  $\theta/\psi = [\psi b + (\gamma + \gamma^*) - \theta^* a^* - (\zeta u_c + \zeta^* u_c^*)]/[\psi a]$ . The value of government funds depends on the Lagrange multipliers abroad,

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<sup>22</sup>Here I make use of the fact that total output in the economy is equal to an individual firm's output, so  $f(K, n)^\rho Y^{1-\rho} = f(K, n)$ .

$\gamma^*$ ,  $\theta^*$ , and  $\zeta^*$ , which are functions of the fiscal policy abroad.<sup>23</sup>

When there is a third production factor as in Correia (1996a) which cannot be taxed, then taxes are generally positive. Assume perfect competition, i.e.  $\rho = 1$ , and that  $f(K, n, v)$  is a constant returns-to-scale production function, with  $v$  as a third input as in the previous section and  $f_{vK} > 0$ , i.e. the marginal product of  $v$  increases in capital (true for instance for any production function with finite constant elasticity of substitution). Assume that this factor is not internationally mobile, though, so that the return in the home country is  $s_t$  and the no-arbitrage conditions for this factor do not hold. Then the optimal steady-state tax is given by:

$$\psi\tau^k r + \psi K \frac{\partial r}{\partial K} + \psi n \frac{\partial w}{\partial K} + \theta v \frac{\partial s}{\partial K} = 0 \quad (40)$$

$$\Leftrightarrow \psi\tau^k r - \psi v \frac{\partial s}{\partial K} + \theta v \frac{\partial s}{\partial K} = 0 \quad (41)$$

$$\Leftrightarrow \tau_k = (\psi - \theta)f_{vK}, \quad (42)$$

since  $K \frac{\partial r}{\partial K} + n \frac{\partial w}{\partial K} = -v \frac{\partial s}{\partial K}$ . Taxes are positive, as long as there is no lump-sum taxation and  $\psi > \theta$ , and they are increasing in the relative value of government funds. Capital taxes are used in this case to indirectly tax the third factor. As was the case when profits were untaxable, the golden rule does not hold and capital taxes depend on the value of government funds and are also dependent on policy abroad. These same conclusions hold when the untaxable factor's supply is not perfectly inelastic (for instance when  $v$  negatively affects utility) and/or when it is internationally mobile.

## 6 Extensions

In this section I present a number of extensions to which the results are robust. Proofs are relegated to the appendix.

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<sup>23</sup>If profits could be taxed, then the government would find it optimal to do so at a confiscatory rate, as it amounts to lump-sum taxes. Equation (38) would then have  $\psi_t \frac{\partial \pi_t}{\partial K_t}$  instead of  $\theta_t \frac{\partial \pi_t}{\partial K_t}$ , so optimal taxes would be  $\tau_k = -(1-\rho)/\rho$ , thus implementing the modified golden rule, independent of the value of government funds or policy abroad.

## 6.1 Asymmetries and Number of Countries

In the literature with an exogenous capital stock, asymmetries between countries can play a large role in determining capital taxes, see for instance Bucovetsky (1991) and Wilson (1991). With dynamic optimal taxation, cross-country differences can account for different tax rates (for instance if the production parameters are different in the baseline economy); the guiding principle remains to implement the golden rule, though.

The results so far do not rely in any way on symmetric utility or production functions; only the time discount factor has to be the same, otherwise a steady state or stable long-run average does not exist in this setup. As is apparent from the analysis in section 3.6, relative country size  $\chi$  does not matter; the number of countries is irrelevant, too. I have assumed that there are only two countries for ease of exposition. It is straightforward to extend the model to any number of countries. Specifically, households' optimality conditions have to hold in each country and the global capital market incorporates all countries' assets.

**Proposition 2.** *Optimal capital taxes are independent of a country's size, the number of countries, and any asymmetries between countries.*

## 6.2 Infrastructure

How does public infrastructure influence tax competition? Governments can use capital tax revenues to finance productive infrastructure spending, which would in turn attract more capital. It is thus conceivable that it is optimal to engage in tax competition in such a setting. Alternatively, there might be competition to provide the best infrastructure: Cai and Treisman (2005) show that global mobility of capital can lead to lower infrastructure investment in the least productive countries as compared to the autarky case. If governments of less productive countries know that they cannot compete for the global capital stock, they will reduce infrastructure spending as the local savings will in any case be invested elsewhere.<sup>24</sup>

With optimal dynamic taxation, neither is true. It is optimal to provide an efficient level of infrastructure, both in an open and a closed economy.<sup>25</sup> The cost of procuring government revenues

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<sup>24</sup>Besides an exogenous capital stock, Cai and Treisman (2005) also assume that there is no labor and just one flat tax on output.

<sup>25</sup>If infrastructure influenced not only the production function, but also the utility function, say as a public consumption good, then it would not be an intermediate good anymore. Hence, the results in this section would no longer hold. However, optimal capital taxes would not be affected.

does not play a role, as pointed out before by Judd (1999) for a closed economy. Kellermann (2008) argues that for a small open economy, the fact that public infrastructure increases the marginal product of capital is in itself not sufficient to warrant capital taxation. The same is true here for a large open economy, where lump-sum taxes are not available as in Kellermann’s paper.<sup>26</sup>

There is a strong analogy between private and public capital (which I use interchangeably with infrastructure). Public capital is an intermediate good and should be provided at the efficient level, independent of the cost of public funds. When private capital is an intermediate good, then it should *a fortiori* fulfill production efficiency, as it is privately provided and society does not incur the extra cost of raising the public funds to finance it.

In technical terms: Assume that the government provides productive infrastructure  $I_t$  with  $I_0$  given. As for private capital, it costs one unit of output to produce and becomes available a period later. Each firm’s production function is  $f(k_t, n_t, I_t) = Zk_m^\alpha n_m^{1-\alpha} I_t^\alpha$ .<sup>27</sup>

**Proposition 3.** *Any optimal response function will feature efficient infrastructure provision, defined by  $f_I(t) = f_K(t) \forall t > 0$ , independent of the strategies of other governments. The optimality of infrastructure provision does not influence optimal steady-state capital taxes, but optimal taxes are a necessary condition for efficient infrastructure provision.*

### 6.3 Endogenous Government Expenditures and Leviathan

What is the impact of endogenous government expenditures, say for a public consumption good, on tax competition and vice versa? Having  $g$  enter the household’s utility function and making it an endogenous choice variable does not affect the relevant first-order conditions, so it still remains optimal for each country to set its capital taxes as in the benchmark model.

