Residence- and source-based capital taxation in open economies with infinitely-lived consumers

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Abstract

In this paper we investigate tax competition in a neoclassical growth model where each country may use both residence- and source-based capital taxes. We show that both types of capital taxes are zero in the long run, just as in a closed economy. For symmetric countries, and even for countries that differ only with respect to size and productivity, we prove analytically and verify numerically that the open-economy policies coincide exactly with the closed-economy policies in all time periods. For countries that are asymmetric in other dimensions, we find that source-based taxes are used to manipulate the intertemporal terms of trade in the short run. Either way, the fiscal externalities of source-based taxes vanish once residence-based taxes are allowed.

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1 Introduction

Capital has become increasingly mobile between countries. This poses potentially large problems for the taxation of capital, since a high tax on capital may lead to capital flight to a country where the tax rate is lower. The risk of capital flight may be even more severe when tax authorities relying mainly on source-based capital taxes, such as corporate income taxes and withholding taxes; this will inevitably be the case if information about capital income is not shared across jurisdictions. In such an environment, countries may engage in capital tax competition, perhaps implying lower capital taxes, higher labour taxes or lower public spending than in an economy without international capital mobility. Concerns over such “harmful tax competition” have been voiced, for instance, in communiqués by the OECD (1998) and the European Union (2003).

However, recent agreements on information sharing between EU and EU countries make it more feasible to levy capital taxes according to the residence principle. In particular, the Common Reporting Standard is now being implemented, allowing for automatic information sharing between governments. This represents a major shift in the enforceability of residence-based capital taxes, making it more important than ever to understand the non-cooperative use of capital taxes by governments who can deploy both residence- and source-based taxes in the presence of capital mobility. The question we address here is the following: what is the effect of capital market integration on capital taxes when governments can tax according to the residence as well as the source principle?

We address this issue in the context of a multi-country neoclassical growth model with an infinite horizon. Our choice of a fully dynamic model with endogenous capital is crucial. In a static model, residence-based (savings) taxes are lump-sum taxes. In a two-period model, the tax externalities are very different from those in a fully dynamic model, as we emphasized in Gross, Klein, and Makris (2017) in a

context where only source-based taxes can be used. This difference may be even more pronounced when residence-based taxes are also available because of their effect on the rates of return to savings, thereby on capital accumulation, and hence the global supply of capital over time. We restrict our attention to the case of perfect commitment, in order to establish a benchmark.

We prove analytically that, in the long run, all capital taxes are zero. This result is quite important for our study: When countries have the same subjective discount factor, a non-degenerate steady state only exists if residence-based capital taxes are identical across countries—otherwise the country with the highest after-tax rate of return will, in the limit, own the entire global stock of wealth. Therefore, if countries were to differ in endowments, technology, or their agents’ preferences, and if these differences were to result in different choices of residence-based capital taxes, then the world economy would not converge to a non-degenerate wealth distribution. However, because we show that all countries choose the same long-run capital tax rate (zero) regardless of asymmetries, we can sensibly study environments where countries differ in more or less arbitrary ways, provided only that they have the same subjective discount factor.

Our next finding in this new setting is that, when countries differ with respect to population size and/or productivity only, the equilibrium of a non-cooperative tax competition game is identical to the equilibrium in the absence of capital mobility; in other words, it is as if the two economies were closed. We prove this analytically (in an n-country world) and verify it numerically (in a two-country world). In such an environment, source-based capital income taxes are always zero. The result that source-based capital income taxes are always zero is similar to those by Bucovetsky and Wilson (1991) and Eggert and Haufler (1999), who focus on identical countries, and can thus be seen as an extension of these results from a two-period to an infinite-horizon setting. In our fully dynamic model, however, residence-based capital taxes are only initially high and then go to zero, as in a closed economy.

In consonance with this surprising result, we show that the fiscal externalities asso-
ciated with source-based capital taxes vanish when residence-based capital income
taxes are allowed. This holds even when countries differ with respect to other fea-
tures than population and productivity.

However, while the fiscal externalities always vanish, when jurisdictions differ with
respect to some fundamentals not related to size or productivity, such as the initial
asset position, source-based taxes are associated with a terms-of-trade externality,
which does not arise for residence-based taxes. This externality, however, is tiny
compared to its counterpart when source-based taxes are the only type of capital
tax allowed. Importantly, while there are significant welfare costs of capital mobility
when only source-based taxes are allowed, we observe small, but positive, welfare
gains from capital mobility once savings taxes are available. The reason is that tax
competition is no longer harmful, and there are potential gains from (intertemporal)
trade. Therefore, increased capital-market integration may not be as problematic as
many have feared.

The rest of the paper is organized as follows. Section 2 discusses some of the related
literature. Section 3 presents the model framework and defines our equilibrium con-
cept. Section 4 contains our analytical results regarding optimal policy and discusses
the externalities stemming from capital taxes. In Section 5 we show our quantitative
results. Section 6 concludes.

2 Related literature

A large literature exists on tax competition with source-based taxes when the capi-
tal stock is exogenously given. The main idea is captured in the seminal papers by
Zodrow and Mieszkowski (1986) and Wilson (1986): When capital becomes interna-
tionally mobile, then countries will lower their capital tax rates and provide less
public goods; this is inefficient and all countries would gain by a coordinated tax
increase. There is not enough space to do justice to the many contributions that fol-

4
ollowed, so we refer here to three excellent summaries/surveys. Wilson and Wildasin (2004a) review the theoretical arguments about whether tax competition is a “bane or boon” by taking into account that tax competition may benefit citizens if, for example, the government is non-benevolent as in Edwards and Keen (1996) and Eggert (2001). Nicodème (2006) situates the policy debate in the context of the theoretical literature. Zodrow (2010) focusses on the nexus of the empirical and theoretical literature, noting that capital mobility has increased over time and is high, that tax competition has taken place over statutory rates, but that the broadening of the tax base has led to relatively constant effective marginal tax rates. One main implication from the literature is that increased capital mobility will lead to an overall decrease in tax rates. Exceptions include Cai and Treisman (2005) with productive government spending and Baldwin and Krugman (2004) with trade by monopolistically competitive firms. In these models, some countries lower their capital taxes in response to tax competition while others increase theirs.

The various externalities associated with tax competition under the source principle and an exogenous capital stock are well understood. The main one, which dominates the tax competition literature, is the fiscal externality; see, for instance, Griffith, Hines, and Sørensen (2010). The intuition can be described as follows: If the global capital stock is fixed, then it is optimal to tax it as much as possible, instead of using distortionary labour taxes. This implies a wedge between the social marginal product of capital and the return to the investor. In an open economy, lowering the tax rate attracts capital from abroad and the country would gain from this, as there is a wedge between the return to the foreign investor and marginal product of capital. Since all countries have the same incentives to attract foreign capital, the end result is that they all have lower capital taxes and higher distortionary labour taxes (or, alternatively, less public goods). Some more recent theoretical work argues that capital market integration might, in some circumstances, lead to an overtaxation of capital at the source. This literature emphasizes the presence of alternative externalities that could counteract the aforementioned fiscal externality.2

\(^2\)See, for example, Keen and Kotsogiannis (2002), Kessler, Lülfeismann, and Myers (2002), Makris
In the context of a static model with an exogenous capital stock, allowing for residence-based capital taxes makes the optimal-tax problem trivial: these taxes are then equivalent to lump-sum taxes which are generally assumed not to be available in this type of framework (otherwise the optimal-tax problem is trivial). One way to avoid triviality is to endogenize capital in the context of a two-period model; that is done in, for instance, Bucovetsky and Wilson (1991) and Eggert and Haufler (1999) in a context of identical countries. Becker and Fuest (2011) also study a two-period model, but capital flows in their setting are in terms of mergers and acquisitions instead of foreign direct investment, in contrast to most of the literature. In this setting, the availability of residence-based taxes may actually result in higher global distortions, whereas policy with only source-based capital taxes is efficient. However, these papers do not take into account the dynamic aspects of taxation.

The literature on optimal taxation in a multi-period setting, pioneered by Chamley (1986) and Judd (1985), has demonstrated that the results concerning capital taxes change markedly between a fully dynamic economy with endogenous capital accumulation and one where capital is given as an endowment. Chamley and Judd found that the optimal capital tax should initially be as high as possible (to tax the initial capital stock, which is given as an endowment in the fully dynamic model as well), but zero in the long run. Even though later work, for instance by Aiyagari (1995) or Erosa and Gervais (2002), qualified the zero-tax result, they obtained the same policy prescription: that capital accumulation should be undistorted in the long run. In a large class of models, including New Dynamic Public Finance work,\(^3\) the modified golden rule of capital holds in the long run.\(^4\) An exception to this rule is found in an environment where the tax system is incomplete (fewer tax instruments than inputs into the production function), as Correia (1996b) and subsequent studies have shown. All these papers assume perfect commitment. Since Kydland

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\(^3\)See Golosov, Kocherlakota, and Tsyvinski (2003) and Kocherlakota (2010).

\(^4\)See also Gross (2015b).
and Prescott (1977) it is well known that capital taxes are too high in the absence of commitment, see also Klein and Ríos-Rull (2003) and Klein, Krusell, and Ríos-Rull (2008). While perfect commitment may not be a realistic assumption, it serves an important role as a benchmark, as Kydland and Prescott (1980) argue.

In summary, there has been a lot of work on tax competition in static or two-period models and on optimal taxation in a fully dynamic, but closed economy. Much less attention has been devoted to optimal (or equilibrium) taxation in a fully dynamic open economy, i.e. when capital taxes distort both the intertemporal savings margin as well as the allocation of capital across countries. A few papers employ a formally dynamic model, but make specific functional-form assumptions so that capital taxes do not affect the savings decision, as for instance in Köthenbürger and Lockwood (2010) and Arcalean (2016). Lejour and Verbon (1998) only analyze steady states without taking into account the transition. Wildasin (2003), Mendoza and Tesar (2005), Becker and Rauscher (2007), and Hatfield (2015) impose time-invariance on tax rates, meaning that the capital taxes at each time are a compromise between the desire to highly tax the initial capital stock and to not tax capital in the long run. This rules out any detailed period-by-period analysis of externalities. Klein, Quadrini, and Ríos-Rull (2005) and Quadrini (2005) study equilibrium taxation in an open economy with limited commitment. Quadrini (2005) shows that in this context, tax competition does reduce capital taxes, but that this constitutes a welfare improvement.

