Dynamic Capital Tax Competition under the Source Principle*

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Abstract

We explore the short- and long-run implications of tax competition between jurisdictions, where governments can only tax capital at source. We do this in the context of a neoclassical growth model under commitment and capital mobility. We provide a new theoretical perspective on the dynamic capital-tax externalities that emerge in this model. Numerically, we show that the net capital-tax externality is positive in the short run but converges to zero in the long run. We also find that non-cooperative source-based capital taxes are initially positive and slowly decline towards zero. Coordinated capital tax rates are higher than non-cooperative ones in the short run, lower in the medium run, and the same in the long run. This stands in contrast to common beliefs and results from static and two-period models, which have informed policy debates in the European Union and elsewhere.

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1 Introduction

The conventional view concerning capital tax competition is that it is a cause for concern. See, for instance, OECD (1998) for a call on countries to refrain from harmful tax competition, and European Commission (2001) for a similar call within the European Union (EU). Particularly in European policy circles, it is clearly a consensus view that tax competition tends to reduce capital taxes, and that this is an undesirable outcome; see Norman (2000a), Norman (2000b) and European Union (2003). The starting point of this view is that it is hard to collect taxes on income from abroad, and that therefore capital income must be taxed at source. Meanwhile, if capital is mobile across borders, then taxing capital income at source quite naturally leads to capital flight. Therefore, unless countries share information that would enable them to tax foreign-source income or coordinate (or harmonize) their source-based tax treatment of capital income, governments, so the argument goes, will engage in tax competition for capital inflows. This would eventually lead to a "race to the bottom" in source-based capital taxes, a decrease in capital tax revenue and, potentially, underprovision of public services. This belief is strikingly reflected in the most recent debate within the EU around plans for a minimum withholding tax on non-residents' income; see, for instance, and more recently, Holehouse and Williams (2015) and Lynch (2015).[1]

This view has also been informed by the academic literature on the subject.[2] At the heart of this literature is the fiscal externality: a higher capital tax rate in one jurisdiction leads to an outflow of capital to other jurisdictions, and thus a higher tax base in them. If governments set capital taxes non-cooperatively, then they do not take into account how their actions affect others' tax bases. Because of this positive externality, capital taxes in an open economy would be lower than in a closed economy.

[1] For the details of the EU directive on the withholding tax, see http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:157:0038:0048:en:PDF

[2] For a highly informative contribution that situates the policy debate in the context of the theoretical literature, see Nicodème (2006).

However, the empirical evidence on the effects of increased capital mobility on capital tax rates and tax revenue shares is mixed.[3] Some more recent theoretical literature has tried to reconcile this fact with theory. This strand of work argues that capital market integration might, in some circumstances, lead to an *over*taxation of capital, emphasizing the presence of alternative externalities that could counteract the aforementioned fiscal externality.[4] Nevertheless, this more recent theoretical work uses either static or, at best, two-period models where capital is taxed only in the last period, and therefore does not properly take into account the dynamic aspects of taxation. Consequently, it cannot account for the fact that statutory tax rates have been gradually decreasing for more than two decades now; see Nicodème (2006).

Our paper takes a fresh look at these issues by identifying and studying the cross-border capital tax externalities that emerge in a fully dynamic (infinite-horizon) model as a consequence of endogenous capital accumulation. These *dynamic* externalities have so far received little or no attention in the literature. The main implications of our theory regarding non-cooperative capital taxes are that (i) capital taxes decrease slowly over time and (ii) the relationship between the level of capital taxes and the degree of capital mobility is ambiguous: while initial capital taxes under perfect capital mobility are lower than those in a closed economy, capital taxes in the medium run are higher in an open economy than in a closed one, with long-run capital taxes being zero in both a closed and an open economy. Importantly, the same relationship (qualitatively) holds between non-cooperative and coordinated capital tax rates under perfect capital mobility. This is in contrast to the common belief, discussed above, among many researchers and practitioners, which has motivated frequent calls for a coordinated increase in capital taxes. At the same time, though, our results remain consistent with the view that, on average, non-cooperating gov-

[3] See Devereux et al. (2008) and Buettner (2003), and the discussions in Nicodème (2006) and Mendoza and Tesar (2005).

[4] See, for instance, the excellent reviews by Wilson (1999) and Wilson and Wildasin (2004), and, for more recent work, Keen and Kotsogiannis (2002), Kessler et al. (2002), Makris (2006), Lockwood and Makris (2006), Wooders et al. (2007), Bénassy-Quéré et al. (2007) and references therein. This literature has helped to identify in a neat and concrete way some very important issues involved in the taxation of mobile capital such as overlapping tax bases, mobile labour, amenities, and the political determination of taxes.

ernments tend to spend less when there is capital mobility. However, this relationship does not hold in every period. In the short run, government spending is higher when there is capital mobility, whereas in the medium/long-run it is lower.

In more detail, what we do in this paper is to examine the implications of tax competition between jurisdictions in the context of a neoclassical growth model under the assumption of perfect capital mobility. The government of each jurisdiction solves an optimal taxation problem under commitment, treating foreign policies as given. The instruments available to governments are time-varying source-based proportional capital income taxes, proportional labour income taxes, and debt. Jurisdictions may differ with respect to population, total factor productivity, initial private assets and public debt. These differences imply that there are potential gains from capital mobility. We solve for the dynamic equilibrium numerically and examine a number of cases chosen for their theoretical interest and/or empirical relevance.

We also analyze, theoretically and numerically, the underlying forces that together determine the equilibrium. In particular, we stress what we call the *savings* externality, emphasizing the fact that our infinite-horizon setup allows us to consider the effects of capital taxes not only on the allocation of capital across space, but also its accumulation over time and hence the global capital supply. In such a setup, the savings externality emerges because a higher tax rate leads to a lower rate of return to savings, and thereby results in less savings and hence a lower global capital stock, which affects all countries, not just the one levying it. This is a *negative* cross-border tax externality and consequently acts in the opposite direction relative to the well-known positive fiscal externality analyzed in the seminal work of Zodrow and Mieszkowski (1986) and Wilson (1986), and discussed above. The deleterious consequences of tax competition are thus reduced, and potentially outweighed, in a fully dynamic as opposed to a static model.

In the literature, the savings externality, to the extent that it is present at all, is dominated by the fiscal externality. This view is captured well by the following statement in Wilson (1999, p. 275): "We may conclude that allowing a variable supply of capital reduces, but does not eliminate, the tax competition problem." However, this finding is driven by the fact that the models considered by Wilson (1999) are at best two-period models, so that capital is either literally a fixed endowment or supplied fairly inelastically relative to what is the case in an infinite-horizon model. In our model, only the initial capital stock is an endowment, and so the impact of capital taxes on the capital supply (and thus the savings externality) increases over time, as the importance of the initial capital endowment for the capital supply diminishes. In our numerical work, we quantify the importance of the various externalities. There is a positive net externality in the short run—as in Wilson (1999)—but it converges to zero in the long term. In striking contrast to the existing consensus, the savings externality completely eliminates the deleterious effects of tax competition beyond the short and medium run. This result has an obvious and profound implication for the policy debate discussed above.

We also find that, in the absence of countervailing forces, a country that consistently has a positive net foreign asset position (i.e. is a capital exporter in every period) consistently sets a lower capital tax rate than a capital-importing one. This is due to the incentive of tax jurisdictions to manipulate the terms of trade to their benefit, as in the static model of De Pater and Myers (1994). However, this effect is mitigated by intertemporal considerations, and so the difference in the capital taxes of capital-trading countries is smaller in a dynamic environment with endogenous savings than in a static setting. To understand this, recall that a higher capital tax leads to a reduction in savings and thus in the supply of worldwide capital, which, in turn, implies a higher world interest rate in the future. This indirect effect is beneficial to a capital-exporting country, but, in our computations, is always outweighed by the direct, negative, effect of higher taxes on the current world interest rate. As a result, the incentive to manipulate the (current) terms of trade is smaller in an intertemporal setting with endogenous savings than with a fixed capital stock.

Our analysis therefore suggests that results from the static and two-period-model based tax competition literature should be interpreted as pertaining to the *short* run rather than the long run, *pace* Sørensen (2004, p. 1189), who writes that "My model of tax competition (called 'TAXCOM') is static, describing a stationary long-run equilibrium."

Our work has an additional, more technical, implication for the study of dynamic capital taxation problems. By way of background, Chamley (1986) shows that the second-best outcome features high taxes on capital in the early periods and zero capital income taxes thereafter. Indeed, the result there is quite stark: if there are no restrictions at all on capital taxes, the only tax ever levied will be on capital income in the first period; the revenue from that is then used to finance all subsequent expenditure. This result is the well-known capital levy problem,[5] which is present in the first period even under perfect commitment. Therefore, it is conventional to restrict at least the initial capital income tax rate to avoid trivializing the problem. Tax competition removes the temptation to impose an unlimited initial capital levy and therefore obviates the need to impose any exogenous restrictions on initial-period capital income taxes.[6]

Our paper is organized as follows. Section 2 discusses some related literature, in addition to what we have already considered. Section 3 lays out the model framework, defines our equilibrium concept, and identifies the externalities stemming from capital taxes. In Section 4 we present our main numerical exercises, chosen for their theoretical interest. In Section 5 we analyze an empirically motivated parameterization of the model, designed to replicate the experience of the United Kingdom and continental Europe. Section 6 considers some robustness checks. Among other things, we study what happens if capital mobility is imperfect. Section 7 concludes.

[5] The capital levy problem, i.e. the temptation on the part of governments to impose a one-time levy on the current capital stock, promising never to do that again, is discussed in Fischer (1980).

[6] A similar result is obtained in Gervais and Mennuni (2015) by assuming that investment becomes productive immediately, without a period's delay.

2 Related literature

To put our contribution in perspective, it is useful to situate our paper in the context of the received literature on capital tax competition. The seminal theoretical work on capital tax competition is by Zodrow and Mieszkowski (1986) and Wilson (1986) (ZMW hereafter). They emphasize that competition between identical tax jurisdictions for mobile capital leads governments to undercut each other in terms of source-based capital taxes, reducing tax rates to below what they would be in a closed-economy setting. The reason is straightforward. In the absence of cross-country spillovers, capital taxes in a closed economy are second-best efficient. When capital is mobile, however, an increase in the domestic tax leads to a decrease in the domestic net rate of return on capital and, thereby, to a capital outflow. This capital outflow translates into an increase in the capital employed in the other tax jurisdictions. Thus, an increase in the domestic tax leads to an increase in foreign capital tax-bases and, thereby, tax revenues abroad, for any given foreign taxes. Therefore, capital taxes under integrated capital markets give rise to a positive externality, and as such will in general be lower compared to the situation when capital is immobile.[7] Importantly, the strength of this externality is positively related to the responsiveness of capital demand to its user-cost, whereas the supply of capital does not play a role, since it is fixed in ZMW.[8]

In Bucovetsky and Wilson (1991) and later papers like Sørensen (2004), the capital stock derives endogenously from an endowment. In this case, the capital supply elasticity also matters, of course, in determining whether capital taxes are inefficiently high or low. However, as the quote in the introduction made clear, the consensus is that an endogenous capital supply cannot eliminate or outweigh tax competition.

[7] Even for the opponents of reducing tax competition, the existing consensus provides an unquestioned backdrop. For instance, Kehoe (1989), when making the case *against* capital tax policy coordination in the absence of commitment, argues that tax competition can serve as a substitute for a commitment device, driving down capital taxes to where they should have been in the first place.

[8] Coates (1993) investigates a *repeated* version of ZMW, and thus maintains the ZMW assumption that the supply of capital (in each period) is exogenously fixed.