When a government acts as a Leviathan, to maximize at least partially its own consumption,

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<sup>26</sup>This contrasts sharply with the findings of Gomes and Pouget (2008), who argue that public infrastructure investment declines with corporate tax rates as the latter is a rate of return on the former. They assume that infrastructure enters directly the government’s utility function and that there are no other variable tax instruments besides corporate taxes. Results are also at odds with Matsumoto (2000), who assumes an exogenous capital stock and finds that public infrastructure subject to congestion is inefficiently provided when tax competition takes places.

<sup>27</sup>As before, the functional form of a Cobb-Douglas technology or that there are increasing returns to scale is not important. I do assume that there are jointly decreasing returns to scale in  $k_t$  and  $I_t$ , otherwise all capital would concentrate in one country. For any such production function which is strictly increasing and concave in its inputs,  $f_k(t) = f_I(t) \forall t > 0$  and  $f_K = 1/\beta$  in steady state (or on average over a long-horizon). Adding depreciation also does not affect results. With an exogenous capital stock, increasing returns to scale as in Burbidge and Cuff (2005) do not affect tax competition, except when agglomeration economies as in Krogstrup (2008) are strong enough so that all exogenous capital flows into one country. Then, capital taxes are high in the country that attracts it all, in line with the economic geography results of Baldwin and Krugman (2004) or Borck and Pflüger (2006).

then tax competition with an exogenous capital stock can limit the Leviathan's tax power and increase the welfare of citizens, see for example Edwards and Keen (1996) and Eggert (2001). The self-interested government can capture less of the rents of the perfectly inelastically supplied capital in an open economy, so the citizens who receive the remainder of the rents are better off. Cai and Treisman (2005), however, show that tax competition does not always work as a disciplining device and can actually make governments and citizens worse off. When there are no rents to be captured and capital is an intermediate good,<sup>28</sup> capital taxation is not affected by the government's objective function, the modified golden rule holds independent of it.

**Proposition 4.** *Optimal capital taxes are independent of whether government expenditures are present in the households' and the government's objective functions or not.*

## 6.4 Steady State Alternative

The steady-state assumption is potentially quite restrictive in this model. I propose an alternative, based on work by Judd (1999), which I have adapted to an open-economy discrete-time model in Gross (2013b). When the value of government funds does not grow on average, then the average distortion on capital is zero and independent of other countries' tax decisions and whether the economy is open or closed. If the marginal utilities of public and private consumption are bounded, then the value of government funds cannot grow on average as the time period grows infinitely large. This assumption accommodates shifting values for government funds, including circles, steep spikes etc. Most importantly, the capital stock and thus the interest rate can differ from period to period. It is thus a much weaker assumption than steady state.

**Proposition 5.** *When the value of government funds does not grow on average, then the ratio of net asset returns to the marginal product of capital is equal to one, independent of other countries' tax decisions and whether the economy is open or closed. When the value of government funds is positive and bounded, then this holds on average over an infinitely long horizon.*

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<sup>28</sup>As Acemoglu, Golosov, and Tsyvinski (2008) show, intermediate goods prices should not be distorted even under the constraints of political economy. They find positive capital taxes when the government's discount rate exceeds the one of their citizens, as there is an over-accumulation of capital from the government's perspective. However, capital accumulation still satisfies the modified golden rule for the discount rate of the ruler and therefore results remain unchanged in an open economy, see proposition 9.

## 6.5 Feasibility, Off-equilibrium behavior, and Mixed Strategies

In the game specified so far, off-equilibrium behavior is not feasible. For instance, if country  $A$  plays the equilibrium strategy, but country  $B$  does not, then the outcome is generally not feasible in the sense of violating the government budget constraints and the worldwide resource constraint (19). In order to allow for off-equilibrium behavior and mixed strategies (which are not feasible in the framework presented so far), one of the government choice variables has to adjust to satisfy the government budget constraint. This variable cannot be government bonds, as this instrument is generally not sufficient to balance the intertemporal budget constraint. When one allows for labor or capital taxes to adjust in such a way, then results remain unchanged (assuming that the government is able to finance its expenditures).

**Proposition 6.** *When labor or capital taxes adjust in each period to satisfy the government budget constraint, the modified golden rule holds in any steady state. Results remain unchanged when one allows for mixed strategies.*

## 6.6 Residential and Consumption Taxes

So far I have assumed that capital taxes are levied according to the territorial or source-based system. This is the prevalent assumption in the literature and thus facilitates the comparison of this paper's results with the ones found in the literature. Moreover, Zodrow (2009) notes that "Indeed, most empirical evidence suggests that [...] host country taxes are the primary determinants of FDI (page 6)." However, governments often employ source-based corporate taxes and residential dividend taxation. Moreover, international treaties such as in the European Union might impose restrictions on consumption taxes.

It is well known in the optimal taxation literature that allocations matter, and not the taxes that implement them (Chari and Kehoe, 1999), especially when some taxes are redundant. What matters is whether the tax system is complete (all factors of production can be taxed separately) or not. With labor and source-based capital taxes, the tax system is already complete. Therefore, when one extends the model to include residential capital taxes and consumption taxes, the modified golden rule still holds in the long run, whether there are restrictions on these tax rates or not. From a modeling perspective, residential taxes equalize in steady state (or are the same on average if a steady state does not exist), so I assume here that countries are symmetric and thus choose equal

tax rates.

**Proposition 7.** *The modified golden rule optimally holds when one includes consumption and residential capital taxes and when these taxes are constrained.*

## 6.7 Direct Investment and Adjustment Costs

So far I have assumed that households accumulate assets and then let investment funds redistribute these assets in the form of equities and bonds across countries. Alternatively, one could assume that households invest capital directly in other countries and that this capital investment is subject to adjustment costs, which can be interpreted as barriers to capital mobility, a common theme in the tax competition literature. This assumption does not affect results. Capital mobility is an important factor in determining optimal capital taxes when the capital stock is taken as exogenously given, such as in static or time-consistent models. They determine the government's ability to capture the associated (perceived) rents, which are zero when the government is able to perfectly commit and capital is accumulated endogenously.<sup>29</sup> While asset holdings and the total capital stock in each country are well specified, the exact portfolio choice depends on the initial conditions when adjustment costs are positive and is indeterminate otherwise.

**Proposition 8.** *When households directly choose where to invest capital and there are adjustment costs, the modified golden rule is optimal in steady state.*

## 7 Tax Competition under the Golden Rule

In this section, I give a general proof of the optimality of the modified golden rule in open economies. Examples of model economies with production efficiency and non-zero capital taxes are an overlapping generations setting as in Erosa and Gervais (2002) or idiosyncratic income shocks with borrowing constraints as in Aiyagari (1995).<sup>30</sup> The modified golden rule is also compatible with

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<sup>29</sup>Furthermore, convex adjustment costs do not affect the net rate of return in the long run, as shown by Abel (2002). Therefore, a government's market power is independent of barriers to capital mobility if the horizon is sufficiently long.