If lack of commitment implies inefficiently high capital taxes, and tax competition drives down capital taxes, then it is important to know what the solution with perfect commitment is. It creates, as mentioned before, a benchmark against which other policies can be evaluated. Under the assumption of perfect commitment, Correia (1996a) and Angyridis (2007) analyze optimal taxation in fully dynamic small open economies, which immediately converge to the long-run steady state and where the international rate of return is exogenously given.5 Gross (2014) pro-

5Correia (1996a, p.698) also discusses the similarity of the small open-economy solution (with
vides a framework to analyze optimal taxation in large open dynamic economies but only considers long-run results; Gross (2015a) extends these results to a larger class of models and Gross (2018) examines the effects of intergovernmental transfers in this context.

Gross, Klein, and Makris (2017) study the entire transition from an arbitrary starting point to a steady state. Our work involved decomposing, analytically and computationally, the externalities stemming from source-based capital taxes. Notably, we found a savings externality (which is obviously not present in static models), whereby governments do not take into account that higher taxes will reduce savings and thus the capital stock and thereby harm other countries. This externality is zero at first, but then grows over time and in the long run completely offsets the other externalities. The present study does for a setting with residence-based and source-based capital taxes what Gross, Klein, and Makris (2017) did for source-based capital taxes alone.

3 Model economy

The world consists of finitely many countries $i = 1, 2, \ldots, m$. Each country has a representative consumer and a representative competitive firm. Physical capital is costlessly and immediately mobile across borders, while labour is immobile. Savings are allocated across capital and government bonds in the various jurisdictions by transnational, competitive investment firms whose behaviour guarantees that after-tax rates of return to all assets are equalized. Governments in each country aim to maximize their respective home representative agent’s utility and can levy capital and labour taxes to finance a stream of endogenous expenditures; they may

residence-based taxes) to the closed-economy solution. However, in her model there is no transition period of intermediate taxes. This happens because the rest of the world is assumed to be in steady state. In our model, which includes the case of a small open economy as a limiting feature, all governments choose their taxes optimally at the same time, which leads to identical solutions in every period for a closed and open economy (with symmetry).
also issue government bonds.

Capital taxes take the form of source-based taxes, which are paid by firms in the country where they produce, and residence-based taxes, which are paid by households in the country where they live. Residence-based taxes are paid on capital income net of source-based taxes. The governments are able to commit to their future taxes and thus 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. Governments form beliefs about other governments’ fiscal policies and determine their best response. In equilibrium, the beliefs are correct. Out of equilibrium, as a government contemplates a deviation, it imagines that it must obey its own government budget constraint, and that consumers and firms all reoptimize in response to the deviation, but that foreign governments do not respond.

3.1 The Representative Agent

Let there be a measure $\chi^i$ of agents in each country $i$. All agents take prices and taxes as given and maximize lifetime utility:

$$\sum_{t=0}^{\infty} \beta^t \left[ u^i(c^i_t, l^i_t) + v^i(g^i_t) \right].$$

(1)

$u^i(c^i_t, l^i_t)$ is a utility function that is strictly increasing and concave in consumption $c^i_t$ and leisure $l^i_t$ (all variables are in per-capita terms). The subjective discount factor is denoted by $\beta \in (0, 1)$. We assume that it is common across countries, to ensure the existence of a non-degenerate steady state. Per-capita government spending is denoted by $g^i_t$ and $v^i(\cdot)$ is an increasing, strictly concave function, with $\lim_{g \to 0} v^i_g = \infty$ for each $i$. The household divides up its total unitized time between labour $n^i_t$ and leisure. The per-period budget constraint is:

$$c^i_t = (1 - \tau^i_{n,t})w^i_t n^i_t + [1 + R_t(1 - \tau^i_{a,t})]a^i_t - a^i_{t+1}.$$

(2)

$w^i_t$ is the wage, $\tau^i_{n,t}$ are labour taxes, $a^i_t$ are asset holdings, and $R_t$ is the international net rate of return. $\tau^i_{a,t}$ is the residence-based tax on capital income; the notation is
motivated by the fact that it is a tax on asset returns (from whatever source). Initial asset holdings $a^i_t$ are exogenously given.

Utility maximization implies the familiar labour-leisure trade-off and “Euler” equation characterizing the optimal trade-off between consumption in the current period versus the next (subscripts denote partial derivatives, e.g. $u^i_{c,t} = \partial u^i(c^i_t, n^i_t) / \partial c^i_t)$:

$$u^i_{c,t} = u^i_{c,t}(1 - \tau^i_{n,t})w^i_t$$

$$u^i_{c,t} = \beta u^i_{c,t+1}[1 + R_{t+1}(1 - \tau^i_{a,t+1})]$$

Equations (2), (3), and (4) characterize the household behaviour together with initial asset holdings and no-Ponzi conditions (which we leave out to avoid tedious notation). That is, for given prices and taxes, these equations pin down household choices $\{c^i_t, l^i_t, a^i_{t+1}\}_{t=0}^{\infty}$ in each country.

### 3.2 Firms and Production

There are many identical firms which are perfectly competitive. They rent capital $k^i_t$ and hire labour $n^i_t$ to produce output according to a concave production function with constant returns to scale, $F^i(k^i_t, n^i_t) = f^i(k^i_t, Z^i n^i_t) - \delta k^i_t$. The production function includes a linear depreciation term, where the depreciation rate is denoted by $\delta$; $Z^i$ is a country’s labour productivity. Our assumptions imply zero profits and the standard conditions regarding the relationship between input prices and marginal products:

$$w^i_t = F^i_{n,t}$$

$$r^i_t = F^i_{k,t}.$$  

We assume throughout that the marginal product of capital is strictly positive, i.e. $r^i_t > 0$. 

10
3.3 Investors

Investors allocate savings from agents to firm capital and government bonds $b^i_t$ to maximize their profits (which are zero in equilibrium due to perfect competition and constant returns to scale).\(^6\) Capital returns are taxed at source in each country at a rate $\tau^i_{k,t}$. Let $\tilde{r}^i_t$ denote the net return on government bonds.\(^7\) The representative investor’s profit maximization problem in each period is

$$\begin{align*}
\max_{\{k^i_t, b^i_t, a^i_t\}_{i=1}^m} & \quad \sum_i x^i \left( r^i_t (1 - \tau^i_{k,t}) k^i_t + \tilde{r}^i_t b^i_t - a^i_t R_t \right) \\
\text{s.t.} & \quad \sum_i x^i a^i_t = \sum_i x^i (k^i_t + b^i_t). 
\end{align*}$$

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

$$R_t = r^i_t (1 - \tau^i_{k,t}) = \tilde{r}^i_t. \quad \text{(9)}$$

Due to our assumption of perfect and immediate capital mobility, these no-arbitrage conditions hold in every period $t$, including at $t=0$. Governments can issue any amount of government debt paying the market rate of return $R_t$ (subject only to a no-Ponzi condition, which we omit here). Equations (8) and (9) characterize the investors’ behaviour; for given taxes, these equations pin down $\left\{\{\tilde{r}^i_t, k^i_t\}_{i=1}^m, R_t\}_{t=0}^\infty$.

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\(^6\) Investors are not a necessary element of our model, but they simplify the exposition and analysis. In the absence of investors, all consumers would have to choose the composition of their investment portfolio, and not just its total value. This means that for each country, the representative consumer there would have to choose how much capital to invest in each of the countries (and similarly for government bonds). The number of variables would thus explode as the number of countries gets larger. In our setup, we have government bonds, capital and private assets in each country, or $3m$ financial variables; without investors, the number of such variables would be $2m^2$. Furthermore, the aggregate capital stock employed in each country and the net foreign asset position in each country are uniquely determined, but not what fraction of a given country’s capital stock is owned by residents of another; without investors, the portfolio composition of each agent would thus be indeterminate. See also Gross (2014).

\(^7\) No-arbitrage requires that returns on government bonds have to be equal to returns on capital, see below. It therefore does not matter whether bond returns are taxed at source or not.
3.4 The Government

Each benevolent (but nationalistic) government maximizes the utility of its own representative consumer. It finances its endogenously chosen government purchases \( \{g^i_t\}_{t=0}^\infty \) via source- and residence-based taxes on capital income, as well as labour income taxes. Governments may also issue one-period debt. Initial government debt \( b_0 \) is exogenously given. In order to avoid confiscatory lump-sum taxation of initial assets, we stipulate that residential capital taxes may not exceed 100%, as is common in the optimal-taxation literature. As mentioned above, residence-based capital taxes are applied to the rate of return net of source-based capital taxes. The government’s per-period budget constraint can be written as

\[
g^i_t + b^i_t (1 + R_t) = \tau^i_{k,t} k^i_t + \tau^i_{a,t} a^i_t + \tau^i_{n,t} w^i_t n^i_t + b^i_{t+1}.
\]  

(10)

3.5 Equilibrium

At time \( t = 0 \), governments simultaneously announce their policies for the infinite future. Households, firms, and investors then react to the announced policies in such a way as to maximize utility/profits. Incorporating their optimality conditions as constraints into the government’s problem allows us to treat all the private sector’s choice variables (both at home and abroad) as each government’s own control variables. Meanwhile, each government considers the policies of other governments as exogenously fixed and equal to the equilibrium policies. Notice that a deviation from equilibrium on the part of one government will typically render the other governments either insolvent or overfunded as private agents respond to the deviation. It follows that our environment is not a game in the sense of Nash (1950). This is because the set of feasible strategies available to any one government depends on what the others are doing; Nash explicitly rules this out.

Our model environment is, instead, a “generalized game” in the sense of Debreu (1952), a concept applied in the seminal work by Arrow and Debreu (1954). In the
words of Dasgupta and Maskin (2015), a generalized game “allow[s] for the possibility that a player’s set of strategies might depend on the strategy choices of other players.” We apply the equilibrium concept that Debreu developed for the purpose of analyzing generalized games, namely a social equilibrium. A social equilibrium is a strategy profile such that each agent chooses the best strategy available to her given the strategies of the other agents. Notice that each agent, when contemplating what to do, ignores the fact that her out-of-equilibrium choices may render the other agents’ equilibrium strategies infeasible. (See, for instance, Equations (4) and (5) in Dasgupta and Maskin, 2015.)