An attempt to deal with equilibrium source-based capital taxes in a dynamic framework with capital accumulation is Mendoza and Tesar (2005), who, however, simplify matters by forcing governments to levy time-invariant tax rates. Correia (1996) studies capital taxation in a small open economy, where the net world interest rate is exogenous and time-invariant. With source-based capital taxes, the transition to a steady state is immediate (after the initial period). A further step forward is found in Gross (2014) who studies large open economies, but confines his attention to long-run outcomes. In the same model environment as the one we study here, he finds that long-run capital taxes coincide with those of a closed economy and hence are equal to zero as in Chamley (1986). Auray et al. (2018) consider a small open economy with two goods and endogenous exchange rates, so that the transition to steady state is not immediate, but capital taxes are only levied in one period. Therefore, whether by construction or focus of analysis, these papers do not study the time path of equilibrium time-varying source-based capital taxes, nor do they discuss the intertemporal capital-tax externalities we focus on here.[9]

Wildasin (2003) discusses capital taxation in a small open economy, by recognizing the dynamics inherent in capital accumulation when capital inputs can only be adjusted by incurring adjustment costs. Here, instead, we assume zero capital adjustment costs in our benchmark case (see Section 6.2 for an analysis of the implications of convex adjustment costs, though), but we emphasize the interaction between non-cooperative capital taxes and the dynamics in capital accumulation that arises due to the dependence of endogenous savings on capital taxes. Other important differences are that in Wildasin (2003) the net world interest rate is, by assumption, exogenous and time-invariant, capital taxes are time-invariant and lump-sum taxes are available. One of the main results in Wildasin (2003) conforms with the traditional view: the capital tax decreases with the mobility of capital.[10]

[9] In Jensen and Toma (1991), a two-period model with public debt is discussed. Nevertheless, the analysis there takes place under a specific utility function which, crucially, implies (see their Lemma 1) that, in equilibrium, capital taxes do not affect future interest rates. Thus, certain intertemporal capital tax externalities we discuss here are absent in their paper. Batina (2009) has analyzed capital tax competition in a simple overlapping generations economy, but only in a steady state.

[10] Wildasin (2011) extends Wildasin (2003) by allowing for mobile labour. See also Becker and Rauscher (2007) for an extension of Wildasin (2003) that incorporates public spending on

In the dynamic models of Lejour and Verbon (1997) and Koethenbuerger and Lockwood (2010) there is a negative cross-border tax externality, but as a result of a preference on the part of households for portfolio diversification. Importantly, the intertemporal externality we investigate here does not arise in their settings. In fact, in the absence of a preference for diversification, the standard "race-to-the-bottom" result survives in those models. Moreover, both Lejour and Verbon (1997) and Koethenbuerger and Lockwood (2010) consider only balanced growth paths, as well as a savings rate which is independent of the rate of return.[11] In our paper, on the other hand, there is no portfolio diversification and the emphasis is on the externality that arises due to the negative effect of capital taxes on savings rates.

Finally, Klein et al. (2005) and Quadrini (2005) study optimal taxation in a fully dynamic open economy, but with limited commitment. Klein et al. (2005) focus on the use of different tax instruments (capital and labour taxes) in asymmetric countries in a steady state. Quadrini (2005) examines the implications of introducing capital mobility, and finds that as soon as capital mobility is allowed, there is a sudden decrease in capital taxes; this is in contrast to the gradual decline that our model implies.

In sum, as far as we know, we are the first to characterize the entire equilibrium path of a fully dynamic open economy with time-varying taxes under commitment, where both the savings rate and the rate of return are endogenous.[12]

infrastructure.

[11] Koethenbuerger and Lockwood (2010) use a Markov-perfect equilibrium, which corresponds to limited commitment (also see below). Wrede (1999) uses the same equilibrium concept, but the savings rate is exogenously fixed, governments are of the revenue-maximizing Leviathan type, and the focus is on federalism.

[12] In parallel work Gross (2018) studies optimal taxation in a fully dynamic open economy, but the focus is on intergovernmental transfers rather than capital-tax externalities.

3 The Model

Consider a world consisting of two countries.[13] In each country there is a representative agent who maximizes her expected discounted utility, and takes prices and policies as given. Output is produced using capital, which is perfectly mobile across countries, and labour, which is immobile.

Each government sets at the beginning of period zero, independently of the other, public debt B_{t+1}, labour taxes τ_t, government consumption G_t, and source-based capital taxes θ_t in every period $t = 0, 1, ..., \infty$, so as to maximize the welfare of its domestic representative agent subject to the government budget constraint in each period:

$$B_{t+1} + \tau_t w_t L_t + \theta_t r_t K_t = [1 + r_t(1 - \theta_t)]B_t + G_t.$$

w_t is the wage rate, r_t is the rate of return on capital and government bonds, L_t and K_t are aggregate labour and capital, respectively.

Private agents in both countries observe the announced policies and make a decision on consumption, labour supply, and next-period assets for each period. Assets can be allocated between home and foreign capital, and home and foreign government bonds. Note that we have already implicitly assumed a no-arbitrage condition between investment in government bonds and capital by defining earlier r_t as the rate of return on both capital and government bonds. Due to perfect capital mobility, there are also no arbitrage opportunities between home and foreign assets; that is, we have the no-arbitrage condition $(1 - \theta_t)r_t = (1 - \theta_t^*)r_t^*$. Therefore, home private agents are indifferent with respect to the allocation of their assets to home and foreign capital and government bonds, and they maximize their utility with respect to consumption, labour and next-period assets, subject to their budget constraints,

[13] In our model, tax jurisdictions could be localities, provinces, cantons or countries; all that matters is that capital income cannot be taxed on a residence basis. To fix ideas we will use throughout the paradigm of countries. Note that allowing for more than two countries would not affect the main thrust of the theoretical discussion. It would complicate the exposition without adding further significant insights. The case of a small open economy is already known from Correia (1996).

taking prices and policies as given. The maximization problem is

$$\max \sum_{t=0}^{\infty} \beta^t [u(c_t, h_t) + v(g_t)]$$

subject to

$$[1 + r_t(1 - \theta_t)]j_t + (1 - \tau_t)w_t h_t = c_t + j_{t+1}$$

for $t = 0, 1, \ldots$ (and a suitable no-Ponzi-scheme condition), where β is the subjective discount factor, u is the utility from private consumption and hours worked, and v is the utility from public consumption. We assume that the discount factor β is common across countries for a non-degenerate steady state to exist, and for simplicity we assume that u and v are also common across countries. We denote private consumption by c_t, g_t is public consumption, h_t is labour supply, and j_t are private assets, all in per-capita terms. The private-sector optimality conditions for each country are the budget constraint shown above, as well as the familiar optimal consumption-leisure trade-off and the optimal intertemporal consumption trade-off:

$$\begin{aligned}
&[1 + r_t(1 - \theta_t)]j_t + (1 - \tau_t)w_t h_t = c_t + j_{t+1} \\
&u_{c,t}(1 - \tau_t)w_t = -u_{h,t} \\
&\beta u_{c,t+1}[1 + r_{t+1}(1 - \theta_{t+1})] = u_{c,t}.
\end{aligned}$$

These three conditions pin down the choices of c_t, h_t, and j_{t+1}, while their foreign counterparts pin down c_t^*, h_t^*, and j_{t+1}^* for given policies and prices.

We now establish some further notation. In general, foreign variables are denoted using an asterisk. N denotes the population size of the "home" country. The relationship between aggregate and per-capita variables is $L_t = Nh_t$, $J_t = Nj_t$, $C_t = Nc_t$, $B_t = Nb_t$, and $G_t = Ng_t$, and similarly for the foreign variables. n^* denotes the relative population size of the "foreign" country, i.e. the ratio of its population to that of the "home" country so that $n^* = N^*/N$.

Output is produced by perfectly competitive firms according to the constant returns to scale (CRS) function $F(K_t, A \cdot L_t) + (1-\delta)K_t$, where A is labour productivity and δ is the capital depreciation rate. For simplicity, we assume that the production function F and the capital depreciation rate δ are common across countries. Profit maximization implies that factors of production are paid their marginal products. This determines wages w_t and capital rental rates r_t. Note that r_t is the return on capital net of depreciation.

Given the above choices, the global allocation of capital, K_t and K_t^* is determined by the global capital-market clearing condition and the no-arbitrage condition, viz.

$$J_t + J_t^* = B_t + B_t^* + K_t + K_t^*$$

and

$$(1-\theta_t)r_t = (1-\theta_t^*)r_t^*.$$

When governments decide on their optimal policy, they know that private agents in both countries will react in a utility-maximizing way; the other government, however, decides on its policy at the same time, so its policy cannot be influenced. Each government thus maximizes its objective function, taking into account how it influences private-sector decisions in both countries, for some belief of the other government's policy. In equilibrium, these beliefs are equal to the actual policies.

In what follows we adopt the dual approach to optimal taxation, treating tax rates, government consumption, and public debt as the formal choice variables of each government. This has expositional advantages in this context of strategic interaction. Not coincidentally, it also has a decisive conceptual advantage in that it allows us to make transparent assumptions about precisely what each government can control, what it takes as given, and what conditions are treated as binding constraints as opposed to other conditions that must be true in equilibrium but which governments do not treat as constraints when they make their choices.

In more detail, we postulate that the home government takes as given the foreign policies and maximizes

$$\sum_{t=0}^{\infty} \beta^t [u(c_t, h_t) + v(g_t)]$$

subject to

$$u_{c,t}(1-\tau_t)w_t + u_{h,t} = 0, \tag{1}$$

$$u_{c^*,t}(1-\tau_t^*)w_t^* + u_{h^*,t} = 0, \tag{2}$$

$$\beta u_{c,t+1}[1 + r_{t+1}(1-\theta_{t+1})] - u_{c,t} = 0, \tag{3}$$

$$\beta u_{c^*,t+1}[1 + r_{t+1}^*(1-\theta_{t+1}^*)] - u_{c^*,t} = 0, \tag{4}$$

$$(1-\theta_t)r_t - (1-\theta_t^*)r_t^* = 0, \tag{5}$$

$$J_t + J_t^* - (B_t + B_t^* + K_t + K_t^*) = 0, \tag{6}$$

$$[1 + r_t(1-\theta_t)]j_t + (1-\tau_t)w_t h_t - c_t - j_{t+1} = 0, \tag{7}$$

$$B_{t+1} - [1 + r_t(1-\theta_t)]B_t + \tau_t w_t L_t + \theta_t r_t K_t - G_t = 0, \tag{8}$$

and

$$[1 + r_t^*(1-\theta_t^*)]j_t^* + (1-\tau_t^*)w_t^* h_t^* - c_t^* - j_{t+1}^* = 0 \tag{9}$$

for all $t = 0, 1, \ldots$, where B_0, J_0, B_0^*, J_0^*, and hence the initial global capital stock (but not its allocation across countries), are also taken as given. The set of choice variables X is

$$X = \{c_t, c_t^*, h_t, h_t^*, j_{t+1}, j_{t+1}^*, K_t, K_t^*, B_{t+1}, \tau_t, \theta_t, G_t\}_{t=0}^{\infty}. \tag{10}$$

We also require that the following two equations have to hold in equilibrium: the foreign government budget constraint, which is

$$B_{t+1}^* + \tau_t^* w_t^* L_t^* + \theta_t^* r_t^* K_t^* = [1 + r_t^*(1-\theta_t^*)]B_t^* + G_t^* \tag{11}$$

and the world resource constraint, which is

$$F(K_t, AL_t) + F(K_t^*, A^*L_t^*) + (1-\delta)(K_t + K_t^*) = C_t + C_t^* + K_{t+1} + K_{t+1}^* + G_t + G_t^*. \quad (12)$$

By Walras's law, one of the six equations given by (6)-(9), (11), and (12) is redundant: it is implied by adding up the rest.

Notice that we do not impose as a constraint on either country's government optimization problem that the other country satisfies its government budget constraint. We elaborate below on the equilibrium concept we deploy.