<sup>30</sup>In the former case, if there is life-cycle savings behavior due to different productivities at different ages, then agents do not necessarily save so that the capital stock conforms to the modified golden rule (agents attempt to smooth consumption over the life-cycle). In the Aiyagari economy, agents engage in precautionary savings in order to self-insure against idiosyncratic risk. For the agents, there is an additional benefit to holding capital in form of insurance beyond the normal rate of return. Therefore, without capital taxes, capital holdings would be excessive and violate the modified golden rule. In both models, non-zero capital taxes realign the marginal product of capital with the modified golden rule and this still holds in an open economy.

models of unemployment.<sup>31</sup>

There are two assumptions involved in this proof.<sup>32</sup> First, assume that the tax system is complete, i.e. that all factors of production can be taxed.

**Assumption 1** (Complete Tax System). *All net returns to factors can be written as  $\tilde{x} = (1 - \tau^x)x$ , where  $x$  is the pre-tax return and  $\tau^x$  is the tax rate on that return, so that all pre-tax returns can be eliminated from the competitive equilibrium conditions and only net returns remain.*

Second, assume, as common in the tax competition literature, that the only connection between the home country and the rest of the world is through capital markets. In these capital markets, investors borrow assets from agents in each country and then invest it in capital and government bonds in the different countries. Assuming a regular production function, after-tax returns across countries equalize in order to maximize investment profits.

**Assumption 2** (Capital Markets Linkage Only). *The only difference between an open and a closed economy is given by capital investments between countries.*

Since the proposition and the proof are abstract, I show as an example how the Aiyagari (1995) model economy maps into it in the appendix.

**Proposition 9** (Modified Golden Rule in Open Economies). *Let  $\mathcal{L}_C$  be the Lagrangian for the government in a closed economy and  $\mathcal{L}_O$  be the equivalent in an open economy. Let  $F(\cdot)$  be the production function (including production externalities and non-depreciated capital) and  $F_K(\cdot)$  the partial derivative with respect to the economy-wide capital stock. Let  $\beta$  be the government's discount factor. If  $\partial \mathcal{L}_C / \partial K = 0 \Rightarrow F_K(\cdot) = 1/\beta$ , then under assumptions one and two  $\partial \mathcal{L}_O / \partial K = 0 \Rightarrow F_K(\cdot) = 1/\beta$ .*

**Proof** In a closed economy, the government's set of constraints consists of the government budget constraint plus potential other constraints and the domestic competitive equilibrium conditions. Call the former  $\Psi_C(K, b, a, \tilde{r}; \dots) = 0$  and the latter  $\Upsilon_C^D(a, \tilde{r}; \dots) \geq 0$ . The set of constraints  $\Psi_C$

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<sup>31</sup>Brecher, Chen, and Choudhri (2010) obtain the modified golden rule in a model of shirking and unemployment of the Stiglitz-Shapiro type. Domeij (2005) analyzes optimal fiscal policy in a model of unemployment due to labor market search. As before, if the government is able to tax all factors of production (and vacancies or labor market tightness is one of them), the modified golden rule holds, otherwise it is violated. Taxing labor market tightness can be achieved through either a subsidy for vacancies by firms or through unemployment benefits. Aronsson and Wehke (2008) is an example of a traditional tax competition models with unemployment where the global capital stock is fixed.

<sup>32</sup>I still assume perfect commitment, a regular utility and production function without endogenous growth etc.

depends on the domestic capital stock  $K$ , government bonds  $b$ , asset holdings  $a$ , the net interest rate  $\tilde{r}$ , and other quantities and net prices, which I have subsumed under the dots, for every period. Households only care about their asset holdings and after-tax prices, so  $\Upsilon_C^D$  does not directly depend on capital and bond holdings. In a closed economy, domestic assets can only be employed in the home economy, capital market clearing is therefore described by  $a = K + b$ .

In an open economy, the constraints (and the government objective function) remain the same, except that capital market clearing requires  $a + \chi a^* = K + K^* + b + b^*$  and that global investment opportunities introduce a no-arbitrage condition,  $\tilde{r} = \tilde{r}^*$ . The set of constraints is also enlarged by the foreign competitive equilibrium conditions. Denote these by  $\Upsilon_O^F(a^*, \tilde{r}^*; \dots) \geq 0$ . Altogether, this means that the government faces the following set of constraints in an open economy:

$$\Psi_O(K, b, a, \tilde{r}; \dots) = 0 \tag{43}$$

$$\Upsilon_O^D(a, \tilde{r}; \dots) \geq 0 \tag{44}$$

$$\Upsilon_O^F(a^*, \tilde{r}^*; \dots) \geq 0 \tag{45}$$

$$a + a^* - K + K^* + b + b^* = 0 \tag{46}$$

$$\tilde{r} - \tilde{r}^* = 0. \tag{47}$$

By assumption one, the tax system is complete and one can therefore use  $\tilde{r}$  as a control variable instead of the capital tax rate  $\tau^k$ , as in Chamley (1986).<sup>33</sup> This can of course not be done for the net return of capital abroad, as  $\tilde{r}^*$  is not a choice variable. It is a function of choice variables such as  $K^*$ , but also of the foreign capital tax rate, which is taken as given in this Nash game between governments. As pointed out before, the first two sets of constraints, (43) and (44), are exactly the same as in a closed economy. The capital-market clearing condition now depends on other variables, notably  $a^*$ ,  $K^*$ , and  $b^*$ , but only additively, so the derivative with respect to  $K$  remains the same. The other constraints do not depend directly on  $K$ . The first-order condition with respect to domestic capital,  $\partial \mathcal{L}_O / \partial K = 0$ , is therefore exactly the same as in a closed economy. Hence, if the first-order condition for capital implies the modified golden rule in a closed economy, then this will also be the case in an open economy.<sup>34</sup>  $\square$

<sup>33</sup>Likewise to previous sections, when the tax system is complete, then all the derivatives of factor prices with respect to capital cancel out, once one takes the first-order conditions with respect to taxes into account.

<sup>34</sup>A weaker version of the assumption of a complete tax system is actually a pre-condition for the modified golden rule in closed economies, as I show in Gross (2013a). The formal requirement is that all co-factors of production

It follows as a corollary that tax-coordination cannot be welfare-improving and that tax-harmonization is generally not optimal (as before, this refers to the long run).