This concept implies that off-equilibrium behaviour is typically not consistent with competitive equilibrium for the world as a whole; the worldwide resource constraint will typically not hold if a single government deviates, though it will of course hold in a social equilibrium.\(^8\)

For the benefit of anyone who is uncomfortable with the idea that deviations take us out of competitive equilibrium, we have a rather satisfying equivalence result. In an economy, such as ours, where government spending is endogenous, we can define the following alternative equilibrium concept, where the consequences of a deviation are modified relative to our favoured equilibrium concept. In this alternative scenario, if a government deviates, thus rendering the other government’s previously chosen policy infeasible, then that other government automatically adjusts its government spending in each period so as to balance its flow budget constraint, keeping government debt in each period unchanged. In this way, a deviating government does not render the other government’s action infeasible. Interestingly, it turns out that this modification implies exactly the same equilibrium policy profile as under our favoured equilibrium concept, provided only that the utility function is additively separable over private and public consumption.

Meanwhile, in economies where government spending is exogenous, the argument

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\(^8\)A more detailed discussion of the equilibrium concept as applied in this paper can be found in Gross (2014), which considers source-based taxes.
just made does not work, because the alternative equilibrium concept described above would not apply. What this means, of course, is that our (Debreu’s) equilibrium concept has a wider set of applications than the alternative just described. This more general applicability seems to us to be a point in favour of Debreu’s concept as opposed to this alternative.

Meanwhile, there are many other equilibrium concepts that are conceptually similar to the alternative described above. For instance, instead of letting government spending adjust automatically so as to satisfy the flow government budget constraint, labour taxes could adjust automatically. These alternative equilibrium concepts are not equivalent; not to our favoured concept and not to each other.\(^9\) That fact seems to us to be yet another point in favour of Debreu’s concept: any alternative that is not equivalent to it depends on an arbitrary choice of adjustment variables, whereas Debreu’s concept does not force us to make any such arbitrary choice.

Moreover, these alternative equilibrium concepts are not, strictly speaking, Nash equilibria either, because the games they define are still not Nash games. For instance, the amount of debt a government can issue in each period still depends on the strategies of the other countries. That too is a consideration that pushes us in the direction of adopting Debreu’s social equilibrium concept as the most natural one in our environment.

\(^9\)For a deeper examination of these equilibrium issues, when one fiscal-policy variable per period adjusts residually, see Gross (2018).
4 Optimal policy

We now characterize the optimal policy of some fixed country $j$’s government, using Lagrange’s theorem. The Lagrangian is

$$L^j = \sum_{t=0}^{\infty} \beta^t \left\{ u^j(c^j_t, l^j_t) + v^j(g^j_t) \right\}$$

$$+ \psi^j_t \left[ \tau_{k,t}^j r^j_k + \tau_{a,t}^j R_t a^j_t + \tau_{n,t}^j w^j_t n^j_t + b^j_{t+1} - (1 + R_t)b^j_t - g^j_t \right]$$

$$+ \sum_{i=1}^{m} \theta^{ij}_t \left[ (1 - \tau_{n,t}^i) w^i_t n^i_t + [1 + R_t(1 - \tau_{a,t}^i)] a^i_t - a^i_{t+1} - c^i_t \right]$$

$$+ \sum_{i=1}^{m} \mu^{ij}_t \left[ (1 - \tau_{n,t}^i) w^i_t u^{i,t}_c - u^{i,t}_l \right]$$

$$+ \sum_{i=1}^{m} \zeta^{ij}_t \left\{ \beta u^{i,t+1}_c [1 + R_{t+1}(1 - \tau_{a,t+1}^i)] - u^{i,t}_c \right\}$$

$$+ \sum_{i=1}^{m} \gamma^{ij}_t \left[ r^i_t (1 - \tau_{k,t}^i) - R_t \right]$$

$$+ \omega^i t \sum_{i=1}^{m} \chi^i (a^i_t - k^i_t - b^i_t)$$

$$+ \phi^j_t R_t (1 - \tau_{a,t}^j) \right\},$$

where, for instance, $\theta^{ij}_t$ is the Lagrange multiplier associated with country $j$’s government optimization problem and the household budget constraint of residents of country $i$. Note that $w^i_t$ and $r^i_t$ are functions of $k^i_t$ and $n^i_t$ as described in Equations (5) and (6), and $l^i_t = 1 - n^i_t$. The constraint associated with the multiplier $\phi^j_t$ states that the after-tax returns on assets cannot be negative.

In what follows, we will never have occasion to explicitly refer to the Lagrange multipliers associated with the optimization problem of more than one country at a time. We will therefore suppress the second superscript $j$ in $\theta^{ij}_t, \mu^{ij}_t, \zeta^{ij}_t$ and $\gamma^{ij}_t$, and write simply $\theta^i_t, \mu^i_t, \zeta^i_t$ and $\gamma^i_t$, where the single superscript $i$ refers to a particular constraint rather than a particular country’s optimization problem. Similarly we shall write $\psi_t, \omega_t$ and $\phi_t$ rather than $\psi^j_t, \omega^j_t$ and $\phi^j_t$. 

15
We have substituted in for the equilibrium prices of governments bonds, i.e. replaced $\hat{r}_t^j$ with $R_t$, thus eliminating the corresponding investors’ optimality conditions from the problem. The set of control variables for country $j$’s government is

$$X = \{(c_t^i, n_t^i, k_t^i, a_{t+1}^i)_{i=1}^m, g_t^i, b_{t+1}^j, \tau_{k,t}^j, \tau_{a,t}^j, \tau_{n,t}^j, R_t\}_{i=0}^{\infty}. \quad (12)$$

### 4.1 Intertemporal Efficiency

In this section, we show that if a country converges to a strictly positive stationary allocation ($c^j > 0$, $n^j > 0$, $g^j > 0$) or “steady state”, then its government wants to set taxes so as to ensure that this allocation is intertemporally efficient. What we mean by that is that it satisfies the modified golden rule:

**Definition 1** A stationary allocation for a given country $j$ is called intertemporally efficient if it satisfies

$$\beta [1 + \Gamma_{k,t}^j] = 1.$$ 

In our context, given our choice of tax instruments, intertemporal efficiency implies that $(1 - \tau_{k,t}^i)(1 - \tau_{a,t}^i) = 1$.

Combining this result with the no-arbitrage condition that must hold under capital mobility, it follows that $\tau_{a,t}^i = \tau_{a,t}^j$ for all $i$ and $j$ so that all countries prefer to tax assets at the same rate in a non-degenerate steady state.

This result is interesting in itself, but it is also crucial for the existence of a non-degenerate steady state for the world as a whole, i.e. one where all countries converge to non-zero levels of private and public consumption. It defuses the following challenge to any open-economy model where taxes are endogenous: We know that if each country has the same subjective discount factor and capital can be traded across countries, then all countries must have the same after-tax rates of return; otherwise, the country or countries with the highest one will own all capital in the long run. With capital mobility, equal after-tax rates of return implies equal residence-based
capital tax rates. But why would asymmetric countries choose the same residence-based tax rates?

Fortunately, what we can show is that the government of any country that converges to a non-degenerate steady state will want to set taxes so as to achieve intertemporal efficiency in the long run, and this implies equal residence-based capital income taxes across countries. Thus we can safely conclude that, for a large set of parameter values, including those where countries differ significantly in many dimensions, there is a non-degenerate steady state for the world, provided only that the subjective time discount factor $\beta$ is identical across countries.

**Proposition 1** If an economy converges to an interior stationary allocation, then its government wants to set taxes so as to ensure that this allocation is intertemporally efficient.

**Proof.** The following first-order conditions are relevant for the proof:

$$k_t^j: \psi_t \tau_{k,t}^j r_t^j + \left( \psi_t \tau_{n,t}^j n_t^j + \theta_t^j n_t^j (1 - \tau_{n,t}^j) + \mu_t^j u_{c,t}^j (1 - \tau_{n,t}^j) \right) \frac{\partial w_t^j}{\partial k_t^j} + \left( \psi_t \tau_{k,t}^j k_t^j + \gamma_t^j (1 - \tau_{k,t}^j) \right) \frac{\partial r_t^j}{\partial k_t^j} = \chi_t^j \omega_t$$

$$g_t^j: \nu_{g,t}^j = \psi_t$$

$$b_{t+1}^j: \psi_t / \beta - (1 + R_{t+1}) \psi_{t+1} = \chi_t^j \omega_{t+1}$$

$$\tau_{n,t}^j: \psi_t w_t^j n_t^j = \mu_t^j u_{c,t}^j w_t^j + \theta_t^j n_t^j w_t^j$$

$$\tau_{k,t}^j: \psi_t r_t^j k_t^j = \gamma_t^j r_t^j.$$  

Combining Equation (13) with Equations (16) and (17) yields

$$\chi_t^j \omega_t = \psi_t \tau_{k,t}^j r_t^j + \psi_t n_t^j \frac{\partial w_t^j}{\partial k_t^j} + \psi_t k_t^j \frac{\partial r_t^j}{\partial k_t^j}. \quad (18)$$

From constant returns to scale we have the identity that $F(k, n) \equiv w n + r k$ (where of course $w$ and $r$ are the marginal products of labour and capital, respectively), so that $n_t^j \cdot \partial w_t^j / \partial k_t^j = -k_t^j \cdot \partial r_t^j / \partial k_t^j$, and therefore

$$\chi_t^j \omega_t = \psi_t \tau_{k,t}^j r_t^j. \quad (19)$$
If the economy converges to a stationary allocation, where $g_{t+1}^j = g_t^j > 0$, it follows that $\psi_t = \psi_{t+1}$ from (14). Moreover, because the stationary allocation also satisfies $c_{t+1}^i = c_t^i$ and $n_{t+1}^i = n_t^i$, we can conclude from the household’s Euler equation (4) and the no-arbitrage condition (9) that

$$1 + r_t^j (1 - \tau_{a,t}^j)(1 - \tau_{k,t}^j) = 1/\beta. \quad (20)$$

Combining this with equation (15), we have

$$\chi^j \omega_t = -\psi_t^j \tau_{a,t}^j (1 - \tau_{k,t}^j) r_t^j. \quad (21)$$

Equations (19) and (21) imply that $(1 - \tau_{a,t}^j)(1 - \tau_{k,t}^j) = 1$. From equation (20), we can thus infer that with a stationary allocation, $1 + F_{k,t}^j = 1/\beta$. ■

### 4.2 Zero Capital Taxes

Chamley (1986) found that optimal capital taxes are zero in the long-run in a closed economy, for the specific model also considered here. Gross (2014) showed that the Chamley result extends to open economies (with only source-based capital taxes). In this section, we prove that if Lagrange multipliers converge, then both residence- and source-based capital taxes are zero in the long run.\(^{11}\) In our numerical experiments, we have not come across any indications that Lagrange multipliers would not converge. Furthermore, it can be shown that if allocations converge and the growth rates of taxes or Lagrange multipliers converge, then the limiting growth rates are zero; in other words, taxes and Lagrange multipliers do in fact converge.