Equilibrium Concept The setting we have in mind is the following. Our game has two stages. At the first stage, each government, independently of the other, chooses its policies (tax rates, public spending, and government debt) for all $t = 0, 1, \ldots, \infty$. At the second stage, private agents make their decisions (labour supply, consumption and saving) in the context of a competitive equilibrium for the two-country world, given the policies chosen at the first stage.

When we define equilibrium policies, we do not allow for conjectural variation; each government takes the equilibrium policies of the other government as given. However, when making decisions at the first stage, each government *does* take into account how private agents *in both countries* will respond at the second stage.

The fact that private agents living in one country are expected to respond to a policy change on the part of the government of another has a crucial conceptual implication. It means that what the government in one country does determine the set of policies that are feasible for the other government. Specifically, a deviation from equilibrium by one country may, and typically will, render the other government either insolvent or overfunded. This in turn implies that we are not dealing with a standard game in the sense of Nash (1950).

Fortunately, however, it is a *generalized* game in the sense of Debreu (1952). Consequently his "social equilibrium" concept is applicable to our economy just as it is in the foundational paper by Arrow and Debreu (1954). A social equilibrium is a strategy profile such that each agent chooses, among the strategies that are feasible for her given the other agents' strategies, the one with the highest payoff for her, again given the strategies of the other agents. This means that each agent, when contemplating whether to deviate from her equilibrium strategy, ignores the fact that such a deviation may render the equilibrium strategies of other agents infeasible. Meanwhile, all equilibrium strategies are, by definition, feasible. An accessible exposition of the social equilibrium concept can be found in Dasgupta and Maskin (2015).

It is worth mentioning in this context that there exist alternative equilibrium concepts, where the expected (hypothetical) response to a deviation is such as to restore competitive equilibrium for the world as a whole. We find Debreu's concept the most compelling. Interestingly, one such alternative concept turns out to be equivalent to ours in the context of the economy analyzed in this paper. Under this alternative equilibrium concept, if a government deviates, then the other government automatically adjusts its government spending in each period so as to balance its flow budget constraint, keeping government debt and taxes in each period unchanged. It turns out that this modification has no effect on the equilibrium policy profile relative to our favoured equilibrium concept, provided only that the utility function is additively separable over private and public consumption. However, this equivalence result is a highly specific one and does not generalize much at all. For a more thorough discussion of alternative equilibrium concepts, see Gross (2014) and Gross (2018).

3.1 Non-cooperative Policies

We now characterize the equilibrium. The full derivation can be found in Appendix A. Here we confine our attention to the key equations, namely the (domestic) optimality conditions for the (domestic) capital stock, the (domestic) labour tax rate, the (domestic) source-based capital income tax rate and, only for $t > 0$, (domestic) private assets. These equations will involve Lagrange multipliers; specifically, the multipliers $\lambda_{1,t}$ to $\lambda_{9,t}$ are associated with the constraints (1)-(9), respectively, where we set $\lambda_{1,-1} = ... = \lambda_{9,-1} = 0$. We also normalize the home country population to one and, to preserve the ratio between them, the foreign country population to n^*. Meanwhile, we redefine the multiplier $\lambda_{9,t}$ so that it is in fact the ratio of the actual multiplier and the foreign population size. All multipliers are defined in current value terms, which means that we would need to multiply them by β^t to get the present-value multipliers. The optimality conditions in question are:

$$\lambda_{3,t-1}u_{c,t}(1-\theta_t)r_{K,t} + \lambda_{1,t}u_{c,t}(1-\tau_t)w_{K,t} + \lambda_{5,t}(1-\theta_t)r_{K,t} \tag{K}$$
$$-\lambda_{6,t} + \lambda_{7,t}\{(1-\tau_t)w_{K,t}L_t + (1-\theta_t)r_{K,t}J_t\}+$$
$$\lambda_{8,t}\{\tau_t w_{K,t}L_t + \theta_t r_{K,t}K_t + \theta_t r_t - (1-\theta_t)r_{K,t}B_t\} = 0.$$

$$-\lambda_{1,t}u_{c,t} - \lambda_{7,t}L_t + \lambda_{8,t}L_t = 0 \tag{τ}$$

$$-\lambda_{3,t-1}u_{c,t} - \lambda_{5,t} - \lambda_{7,t}J_t + \lambda_{8,t}(K_t + B_t) = 0 \tag{θ}$$

and

$$\lambda_{8,t-1}/\beta - \lambda_{6,t} - \lambda_{8,t}[1 + r_t(1-\theta_t)] = 0. \tag{B}$$

Our aim now is to use these equations to investigate the relationship between the closed-economy and open-economy capital taxes. It should be clear that the closed-economy capital tax (i.e. when capital is immobile) is second-best efficient when countries are symmetric.

An obvious way in which tax rates in closed and open economies are different is that, in the presence of capital mobility, there is no temptation on the part of either government to impose a confiscatory initial-period capital tax rate, because if it did, capital would immediately flow out and domestic wages would plummet. This is confirmed by our numerical exercise in Section 4. There, we confine capital taxes to be less than 1, a constraint that is binding in a closed economy for a finite number of periods. In an open economy, however, this constraint never binds and governments tax capital at a rate that is far from confiscatory.

Another source of differences between the closed and the open economy is the presence of capital-tax externalities under capital mobility. These externalities arise in our model because capital taxes affect the allocation of capital between countries *and* across time, and thereby foreign welfare. These externalities tend to operate in different directions. In particular, the novel externalities across time we identify shortly can cancel the standard fiscal capital-tax externality analyzed in the received literature. We discuss this further below.

Now we show that the steady-state capital tax coincides with that in a closed economy, i.e. it is equal to zero (as in Chamley, 1986). That is, the capital-tax externalities cancel each other out at the steady state. To see this, we use first Equations (τ) and (θ) to eliminate $\lambda_{1,t}$ and $\lambda_{5,t}$ from Equation (K). Next, we use that $F_{KK,t}K_t + F_{KL,t}L_t = 0$ for a CRS technology (which is equivalent to $r_{K,t}K_t + w_{K,t}L_t = 0$). With these steps, Equation (K) reduces to

$$\lambda_{8,t}\theta_t r_t = \lambda_{6,t}. \tag{13}$$

At an interior steady state, we have $1 = \beta[1 + r(1-\theta)]$, an implication of Equation (3) when evaluated at steady state. Using this result together with the steady-state condition $\lambda_{8,t} = \lambda_{8,t-1}$ in Equation (B), we conclude that, in a steady state, $\lambda_{6,t} = 0$. The shadow cost of public expenditures, $\lambda_{8,t}$, is greater than zero because of the optimality condition for public expenditures $\lambda_{8,t} = v'(g_t) > 0$. Thus, we confirm the Gross (2014) result that in the long run, the capital tax is the same as the closed-economy one.[14]

[14] The apparent alternative possibility, $r_t = 0$, cannot hold in equilibrium, because it would imply, given $1 = \beta[1 + r(1-\theta)]$, that $\beta = 1$. Also, the possibility that $\lambda_{8,t}$ diverges does not arise, since at an interior steady state $g_t = g_{t-1}$ and hence $\lambda_{8,t} = \lambda_{8,t-1}$.

3.2 Cooperative policies

In general, it is possible to improve upon the welfare attained from the non-cooperative policies in an open economy by coordinating policy. A coordinated policy is one that maximizes the weighted sum of welfares across the two jurisdictions subject to the constraint that both jurisdictions are in a competitive equilibrium. We rule out intergovernmental transfers, i.e. taxes paid in one country can only be used to finance government expenditures and debt service in that same country. We denote the Pareto weights by P and P^*, so that the objective function is

$$\sum_{t=0}^{\infty} \beta^t \left(P[u(c_t, h_t) + \nu(g_t)] + P^*[u(c_t^*, h_t^*) + \nu(g_t^*)] \right). \tag{14}$$

The set of constraints is the same as in the domestic government's non-cooperative problem, equations (1) - (9), except that we also have to add the foreign government budget constraint, equation (11). We also impose the constraint that capital taxes may not exceed 100% for each country, which is now binding in some periods. The set of choice variables X_{coord} is the same as X except that we add the foreign government's policy variables, $B_{t+1}^*, \tau_t^*, \theta_t^*, G_t^*$:

$$X_{\text{coord}} = \{c_t, c_t^*, h_t, h_t^*, j_{t+1}, j_{t+1}^*, K_t, K_t^*, B_{t+1}, \tau_t, \theta_t, , G_t, B_{t+1}^*, \tau_t^*, \theta_t^*, G_t^*\}_{t=0}^{\infty}. \tag{15}$$

In the symmetric case and with equal Pareto weights, the solution to the coordinated problem is identical to the closed-economy solution; for other Pareto-weights, the planner may seek redistribution across countries. When countries differ by population size and we set the Pareto weights equal to the respective population size, then coordination still achieves the same outcome as a closed economy (assuming that initial debt and assets per capita remain the same). If preferences are consistent with balanced growth, then the intertemporal elasticity of substitution, σ, is constant; in that case, if we set Pareto weights to $P = A^\sigma$ and $P^* = n^*(A^*)^\sigma$, the solution under coordination is yet again equal to the closed economy one, given that initial debt and assets as a fraction of output are the same across countries. In any case, it is easy to show that the steady-state capital taxes will still be zero with coordination.

3.3 Discussion of Capital-Tax Externalities

We now discuss the welfare effects on the home country of a (hypothetical) small deviation in the foreign country's (non-cooperative) equilibrium policy, namely a small shift from labour to capital taxes in one period. The goal is to identify and decompose the overall externalities associated with capital taxes.

Specifically, we analyze the effects on the home country's welfare of increasing the foreign capital tax rate by a small amount $\Delta\theta_t^*$ in a given period t, which we call the *period of intervention*. We let foreign government debt adjust in each period $s > 0$ in order to satisfy the foreign government flow budget constraint each period, with the adjustment denoted by ΔB_s^*. We also let the foreign labour tax in period t adjust to satisfy the foreign intertemporal government budget constraint, with the adjustment denoted by $\Delta\tau_t^*$. Every other aspect of the foreign government's policy remains unchanged. Meanwhile, private agents in both countries respond in such a way as to solve the now modified optimization problems that they face. We note that while per-period public spending remains unchanged the net present value of public expenditures may change following such intervention. Tax revenues and hence disposable incomes may also change. These changes take into account how the domestic and foreign households react, and thereby how the interest rates adjust to the intervention in question, while keeping the domestic policies unchanged at their non-cooperative equilibrium level.[15] This exercise is therefore well-specified in terms of the game outlined above.

To define the impact of the above intervention on home welfare (i.e., the externality), we thus derive the differential of the home government's Lagrangian (which can be found in Appendix A) with respect to θ_t^*, τ_t^* and B_s^* for all $s > 0$, evaluated at the non-cooperative equilibrium. We also divide the result of this differentiation by β^t

[15] Results would not change if we allowed the home (i.e. non-deviating) government to adjust its spending to ensure its solvency following the intervention.

in order to have a comparable expression in current value terms at the time period of intervention, otherwise the measured externality would trivially tend to zero as time goes to infinity. The externality, $\mathcal{E}(\Delta\theta_t^*)$, of the foreign government substituting from labour to capital taxes at time period t is then given by:

$$\mathcal{E}(\Delta\theta_t^*) \approx r_t^*(-\lambda_{4,t-1}u_{c^*,t} + \lambda_{5,t} - \lambda_{9,t}J_t^*)\Delta\theta_t^* + w_t^*(-\lambda_{2,t}u_{c^*,t} - \lambda_{9,t}L_t^*)\Delta\tau_t^* - \sum_{s=1}^{\infty}\beta^{s-t}\lambda_{6,s}\Delta B_s^* \tag{16}$$

where the approximate nature of the equation is due to the fact that it is merely a first-order approximation of the actual effect.