**Corollary 1** (No Benefits of Capital Tax Coordination). *When the modified golden rule holds in steady-state in a closed economy, then a co-ordinating social-planner will also choose to implement it in steady state for open economies. It is generally not optimal to equalize steady-state tax rates across countries.*

**Proof** If a central planning agency could determine the fiscal policy in all countries, maximizing some increasing function of the welfare in each country, then it would still face the same first-order conditions for capital in each country (the constraints are the same as above, the objective function does not depend on capital, and the social planner uses foreign policy as additional choice variables). Therefore, the central planner would still choose the modified golden rule in all countries in the long run. The tax rates that implement the modified golden rule in each country are potentially different from each other, so the planner will generally not harmonize them.  $\square$

## 8 Conclusion

This paper investigates a strategic tax game between jurisdictions where the capital stock is mobile and endogenously determined as in a standard neoclassical growth model. Governments are able to commit fully, so it is a one-shot game. In order to avoid issues of surprise taxation of the initial capital stock, I focus on taxes in the long run. I find that with an endogenous capital stock, governments do not find it optimal to engage in tax competition, i.e. they will set their taxes to implement the modified golden rule both in a closed and an open economy. Capital taxes are optimally set so that net private returns to capital coincide with its social marginal product. This is independent of capital taxes abroad. Results are robust to many model variations found in the literature, such as asymmetries, the number and size of countries, productive infrastructure spending or public consumption goods, and self-interested governments.

Capital is an intermediate good and unlike labor does not influence utility directly. When the tax system is complete, it is optimal to equalize the private after-tax return to capital with the

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of capital can be taxed independently (so that prices which depend on capital are choice variables after taxes are included). The assumption of a complete tax system is therefore not necessary to prove proposition 9, but I have included it here so that the proof does not rely on the more complex framework in Gross (2013a).

social return to capital (usually the marginal product), i.e. to implement the modified golden rule. This holds both for a closed and an open economy with strategic interaction between jurisdictions. Governments do not find it optimal to engage in tax competition, that is to set capital tax rates below the one to implement the modified golden rule, as this would lead to a higher net capital return for foreign investors than what the capital is actually producing. With an exogenously given global capital stock, though, there are rents which governments aim to capture; in an open economy a government's ability to tax these rents is limited through capital flight. In an uncooperative equilibrium, governments engage in tax competition which is inefficient from an optimal taxation perspective.

Throughout the paper I assume perfect commitment. If the government is unable to credibly commit to its tax announcement as in Klein, Quadrini, and Rios-Rull (2005), then it is welfare-improving if tax competition drives capital taxes down towards the efficient level, see Quadrini (2005). In that sense, the assumption of perfect commitment can be seen as a benchmark against which one can evaluate the time-consistent solution.

It is difficult to derive policy prescriptions from a stylized model, but under a fairly wide range of assumptions, capital mobility does not affect a country's optimal capital tax policy, as long as all factors of production can be taxed separately. When the tax system is incomplete, however, then capital taxes are used for revenue purposes and tax competition is an issue again. For instance, as Diamond and Saez (2011) argue, it is difficult to distinguish between capital taxes and taxes on entrepreneurial labor income. Reis (2011) has shown that this leads to a departure from the modified golden rule; capital mobility reduces in this case the government's ability to tax capital. Furthermore, if governments value capital directly in their objective function, for instance for political economy reasons, then capital is no longer an intermediate good from the government's perspective and tax competition concerns arise.

The reallocation of earnings in multinational companies (see e.g. Bucovetsky and Hauffer (2008)) is also not captured in this model. I suspect that tax competition would take place in such a case, since profits could be transferred without affecting production, and the fact that capital is an intermediate good is driving the results here. However, the welfare effects of tax competition over earnings reallocation are much less severe than for productive capital.

The inclusion of trade seems to be an interesting research question. Baldwin and Krugman (2004) and Ottaviano and van Ypersele (2005) examine this subject, but also with an exogenous

capital stock. Technology capital as in McGrattan and Prescott (2009), which can be used by a firm in any country in a non-rivalrous manner, could give different incentives to tax capital income in an open economy. Another possibly interesting question is how endogenous growth affects optimal fiscal policy in large open economies.

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## A Appendix: Proofs for Extensions

### A.1 Asymmetries and Number of Countries

To incorporate any number of countries, let  $h$  denote the home country, which is part of a set  $J$ .  $J$  is the number of countries, which I index by  $j$  including home country  $h$ . The population size is given by  $\chi_j$ , with  $\chi_h = 1$ . The Lagrangean is

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \{u(c_{h,t}, l_{h,t}) \\
& + \psi_t [\tau_{h,t}^k r_{h,t} K_{h,t} + \tau_{h,t}^n w_{h,t} n_{h,t} + b_{h,t+1} - (1 + R_t) b_{h,t} - g_{h,t}] \\
& + \sum_J \theta_{j,t} [(1 - \tau_{j,t}^n) w_{j,t} n_{j,t} + (1 + R_t) a_{j,t} - a_{j,t+1} - c_{j,t}] \\
& + \sum_J \mu_{j,t} [(1 - \tau_{j,t}^n) w_{j,t} u_c(j, t) - u_l(j, t)] \\
& + \sum_J \zeta_{j,t|t>0} [(1 + R_t) u_c(j, t) - u_c(j, t - 1) / \beta] \\
& + \sum_J \gamma_{j,t} [r_{j,t} (1 - \tau_{j,t}^k) - R_t] \\
& + \omega_t [\sum_J \chi_j a_{j,t} - \sum_J (K_{j,t} + b_{j,t})] \}.
\end{aligned} \tag{48}$$

The relevant first-order conditions do not change, so the result that in steady state  $f_K(K_h, n_h) = 1/\beta$  holds independent of the number of countries, country-size  $\chi$ , or the specifics of the production and utility functions.

### A.2 Infrastructure

The problem remains the same as in the original setup, except that the government budget constraint becomes

$$\tau_t^k r_t K_t + \tau_t^v s_t v_t + \tau_t^n w_t n_t + b_{t+1} - (1 + R_t) b_t - g_t - I_{t+1} + I_t = 0. \tag{49}$$

The first-order conditions with respect to capital, government bonds, and capital and labor taxes do not change; the optimal steady-state capital taxes are therefore not affected by infrastructure

decisions. The first-order condition with respect to infrastructure is

$$I_t|_{t>0}: \psi_t + \psi_t \tau_t^k K_t \frac{\partial r_t}{\partial I_t} + \psi_t \tau_t^n n_t \frac{\partial w_t}{\partial I_t} + \theta_t (1 - \tau_t^n) n_t \frac{\partial w_t}{\partial I_t} + \mu u_c(t) (1 - \tau_t^n) \frac{\partial w_t}{\partial I_t} + \gamma_t (1 - \tau_t^k) \frac{\partial r_t}{\partial I_t} = \psi_{t-1} / \beta, \quad (50)$$