**Proposition 2** If all economies converge to an interior stationary allocation and Lagrange multipliers converge, then both source- and residence-based capital taxes converge to zero.

\(^{10}\)To put this in the context of Straub and Werning (2014), we do not assume that Lagrange multipliers converge. However, our result does depend on the assumption that the economy converges to an interior (non-degenerate) steady state. The contrary possibility, while genuine, is a remote one. It arises only if initial government debt is extremely high and the intertemporal elasticity of substitution is strictly below unity.

\(^{11}\)All results hold whether government spending is endogenous or exogenous (as long as the economy converges to an interior steady state). Including transfer payments from governments to citizens does not affect this result either (although the transition certainly looks different).
Proof. The following additional first-order conditions are relevant for the proof:

\[
q_{t+1}^i: \psi_{t+1}^i \tau_{a,t+1}^i R_{t+1} + \theta_{i,t+1}^i (1 + R_{t+1} (1 - \tau_{a,t+1}^i)) - \theta_{i,t}^i / \beta = -\chi^i \omega_{t+1} \quad (22)
\]

\[
q_{t+1}^{i,j} \neq i: \theta_{i,t+1}^i (1 + R_{t+1} (1 - \tau_{a,t+1}^i)) - \theta_{i,t}^i / \beta = -\chi^i \omega_{t+1}. \quad (23)
\]

From the Euler equation (4) of household \( i \neq j \), we have \( 1/\beta = 1 + R_{t+1} (1 - \tau_{a,t+1}^i) \), which together with Equation (23) implies \( \omega = 0 \). Doing the same for the households in country \( j \) and using \( \omega = 0 \) shows that \( \psi \tau_{a,t}^j R_t = 0 \); since \( \psi > 0 \) and \( R_t > 0 \), it follows that \( \tau_{a,t}^j = 0 \). As shown before, \( 1 + \tau_{t}^j (1 - \tau_{a,t}^j) (1 - \tau_{k,t}^j) = 1 / \beta \) and \( 1 + \tau_{t}^j = 1 / \beta \), so \( \tau_{k,t}^j = 0 \). \( \blacksquare \)

For completeness, we establish that the same result applies with residence-based capital taxes only:

**Corollary 1** With residence-based and without source-based capital taxation, if all economies converge to an interior stationary allocation and Lagrange multipliers converge, then residence-based capital taxes converge to zero.

### 4.3 Equivalence of Closed and Open Economies

Our most surprising result is that if countries are symmetric, except possibly in terms of population size and/or labour productivity, then the solution to each government’s optimization problem is identical in all periods for a closed and an open economy. The main idea of the proof is to establish that, if there is sufficient symmetry across jurisdictions, the additional constraints implied by international capital mobility (no-arbitrage conditions and world capital market clearing) are non-binding in the sense that the associated Lagrange multipliers vanish.

**Proposition 3** If all economies differ only, if at all, in country size \( \chi^i \) and/or labour productivity \( Z^i \), and if initial assets \( a_{0}^i / Z^i \) and debt \( b_{0}^i / Z^i \) per efficiency unit of labour are common across countries, then the open-economy solution is identical to the closed-economy solution.
Proof. We reformulate the problem slightly, by eliminating $R_t$ as a choice variable and replacing it with the after-tax return $r_t^i (1 - \tau_{k,t}^i)$; this obviously removes one constraint, now there are only $m - 1$ constraints related to the no-arbitrage condition. We also define $\tilde{r}_t^i \equiv r_t^i (1 - \tau_{k,t}^i)$ and use $\tilde{r}_t^i$ as a choice variable instead of $\tau_{k,t}^i$.

This is possible because $\tau_{k,t}^i$ is always multiplied by $r_t^i$ in the problem above. $\tilde{r}_t^i$, for $i \neq j$, is not a choice variable, since the foreign taxes are not choice variables. The newly formulated problem is then

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left\{ u^i(c_{t,t}^i, u_{t}^i) + v^i(g_{t}^i) \right\}$$

$$+ \psi_t \left[ r_t^i k_{t}^i - \tilde{r}_t^i k_{t}^i + \tau_{a,t}^i r_t^i a_{t}^i + \tau_{n,t}^i w_t^i n_{t}^i + b_{t+1}^i - (1 + r_t^i) b_t^i - g_t^i \right]$$

$$+ \sum_{i=1}^{m} \theta_t^i \left[ (1 - \tau_{n,t}^i) w_t^i n_{t}^i + [1 + \tilde{r}_t^i (1 - \tau_{a,t}^i)] a_{t}^i - a_{t+1}^i - c_{t}^i \right]$$

$$+ \sum_{i=1}^{m} \mu_t^i \left[ (1 - \tau_{n,t}^i) w_t^i u_{c,t}^i - u_{t}^i \right]$$

$$+ \sum_{i=1}^{m} \zeta_t^i \left\{ \beta u_{c,t+1}^i \left[ 1 + \tilde{r}_{t+1}^i (1 - \tau_{a,t+1}^i) \right] - u_{t}^i \right\}$$

$$+ \sum_{i \neq j} \gamma_t^i \left[ \tilde{r}_t^j - \tilde{r}_t^i \right]$$

$$+ \omega_t \sum_{i=1}^{m} \chi^i (a_{t}^i - k_{t}^i - b_t^i)$$

$$+ \phi_t \tilde{r}_t^i (1 - \tau_{a,t}^i) \right\},$$

with the following set of choice variables (bearing in mind that $\tilde{r}_t^i = r_t^i (k_{t}^i, n_{t}^i)(1 - \tau_{k,t}^i)$):

$$\bar{X} = \{ (c_{t}^i, n_{t}^i, k_{t}^i, a_{t+1}^i, g_t^i, b_t^i, \tau_{a,t}^i, \tau_{n,t}^i, \tilde{r}_t^i) \}_{t=0}^{\infty}.$$  \hspace{1cm} (25)

The difference between an open and a closed economy is that in an open economy the capital-market clearing condition (with multiplier $\omega_t$) does not necessarily imply that $a_{t}^i = k_{t}^i + b_t^i$ and that there are the additional no-arbitrage conditions (with multipliers $\gamma_t^i, i \neq j$). The other countries’ household optimality conditions and budget constraints (with multipliers $\theta_t^i, \mu_t^i, \zeta_t^i, i \neq j$) are not directly affected by
domestic choice variables. Therefore, if we can show that the capital-market clearing condition in an open economy satisfies \( q^i_t = k^i_t + b^i_t \) in equilibrium and that the no-arbitrage conditions are non-binding, i.e. the Lagrange multipliers \( \gamma^i_t, i \neq j \) are equal to zero, then the closed and open economy solutions have to be identical. The domestic government’s first-order conditions with respect to foreign private decisions will then only determine the domestic government’s multipliers attached to foreign households’ optimality conditions and budget constraints.

When countries are symmetric, then the open-economy capital-market clearing condition implies \( a^i_t = k^i_t + b^i_t \). Note that since the constraints and variables are defined in per-capita terms, this also applies to countries which are asymmetric only in population size; moreover, due to constant returns to scale, this extends to differences in TFP. The first-order condition with respect to \( \tilde{r}^i_t \) is

\[
-\psi_t k^i_t + \psi_t a^i_t \tau^i_{a,t} - \psi_t b^i_t + \theta^i_t a^i_t (1 - \tau^i_{a,t}) + \zeta^i_{k-1} u^i_{c,t} (1 - \tau^i_{a,t}) + \sum_{i \neq j} \gamma^i_t + \phi (1 - \tau^i_{a,t}) = 0, \tag{26}
\]

where \( \zeta^i_{k-1} \equiv 0 \). From this condition it generally does not follow that \( \gamma^i_t = 0 \). This is reassuring, as open and closed economies are not identical when only source-based taxes are available. The first-order condition with respect to \( \tau^i_{a,t} \) is

\[
\psi_t a^i_t \tilde{r}^i_t - \theta^i_t a^i_t \tilde{r}^i_t - \zeta^i_{k-1} u^i_{c,t} \tilde{r}^i_t - \phi \tilde{r}^i_t = 0. \tag{27}
\]

In an open economy, \( \tilde{r}^i_t \) will optimally never be zero (otherwise it would lead to a complete exodus of capital),\(^\text{12}\) so we can conclude from equation (27) that

\[
\psi_t a^i_t (1 - \tau^i_{a,t}) - \theta^i_t a^i_t (1 - \tau^i_{a,t}) = \zeta^i_{k-1} u^i_{c,t} (1 - \tau^i_{a,t}) + \phi (1 - \tau^i_{a,t}).
\]

Inserting this into equation (26) yields

\[
\sum_{i \neq j} \gamma^i_t = \psi_t (k_t + b_t - a_t).
\]

\(^\text{12}\) Under our assumption that the marginal product of capital is positive, i.e. \( r^i_t > 0 \forall i \), the possibility that \( \tilde{r}^i_t = 0 \forall i \) would imply that \( \tau^i_{k,t} = 1 \forall i \). This cannot be an equilibrium, as an infinitesimal decrease in the source-based capital tax \( \tau^i_{k,t} \) would lead to a non-continuous jump of the capital stock (in fact, all the capital would move into country \( j \)).

21
Since countries are symmetric, $\gamma_i = 0$, for all $i \neq j$.\footnote{Since the constraints and endowments for all foreign countries are identical, the Lagrange multipliers must be identical, $\gamma_i = \gamma_j$, for $i, i \neq j$, otherwise the first-order conditions with respect to variables $k_i$ and $n_i$ could not be met at the same time as those for $k_j$ and $n_j$. Because variables are defined in per-capita terms, and can be defined in terms of efficiency units of labour, this is true for differences in country size or labour productivity, too. For different country sizes, for example, the Lagrange multipliers of foreign constraints would then simply be multiplied by $\chi^j$.} It follows that the open and closed economy solutions are identical, if residence-based taxes are available.

This result also illustrates that source-based capital taxes are only used to manipulate the terms of trade, depending on whether the country is a capital importer ($k_t + b_t > a_t$) or a capital exporter ($k_t + b_t < a_t$). We explore this further in the next section.