From the first-order condition with respect to domestic capital taxes, equation (θ), we substitute out for $\lambda_{5,t}$, and use the fact that $B_t + K_t - J_t = -(B_t^* + K_t^* - J_t^*)$ to obtain

$$\begin{aligned}\mathcal{E}(\Delta\theta_t^*) \approx & \underbrace{-r_t^*\left(\lambda_{3,t-1}u_{c,t} + \lambda_{4,t-1}u_{c^*,t}\right)\Delta\theta_t^*}_{\text{Savings Externality}} \\ & \underbrace{+r_t^*\left(\lambda_{8,t} - \lambda_{7,t}\right)J_t\Delta\theta_t^*}_{\text{Fiscal Externality}} \\ & \underbrace{+r_t^*\left(\lambda_{8,t} - \lambda_{9,t}\right)\left(B_t + K_t - J_t\right)\Delta\theta_t^*}_{\text{Terms of Trade Externality}} \\ & \underbrace{-w_t^*\left(\lambda_{2,t}u_{c^*,t} + \lambda_{9,t}L_t^*\left(1 + \frac{r_t^*}{w_t^*}\frac{K_t^* + B_t^*}{L_t^*}\frac{\Delta\theta_t^*}{\Delta\tau_t^*}\right)\right)\Delta\tau_t^*}_{\text{Foreign Labour Externality}} \\ & \underbrace{-\sum_{s=1}^{\infty}\beta^{s-t}\lambda_{6,s}\Delta B_s^*\}.}_{\text{Debt Externality}}\end{aligned} \tag{17}$$

We can identify five externalities from here: (i) the savings externality, (ii) the fiscal externality, (iii) the terms-of-trade externality, (iv) the foreign-labour externality, and (v) the debt externality. Unlike the traditional public finance literature, we present these externalities in terms of Lagrange multipliers, since the technique of expressing them purely in terms of quantities and prices is not helpful in an infinite horizon setting. Moreover, the savings externality is usually subsumed in the fiscal externality, but in our model we can neatly separate the two and study the impact of capital accumulation on their relative strength.

We start with the savings externality. The study of this externality is the main novelty of our contribution. The sign of the savings externality is determined by $-\lambda_{3,t-1}u_{c,t} - \lambda_{4,t-1}u_{c^*,t}$. $\lambda_{3,t-1}$ and $\lambda_{4,t-1}$ are the multipliers for the domestic and foreign household's intertemporal consumption optimality condition, respectively. These multipliers are positive, and thereby the savings externality is negative.[16] The intertemporal consumption optimality conditions are naturally absent in static models and reflect that an increase in capital taxes decreases savings.[17] Lower savings imply a smaller future capital stock and therefore reduce the worldwide potential future output. While the foreign government takes into account how its taxes affect worldwide savings, it does not incorporate the implications of this for domestic welfare. Since the global capital stock is shared, lower savings and less capital affect both countries in a negative way and we thus have a dynamic negative externality.

The fiscal externality, represented by the term $r_t^* \left(\lambda_{8,t} - \lambda_{7,t}\right) J_t$, is the effect at the centre of the analysis in ZMW and the subsequent literature. As long as $\lambda_{8,t} > \lambda_{7,t} > 0$, i.e. that resources are valued and more so in the government's coffers than in private hands (due to distortionary taxation), then this is a positive externality. If governments had access to lump-sum taxes, then this externality would of course be zero. To better understand this effect in our context, note that an increase in foreign capital taxes leads to a lower return on savings for domestic private households (a neg-

[16] To see why he Lagrange multipliers $\lambda_{3,t-1}$ and $\lambda_{4,t-1}$ are positive, it is easiest to consider the first-order condition with respect to capital taxes in a closed economy: $-\lambda_{3,t-1}u_{c,t} + (\lambda_{8,t} - \lambda_{7,t})J_t = 0$, where we used the fact that $J_t = K_t + B_t$. Since $\lambda_{8,t} > \lambda_{7,t}$ in the absence of lump-sum taxes, it has to be that $\lambda_{3,t-1} > 0$. Put in a different way, if $\lambda_{3,t-1}$ were not strictly positive, then capital taxes would be non-distortionary.

[17] Since net returns equalize across countries (recall the no-arbitrage condition), an increase in one country's capital tax means that the current net rate of return decreases in both countries. This implies that the marginal utility of consumption in the previous period has to fall, resulting in higher consumption and lower savings in the previous period.

ative welfare effect, captured by the term $-\lambda_{7,t}$), but at the same time more capital flows into the country, thereby boosting domestic tax revenues (a positive welfare effect, captured by the term $\lambda_{8,t}$). This externality captures together all fiscal effects discussed in the received literature: the tax bases for both capital and labour are increased (the latter via a higher marginal product of labour), and debt becomes less expensive to finance.

The terms-of-trade externality within a period is seen in the expression $r_t^*(\lambda_{8,t} - \lambda_{9,t})\,(K_t + B_t - J_t)$, which is positive for a "capital-importing" country, i.e. if $K_t + B_t > J_t$.[18] It represents the welfare gain (resp. loss) of a capital-importing (resp. capital-exporting) country due to the fact that a lower world interest rate decreases the interest payments to (resp. from) foreigners; see also De Pater and Myers (1994). This externality vanishes in a symmetric equilibrium with no capital flows between countries, as in the ZMW model where countries are identical.

The foreign-labour externality is captured by the terms

$$-w_t^*\lambda_{2,t}u_{c^*,t} - \lambda_{9,t}\left(w_t^*L_t^* + r_t^*(K_t^* + B_t^*)\frac{\Delta\theta_t^*}{\Delta\tau_t^*}\right).$$

We start our discussion of this externality by focusing on the first term: when the foreign country increases its capital taxes and lowers, as a result, its labour taxes to balance its budget, it takes into account that this affects the labour supply of its own citizens. However, the change in labour supply also has an impact on domestic welfare; observe that $\lambda_{2,t}$ is the Lagrange multiplier of the domestic government for the foreign household's labour-leisure decision. Lower foreign labour taxes will lead (in this model) to an increase in foreign labour supply and this may in principle have a positive or negative impact on domestic welfare. Specifically, more foreign labour increases the world rate of return on capital and increases savings (positive effects), but at the same time it also results in a higher marginal product of capital abroad, thereby attracting capital from the home country (a negative effect). We now turn

[18] The Lagrange multiplier on the government budget constraint, $\lambda_{8,t}$, is naturally always larger than the one on the foreign household's budget constraint, $\lambda_{9,t}$.

to the second part of the above term. This part describes a "wealth effect" for the foreign household and how this affects domestic welfare. To understand this, recall from our description of the intervention that a shift from labour to capital taxes may change tax revenues and thereby the disposable income of foreign households. This influences of course the savings and labour supply decisions of foreign households, which in turn affects domestic welfare. As the foreign government does not internalize this effect, this constitutes an externality. However, we expect the wealth effect to be of minor importance: a *small* change from the *optimal* equilibrium policy should not lead to significant changes in the income available to the household.

The (foreign) debt externality is represented by $-\sum_{s=1}^{\infty}\beta^{s-t}\lambda_{6,s}\Delta B_s^*$. It arises from the adjustment of foreign government debt in order to satisfy the foreign government flow budget constraint in each period. We expect this term to be small in the short run and zero in the long run: The small policy deviation is likely to lead to an increase in debt before the tax hike and a decrease afterwards, so that the effects would roughly cancel out. Moreover, in the long run $\lambda_{6,s} = 0$ as shown in Section 3.1.

Since the fiscal, terms-of-trade, and foreign-labour externalities are all present in a static model, we expect that a dynamic model with the additional negative savings externality will feature relatively higher capital taxes than a static model (or any model in which the capital stock does not evolve endogenously through savings). In other words, models with an exogenous capital stock will exaggerate the negative effects of tax competition. In fact, in the medium run capital taxes may even be too high, rather than too low. In the long run, we expect capital taxes to have no net externality, since we have shown analytically that steady-state capital taxes in an open economy coincide with those in a closed one.

It is worth emphasizing that while only the savings and debt externalities are dynamic in the sense that they are new compared to a static model, the fiscal, terms-of-trade, and foreign-labour externalities will in general differ quantitatively and potentially even qualitatively from those in a static model. To explain this, let us consider the example of the foreign-labour externality: As explained above, a lower foreign labour tax negatively affects the home country because it intensifies tax competition, which is most important in the short run. At the same time, a lower foreign labour tax results in higher foreign labour supply and thereby a higher global marginal product of capital, which would benefit the home country at any time. Since the importance of each effect can change over time, the sign of the externality may change, and this is indeed what we find in our quantitative exercises.

4 Quantitative results

The main purpose of this section is to explore the quantitative implications of the model for a range of parameter values, which are chosen so as to make the results broadly speaking empirically relevant. Rather than attempting to account for any particular historical episode, we will investigate capital tax paths for a range of scenarios designed to shed light on the mechanisms involved.

In our baseline computational experiment with symmetry, we consider the following scenario. We imagine that the world economy has existed for a long time, with fiscal policy *optimally* chosen, and no capital mobility. We call this situation the "initial steady state." The level of debt in this initial steady state depends on the conditions before then, and so we set it to an exogenously given percentage of GDP, see below. Without coordination, at time $t = 0$, each of the two governments simultaneously and independently choose their policies so as to maximize welfare of the representative citizen under its jurisdiction, given the policies of the other government. With coordination, at time $t = 0$, the central planner chooses the policies in each country so as to maximize the weighted average of the welfare of the representative citizens in both jurisdictions, with the weights being equal to the relative populations in efficiency units. From period $t = 0$ and onwards, capital is perfectly mobile (for open economies). We impose an upper bound of 100 percent on capital taxes, which is non-binding in the open economy equilibrium without coordination.

The initial steady state determines the following variables that we use to initialize the equilibrium with optimal policy set at $t = 0$: the initial world capital stock, the initial stock of government debt in each country, and the initial asset holdings of inhabitants of each country. When we consider asymmetries, we simply vary key parameters or initial values of one country only instead of recalibrating the entire economy. This strategy enables us to best understand what the role of each of these parts is in isolation (rather than having a number of parameters change at the same time and thus confounding results). As a convention we choose to vary key parameters or initial values that pertain to the home country, while keeping the foreign country unchanged relative to the symmetric environment.

4.1 Calibration and computation

We now describe the benchmark parameterization of the symmetric two-country model. We calibrate the initial level of government debt to be 60 percent of GDP in both jurisdictions, corresponding roughly to the (unweighted) EU average (excluding the UK) in 1992 according to the OECD.[19]

The per-period utility function is assumed to take the following form:

$$u(c, h) + v(g) = (1 - \gamma) \ln(c) - \psi \cdot \frac{h^{1+\frac{1}{\varepsilon}}}{1 + \frac{1}{\varepsilon}} + \gamma \ln(g)$$

where ε is the (constant) Frisch elasticity of labour supply. We set $\varepsilon = 1/2$ and $\psi = 3.52$; the latter is a normalization implying that labour supply h is about a third. The subjective discount factor, β, is set equal to 0.96 so that each period can be thought of as one year. We set $\gamma = 0.43$ so that government revenue (and hence roughly spending) is 35 percent of GDP, approximately equal to the 1992 unweighted EU average.[20]

[19] See OECD (2020a).
[20] See OECD (2020b).

The production function is assumed to be Cobb-Douglas so that

$$F(K, L) = K^{\alpha}(AL)^{1-\alpha}$$

where $\alpha = 0.35$ and $\delta = 0.08$, which are empirically plausible values for the capital share and the depreciation rate. The value we obtain for the initial debt is $b_0 = 0.36$ and for the initial assets $j_0 = 2.09$, resulting in a capital-to-GDP ratio of 2.92. We normalize labour productivity to $A = 1$.