Using the first-order conditions for capital and labor taxes, equations (23) and (22), leads to

$$\psi_t + \psi_t K_t \frac{\partial r_t}{\partial I_t} + \psi_t n_t \frac{\partial w_t}{\partial I_t} = \psi_{t-1} / \beta. \quad (51)$$

The first-order condition for government bonds along with the equation for optimal capital accumulation (24) can be used to substitute in for  $\psi_{t-1} / \beta$ :

$$\psi_t \left( 1 + K_t \frac{\partial r_t}{\partial I_t} + n_t \frac{\partial w_t}{\partial I_t} \right) = \psi_t \left( 1 + R_t + r_t \tau_t^k + K_t \frac{\partial r_t}{\partial K_t} + n_t \frac{\partial w_t}{\partial K_t} \right). \quad (52)$$

Differentiating the equality  $f(\cdot) = rK + wn$  with respect to  $K$  and  $I$  yields  $F_K = K_t(\partial r_t) / (\partial K_t) + r_t + n_t(\partial w_t) / (\partial K_t)$  and  $f_I = K_t(\partial r_t) / (\partial I_t) + n_t(\partial w_t) / (\partial I_t)$ , so

$$f_K(t) = R_t - r_t(1 - \tau_t^k) + f_I(t) \quad (53)$$

$$= f_I(t). \quad (54)$$

□

### A.3 Endogenous Government Expenditures and Leviathan

Assume that the government can choose spending  $g_t$ . Let the government's per-period objective function be  $v(c, l, g)$ .  $g$  can either be a public good which also enters the household's utility function or it can represent government consumption or some of both. Assume that the objective function is strictly increasing and concave in all of its arguments. Also assume that  $\lim_{g \rightarrow \infty} v_g = 0$  and that  $\lim_{g \rightarrow 0} v_g = \infty$ . This ensures a positive, bounded value for government funds. Since  $\tau_t^k$ ,  $\tau_t^n$ ,  $a_{t+1}$ , and  $K_t$  are not in the objective function, equations (20) to (23) as well as the household's Euler equation (4) are unaffected.

## A.4 Steady State Alternative

Define the marginal social value of government wealth as  $m_t = \psi_t/u_c(t)$ . Assume there is a public good  $\tilde{g}$ , which satisfies  $u_{c\tilde{g}} = u_{l\tilde{g}} = 0$ ,  $\lim_{\tilde{g} \rightarrow \infty} u_{\tilde{g}} = 0$  and  $\lim_{\tilde{g} \rightarrow 0} u_{\tilde{g}} = \infty$ . The first-order condition implies  $\psi = u_{\tilde{g}}$ .  $u_{\tilde{g}}/u_c$  is the marginal rate of substitution between government and private funds. Assume that its growth rate is zero on average over a time interval  $T_1$ . This can be expressed as

$$\frac{1}{T_1} \sum_{i=t}^{t+T_1} m_i/m_{i-1} = 1. \quad (55)$$

Combining equations (25) and (21), one obtains

$$\frac{\psi_{t-1}}{\beta} - \psi_t(1 + R_t) = \psi_t \tau_t^k r_t + \psi_t (f_K(t) - r_t). \quad (56)$$

Substituting for  $\beta$  from the domestic household's first-order condition with respect to assets, (4), and for  $R_t$  from the no-arbitrage condition (12) leads to

$$\frac{\psi_{t-1}}{u_c(t-1)} = \frac{\psi_t}{u_c(t)} \frac{1 + f_K(t)}{1 + r_t(1 - \tau_t^k)}. \quad (57)$$

Using the definition of the marginal social value of government funds, this becomes

$$\frac{m_t}{m_{t-1}} = \frac{1 + r_t(1 - \tau_t^k)}{1 + f_K(t)}. \quad (58)$$

Summing over  $T_1$  time periods, and dividing by  $T_1$  yields

$$\frac{1}{T_1} \sum_{i=t}^{t+T_1} m_i/m_{i-1} = 1 = \frac{1}{T_1} \sum_{i=t}^{t+T_1} \frac{1 + r_i(1 - \tau_i^k)}{1 + f_K(i)}. \quad (59)$$

Hence the average ratio of net asset returns to the marginal product of capital is one – independent of other countries' policies and whether the economy is open or closed. In particular, if one considers the example economy in section 3, then the same constant tax rate of  $\tau^k = (1-\rho)(1-\alpha)/(1-\rho(1-\alpha))$  is optimal even out of steady state.

Over an infinitely long horizon, if the growth rate is positive or negative on average, then the value of government funds tends towards infinity or zero respectively, which is incompatible with

the assumption on  $\tilde{g}$ . Thus, the average ratio of net asset returns to the marginal product of capital is one over an infinitely long horizon.

## A.5 Feasibility, Off-equilibrium behavior, and Mixed Strategies

Assume there is an endogenously chosen public good  $g$ , with infinite marginal utility at zero.<sup>35</sup> The government chooses a sequence of capital taxes, government expenditures, and bond holdings  $\{\tau_t^k, g_t, b_{t+1}\}_{t=0}^\infty$  maximizing the agent's expected discounted lifetime utility for a given belief of foreign policy (which can also be a mixed strategy). Labor taxes adjust in each period to satisfy the government budget constraint. Since this is also true for the other country, labor taxes in both countries are choice variables in the maximization problem as long as the budget constraints are included.<sup>36</sup> I assume that the foreign country plays a mixed strategy with  $J$  elements and a probability  $0 < \pi_j \leq 1$  for each element.

The government's problem is to maximize expected lifetime utility of its agents,  $\sum_J \pi_j L_j$ , where  $L_j$  is the Lagrangian as in section 3 extended to include the foreign government's budget constraint per period (and with domestic government expenditures and foreign labor taxes as additional control variables). The set of control variables is

$$X = \{ \{c_{t,j}, c_{t,j}^*, n_{t,j}, n_{t,j}^*, K_{t,j}, K_{t,j}^*, a_{t+1,j}, a_{t+1,j}^*, \tau_{t,j}^n, \tau_{t,j}^{n*}\}_{j=1}^J, b_{t+1}, \tau_t^k, g_t \}_{t=0}^\infty. \quad (60)$$

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<sup>35</sup>I include government consumption here as it could also adjust to satisfy the government budget constraint. In this case, with initial government liabilities  $b_0 = b_0^* = 0$ , each government is always able to finance its expenditures.