**Discussion** We now turn to a discussion of the intuition behind our equivalence result. To set the stage, notice that each government would ideally like to tax exogenously given endowments. In a dynamic economy such as ours, the endowments are (i) the representative agent’s efficiency units of labour in each period and (ii) initial assets. Labour taxes, though they are distortive because leisure is endogenous, are the nearest available instrument for taxing efficiency units of labour, and so labour taxes are used in all periods under a very wide range of assumptions.

Now notice that a residence-based capital tax in the initial period is literally a lump-sum tax on an endowment, in contrast to a source-based tax, which is not. More generally, if a government has a choice between raising revenue by levying an asset income (residence-based) tax and a capital income (source-based) tax, it always chooses to tax assets rather than capital, because the former comes closer to being a lump-sum tax than the latter. Asset income and capital income taxes distort the intertemporal margin in the same way, discouraging the accumulation of assets. Capital taxes also lead to an outflow of capital from the jurisdiction that levies them, while asset taxes do not. This makes capital taxes more distortionary than asset taxes, rendering them a less attractive source of revenue.

The point here is not that a government with access to residence-based taxes will
never tax capital at source; the point is that no government will do it *in order to raise revenue*. It will not because revenue can be raised at less cost by taxing asset income. It may nevertheless tax capital at source *in order to manipulate the intertemporal terms of trade*, but this only happens in an economy where one country is a capital exporter and hence at least one other an importer, and that in turn does not happen if the countries are relevantly symmetric so that there are no capital flows in equilibrium.

Moreover, in an economy where capital income is not taxed at source and where neither country is a capital exporter or importer, source-based capital income taxes are not associated with any externalities (see below for a precise definition of externalities). In that situation, a small flow of capital from one jurisdiction to another, induced by a small change in the capital tax, does not affect welfare in either place. The reason is that, in a situation where capital is not taxed at source so that capital is paid its marginal product, receiving a small inflow of capital leaves residents of a country no better and no worse off.

In general, the representative native of a competitive economy (with constant returns to scale and diminishing returns to labour and capital separately), is indifferent with respect to a small inflow of either capital or labour. The intuition is that relative capitalists (people who rely more than the average resident on capital income as opposed to labour income) benefit from an inflow of labour and relative workers (people who rely more than the average resident on labour income as opposed to capital income) benefit from an inflow of capital. Thus in the absence of any inflow, the representative native is neither a relative worker nor a relative capitalist, and so is indifferent to a small inflow of either capital or labour. (She is not indifferent with respect to a *large* inflow, but that is not the point here.)

A similar argument can be constructed to establish why, in an economy where capital income is not taxed at source and economies are sufficiently symmetric so that capital flows are zero, the externalities associated with residence-based capital income taxes are zero as well. The reason is that a resident of either country is indifferent on the margin with respect to an increase in the world capital stock, keeping
her own wealth constant. That is, if residents of country 1 accumulate a bit more or a bit less savings, that is a matter of indifference to residents of country 2. So if the government of country 1 raises or cuts the residence based capital income tax slightly, this will have no first-order effect on the welfare of residents of country 2.

The conclusion, then, is that, in an economy where (i) both source-based and residence-based capital taxes are available and (ii), jurisdictions are sufficiently symmetric that there are no capital flows between them in equilibrium, the equilibrium is such that (a) source-based capital income taxes are not used and (b) residence-based capital income taxes are set exactly as they would be in a closed economy, rendering capital mobility irrelevant.

4.4 Externalities

In Gross, Klein, and Makris (2017) we identified the cross-border externality from source-based capital taxes when residence-based capital taxes are not available. In order to facilitate a comparison, we restrict our attention here to the case of two countries, “home” and “foreign”, where variables associated with the “home” country are denoted by \( h \) and the foreign country by \( f \). For instance, \( c^h_t \) is per capita consumption at home and \( c^f_t \) is consumption abroad. Meanwhile, \( \theta^h_t \) is the Lagrange multiplier of the home government’s problem associated with the home house households’ period \( t \) budget constraint and \( \theta^f_t \) is the Lagrange multiplier of the home government’s problem associated with the foreign households’ period \( t \) budget constraint.\(^{14}\)

We show here that the externalities associated with source-based capital taxes in the context of a hybrid system \( H \) are very different from their counterparts in a source-based only system \( S \): the fiscal externality vanishes. On the other hand, they are very similar to the externalities associated with residence-based capital taxes.

\(^{14}\)Notice, again, that we will never have occasion to refer explicitly to the Lagrange multipliers of the foreign government’s problem, though of course they exist in the background and may differ from those of the home government’s problem.
As in Gross, Klein, and Makris (2017), we define the period $t$ externality associated with a tax as the effect on domestic welfare of a marginal change in the foreign government’s source or residence-based capital tax rate at some date $t$, where the foreign government offsets the change in revenues by adjusting its bonds in each period and the labour tax at date $t$ to balance its budget constraint. It is thus a well-defined deviation from the optimal policy of the foreign government, feasible from its point of view. Note that foreign and domestic households react to this change in policy, but not the home government, in accordance with our equilibrium concept. Nevertheless, the externality does take into account how the policy change affects the home government’s budget constraints. We want to emphasize that all results would remain the same under the alternative equilibrium definition, that domestic government consumption $g_t$ adjusts in every period to satisfy the home government budget constraint. This follows immediately from the optimal choice of $g_t$.

The externality $E_H(\tau_{k,t}^f)$ associated with source-based capital taxes at time $t$ is

$$E_H(\tau_{k,t}^f) = -\gamma t^f \Delta \tau_{k,t}^f - w_t(\theta t^f n_t^f + \mu t^f u_{c,t}^f)\Delta \tau_{n,t}^f - \sum_{s=1}^{\infty} \beta^{s-t} \chi f \omega_s \Delta b_s^f. \quad (28)$$

Using the first-order conditions with respect to $R_t$ and $\tau_{k,t}^l$ this becomes

$$E_H(\tau_{k,t}^l) = -r_t^f \psi_t(a_t^h - k_t^h - b_t^h) - (\psi_t - \theta_t^h) a_t^h (1 - \tau_{a,t}^h) + \theta_t^f a_t^f (1 - \tau_{a,t}^f) \quad (29)$$

$$+ \zeta_{t-1}^l u_{c,t}^l (1 - \tau_{a,t}^l) + \zeta_{t-1}^f u_{c,t}^f (1 - \tau_{a,t}^f) + \chi_t (1 - \tau_{a,t}^f) \Delta \tau_{k,t}^f$$

$$- w_t(\theta t^f n_t^f + \mu t^f u_{c,t}^f)\Delta \tau_{n,t}^f - \chi f \sum_{s=1}^{\infty} \beta^{s-t} \omega_s \Delta b_s^f.$$

$^{15}$An increase in foreign capital taxes at time $t$ leads to an increase in tax revenues in that time period, and it also changes the entire sequence of prices (such as $r_t$) and private-sector choices (such as $a_t^f$ and $a_t^h$). The foreign government budget constraint would thus not hold with equality in any time period. To analyze deviations that are feasible from the foreign government’s point of view, we therefore adjust new government bonds $b_{s,t}^f$ in every time period $s \geq 0$ and labour taxes $\tau_{n,t}^f$ in time period $t$, so that the government budget constraint holds in every period, as well as intertemporally. Changing only government bonds in every period, but not labour taxes at time $t$ would lead to a total increase in tax revenues. If we only changed labour taxes at time $t$, then the foreign government budget constraint in period $t - 1$, for example, would not hold with equality.
For notational convenience, we have written this for any time period $t$ and define $\zeta_{i}^{-1} \equiv 0$ for $i = \{h, f\}$. From here one could derive precisely the externalities we had identified in Gross, Klein, and Makris (2017), including the familiar fiscal externality represented by the term $r_{f}(\psi_{t} - \theta^{h})a_{h}^{h}(1 - \tau_{a,t}^{h})$, by setting $\tau_{a,t}^{h} = 0$. But we can also use the first-order condition with respect to $\tau_{a,t}^{f}$ to determine how the externality changes in the hybrid system:

$$
E_{H}(\tau_{k,t}^{f}) = -r_{f}^{f}(\psi_{t}(a_{t}^{h} - k_{t}^{h} - b_{t}^{h}) + \theta_{t}^{f}a_{t}^{f}(1 - \tau_{a,t}^{f}) + \zeta_{t-1}^{f}u_{c,t}^{f}(1 - \tau_{a,t}^{f}))\Delta\tau_{k,t}^{f} \tag{30}
$$

$$
- w_{f}^{f}(\theta_{t}^{f}n_{t}^{f} + \mu_{t}^{f}u_{c,t}^{f})\Delta\tau_{f,t}^{f} - \sum_{s=1}^{\infty} \beta^{s-t} \chi_{f}^{s} \omega_{s} \Delta b_{s}^{f}.
$$

We rewrite this, using the capital-market clearing condition, as

$$
E_{H}(\tau_{k,t}^{f}) = -r_{f}^{f}(1 - \tau_{a,t}^{f})\zeta_{t-1}^{f}u_{c,t}^{f}\Delta\tau_{k,t}^{f}
$$

- Terms of Trade Externality

- Foreign Labour Externality

- Debt Externality

We now describe these externalities briefly: The Savings Externality results from the fact that the foreign government does not take into account that an increase in its capital tax will negatively affect the home government through reduced global savings (and hence a smaller global capital stock). A higher capital tax reduces the world-wide rate of return and thereby diminishes savings. The key is the Lagrange multiplier of the household’s intertemporal optimality condition, $\zeta_{t-1}^{f}$. The lower global rate of return due to higher capital taxes also benefits borrowers and hurts lenders, so there is a positive Terms of Trade Externality when $k_{t}^{h} + b_{t}^{h} > a_{t}^{h}$ and a neg-
ative one when \( k^h_t + b^h_t < a^h_t \). The next two externalities are more subtle. When the foreign government increases its source-based taxes at time \( t \), then new debt issues \( b^f_{s+1} \) in all periods \( s = 0, 1 \ldots, \infty \) adjust, as well as labour taxes at time \( t \). Because changes in capital taxes at any time period change the entire sequence of prices and private-sector choices, this is necessary to satisfy the government budget constraint in all periods; moreover, labour taxes decrease to satisfy the intertemporal budget constraint. The foreign government does not take into account how these changes in its debt and labour taxes affect the home government, whence the Debt and Foreign Labour Externality. For the latter, a reduction in foreign labour taxes implies that foreign households work more (see the term with Lagrange multiplier \( \mu^f_t \), which is for the foreign household’s optimal labour-leisure tradeoff). The foreign household may also have more or less resources left after the shift from labour to capital taxes, in net terms this is \(-w^f_t n^f_t \Delta \tau^f_{n,t} - \tau^f_t(k^f_t + b^f_t - \tau^f_{a,t} a^f_t)\Delta \tau^f_{k,t} \). Note that the entire term would be zero if there were no change in the relative size of the tax bases (of labour and both types of capital taxes). In general, the term should be small, because the foreign government raises the same amount of tax revenues and merely shifts the composition of its taxes, especially since we consider a small change from the optimal equilibrium policy. The Debt Externality arises because an increase (a decrease) in foreign government debt leaves less (more) assets in global capital markets for capital and domestic debt; the foreign government takes this effect of course into account when making its decisions, but not how it affects the domestic government.