Every transition path is solved for in the following conceptually straightforward way.[21] We fix a time horizon T after which we conjecture that the economy has come very close to the long-run allocation. We then stack the equilibrium conditions up until period T and force variables at time periods T and $T+1$ to equal each other. An approximate solution to the resulting system of equations is then found by using the Gauss-Newton method of minimizing the sum of squared deviations. In particular, the system of equations consists of all the constraints from each government problem, as well as each government's first-order conditions. The variables are the allocations, taxes, debt, assets, and Lagrange multipliers in each country. That is, we solve for the two governments' policies simultaneously, which ensures that the global resource constraint is also satisfied.[22]

4.2 Symmetric countries

We begin by considering a case where the two jurisdictions are identical. Given the parameter values described above and the initial conditions, there appears to be a unique equilibrium, and it is symmetric. Because of the symmetry, there is no

[21] The method is known in the literature as the *extended path* method and was first described in Fair and Taylor (1983).

[22] We essentially have a large system of equations with no exact root, because the world economy does not converge to a steady state in finite time. Any solution therefore has to be an approximation. For our equilibrium determination, the maximum error size is 10^{-6}. We have been able to bring this down to 10^{-8}, but it is very cumbersome and does not change the results in any visible way, so all of our current results are based on a maximum error size of 10^{-6}. Most error terms are of course much smaller and the mean error size is in the order of 10^{-10} or smaller.

terms-of-trade externality. Also, if countries coordinate, the solution is the same as in a closed economy: the rates of return are the same in both countries even if there is no trade in capital, and hence there are no gains from capital movements.

The implications for capital tax rates of this symmetric case are shown in Table 1 and Figures 1 and 2. The first result we immediately see here is that the period-0 open-economy capital tax rate is most definitely not confiscatory. In contrast to a closed economy, there is no need to impose any constraint on what capital income taxes can be; capital mobility provides enough discipline to keep them in check. Indeed, equilibrium capital taxes are about 40 percent in the initial period. This is not too far from what we saw in the European Union on average when the 1992 program was completed and full freedom of movement of capital was realized.[23]

As a second result, capital tax rates in an open economy only very gradually fall towards zero; in year 30, they are still at 2 percent. This is in contrast to the closed economy, where the transition from 100 percent to zero takes only 10 years. Thus, a rather natural extension of the seminal ZMW model—namely, allowing for capital accumulation—is sufficient to completely overturn its prediction from year 10 onwards, at least under the parameter values considered here. Moreover, government spending is *higher* in the short run when there is capital mobility, whereas in the medium/long-run it is lower. However, it is worth emphasizing that on average the level of public expenditures in the closed economy is higher than in the open economy, consistent with ZMW. We discuss government spending, debt, and labour taxes in more detail in Subsection 4.5. Furthermore, in our model welfare is also lowered by capital mobility, a loss equivalent to a drop of 1.19% in private consumption every period. Henceforth, whenever we report welfare changes, we measure them in terms of the equivalent percentage change in private consumption in every period.

What can explain the different paths of capital taxes in a closed and an open economy? In both cases the government aims to tax the initial asset endowment. In

[23] See OECD (1999).

a closed economy, the exogenous cap of 100% taxes prevents the government from completely expropriating the initial asset endowment at $t = 0$, where capital taxes are non-distortionary. Capital taxes after $t = 0$ are distortionary in terms of creating a wedge in intertemporal decision making, but they still tax the initial asset endowment, as they lower its net present value (NPV). As one moves further away from time 0, the more distortionary the tax, since it taxes the initial asset endowment less directly. Therefore, capital taxes are initially as high as possible and then abruptly go to zero.

In an open economy, the rationale for taxing capital is the same, but capital taxes are immediately distortionary, as they lead to capital flight to other countries. Capital taxes are thus at first lower than in a closed economy. However, each country perceives the welfare costs of a lower global capital stock (due to reduced savings) to be smaller than in a closed economy, since the global capital stock is shared, and the costs of reduced savings are therefore partially borne by other countries. This is why capital taxes in an open economy tend to be higher in the medium run than in a closed economy.

Quantitative analysis of externalities in the symmetric case Here we consider the effects on welfare in the home country of small changes to capital taxes in the foreign country, taking into account the implied change, via the foreign government's budget constraints, in the labour tax and public debt sequence abroad. The numbers we compute can be thought of as numerical derivatives; they are literally ratios of small changes. Figure 3 displays the various components of the capital tax externality, as defined in Section 3.3, but divided by the change itself so as to yield a numerical derivative. In the figure, we display the fiscal externality, the savings externality, and the foreign labour externality.[24] All externalities are measured in terms of the equivalent percentage change in private consumption in every period.

This quantitative analysis clearly reveals the importance of introducing capital accu-

[24] The debt externality is only of minor importance and is left out so as to avoid cluttering the figure; the same applies to the terms-of-trade externality, which is zero in a symmetric environment.

mulation. All components of the externality are affected by dynamics, but the effect is most striking in the savings externality, which is absent in a static model. It is zero at time zero but then grows in magnitude over time (as households can change their behaviour in more periods before the tax is due for payment).

The fiscal externality shrinks somewhat over time, but remains important at any period of intervention. From the perspective of introducing dynamics, the foreign-labour externality—even though small in size—exhibits interesting behavior: It starts off negative at time zero, but then becomes positive in the long run. What this shows is that a static model may not only differ in predicting a different magnitude of the externalities but even a different sign as compared to a dynamic model.

The importance of dynamics also becomes apparent when we look at the total externality: There is a large positive externality at time zero driven by the fiscal externality, in line with the findings of ZMW. Then the total externality shrinks to zero as we approach steady state, in consonance with the result in Gross (2014) that the capital distortions of a closed and open economy coincide in the long run. The intuition is simple, but powerful: In the long run, lower capital tax rates do not "steal" capital from abroad anymore (because the net rate of return to capital is equal to $1/\beta - 1$), but instead increased savings fill the higher demand for capital associated with the lower capital tax rate. The savings externality completely counteracts the other externalities.

4.3 Asymmetric countries

We now turn to cases where countries are not identical and there are potential gains from trade in capital. In these cases the terms-of trade externality emerges alongside the rest of the externalities, affecting the paths of capital taxes.

4.3.1 Differences in initial asset positions

Here we assume that the domestic stock of assets is initially 20 percent greater than the foreign one. Again, convergence to zero of the capital tax is a protracted affair; see Table 2 and Figure 4.

Notice that the home country taxes capital less than the foreign country under capital mobility, even though in autarky it taxes capital more heavily than the foreign country. The reason is that the home country is a net capital exporter, as indicated by the positive net foreign asset position of the home country presented in Table 2. As a result of the non-zero net foreign asset position, each country attempts to manipulate the terms of trade in its favor. The capital exporter lowers capital taxes to increase the worldwide rate of return, whereas it is the opposite for the capital importer. The resulting terms-of-trade externality is negative as we can see in Figure 5, which shows how the home country is affected by an increase in capital taxes in the foreign country.

The sign of the externality is in line with the results in De Pater and Myers (1994) for a static model, because our terms-of-trade externality captures only the effects within the same period.[25] We call this the direct effect. As mentioned in the Introduction, a change in capital taxes affects the terms of trade not only in the same period, but also in other periods, through capital accumulation. We call this the indirect effect. In more detail, an increase in the capital tax rate in the foreign country leads to a decrease in the current rate of return as well as, in a dynamic setting, to a decrease in past savings. The latter of course leads to a lower capital stock, which, in turn, raises the rate of return. Thus, these indirect effects (which are absent in a static model) mitigate the direct effect, and so the difference in the capital taxes of capital-trading countries is smaller in magnitude in a dynamic environment with endogenous savings than in a static setting.[26] It is also interesting to note that the

[25] De Pater and Myers (1994) deal in their model only with the case of exogenously fixed labour supply. Here, however, we confirm that the effect they identify is valid in our computations where labour supply is endogenous.

[26] Details on this are available upon request.

total externality converges to zero in the long run, even though the net-foreign asset position remains positive and large, at 26 percent of domestic GDP. As shown analytically and confirmed numerically, capital taxes of both the capital-exporting and importing country converge to zero and there is no manipulation of the terms of trade in the long run.

The welfare consequences of open capital markets are still negative for both countries, meaning that the deleterious consequences of tax competition outweigh the benefits of trade in capital. However, the capital-exporting home country's welfare decreases by 1.69%, whereas the foreign country only loses 0.31%.

4.3.2 Differences in population size

Next we assume that the home country is twice as populous as the foreign country.[27] The parameterization is otherwise the same as in the baseline (symmetric) set up. The implications for capital taxes are shown in Table 3 and Figure 6. Convergence to zero is again rather protracted, with domestic capital taxes remaining above 12 percent after 15 years. As we can also see in Table 3, equilibrium capital taxes in the open economy start out at 51 percent at home and 31 percent abroad. In addition, they are consistently higher at home than abroad, even though each country would have had the same capital taxes in a closed economy. This reflects the results from the literature based on static models, that larger countries have more "market power" and as a consequence set higher capital taxes than smaller countries, see e.g. Wilson (1991). The intuition is simple: In the short run, an increase in capital taxes in the home country leads to a relatively smaller outflow of capital than in the foreign country.[28]

[27] An alternative situation is one where the home country is more productive than the foreign one in the sense that its labour productivity is higher. However, that case is completely isomorphic to the one where the home country is more populous, so we do not discuss it further.

[28] Since the foreign country is smaller, an outflow of, say, one percent of domestic capital would decrease the foreign rate of return by more than an outflow of one percent of foreign capital would decrease the domestic rate of return. In other words, in the short run, the home capital stock is less elastic with respect to domestic capital taxes than the foreign one. In the long run, this logic no longer applies, and both countries set a zero capital-tax rate.

However, since the home country sets higher capital taxes than the foreign country, the home country's net foreign asset position is positive in the early periods (despite both countries having identical initial asset endowments). This implies that there is an incentive on the part of the home government to lower its capital taxes to manipulate the terms-of-trade to its benefit. This partially counteracts the incentives to tax capital more due to the greater market power. As the gap between the two countries' tax rates closes, the home country's net foreign asset position gradually shrinks.

The externalities, shown in Figure 7 are qualitatively similar to the previous case. Both countries experience a decline in welfare, and more strongly in the capital-exporting, larger home country (-1.28%) than abroad (-0.78%).

4.3.3 Differences in government debt

We now turn to the case where the home country has a lower level of initial government debt. We set the home public debt to zero in this experiment, and adjust home private assets accordingly, so that net domestic assets remain the same. The home country needs to raise less tax revenues than the foreign country, and so it sets lower capital (and labour) taxes. Convergence to zero of capital taxes is, as before, protracted (see Table 4 and Figure 8). Because of the negative net foreign asset position (see Table 4) the resulting terms-of-trade effect pushes in the opposite direction, but does not outweigh the need to set lower capital taxes to finance the lower tax revenue requirements.

The externalities, shown in Figure 9, are again qualitatively similar to what is displayed in Figure 5. Perhaps more interesting are the welfare consequences. The home country only faces a welfare loss of 0.73%, whereas the loss amounts to 1.39% in the foreign country. This difference can be attributed to two facts: one, the home country is a capital importer (the NFAP is relatively small); and two, the home country is less affected by the negative effects of tax competition on public finances, as its need for public funds is lower.

4.4 Coordination

In this section, we report some results on how the solution changes in a cooperative equilibrium as compared to the non-cooperative equilibrium studied so far. We refer to exactly the same scenarios as previously described. We use Pareto weights that are equal to a country's population size.

Our first result is unsurprising: the coordinated solution in a symmetric environment is identical to the solution in the closed economy, which is the second-best policy. Therefore, coordinated capital taxes are higher than the non-cooperative ones in the short run, but *lower* in the medium run. The latter is in contrast to common beliefs that have influenced policy debates in Europe and elsewhere. Capital taxes are initially at the maximum 100% for years 0 to 8, and immediately switch from 100% to zero with only one intermediate period, as in Atkeson et al. (1999).