<sup>36</sup>A detailed discussion of adjusted best response functions can be found in Gross (2013b).

and the Lagrangean is

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \sum_J \{u(c_{t,j}, l_{t,j}, g_t) \\
& + \psi_{t,j} [\tau_t^k r_{t,j} K_{t,j} + \tau_{t,j}^n w_{t,j} n_{t,j} + b_{t+1} - (1 + R_{t,j}) b_t - g_t] \\
& + \theta_{t,j} [(1 - \tau_{t,j}^n) w_{t,j} n_{t,j} + (1 + R_{t,j}) a_{t,j} - a_{t+1,j} - c_{t,j}] \\
& + \mu_t [(1 - \tau_{t,j}^n) w_{t,j} u_c(t, j) - u_l(t, j)] \\
& + \zeta_{t,j|t>0} [(1 + R_{t,j}) u_c(t, j) - u_c(t-1, j) / \beta] \\
& + \psi_{t,j}^* [\tau_{t,j}^{k*} r_{t,j}^* K_{t,j}^* + \tau_{t,j}^{n*} w_{t,j}^* n_{t,j}^* + b_{t+1,j}^* - (1 + R_{t,j}) b_{t,j}^* - g_{t,j}^*] \\
& + \theta_{t,j}^* [(1 - \tau_{t,j}^{n*}) w_{t,j}^* n_{t,j}^* + (1 + R_{t,j}) a_{t,j}^* - a_{t+1,j}^* - c_{t,j}^*] \\
& + \mu_{t,j}^* [(1 - \tau_{t,j}^{n*}) w_{t,j}^* u_c^*(t, j) - u_l^*(t, j)] \\
& + \zeta_{t,j|t>0}^* [(1 + R_{t,j}) u_c^*(t, j) - u_c^*(t-1, j) / \beta] \\
& + \gamma_{t,j} [r_{t,j} (1 - \tau_t^k) - R_{t,j}] \\
& + \gamma_{t,j}^* [r_{t,j}^* (1 - \tau_{t,j}^{k*}) - R_{t,j}] \\
& + \omega_{t,j} [a_{t,j} + \chi a_{t,j}^* - (K_{t,j} + K_{t,j}^* + b_t + b_{t,j}^*)] \}.
\end{aligned} \tag{61}$$

I define a best-response in this case as

**Definition 3** (Optimal Adjusted Response Function). *An optimal adjusted response function is a sequence of government expenditures  $\{g_t\}_{t=0}^{\infty}$ , capital taxes  $\{\tau_t^k\}_{t=1}^{\infty}$ , and bond issues  $\{b_t\}_{t=1}^{\infty}$  for each belief of foreign policy  $\{\pi_j, \{g_{t,j}^*, \tau_{t+1,j}^{k*}, b_{t+1,j}^*\}_{t=0}^{\infty}\}_{j=1}^J$  maximizing the agent's expected discounted lifetime utility such that labor tax rates adjust so that the government budget constraints hold every period at home and abroad and that the allocations of consumption, labor supply, and bond and capital holdings at home and abroad satisfy*

1. *agents maximizing utility subject to their budget constraints, taking prices and taxes as given;*
2. *firms maximizing profits, taking prices as given.*

The first-order conditions with respect to  $K_{t,j}$ ,  $a_{t+1,j}$  and  $\tau_{t,j}^n$  are the same as before, but the

condition for  $\tau_t^k$  changes:

$$K_{t,j} : \psi_{t,j} \tau_t^k r_{t,j} + \psi_{t,j} \tau_t^k K_{t,j} \frac{\partial r_{t,j}}{\partial K_{t,j}} + \psi_{t,j} \tau_{t,j}^n n_{t,j} \frac{\partial w_{t,j}}{\partial K_{t,j}} + \theta_{t,j} (1 - \tau_{t,j}^n) n_{t,j} \frac{\partial w_{t,j}}{\partial K_{t,j}} \quad (62)$$

$$+ \mu_{t,j} u_c(t,j) (1 - \tau_{t,j}^n) \frac{\partial w_{t,j}}{\partial K_{t,j}} + \gamma_{t,j} (1 - \tau_t^k) \frac{\partial r_{t,j}}{\partial K_{t,j}} = \omega_{t,j},$$

$$a_{t|t>0,j} : \theta_{t,j} (1 + R_{t,j}) = \theta_{t-1,j} / \beta + \omega_{t,j}, \quad (63)$$

$$\tau_{t,j}^n : \psi_{t,j} n_{t,j} w_{t,j} = \theta_{t,j} n_{t,j} w_{t,j} + \mu_{t,j} u_c(t,j) w_{t,j}, \quad (64)$$

$$\tau_t^k : \sum_J \psi_{t,j} K_{t,j} r_{t,j} = \sum_J \gamma_{t,j} r_{t,j}. \quad (65)$$

In any steady state,  $1/\beta = 1 + R_{t,j}$  from the household's Euler equation, which implies together with equation (63) that  $\omega_j = 0 \forall j \in J$ . Inserting equation (64) into (62) and multiplying by  $r_j \pi_j / (\partial r_j / \partial K_j)$  and summing over all  $j$ , it becomes

$$\sum_J \frac{\psi_j \tau_j^k r_j^2}{\partial r_j / \partial K_j} + \sum_J \psi_j \tau_j^k K_j r_j + \sum_J \frac{\psi_j n_j r_j (\partial w_j / \partial K_j)}{\partial r_j / \partial K_j} + \sum_J \gamma_j (1 - \tau_j^k) r_j = 0. \quad (66)$$

Using equation (65) along with the accounting identity  $(\partial w_j / \partial K_j) n_j + (\partial r_j / \partial K_j) K_j = f_K(j) - r_j$  leads to

$$\sum_J \frac{\psi_j r_j}{\partial r_j / \partial K_j} (f_K(j) - r_j (1 - \tau_j^k)) = 0. \quad (67)$$

The net return to assets is therefore always equal to the marginal product of capital and the modified golden rule is achieved in any steady state, even when one allows for mixed strategies.<sup>37</sup> Specifically, for the example economy in section 3 the optimal tax rate is still the same even when allowing for mixed strategies. When capital taxes adjust, the proof follows similarly to what is laid out above and the following equation has to hold:

$$\sum_J \frac{\psi_j w_j}{\partial w_j / \partial K_j} (f_K(j) - r_j (1 - \tau_j^k)) = 0. \quad (68)$$

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<sup>37</sup>As mentioned above,  $1 + R_j = 1/\beta$  for all  $j$ , so  $R_j$  is the same for all steady states, and therefore  $1 + r_j (1 - \tau_j^k) = 1 + R_j = 1/\beta$ . Since  $\psi_j r_j / (\partial r_j / \partial K_j) < 0 \forall j$ , it follows that  $1 + f_K(j) = 1/\beta \forall j$ .

## A.6 Residential and Consumption Taxes

Let the government have access to consumption and residential capital taxes, denoted by  $\tau_t^c$  and  $\tau_t^r$  respectively. In order to avoid the possibility of lump-sum taxation, let  $\tau_0^c = \tau_0^r = 0$ .