For ease of reference, we restate here the externality \( E_S(\tau^f_{k,t}) \) associated with source-based capital taxes when residence-based capital taxes are not available, as in Gross,

\(^{16}\)The \( \theta^f_t \) appears in this term because the home government also values resources that the foreign households lose/gain due to the changing terms of trade; \( \theta^f_t \) may be positive or negative.
Klein, and Makris (2017), but in the notation of the present paper:

\[
E_S(\tau_{k,t}) = -\tau_t^{f}(\zeta_{t-1}^{h}u_{c,t}^{h} + \zeta_{t-1}^{f}u_{c,t}^{f})\Delta\tau_{k,t}^{f} \tag{32}
\]

Savings Externality

\[
+\tau_t^{f}(\psi_t - \theta_t^h)a_t^h\Delta\tau_{k,t}^{f}
\]

Fiscal Externality

\[
+\tau_t^{f}\left(\psi_t - \frac{\chi_t^h}{\chi_t^f}\theta_t^f\right)(k_t^h + b_t^h - a_t^h)\Delta\tau_{k,t}^{f}
\]

Terms of Trade Externality

\[
-\left(w_t^f\mu_t^f u_{c,t}^f + \theta_t^f\left(w_t^f n_t^f + \tau_t^f(k_t^f + b_t^f)\frac{\Delta\tau_{k,t}^{f}}{\Delta\tau_{n,t}^{f}}\right)\right)\Delta\tau_{n,t}^{f}
\]

Foreign Labour Externality

\[-\sum_{s=1}^{\infty} \beta^{s-t} \omega_s^f \Delta b_{s}^{f}.\]

Debt Externality

We can note the following two main differences:

1. The fiscal externality has completely disappeared—this is the most important difference. Governments use source-based capital income taxes only to manipulate the intertemporal terms of trade, not to raise revenues, because it is more efficient to raise revenues through residence-based taxes. The reason is that residence-based taxes distort only savings, whereas source-based taxes distort savings and the allocation of capital across jurisdictions. Thus, when foreign source-based taxes increase, leading to an inflow of capital into the home country, then this does not relevantly affect the domestic tax base.

2. The savings externality when residence-based capital taxes are available stems only from the foreign households (the term with \(\zeta_{t-1}^f\)) and not from the home households: the term with \(\zeta_{t-1}^h\) has disappeared. This is because the home government can perfectly determine the rate of return of the home agent through residence-based taxes, while the source-based tax only does so imperfectly.
Of course \( r^f_t \) is also multiplied by \( 1 - \tau^f_{a,t} \), as the rate of return on savings is \( r^f_t(1 - \tau^f_{k,t})(1 - \tau^f_{a,t}) \).

In addition, a minor difference is in the foreign-labour externality, with the additional term \( r^f_t \tau^f_{a,t} \theta^f_t a^f_t \Delta \tau^f_{a,t} \). This stems from the fact that higher capital taxes reduce the tax base for asset taxes.

It is also instructive to consider the externality from residence-based capital taxes, i.e. \( E_H(\tau^f_{a,t}) \), and how it differs from the externality from source-based taxes (the derivation is straightforward and similar to the previous one):

\[
E_H(\tau^f_{a,t}) = -r^f_t(1 - \tau^f_{k,t}) c^f_{t-1} u^f_{c,t} \Delta \tau^f_{a,t} \overbrace{\text{Savings Externality}}^{\text{(33)}} - \left( w^f_t \mu^f_t u^f_{c,t} + \theta^f_t \left( w^f_t n^f_t + r^f_t(1 - \tau^f_{k,t}) a^f_t \frac{\Delta \tau^f_{a,t}}{\Delta \tau^f_{n,t}} \right) \right) \Delta \tau^f_{n,t} \overbrace{\text{Foreign labour Externality}}^{\text{Debt Externality}} - \sum_{s=1}^{\infty} \beta^{s-t} \omega_t \chi^f \Delta b^f_s \).
\]

In a symmetric environment, when \( k^h_t + b^h_t = a^h_t \) (and of course \( k^f_t + b^f_t = a^f_t \)), the expressions \( E_H(\tau^f_{k,t}) \) and \( E_H(\tau^f_{a,t}) \) are exactly the same, except that every \( \tau^f_{a,t} \) is switched for \( \tau^f_{k,t} \) and vice versa.\(^{17}\) It is only with per-capita asymmetries and non-zero net foreign asset positions that the terms of trade externality really distinguishes the two types of externalities. This also follows of course from our previous result that there all externalities are zero when countries are symmetric (since \( \gamma^f_t = 0 \)).

\(^{17}\)To see this, note that \( r^f_t(1 - \tau^f_{k,t}) a^f_t \) is then equal to \( r^f_t(k^f_t + b^f_t - \tau^f_{k,t} a^f_t) \).
5 Numerical results

In this section we investigate the quantitative implications of the model for a range of parameter values. We view this as an exercise in quantitative theory, where we parameterize the model so as to make the results broadly speaking empirically relevant. The goal is to highlight the mechanisms at play in this form of tax competition, not to account for any specific historical episode. For computational and expositional ease we again confine our attention to a two-country world.

First, we describe the calibration of a scenario with symmetric countries. Second, we exhibit optimal fiscal policy for a closed economy to establish a baseline and contrast it with the results we obtain in an open economy, once with only source-based capital taxes and then with both source and residence-based ones. Third, we introduce asymmetries which highlight when and how optimal policy in an open economy differs from a closed economy. We show our main results concerning capital taxes in table format in the paper, and we relegate figures to Appendix C.

5.1 Parameterization

For the parametrization we use a model economy in steady state (which we call the “pre-initial steady state”), satisfying all the government’s optimality conditions, except that government debt is exogenously given. That is, the government optimizes over capital and labour taxes, as well as government spending, in steady state; the private-sector variables are determined endogenously as described above.18 The production function is assumed to be Cobb-Douglas,

\[ F(k, n) = Zk^\alpha n^{1-\alpha} - \delta k. \]

\[ ^{18} \text{In particular, the “pre-initial steady state” satisfies all the constraints in the planning problem (11), as well as the first-order conditions of its choice variables, except for bonds } b_{t+1}. \]
We set $Z = 1.0$, the capital share $\alpha = 0.35$, and the depreciation rate to $\delta = 0.08$. The utility functions take the form $u(c_t, n_t) = \ln(c_t) - \rho n_t^\sigma$ and $v(g_t) = \Gamma \ln(g_t)$. We choose $\sigma = 3$ in order for the Frisch labour-supply elasticity to be $0.5$. The subjective discount factor, $\beta$, is set equal to $0.9615$ so that the annual return to capital (net of depreciation and taxes) in the pre-initial steady state is $4.0\%$. We then calibrate the remaining parameters ($\rho = 6.13$ and $\Gamma = 0.74$ in the utility function) and initial government debt ($b_0 = 0.36$) so that hours worked are $0.33$, government debt is $60\%$ of GDP, and government revenues are $35\%$ of GDP in the pre-initial steady state. Initial total assets held by households ($a_0 = 2.09$) are determined as the sum of government debt and capital in each country. The target that hours worked are $0.33$ follows convention, but it is inconsequential, as it merely determines the unit in which hours worked are measured. In the OECD, government revenues were roughly $35\%$ on average in 2016. Since we do not distinguish between transfers and government purchases, we calibrate the model from the revenue side.

### 5.2 Symmetric environment

A result in Atkeson, Chari, and Kehoe (1999) applies to our closed economy model, which says that the constraint for maximum capital taxes binds for a finite number of periods, after which we have a non-zero capital tax for exactly one more period, followed by zero asset taxes. The results we present here for a closed economy are thus not new or of any particular importance by themselves; the purpose they serve here is merely to establish a reference point to which we can compare our new findings in an open economy. We first show in Table 1 a numerical verification our most important analytic result: taxes and allocations of symmetric countries, when capital can flow freely across the border (allowing for residence-based taxes), are exactly identical to the ones in a closed economy.
We contrast this with the results we obtain when we do not allow for residence-based taxes, the classic case of tax competition, in Table 2 and Figure 1.\textsuperscript{19} Even though the two countries are symmetric, the positive externality of source-based

\textsuperscript{19}These results are very similar to the ones from our previous work, Gross, Klein, and Makris (2017). Also note that there is no expropriation of capital in the first period $t = 0$, because capital is mobile in each period, including time period 0. The stock of assets in each country (and thus the global capital stock) is determined one period in advance, but at the beginning of each period investors decide where to allocate capital. Hence, $\sum_{i=1}^{m} \chi^i k^i_0$ is given, but $k^0_0$ is not.
capital taxes (in the absence of savings taxes) leads to a significant reduction in capital taxes in the short run and to a protracted convergence to zero in the long run. Comparing a closed to an open economy, there are substantial welfare losses, equivalent to the loss of 1.19% of private consumption in each period. This welfare loss is of course due to the externalities associated with tax competition (see Figure 2), and the fact that there are no offsetting gains from trade in capital since the countries are symmetric.

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Table 2: $\tau_k^h$ and $\tau_k^f$ are the home residence- and source-based capital tax rates, $\tau_a^h$ and $\tau_a^f$ are the foreign counterparts. NFAP is the net foreign asset position from the point of view of the home country, expressed as a fraction of home output.
Our main result has important ramifications for tax competition: the famous race to the bottom in capital taxes known from the received literature on tax competition seems to rely entirely on the inability to tax the initial asset holdings of domestic residents through residence-based taxes. As shown before in Gross (2014) and Gross (2015a), steady-state capital taxes are the same whether the economy is open or closed, and tax competition is thus not an issue in the long run. If governments are able to tax initial asset holdings through residence-based taxes as in this paper, then tax competition has no effects whatsoever, even in the short run. The welfare gains/losses from an open economy as compared to a closed economy are thus zero.