The welfare implications are worth noting as well. The gains from coordination—relative to the non-cooperative outcome under capital mobility—are equivalent to an increase by 1.21% of private consumption in every period in each country. With symmetry, there is no upside from capital-market integration: because the two countries are identical, there are no potential gains from trade in capital. Without coordination, the tax externalities that emerge when the capital market is integrated lead to welfare losses. Coordination then reverses the welfare losses by internalizing the externalities.

Interestingly, if one country is more populous or more productive than the other, then the coordinated solution is still identical to the closed-economy solution. While the non-cooperative game features different policies between the larger and the smaller countries, the coordinated solution has identical policies for both countries. The larger country gains more from coordination (relative to non-cooperation) than the smaller country: 1.3% and 0.79%, respectively.

When one country has more initial assets than the other (in our case the home country, as specified in the previous section), then optimal coordinated policies differ by country, as one may expect. Interestingly, though, the main difference is in the labour tax rates: The country with more assets sets higher labour taxes, since its citizens are richer and therefore supply less labour at the same net wage. Capital-tax rates, however, are virtually indistinguishable between countries; see Figure 10. Coordination thus roughly preserves production efficiency, i.e. that the marginal products of capital are the same in both countries.[29] An unexpected and possibly highly policy-relevant implication of this result is that *capital-tax harmonization is (roughly) optimal, even when countries differ in their initial asset position.*

While both countries gain from coordination, 0.75% and 1.46% for the home and the foreign country respectively, the capital-exporting country (the home country here) would prefer the closed-economy outcome to the coordinated outcome (and vice versa for the capital-importing country). The intuition is that the home-country suffers relatively more from tax competition in the sense that part of its capital migrates abroad; moreover, it suffers relatively more from the inability to efficiently tax the initial capital stock.

When one country has a lower initial public debt than the other (in our case the home country, as specified in the previous section), then, again, optimal coordinated policies differ by country. As in the case above, the main difference is in the labour tax rates: The country with higher debt sets higher labour taxes, since it has higher revenue needs. Capital-tax rates, however, are virtually indistinguishable between countries. Coordination, in this case as well, thus roughly preserves production efficiency and capital-tax harmonization is (roughly) optimal.

In this scenario, both countries gain from coordination (relative to non-cooperation), 0.72% and 1.4% for the home and the foreign country respectively. Moreover, be-

[29] It is generally not true, however, that a coordinated solution satisfies production efficiency in the absence of intergovernmental transfers; in fact, one can show that if there are per-capita asymmetries (and the government budget constraint Lagrange multipliers differ between countries), then production efficiency will be violated. A similar point has been made in Kotsogiannis and Makris (2002) and Keen and Wildasin (2004) in static models. The first paper discusses optimal federal tax policy when the federal government is a Stackelberg leader vis-vis asymmetric state tax authorities, while the second paper discusses Pareto-improving reforms. In both papers, there are no transfers to redistribute tax revenues between (state) tax jurisdictions.

cause there is very small trade in capital (recall the NFAP in Table 4), both countries are virtually indifferent between the closed-economy outcome and the coordinated outcome.

4.5 Government spending, debt, and labour taxes

One important consideration in the public-finance literature (where models are typically static in nature) is how tax competition may drive down capital taxes and in consequence lower government spending or increase (more) distortionary labour taxes. Due to the dynamic nature of our exercise, it is not clear whether these effects will be present, and in what form. For instance, one result we have observed in all of our numerical exercises is that (total) discounted revenues from capital taxes as a share of discounted government revenues are lower in an open economy than in a closed economy. This echoes the results in the static counterpart of our model. Nevertheless, as highlighted before, capital taxes in an open economy may be higher for *several periods* than in a closed economy.

Because governments can tax capital less efficiently in an open economy, government spending tends to be lower and labour taxes and debt tend to be higher compared to a closed economy. However, this is not true in every period (see Table 5). This warrants an explanation, which we provide next.

To start with, it is important to bear in mind that the principal goal of optimal taxation of verifiable tax bases is to tax endowments; in our model economy, there is a time endowment (in efficiency units) in every period and the initial asset endowment. Labour taxes are used in effect to tax the time endowment, and capital taxes for the taxation of the initial asset endowment. The taxation of the initial asset endowment is highlighted by the implementability condition:

$$\sum_{t=0}^{\infty} \beta^t \left[u^i_{c,t} c^i_t + u^i_{h,t} h^i_t \right] = u^i_{c,0} \left[1 + r^i_0 (1 - \tau^i_0) \right] a^i_0. \tag{18}$$

Equation (18) follows from eliminating after-tax prices from the agent's intertemporal budget constraint by using the private sector optimality conditions. Since this is standard, we do not derive it in detail here. It simply says that the total discounted valuation (at the margin) of consumption net of labour utility costs must be equal to the valuation (at the margin) of the returns from the initial asset endowment. The implementability condition describes which allocations can be implemented by means of (proportional) taxes.

In particular, as is clear from the above condition, capital taxes at time zero directly tax the initial asset endowment (the right-hand-side of the above condition). Since capital taxes are capped at 100%, this constrains the ability of the government to decrease the value of the initial asset endowment. However, notice also that the lower the marginal utility of consumption at time 0, the lower the value of the initial asset endowment, thereby relaxing the implementability constraint. This provides an alternative channel through which the government can tax (indirectly) the value of the initial asset endowment; namely, through keeping government spending at lower levels in the earlier periods.

To understand this, consider first a closed economy, and let us focus on the early periods (when capital taxation is higher in a closed economy). Keeping government spending low in the early periods, comes at the expense of not smoothing government spending over time (which would ideally be constant). But, it also comes with two benefits due to households now having more resources in those periods. First, it increases consumption at time zero, thereby reducing the marginal utility of consumption at time zero and hence the value of the initial asset endowment; this relaxes the implementability constraint by indirectly taxing the initial asset endowment. Second, it increases savings (due to consumption smoothing), thereby increasing the capital stock in future periods, which has been depressed in the early periods due to high capital taxes.

In an open economy, the costs of maintaining relatively low government spending in the early periods are the same as in a closed economy, but the benefits are reduced from the point of view of a single country. The reason for this is that the worldwide capital stock is shared between countries, and so the benefits of increased savings are shared with the rest of the world too. Therefore, government spending is higher at first (in periods 0 to 3 in our computations when countries are symmetric) in an open economy compared to a closed economy, even though total discounted government spending is lower in an open economy (in total or as a fraction of GDP).

Similar findings are also observed in relation to labour taxes and government debt, for essentially the same reason. Labour taxes are initially much lower in a closed economy, in order to encourage spending and savings by households in the early periods. But then labour taxes increase more rapidly in a closed economy, so that they are higher than in an open economy in periods 8 to 14. The reason for the faster growth of labour taxes in a closed economy is that, as we have explained above, governments in a closed economy have a weaker desire to smooth government consumption relative to taxing the initial endowment than in an open economy, which call for less smooth labour taxes. Since labour taxes grow faster and capital taxes are initially higher in a closed economy, governments can then engage in a massive reduction of debt, leading to lower debt (compared to an open economy) at all times except for the first two periods. In those early periods debt is reduced less quickly in a closed economy because labour taxes are much lower than in an open economy.

5 The United Kingdom and Continental Europe

In this section we describe the results from calibrating our model to an empirically relevant setting. Following Mendoza and Tesar (2005), MT hereafter, we focus on the United Kingdom (UK) and the three largest countries in Continental Europe (CE), viz. (West) Germany, France, and Italy. Throughout, we compare and contrast our assumptions and results to the influential work by MT.

We are aware that tax competition did not only take place between these countries, but also involved the rest of the world. Nonetheless, it seems to us to be an interesting exercise, because it puts together all of the asymmetries discussed above in a fairly realistic setting. Moreover, the capital mobility between these European countries is likely higher than with the rest of the world.

As in MT, we assume that the UK and the countries of CE are of equal size and equal productivity, and that the latter are identical. Where we differ importantly from these authors, is that we treat each of the CE countries as an individual player, whereas MT assume that CE acts as one united player coordinating policies. MT use a different definition of the game between countries and hence a different equilibrium concept than we do. Each country's fiscal policy consists of only one choice, a time-invariant capital tax. The government budget is balanced by adjusting labour taxes.[30]

Unlike MT, public debt plays an important role in our model, and so we calibrate the debt-to-GDP ratio in the initial steady state to 42% for the UK and to 50% in CE, corresponding to the 1985 values according to IMF (2020). Similarly, the ratio of tax revenues to GDP is 35% for the UK and 37% for CE in the initial steady state; see the numbers for 1985 in OECD (2020b). One can thus think of the year 1985 as period $t = -1$ in our model and 1986 as $t = 0$. Capital taxes in the initial steady state are 53% in the UK and 26.5% in CE, as in MT.

The rest of the calibration is as in the baseline, except that we force the parameter ψ to be the same in the UK and CE. Hours worked in the initial steady state are then 1/3 in the UK and somewhat lower, 0.311, in CE. In MT, estimated labour and consumption taxes in the initial steady state are 25% and 14% for the UK (a total labour wedge of 34.2%) and 37.4% and 16.6% for CE (a total labour wedge of 46.3%), while we have labour taxes of 39.1% and 51.2%, so the labour wedges are roughly comparable. The GDP in the initial steady state is somewhat higher (4.36%) in CE than in the UK.

There are thus two key differences between the UK and CE: (i) CE has a larger initial

[30] They also consider a different scenario, of adjusting consumption taxes, but we will not refer to that here.

asset position than the UK, due to the lower capital taxes in the initial steady state ($j_0^{CE} - b_0^{CE} = 1.36$ vs. $j_0^{UK} - b_0^{UK} = 1.06$), and (ii) CE has a larger need for public funds, because its initial debt is higher ($b_0^{CE} = 0.26$ vs. $b_0^{UK} = 0.21$) and because it has a more pronounced taste for public goods ($\gamma^{CE} = 0.43$ vs. $\gamma^{UK} = 0.37$), which stems from calibrating the ratio of government spending to GDP in the initial steady state.

Our results can be found in Table 6 and are depicted in Figure 11. The UK sets higher capital taxes than CE, since it has a lower initial capital stock and is hence a capital importer. (In a closed economy, the UK would set *lower* capital taxes than CE.) The fact that the UK has a less pronounced taste for public goods counteracts this, but are not enough to overcome the desire to manipulate the terms of trade in its favor by increasing capital taxes. At the same time, the UK's labour taxes are lower than in CE, due to its lesser need for public funds (the UK also spends less on public consumption than CE).

Motivated by calls within the EU for tax coordination, as mentioned in the Introduction, we calculate the welfare effects on the UK of all three CE countries simultaneously increasing their capital taxes by the same small amount. This welfare effect can be calculated and decomposed in an (almost) identical manner to the externality discussed above. This externalitiy (shown in Figure 12) follows the pattern one would expect for a capital importer: the total externality is positive and declines to zero, with a sizable, positive terms-of-trade externality, a positive fiscal externality, and a negative savings externality that grows over time. We find small welfare gains for the UK from an open economy (0.07%), and fairly large welfare losses for CE (−2.20%).

Unlike MT, we make a welfare comparison between optimal fiscal policy in an open vs. a closed economy, whereas they compare welfare in an open economy to that in the (non-optimal) initial steady state. Another contrast to MT is that we do find a race to the bottom in the sense that capital taxes contribute a much smaller share of discounted government revenues in an open compared to a closed economy (11.3%

vs. 2.5% for the UK and 10.8% vs. 1.8% in CE). This can be explained by the fact that MT do not allow for time-varying tax rates.

Moreover, while MT and our paper coincide in terms of lower government spending and lower labour taxes in the UK than CE (which matches with the data), they find counterfactually that the UK sets lower capital taxes than CE, in contrast to our paper. This stems from the fact that they assume that CE acts as one unified country (presumably because their computational approach does not allow for a scenario with more than two countries), while we assume that CE is symmetric, but each country acts uncooperatively. Our model generates a downward trend in capital taxes, while they are constant by construction in MT. On the other hand, the levels of capital taxes in our model are counterfactually low and converge to zero. Since we assume perfect commitment, capital taxes in our model should be lower than in reality (where commitment is presumably less than perfect); see for instance Quadrini (2005) for a model with limited commitment. Moreover, we have not included any factors that would induce positive capital taxes in the long run. We have made these assumptions in order to keep the model tractable, and to focus on the implications of capital accumulation on dynamic capital taxation in an open economy.