Compared to the baseline setup, the household's budget constraint and Euler equation change, as well as the government budget constraint. For a steady-state or a stable long-run average to exist (where taxes are also time-invariant), residential taxes in all countries have to be equal, so I assume that countries are symmetric. The government's Lagrangean is then

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t) \\
& + \psi_t [\tau_t^k r_t K_t + \tau_t^r R_t a_t + \tau_t^n w_t n_t + \tau_t^c c_t + b_{t+1} - (1 + R_t) b_t - g_t] \\
& + \theta_t [(1 - \tau_t^n) w_t n_t + (1 + R_t (1 - \tau_t^r)) a_t - a_{t+1} - c_t (1 + \tau_t^c)] \\
& + \mu_t [(1 - \tau_t^n) w_t u_c(t) - u_l(t) (1 + \tau_t^c)] \\
& + \zeta_{t|t>0} [(1 + R_t (1 - \tau_t^r)) u_c(t) (1 + \tau_{t-1}^c) - u_c(t-1) (1 + \tau_t^c) / \beta] \\
& + \theta_t^* [(1 - \tau_t^{n*}) w_t^* n_t^* + (1 + R_t (1 - \tau_t^{r*})) a_t^* - a_{t+1}^* - c_t^* (1 + \tau_t^{c*})] \\
& + \mu_t^* [(1 - \tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t) (1 + \tau_t^{c*})] \\
& + \zeta_{t|t>0}^* [(1 + R_t (1 - \tau_t^{r*})) u_c^*(t) (1 + \tau_{t-1}^{c*}) - u_c^*(t-1) (1 + \tau_t^{c*}) / \beta] \\
& + \gamma_t [r_t (1 - \tau_t^k) - R_t] \\
& + \gamma_t^* [r_t^* (1 - \tau_t^{k*}) - R_t] \\
& + \omega_t [a_t + \chi a_t^* - (K_t + K_t^* + b_t + b_t^*)] \},
\end{aligned} \tag{69}$$

Compared to the baseline model, only the first-order condition with respect to assets changes:

$$a_{t|t>0,j} : \theta_{t,j} (1 + R_t (1 - \tau_t^r)) = \theta_{t-1} / \beta + \omega_t. \tag{70}$$

In steady state, the household's Euler equation implies that  $(1 + R(1 - \tau^r)) = 1/\beta$ , and therefore  $\omega = 0$ . It follows that the modified golden rule holds.

Furthermore, if there is any binding restriction on the consumption tax and / or residential taxes, it will not affect any of the first-order conditions regarding capital  $K_t$ , assets  $a_{t+1}$ , labor taxes  $\tau_t^n$ , or source-based capital taxes  $\tau_t^k$ , and therefore does not affect the result above.

## A.7 Direct Investment and Adjustment Costs

Assume that production in each country takes place as described in section 3.2, but that there are no investors. Instead, households choose directly where to employ their assets. Assume for simplicity (without loss of generality) that there are no government bonds.

The household thus owns two types of capital, at home  $k_t$  and abroad  $k_t^*$ , with  $k_0$  and  $k_0^*$  given (and similarly for foreign capital  $q$  and  $q^*$ ). Whenever the household wants to change capital holdings abroad, it faces an adjustment cost  $Z(k_t^*, k_{t+1}^*)$ .  $Z(\cdot)$  is convex, continuously differentiable, increasing in the difference of its arguments, and symmetric.<sup>38</sup> Here I use it as a proxy for barriers to capital movement. For example, domestic agents might have an informational disadvantage or face legal difficulties when investing abroad, thus resulting in some price difference they pay as compared to locals. Similarly, when selling their investment, they also do so at a discount. The total amount of capital used in the home country is  $K = k + q$  and abroad it is  $K^* = k^* + q^*$ .

The government's Lagrangean is

$$\begin{aligned}
L = & \sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t) \\
& + \psi_t [\tau_t^k r_t K_t + \tau_t^n w_t n_t - g_t] \\
& + \theta_t [(1 - \tau_t^n) w_t n_t + (1 + r_t(1 - \tau_t^k)) k_t - k_{t+1} + (1 + r_t^*(1 - \tau_t^{k*})) k_t^* - k_{t+1}^* - Z(k_t^*, k_{t+1}^*) - c_t] \\
& + \mu_t [(1 - \tau_t^n) w_t u_c(t) - u_l(t)] \\
& + \zeta_{t|t>0} [(1 + r_t(1 - \tau_t^k)) u_c(t) - u_c(t-1)/\beta] \\
& + \gamma_{t|t>0} [(1 + r_t^*(1 - \tau_t^{k*}) - Z_{k_t^*}(k_t^*, k_{t+1}^*)) u_c(t) - (1 + Z_{k_t^*}(k_{t-1}^*, k_t^*)) u_c(t-1)/\beta] \\
& + \theta_t^* [(1 - \tau_t^{n*}) w_t^* n_t^* + (1 + r_t(1 - \tau_t^k)) q_t - q_{t+1} + (1 + r_t^*(1 - \tau_t^{k*})) q_t^* - q_{t+1}^* - Z(q_t^*, q_{t+1}^*) - c_t^*] \\
& + \mu_t^* [(1 - \tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t)] \\
& + \zeta_{t|t>0}^* [(1 + r_t(1 - \tau_t^k)) u_c^*(t) - u_c^*(t-1)/\beta] \\
& + \gamma_{t|t>0}^* [(1 + r_t^*(1 - \tau_t^{k*}) - Z_{q_t^*}(q_t^*, q_{t+1}^*)) u_c^*(t) - (1 + Z_{q_t^*}(q_{t-1}^*, q_t^*)) u_c^*(t-1)/\beta] \},
\end{aligned} \tag{71}$$

<sup>38</sup>By symmetric I mean that the second derivatives are equal to another and the negative of the cross-derivative when  $k_t^* = k_{t+1}^*$ , i.e.  $Z_{k_t^*, k_t^*}(k_t^*, k_{t+1}^*) = Z_{k_{t+1}^*, k_{t+1}^*}(k_t^*, k_{t+1}^*) = -Z_{k_t^* k_{t+1}^*}(k_t^*, k_{t+1}^*)$ . A standard quadratic adjustment cost function serves as an example that meets this condition. One can also introduce adjustment costs for domestic capital without changing results. Adjustment cost functions can differ across countries.