5.3 Asymmetries

As we have shown in our theoretical description of externalities, source-based taxes have the same externality as residence-based taxes as long as the net foreign asset position (NFAP) is zero. In this section, we introduce some asymmetries which highlight how countries use source-based taxes to manipulate the terms of trade. We only change one parameter/initial value at a time and do not recalibrate the remaining values. This allows for a clean evaluation of the importance of different dimensions of heterogeneity.

Differences in the Initial Asset Position  In this scenario, we alter the initial asset position of the home country so that it is 20% higher than in the foreign country. Therefore, if everything else were the same (including the endogenous variables), then the return to capital at home would be lower than abroad; therefore, capital will flow from the home to the foreign country and the NFAP is positive. The home country thus aims to increase the price of its export good (capital), and reduces the

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20 This inability to tax initial assets is also reflected in the path of government debt, see Figure 3. With access to source-based capital taxes only, the government is able to reduce its debt somewhat in the short run, but keeps a substantial positive debt burden in the long run. In the hybrid system, the government uses asset taxes to completely pay off its original debt and even accumulate some government assets (negative debt).
source-based tax rate to increase the global rate of return, \( R_t \). The foreign country has the exact opposite incentives and thus increases its source-based tax rate. The differences in the tax rates lead to a partial reversal of capital flows. We show the results in Table 3 and Figure 4.

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Table 3: \( \tau_h^a \) and \( \tau_h^f \) are the home residence- and source-based capital tax rates, \( \tau_f^a \) and \( \tau_k^f \) are the foreign counterparts. NFAP is the net foreign asset position from the point of view of the home country, expressed as a fraction of home output.
One can also observe that the home country taxes assets more than the foreign country in a closed economy, which is unsurprising given that its initial capital stock is larger. These differences also carry over to an open economy and the profile of savings taxes is remarkably similar to the closed economy. The home country has lower savings taxes in period 10 in an open compared to a closed economy, but then compensates with taxes slightly above zero in the following few periods. The foreign country has slightly higher savings taxes in period 9, and compensates by slightly negative taxes in the ensuing periods. We are not showing the labour taxes here, but in the long run they are higher for the country with the larger initial asset position. This can be explained by the fact that domestic households are richer and therefore provide less labour supply, which implies higher labour taxes. Domestic government consumption is initially higher, but converges to almost exactly the same level as abroad, while domestic debt is always larger (except for period zero, of course).

There are small, but positive welfare effects of opening up capital markets, of 0.051% in the home country and 0.059% in the foreign country (all welfare changes are in terms of private consumption equivalence each period). The decomposition of the externalities is shown in Figure 5: There is a negative terms-of-trade externality, leading to a total negative externality in the short run. In the long run a positive savings externality counteracts this effect, so that the total externality converges to zero. Note that the savings externality has to equal zero while asset taxes are at 100%: a change in $\tau_k^f$ cannot have any effect on savings then.

The units in which externalities are measured deserve explicit comment. Firstly, the externalities are measured in current value, discounted back to the period in which the intervention occurs, not to period 0. Secondly, they are the derivative of the period utility function with respect to the relevant tax rate. Because the period utility function is additively separable between consumption and labour and because it is logarithmic in consumption, this derivative has a very concrete interpretation. It is the percentage change in the consumption equivalent with respect to the percentage point change in the relevant tax rate.
The externality from the perspective of the foreign country is the (almost exact) mirror image: a positive terms-of-trade externality and a negative savings externality. The two countries would thus never agree to jointly increase or decrease source-based capital taxes. The same applies in all of the following cases.

**Differences in Government Spending** Countries may also differ in their tastes for government spending. In this exercise, we set the parameter $\Gamma^h$ to 0.30 ($\Gamma^f$ stays at 0.74), so that the ratio of government spending to GDP in the pre-initial steady state would be 0.20 in the home economy (as opposed to 0.35 in the foreign economy). We show the results in Table 4 and Figure 6.
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Table 4: $\tau^h_a$ and $\tau^h_k$ are the home residence- and source-based capital tax rates, $\tau^f_a$ and $\tau^f_k$ are the foreign counterparts. NFAP is the net foreign asset position from the point of view of the home country, expressed as a fraction of home output.

The home country taxes assets less than the foreign country in a closed economy, because its thirst for tax revenues is smaller and therefore all taxes are lower. Very similarly to the previous case, these differences in savings taxes remain largely intact in an open economy. The NFAP is negative at first, since labour taxes are lower and hence labour supply is higher in the home country, which would lead (off-equilibrium) to a higher marginal product of capital, and hence results in an inflow.
of capital. Interestingly, the sign of the NFAP changes and the home country becomes a net exporter of capital. This is because the savings taxes and labour taxes in the home country are lower and domestic households accumulate more assets than their foreign counterparts.

The importance of dynamics is underscored by the sign of the source-based taxes (the magnitude is small): They are always negative for the home country and positive for the foreign country, even though the NFAP changes signs. The intuition is that capital taxes at time $t$ influence the terms of trade not only at time $t$, but also in the other periods through the dynamic capital accumulation effects, as emphasized in our previous work, Gross, Klein, and Makris (2017). Since the NFAP is smaller in magnitude when negative than later when positive, the home country is over time effectively a capital exporter. As before, there are very small but positive welfare gains from capital mobility for both countries; $0.005\%$ at home and $0.005\%$ abroad.

The externalities, see Figure 7, reflect the changing sign of the NFAP, so that the total externality follows a u-shaped pattern. At first, the positive terms-of-trade externality implies a positive total externality, then both turn negative, while the total externality converges to zero in the long run, due to the positive savings externality.

**Differences in Initial Debt**  We now consider the case where the home government starts with no initial debt, i.e. we set $b_0 = 0$. In order to keep the initial capital stock constant so that we do not confound the effects with what we observed earlier, we also change the initial home assets $a_0$ by the same amount. We show the results in Table 5 and Figure 8.
Capital taxes when home country has zero initial government debt

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Table 5: $\tau^h_a$ and $\tau^h_k$ are the home residence- and source-based capital tax rates, $\tau^f_a$ and $\tau^f_k$ are the foreign counterparts. NFAP is the net foreign asset position from the point of view of the home country, expressed as a fraction of home output.

The home country taxes capital less than the foreign country in a closed economy, which stems from the fact that it has lower revenue requirements to finance its initial debt. The time path of savings taxes stays almost exactly the same in an open economy. The NFAP is initially negative, since employment is higher in the home country, and thus the marginal product of capital would be higher if it were not for capital inflows. Similar to the previous case, the NFAP changes signs, for exactly the
same reasons. It is interesting to note, however, that in this case source-based capital taxes switch signs: domestic rates are initially positive and then turn negative (if very small in magnitude) and vice versa for foreign rates.\textsuperscript{21} The welfare gains are tiny (0.001\% at home and abroad), as indicated by the small NFAP, but still positive. The externalities, depicted in Figure 9, follow a similar pattern as in the previous exercise, but are smaller in magnitude.

**Differences in Economy Size**  While cross-country differences in terms of the population size $\chi$ or productivity $Z$ (and appropriately rescaling the initial values $a_0$ and $b_0$) lead to quite different tax rates when only source-based taxes are allowed, optimal policy is still the same as in a closed economy when we allow residence-based savings taxes. The reason is that larger economies face a lower elasticity of capital flight with respect to their source-based tax rate, so that they can tax the initial capital stock better with source-based taxes. However, when countries tax initial assets through savings taxes, then capital flight is not an issue and the elasticity of capital supply does not play a role in determining optimal capital taxes.

Differences in population size or productivity do play a role once we introduce them along with other asymmetries. For instance, when one country has larger initial assets and is a larger economy, then the bigger size of its economy allows it to manipulate the terms of trade more in its favor. In Table 6 and Figure 10 we show the results for the case when the home country’s initial asset position per capita is 20\% larger than in the symmetric case (as in our earlier exercise) and its population size is twice that of the foreign country.

\textsuperscript{21}Compared to the previous case shown in Table 4, where the tax rates did not switch signs, the magnitudes of the future NFAPs are lower here.
### Capital taxes when home country has a greater population and initial asset position

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Table 6: $\tau^h_a$ and $\tau^h_k$ are the home residence- and source-based capital tax rates, $\tau^f_a$ and $\tau^f_k$ are the foreign counterparts. NFAP is the net foreign asset position from the point of view of the home country, expressed as a fraction of home output.

In comparison with what we had observed in Table 3 when countries differed in their initial asset position, but not country size, we see the following: The larger country sets higher savings taxes for a longer period of time; they are still at 1% in period 20. Moreover, the magnitude of source-based taxes is larger for the big-
ger country and smaller for the other country—the larger country can influence the world-wide rate of return more and uses this market power.

An interesting and potentially important implication of these results is that the cross-border externalities of manipulating the terms of trade are less severe the smaller each country is compared to the rest of the world. For example, if there were a large number of countries of each of two types (with low and high initial assets), then each country would find it difficult to change the global terms of trade and source-based taxes would be zero.\(^{22}\) This is exactly the opposite of the fiscal externality (with only source-based taxes), which worsens as the number of countries increases, as emphasized by the received tax competition literature. A similar point emerges from Razin and Sadka (1991) in an essentially static model (with an endogenous capital supply), but it bears emphasizing that the current NFAP is not necessarily the relevant statistic when countries manipulate their terms of trade.

The welfare gains from capital mobility are a bit smaller at home (0.039\%) and a bit larger abroad (0.064\%) as compared to the case when country size was the same. This naturally follows from the fact that moving one unit of capital (per capita) abroad leads to a larger change in the foreign rate of return when the domestic population is larger. We show the externalities in Figure 11, which follow the same pattern as when only assets per capita differ. The magnitude is smaller, since foreign actions influence the home country less the larger the home country is in relative terms. For the foreign country, the externalities pattern is the mirror image of the home country, but larger in magnitude compared to the case when only assets per capita differ.