6 Robustness checks

In this section we explore the robustness of our results with respect to changes in various parameter values and regarding our assumption of perfect capital mobility.[31]

[31] Another potentially interesting extension is to consider labour mobility. This raises conceptual issues such as the objective of a benevolent government, but it also poses significant computational problems. Gross (2018) takes a first step towards this difficult issue and analyzes the impact of labour mobility on tax competition as a robustness check. When countries are symmetric, returns to scale are constant, and government consumption is perfectly rivalrous, then the effect of labour mobility on tax competition is relatively minor. The reason is that (in the absence of government debt), an additional citizen contributes just as much in additional government revenues as the citizen "costs" in terms of additional government spending. With perfect capital mobility and symmetry, the capital-labour ratio and thus wages and the rate of return on capital remain constant. The only way in which an additional citizen matters is through the dilution of public

6.1 Sensitivity to parameter values

The parameter values we chose are all in the conventional/empirically plausible range. The question of the robustness of our results with respect to these parameter values arises, though. We have thus solved the equilibrium with the following changes: 1) an intertemporal elasticity of substitution (IES) of 2/3 and 3/2 instead of 1 in our baseline log specification, 2) a discount factor β of 0.95 and 0.97 instead of 0.96, 3) a Frisch elasticity ε of 0.3 and 0.7 instead of 0.5, 4) a capital share α of 0.4 and 0.3 instead of 0.35, 5) a depreciation rate δ of 0.1 and 0.06 instead of 0.08, and 6) government revenues that amount to 30% and 40% of GDP in the initial steady state instead of 35%. All our results remain qualitatively the same, and quantitatively comparable; see Appendix B.

6.2 Capital adjustment costs

In this section, we investigate the implications of convex (quadratic) adjustment costs associated with capital accumulation. Such adjustment costs imply that capital is not perfectly mobile, since any movement of capital from one jurisdiction to another involves costly adjustment either in the receiving or the sending location, or both.

Suppose that, at the firm level, it is costly to change the capital stock so that per period profits are given by

$$\pi_t = F(K_t, AL_t) - w_t L_t - (r_t + \delta)K_t - \omega \cdot \Omega(K_t, K_{t-1}) \tag{19}$$

where

$$\Omega(x, y) = \frac{(x - y)^2}{x + y}. \tag{20}$$

Notice that this specification preserves constant returns to scale so that neither the

debt; that is, more citizens share the same total burden of debt, which leads to a per-capita welfare gain for the receiving country. However, if the net asset position of a government is positive, then an additional citizen would imply a per-capita welfare loss.

number of firms in a given country, nor the distribution of capital between them, matters. For the record, we have

$$\Omega_x = \frac{x^2 + 2xy - 3y^2}{(x+y)^2},$$

$$\Omega_y = \frac{-3x^2 + 2xy + y^2}{(x+y)^2},$$

$$\Omega_{xx} = \frac{8y^2}{(x+y)^3},$$

$$\Omega_{yy} = \frac{8x^2}{(x+y)^3}$$

and

$$\Omega_{xy} = -\frac{8xy}{(x+y)^3}.$$

The sum of discounted profits is given by

$$\Pi_0 = \sum_{t=0}^{\infty} \left(\prod_{s=0}^{t} R_s^{-1} \right) \pi_t \tag{21}$$

where $R_s = 1 + r_s(1 - \theta_s)$. Profit maximization[32] still implies that the wage equals the marginal product of labour, but the condition for capital becomes more complicated:

$$r_t = F_{K,t} - \delta - \omega \cdot \Omega_x(K_t, K_{t-1}) - \frac{1}{R_{t+1}} \cdot \omega \cdot \Omega_y(K_{t+1}, K_t). \tag{22}$$

Suppose $\omega = 0.03$. The results are found in Table 7 and Figure 13. We show the externalities in Figure 14. Naturally, open-economy capital taxes are higher with capital adjustment costs, since capital flight is not as important a concern as with perfect capital mobility. Consequently, the welfare costs of tax competition are smaller (-0.99% compared to -1.19% in the baseline case).

[32] As in the simpler case without capital adjustment costs, expected profits and profits in any given period are zero.

7 Concluding remarks

In this paper, we examined the implications for capital tax policy of capital mobility across borders. We considered a model economy where two benevolent (but nationalistic) governments, each independently of the other, committed simultaneously, at the beginning of time, to a time-varying tax policy that applies in perpetuity. We chose an appropriate equilibrium concept for this environment and characterized and computed the dynamic equilibrium, not just the steady state. We think of this as a substantial methodological contribution of our paper.

Our main finding was that, though as in Chamley (1986) and Gross (2014), capital taxes tend to zero in the long run, they may in empirically relevant scenarios be high and positive during a highly protracted transition to that long run. We also found that coordinated capital tax rates are higher than the non-cooperative ones in the short run, lower in the medium run and the same in the long run. This is in contrast to the common belief among many researchers and practitioners that more integrated capital markets will lead to lower taxes in the absence of cooperation among tax authorities, which has motivated frequent calls for a coordinated increase in capital taxes. Furthermore, while we find a positive fiscal externality at all times, a negative savings externality emerges over time, so that the net cross-border externality from capital taxes converges to zero in the long run. We think of this as an important substantive contribution towards understanding the interaction of capital tax setting in dynamic economies and capital market integration.

In our analysis, we deployed the simplest possible model for the task at hand, and one that extends existing work in a minimal way. In particular, the choice of the representative agent paradigm is consistent with the framework in ZMW and most of the literature that it spawned, and it is instructive to be able to directly compare our results with those of this canonical model. Allowing for heterogeneous agents and ensuing political economy considerations such as those in Lockwood and Makris (2006) but in a dynamic set-up is an interesting task for future research. Fully understanding the net externalities involved in taxing mobile capital in the presence of heterogeneous consumers would also require the study of alternative dynamic environments such as overlapping-generation models. The reason is that, as our analysis makes clear, the specifics of capital accumulation are important for intertemporal capital tax externalities.

8 Tables

Table 1: Capital taxes when countries are symmetric

	Open economy			Closed economies	
Period	θ	θ^*	NFAP	θ	θ^*
0	38.6	38.6	0.00	100.0	100.0
1	35.5	35.5	0.00	100.0	100.0
2	32.6	32.6	0.00	100.0	100.0
3	29.9	29.9	0.00	100.0	100.0
4	27.4	27.4	0.00	100.0	100.0
5	25.1	25.1	0.00	100.0	100.0
6	22.9	22.9	0.00	100.0	100.0
7	20.9	20.9	0.00	100.0	100.0
8	19.1	19.1	0.00	100.0	100.0
9	17.4	17.4	0.00	16.0	16.0
10	15.9	15.9	0.00	0.0	0.0
11	14.4	14.4	0.00	0.0	0.0
12	13.1	13.1	0.00	0.0	0.0
13	11.9	11.9	0.00	0.0	0.0
14	10.8	10.8	0.00	0.0	0.0
15	9.8	9.8	0.00	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
30	2.2	2.2	0.00	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
50	0.3	0.3	0.00	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
100	0.0	0.0	0.00	0.0	0.0

Note: θ is the home capital tax rate (in percent), θ^* is the foreign counterpart. NFAP is the net foreign asset position from the point of view of the home country as a fraction of the home country's GDP.

Table 2: Capital taxes when the home country has a stronger initial asset position

	Open economy			Closed economies	
Period	θ	θ^*	NFAP	θ	θ^*
0	40.8	45.9	0.31	100.0	100.0
1	37.1	42.1	0.31	100.0	100.0
2	33.7	38.6	0.30	100.0	100.0
3	30.6	35.3	0.29	100.0	100.0
4	27.8	32.3	0.29	100.0	100.0
5	25.3	29.6	0.28	100.0	100.0
6	22.9	27.0	0.28	100.0	100.0
7	20.8	24.7	0.28	100.0	100.0
8	18.9	22.5	0.27	100.0	100.0
9	17.2	20.5	0.27	100.0	16.0
10	15.6	18.7	0.27	76.6	0.0
11	14.1	17.0	0.27	0.0	0.0
12	12.8	15.5	0.27	0.0	0.0
13	11.6	14.1	0.27	0.0	0.0
14	10.5	12.8	0.26	0.0	0.0
15	9.5	11.6	0.26	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
30	2.1	2.6	0.26	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
50	0.3	0.3	0.26	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
100	0.0	0.0	0.26	0.0	0.0

Note: θ is the home capital tax rate (in percent), θ^* is the foreign counterpart. NFAP is the net foreign asset position from the point of view of the home country as a fraction of the home country's GDP.

Table 3: Capital taxes when the home country is twice as populous

	Open economy			Closed economies	
Period	θ	θ^*	NFAP	θ	θ^*
0	50.5	31.2	0.15	100.0	100.0
1	46.8	28.2	0.15	100.0	100.0
2	43.2	25.5	0.15	100.0	100.0
3	39.7	23.1	0.14	100.0	100.0
4	36.4	21.0	0.14	100.0	100.0
5	33.3	19.0	0.13	100.0	100.0
6	30.4	17.2	0.13	100.0	100.0
7	27.6	15.7	0.12	100.0	100.0
8	25.1	14.2	0.12	100.0	100.0
9	22.7	12.9	0.12	16.0	16.0
10	20.5	11.7	0.11	0.0	0.0
11	18.5	10.7	0.11	0.0	0.0
12	16.6	9.7	0.10	0.0	0.0
13	15.0	8.8	0.10	0.0	0.0
14	13.4	8.0	0.10	0.0	0.0
15	12.0	7.3	0.09	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
30	2.1	1.8	0.08	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
50	0.2	0.3	0.07	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
100	0.0	0.0	0.07	0.0	0.0

Note: θ is the home capital tax rate (in percent), θ^* is the foreign counterpart. NFAP is the net foreign asset position from the point of view of the home country as a fraction of the home country's GDP.