The first-order conditions with respect to capital holdings at home, labor, and capital taxes are:

$$\begin{aligned}
k_{t|t>0}: \psi_t \tau_t^k r_t + \psi_t \tau_t^k K_t \frac{\partial r_t}{\partial k_t} + \psi_t \tau_t^n n_t \frac{\partial w_t}{\partial k_t} + \\
\theta_t [1 + (1 - \tau_t^k) r_t] + \theta_t (1 - \tau_t^k) k_t \frac{\partial r_t}{\partial k_t} + \theta_t (1 - \tau_t^n) n_t \frac{\partial w_t}{\partial k_t} + \\
\theta_t^* q_t (1 - \tau_t^k) \frac{\partial r_t}{\partial k_t} + \mu u_c(t) (1 - \tau_t^n) \frac{\partial w_t}{\partial k_t} + \zeta_t (1 - \tau_t^k) \frac{\partial r_t}{\partial k_t} + \gamma_t^* (1 - \tau_t^k) \frac{\partial r_t}{\partial k_t} = \theta_{t-1} / \beta, \quad (72)
\end{aligned}$$

$$\tau_t^n: \psi_t n_t w_t = \mu_t u_c(t) w_t + \theta_t n_t w_t, \quad (73)$$

$$\tau_{t|t>0}^k: \psi_t K_t r_t + \psi_t b_t r_t = \theta_t k_t r_t + \theta_t b_t r_t + \theta_t^* k_t^* r_t + \zeta_t r_t + \gamma_t^* r_t. \quad (74)$$

Substituting (73) and (74) into (72) leads to

$$\psi_t \tau_t^k r_t + \psi_t K_t \frac{\partial r_t}{\partial k_t} + \psi_t n_t \frac{\partial w_t}{\partial k_t} + \theta_t [1 + r_t (1 - \tau_t^k)] = \theta_{t-1} / \beta. \quad (75)$$

Total production equals total factor remuneration  $f(\cdot) = Kr + nw$ . Differentiating with respect to capital leads to  $f_k = K \frac{\partial r_t}{\partial k_t} + r + \frac{\partial w_t}{\partial k_t} n$ . Equation (75) can now be rewritten as

$$\psi_t \tau_t^k r_t + \psi_t (f_k(t) - r_t) + \theta_t [1 + r_t (1 - \tau_t^k)] = \theta_{t-1} / \beta. \quad (76)$$

Furthermore, in steady state one can drop time subscripts. The household's Euler equation then implies  $1/\beta = (1 + r(1 - \tau^k))$  and therefore, as  $\psi > 0$ ,

$$\psi \tau^k r = (r - f_k(\cdot)) \psi \quad (77)$$

$$\Leftrightarrow \tau^k = (r - f_k(\cdot)) / r. \quad (78)$$

Reintroducing the optimal tax rate into the Euler equation yields the modified golden rule:

$$1 + f_k(\cdot) = 1/\beta. \quad (79)$$

Adjustment costs do not play any role in this. When adjustment costs for domestic capital are included,  $Z(k_t, k_{t+1})$ , the first-order condition for domestic capital changes, but one can show that the modified golden rule still holds.

## B Appendix: Example Aiyagari economy

Assume an economy as in Aiyagari (1995). The notation is very similar, so sticking to the notation in this paper should still leave it easily comparable. In particular, I call the idiosyncratic productivity shocks  $\pi$  instead of  $\theta$ , after-tax returns are denoted by a tilde instead of a bar (e.g.  $\tilde{r}$  instead of  $\bar{r}$ ), and government expenditure and debt are  $g$  and  $b$  instead of the capitalized letters. Moreover, I introduce the borrowing constraint  $\epsilon \leq 0$  (instead of zero). The borrowing constraint is generally not binding for the entire population.  $J(a, \pi)$  is the distribution over assets and skills and all per-capita terms are functions of  $a, \pi$  over this distribution.

I first show how one can map this economy into the framework laid out in section 7 and then show how the modified golden rule is not affected if the economy is open. The government's maximization problem can be written as

$$\begin{aligned}
 L = \sum_{t=0}^{\infty} \beta^t \{ & \int_{J_t} \{u(c_t) + U(g_t) \\
 & + \theta_t [\tilde{w}_t n_t + \pi_t H(1 - n_t) + (1 + \tilde{r}_t) a_t - a_{t+1} - c_t] \\
 & + \mu_t [\tilde{w}_t - \pi_t H'(1 - n_t)] \\
 & + \zeta_{t|t>0} [u_c(t) - \beta E_t \{(1 + \tilde{r}_{t+1}) u_c(t+1)\}] \\
 & + \phi_t [a_{t+1} - \epsilon] \} dJ_t \\
 & + \psi_t [f(K_t, N_t) - \tilde{w}_t N_t - \tilde{r}_t K_t + b_{t+1} - (1 + \tilde{r}_t) b_t - g_t] \\
 & + \omega_t [a_t - (K_t + b_t)] \}, \tag{80}
 \end{aligned}$$

The government's constraint set  $\Psi_C(K, b, a, \tilde{r}; \dots) = 0$  is therefore given by the constraint with multiplier  $\psi_t$  for all  $t$  and the set of competitive equilibrium conditions  $\Upsilon_C^D(a, \tilde{r}; \dots) \geq 0$  is given by the constraints with multipliers  $\theta_t, \mu_t, \zeta_t$ , and  $\phi_t$  over the distribution  $J_t$  for all  $t$ .

The first-order conditions with respect to  $K_t$  and  $b_t$  are given by

$$K_{t|t>0}: \psi_t (f_K(t) - \tilde{r}_t) = \omega_t \tag{81}$$

$$b_{t|t>0}: \psi_{t-1}/\beta - \psi_t (1 + \tilde{r}_t) = \omega_t. \tag{82}$$

It follows that in steady state, when  $\psi_t = \psi_{t-1}$ , the modified golden rule holds. Furthermore, the

tax rate has to be positive. To see it in this context, the household's Euler equation, when summing over all types, is

$$\int_{J_t} u_c(t) = \int_{J_{t+1}} \beta E_t \{ (1 + \tilde{r}_{t+1}) u_c(t+1) \}. \quad (83)$$

Unless agents are able to perfectly insure themselves – which would require infinite assets – consumption depends positively on the idiosyncratic shock. It follows that in steady state, the average expected marginal utility in period  $t+1$  is higher than the average marginal utility in period  $t$  (by the concavity of the utility function). In order to implement the modified golden rule, a positive capital tax is therefore necessary, since  $1 + f_K(1 - \tau^k) < 1/\beta$  and using  $1 + f_K = 1/\beta$ , it must be that  $\tau^k > 0$ .

In an open economy, the competitive equilibrium conditions abroad have to be added to the problem, which do not depend on domestic capital or bonds, as well as a no-arbitrage condition  $\tilde{r}_t = \tilde{r}_t^*$ . Moreover, capital market clearing is then  $a_t + a_t^* - (K_t + b_t + K_t^* + b_t^*) = 0$ . None of this changes the first-order conditions (81) and (82). The modified golden rule therefore remains optimal in an open economy, although the capital taxes which implement it may be different.