\(^{22}\)In Appendix A, we prove that source-based taxes for small open economies are zero at all times, similar to what Correia (1996b) has shown, except that she does not consider a hybrid system with both types of capital taxes at the same time and that she assumes symmetry.
6 Conclusion

In this paper we explored the implications of allowing residence-based capital taxes in a multi-jurisdiction environment where capital is mobile and endogenously accumulated, i.e. a fully dynamic open-economy model. We prove analytically that, in this setting, capital taxes are zero in the long run, whether there are residence-based taxes only or both residence-based and source-based taxes. We thus extend the results by Chamley (1986) for a closed economy and Gross (2014) for an open economy with source-based taxes only. We also show analytically that the fiscal externality of source-based capital taxes vanishes when we allow for residence-based taxes. Furthermore, the externalities from residence-based and source-based taxes are identical, except for a terms of trade externality from source-based taxes (which is zero when countries differ only by population size or productivity). This is in sharp contrast to our results in Gross, Klein, and Makris (2017).

Our most surprising result is that governments choose identical fiscal policies in a closed as in an open economy, when countries differ only by population size or productivity. In that case, the cross-country externalities are zero in all time periods. What are the implications of this? In our previous work, we found that the cross-country externalities with source-based taxes are zero only in the long run, negative in the medium run, and positive (but smaller than in a static model) in the short run. That is, in a fully dynamic model, source-based tax competition is less grave a problem than in a static world. With residence-based taxes it ceases to be a problem at all. In this respect, we extend earlier work in a pseudo-dynamic two-period model, e.g. Bucovetsky and Wilson (1991) and Eggert and Haufler (1999), to an infinite horizon setting.

When countries differ with respect to other features, such as initial assets, preference for government spending, or initial debt, so that net foreign asset positions become non-zero, then governments use source-based taxes to manipulate the intertemporal terms of trade in the short and medium run. This is in consonance with previous
results by De Pater and Myers (1994) in a static model with lump-sum taxes and an exogenous labour supply and our results in Gross, Klein, and Makris (2017). While the problem of fiscal externalities in a world of only source-based taxes is exacerbated when there are more countries, terms of trade externalities diminish as the size of any given country compared to the rest of the world shrinks.

What are the potential policy implications of our work? Our results suggest that the problems of integrated capital markets in terms of harmful tax competition are much less severe than one might have thought in light of earlier models. Cross-border externalities only arise when there are asymmetries between countries and therefore also gains from trade in capital. In fact, both countries experienced welfare gains as compared to a closed economy in all our computational experiments, in sharp distinction to the welfare losses when only source-based taxes were allowed. Moreover, all externalities vanish in the long run. Thus we conclude that, in light of our analysis, that as information sharing across jurisdictions is enhanced, concerns about the damaging effects of tax competition should fade away.

We end with a few caveats. In order to keep our model tractable and to establish some baseline results in a standard environment, we abstract from several key aspects of fiscal policy. Here are but a few important issues that appear particularly interesting in dynamic models: (i) heterogeneous agents and political economy (cf. Lockwood and Makris, 2006), since the accumulation of wealth plays a major role in determining inequality; (ii) overlapping generations, which generate a different savings motive than with infinitely-lived dynasties (cf. Erosa and Gervais, 2002, vs. Chamley, 1986); (iii) imperfect capital mobility and imperfect trade (cf. Janeba and Wilson, 1999), since barriers to trade and investment are still important and affect savings behaviour. We believe that our approach is flexible and tractable enough to pursue these questions and thus view our paper also as a stepping stone for future research.
Appendix A: A small open economy

In a small open economy, the Lagrangian is

\[ L = \sum_{t=0}^{\infty} \beta^t \left( u(c_t, l_t) + v(g_t) + \psi_t [\tau_{k,t} r_t k_t + \tau_{a,t} R_t a_t + \tau_{n,t} w_t n_t + b_{t+1} - (1 + R_t)b_t - g_t] ight. \\
+ \theta_t [(1 - \tau_{n,t}) w_t n_t + (1 + R_t(1 - \tau_{a,t}))a_t - a_{t+1} - c_t] \\
+ \mu_t [(1 - \tau_{n,t}) w_t u_{c,t} - u_{l,t}] \\
+ \zeta_t [\beta u_{c,t+1} (1 + R_t(1 - \tau_{a,t})) - u_{c,t}] \\
+ \gamma_t [r_t (1 - \tau_{k,t}) - R_t] \\
+ \phi_t R_t (1 - \tau_{a,t}) \right), \] (34)

and the set of choice variables is

\[ \chi_{\text{small}} = \{ c_t, n_t, k_t, a_{t+1}, g_t, b_{t+1}, \tau_{a,t}, \tau_{k,t}, \tau_{n,t} \}_{t=0}^{\infty}. \] (35)

\( R_t \) is exogenous and the world-wide supply of assets is infinite from the perspective of a small open economy (even though it is determined in equilibrium through the choices of all economies), so \( R_t \) is no longer a choice variable and capital-market clearing is no longer a constraint for an individual small country (in equilibrium it has to hold, of course). Foreign private-sector decisions no longer depend on a single other country’s policies, so we have eliminated all foreign choice variables and the corresponding constraints.

Similar to what we had shown previously, the first-order conditions for domestic capital, source-based capital taxes, and labour taxes are

\[ k_t : \psi_t \tau_{k,t} r_t + (\psi_t \tau_{n,t} n_t + \theta_t n_t (1 - \tau_{n,t}) + \mu_t (1 - \tau_{n,t}) u_{c,t}) \frac{\partial w_t}{\partial k_t} \]
\[ + (\psi_t \tau_{k,t} k_t + \gamma_t (1 - \tau_{k,t})) \frac{\partial r_t}{\partial k_t} = 0 \] (36)

\[ \tau_{n,t} : \psi_t w_t n_t = \mu_t w_t u_{c,t} + \theta_t n_t w_t \] (37)

\[ \tau_{k,t} : \psi_t r_t k_t = \gamma_t r_t. \] (38)
Combining Equation (36) with Equations (37) and (38) yields
\[ 0 = \psi_t \tau_{k,t} r_t + \psi_t n_t \frac{\partial w_t}{\partial k_t} + \psi_t k_t \frac{\partial r_t}{\partial k_t}. \] (39)

From constant returns to scale we have the identity that \( F(k, n) = wn + rk \), so that
\[ n_t \frac{\partial w_t}{\partial k_t} = -k_t \frac{\partial r_t}{\partial k_t}, \] and therefore
\[ 0 = \psi_t \tau_{k,t} r_t. \] (40)

Since \( r_t > 0 \) (which follows from \( R_t > 0 \), a reasonable assumption) and \( \psi_t > 0 \) (otherwise taxes are not distortive), it follows that \( \tau_{k,t} = 0 \) for all \( t \).

**Appendix B: Calibration and the “pre-initial steady state”**

For our calibration, we would like some target moments to be met in a “pre-initial steady state,” as outlined in Section 5.1. We do this for a closed economy, so we do not include asset taxes (which are redundant), and drop the country superscripts. Since it is a steady state, variables are time-invariable, and we drop time subscripts. We use subscripts to denote derivatives, for instance we define \( r_K \equiv \frac{\partial r}{\partial k}. \) We do not include a first-order condition for government debt \( b \), since it always holds in steady state; it does not pin down any additional variables, as \( \beta(1 + R) - 1 = 0 \) has to hold from the household’s optimal intertemporal tradeoff. The amount of steady-state debt is determined by initial conditions (i.e. the initial amount of debt). We therefore replace this first-order condition with the condition that government debt in the “pre-initial steady state” is 60% of GDP.

The system of equations that we solve (numerically) consists of the following elements:

**Government budget constraint:**
\[ \tau_k r_k + \tau_n w_n - g - bR = 0 \]
Household budget constraint:
\[(1 - \tau_n)w_n + R \alpha - c = 0\]

Household optimal labor-leisure tradeoff:
\[u_c w(1 - \tau_n) + u_n = 0\]

Household optimal intertemporal tradeoff:
\[\beta (1 + R) - 1 = 0\]

Capital-market clearing condition:
\[a - k - b = 0\]

Investor no-arbitrage condition:
\[\tau (1 - \tau_k) - R = 0\]

Government spending first-order condition:
\[u_g - \psi = 0\]

Labour tax first-order condition:
\[\psi w_n - \theta w_n - \mu u_c w = 0\]

Capital tax first-order condition:
\[\psi k - \gamma = 0\]

Labour first-order condition:
\[u_n + \psi \tau_k r_n + \psi \tau_n n w_n + \theta (1 - \tau_n) n w_n + \mu u_c (1 - \tau_n) w_n + \gamma (1 - \tau_k) r_n + \psi \tau_n w + \theta (1 - \tau_n) w + \mu u_{nn} = 0\]
Consumption first-order condition:
\[ u_c - \theta + \mu u_c c w(1 - \tau_n) + Ru_c c \zeta = 0 \]

Capital first-order condition:
\[ \psi \tau_k r_k + \psi \tau_n n w_k + \theta (1 - \tau_n) n w_k + \mu u_c (1 - \tau_n) w_k + \gamma (1 - \tau_k) r_k + \psi \tau_k r - \omega = 0 \]

Assets first-order condition:
\[ \theta (1 + R) - \theta / \beta + \omega = 0 \]

Interest rate first-order condition:
\[ -\psi b + \theta a - \gamma + \zeta u_c = 0 \]

Target for the net interest rate:
\[ R - 0.04 = 0 \]

Target for the government debt to GDP ratio:
\[ b - 0.6 f(k, n) = 0 \]

Target for the tax revenues to GDP ratio:
\[ \tau_k r_k + \tau_n w_n - 0.35 f(k, n) = 0 \]

Target for hours worked:
\[ n - 1/3 = 0 \]

Target for the Frisch labour-supply elasticity:
\[ 1/(\sigma - 1) - 0.5 = 0. \]
Appendix C: Figures

Figure 1. Capital (asset) taxes under the hybrid and source-based system when countries are symmetric.
Figure 2. Externalities of source-based capital taxes in source-based and hybrid system when countries are symmetric
Figure 3. Government debt under the hybrid and source-based system when countries are symmetric
Figure 4. Capital taxes when the home country has greater initial assets
Figure 5. Externalities when the home country has greater initial assets

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Figure 6. Capital taxes when the home country government spends less
Figure 7. Externalities when the home country government spends less
Figure 8. Capital taxes when the home country has zero initial government debt
Figure 9. Externalities when the home country has zero initial government debt
Figure 10. Capital taxes when the home country has greater population and stronger initial asset position
Figure 11. Externalities when the home country has greater population and stronger initial asset position
References