Table 4: Capital taxes when the home country has zero initial government debt

	Open economy			Closed economies	
Period	θ	θ*	NFAP	θ	θ*
0	33.7	38.0	-0.08	100.0	100.0
1	30.8	34.9	-0.07	100.0	100.0
2	28.2	32.1	-0.07	100.0	100.0
3	25.7	29.4	-0.07	100.0	100.0
4	23.4	26.8	-0.07	100.0	100.0
5	21.3	24.5	-0.07	100.0	100.0
6	19.4	22.4	-0.07	100.0	100.0
7	17.6	20.4	-0.07	100.0	100.0
8	16.0	18.5	-0.07	12.5	100.0
9	14.5	16.8	-0.07	0.0	16.0
10	13.2	15.3	-0.07	0.0	0.0
11	11.9	13.8	-0.07	0.0	0.0
12	10.8	12.5	-0.07	0.0	0.0
13	9.8	11.3	-0.07	0.0	0.0
14	8.9	10.3	-0.07	0.0	0.0
15	8.0	9.3	-0.07	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
30	1.7	1.9	-0.06	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
50	0.2	0.2	-0.06	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
100	0.0	0.0	-0.06	0.0	0.0

Note: θ *is the home capital tax rate (in percent),* θ* *is the foreign counterpart. NFAP is the net foreign asset position from the point of view of the home country as a fraction of the home country's GDP.*

Table 5: Government spending, debt, output and labour taxes when countries are symmetric

	Open economy				Closed economy			
Period	g	b	y	τ	g	b	y	τ
0	0.178	0.356	0.608	0.424	0.175	0.356	0.626	0.247
1	0.179	0.347	0.608	0.432	0.177	0.350	0.618	0.282
2	0.179	0.339	0.608	0.440	0.178	0.333	0.611	0.315
3	0.180	0.331	0.608	0.447	0.180	0.305	0.605	0.348
4	0.181	0.324	0.608	0.453	0.182	0.267	0.601	0.379
5	0.181	0.317	0.608	0.459	0.184	0.220	0.597	0.409
6	0.182	0.310	0.608	0.464	0.185	0.164	0.595	0.437
7	0.182	0.304	0.608	0.469	0.187	0.100	0.594	0.463
8	0.183	0.298	0.608	0.473	0.189	0.028	0.595	0.488
9	0.183	0.292	0.608	0.477	0.190	-0.051	0.597	0.492
10	0.184	0.287	0.608	0.480	0.191	-0.066	0.599	0.492
11	0.184	0.283	0.600	0.483	0.192	-0.069	0.601	0.492
12	0.185	0.278	0.599	0.486	0.193	-0.072	0.602	0.492
13	0.185	0.274	0.599	0.488	0.194	-0.075	0.603	0.492
14	0.185	0.271	0.599	0.491	0.195	-0.077	0.605	0.492
15	0.186	0.267	0.599	0.493	0.195	-0.079	0.606	0.492
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.189	0.242	0.600	0.507	0.199	-0.091	0.612	0.492
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.190	0.235	0.600	0.511	0.200	-0.093	0.612	0.492
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.190	0.234	0.600	0.511	0.200	-0.093	0.612	0.492

Note: g *is government spending,* b *is government debt,* y *is output, and* τ *is the labour income tax rate.*

Table 6: Capital taxes in the UK and continental Europe (model)

	Open economy			Closed economies	
Year	θ	θ^*	NFAP	θ	θ^*
1985	53.0	26.5	0.00	53.0	26.5
1986	14.2	12.2	-0.13	100.0	100.0
1987	13.3	11.4	-0.13	100.0	100.0
1988	12.4	10.6	-0.14	100.0	100.0
1989	11.6	9.8	-0.14	100.0	100.0
1990	10.8	9.1	-0.14	100.0	100.0
1991	10.0	8.4	-0.14	54.2	100.0
1992	9.3	7.8	-0.14	0.0	100.0
1993	8.7	7.2	-0.14	0.0	100.0
1994	8.0	6.7	-0.14	0.0	6.5
1995	7.5	6.2	-0.14	0.0	0.0
1996	6.9	5.7	-0.14	0.0	0.0
1997	6.4	5.3	-0.14	0.0	0.0
1998	5.9	4.9	-0.14	0.0	0.0
1999	5.5	4.5	-0.14	0.0	0.0
2000	5.1	4.1	-0.14	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
2015	1.5	1.2	-0.14	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
2035	0.3	0.2	-0.14	0.0	0.0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
2085	0.0	0.0	-0.14	0.0	0.0

Note: θ is the UK capital tax rate (in percent), θ^* is the CE counterpart. NFAP is the net foreign asset position of the UK as a fraction of total GDP (UK + CE).

Table 7: Capital taxes when the countries are symmetric and $\omega = 0.03$ (capital adjustment costs)

	Open economy			Closed economies	
Period	θ	θ^*	NFAP	θ	θ^*
0	87.2	87.2	0.00	100.0	100.0
1	39.2	39.2	0.00	100.0	100.0
2	31.9	31.9	0.00	100.0	100.0
3	28.9	28.9	0.00	100.0	100.0
4	26.4	26.4	0.00	100.0	100.0
5	24.1	24.1	0.00	100.0	100.0
6	22.0	22.0	0.00	100.0	100.0
7	20.1	20.1	0.00	100.0	100.0
8	18.3	18.3	0.00	100.0	100.0
9	16.7	16.7	0.00	13.3	13.3
10	15.2	15.2	0.00	0.1	0.1
11	13.8	13.8	0.00	-0.1	-0.1
12	12.5	12.5	0.00	-0.1	-0.1
13	11.4	11.4	0.00	-0.1	-0.1
14	10.3	10.3	0.00	-0.1	-0.1
15	9.4	9.4	0.00	-0.1	-0.1
⋮	⋮	⋮	⋮	⋮	⋮
30	2.1	2.1	0.00	-0.0	-0.0
⋮	⋮	⋮	⋮	⋮	⋮
50	0.3	0.3	0.00	0.0	0.0
⋮	⋮	⋮	⋮	⋮	⋮
100	0.0	0.0	0.00	0.0	0.0

Note: θ is the home capital tax rate (in percent), θ^* is the foreign counterpart. NFAP is the net foreign asset position from the point of view of the home country as a fraction of the home country's GDP.

9 Figures

Figure 1: Capital taxes when countries are symmetric

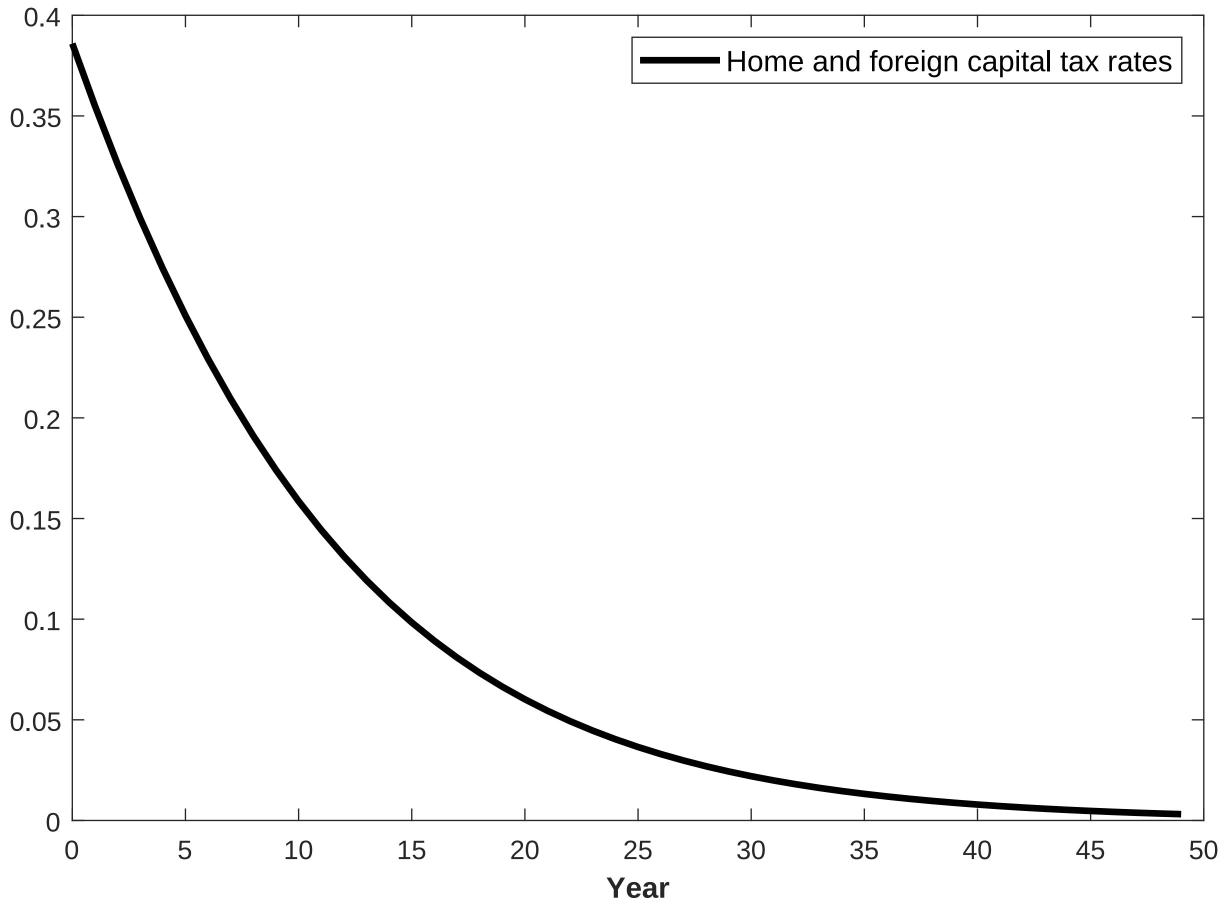


Figure 2: Capital taxes in open and closed economy when countries are symmetric

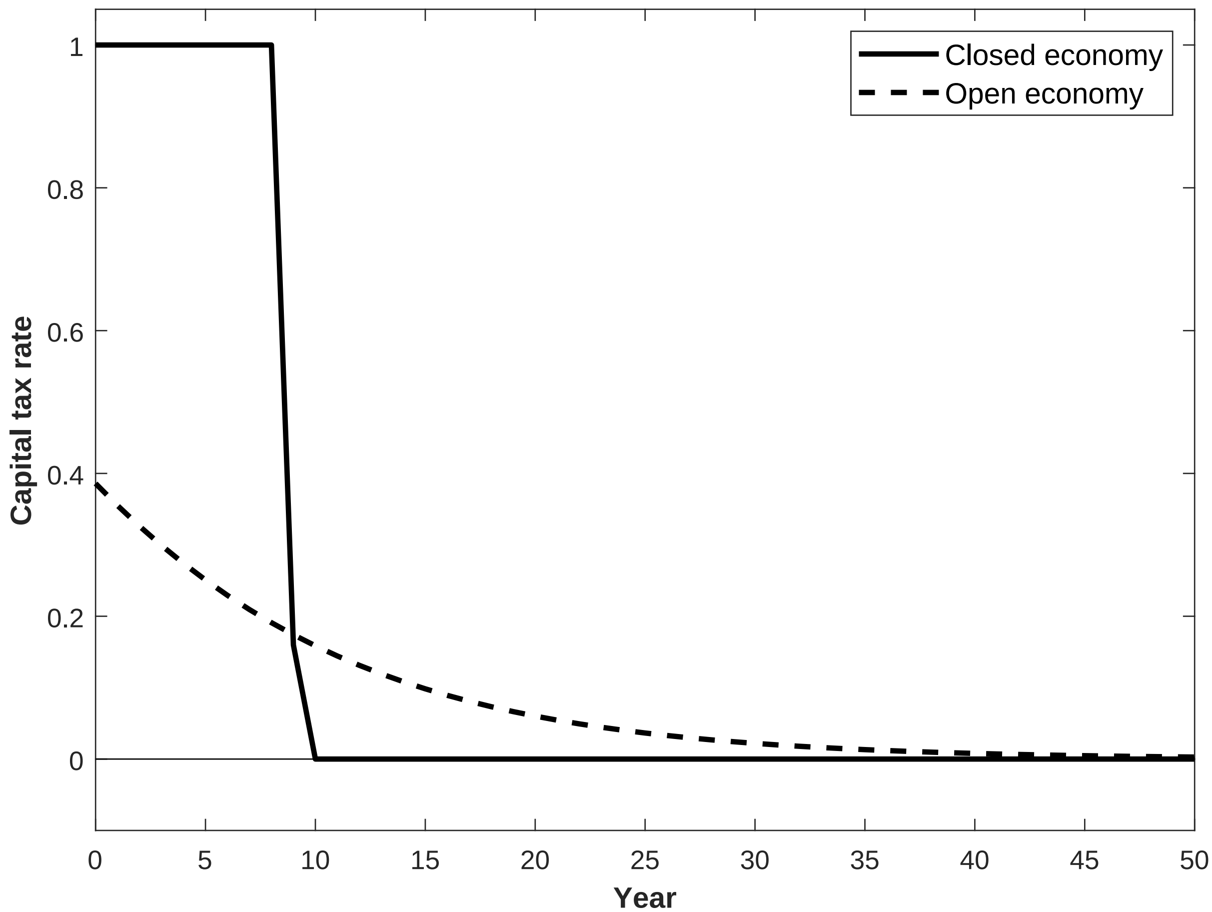


Figure 3: Capital tax externalities when countries are symmetric

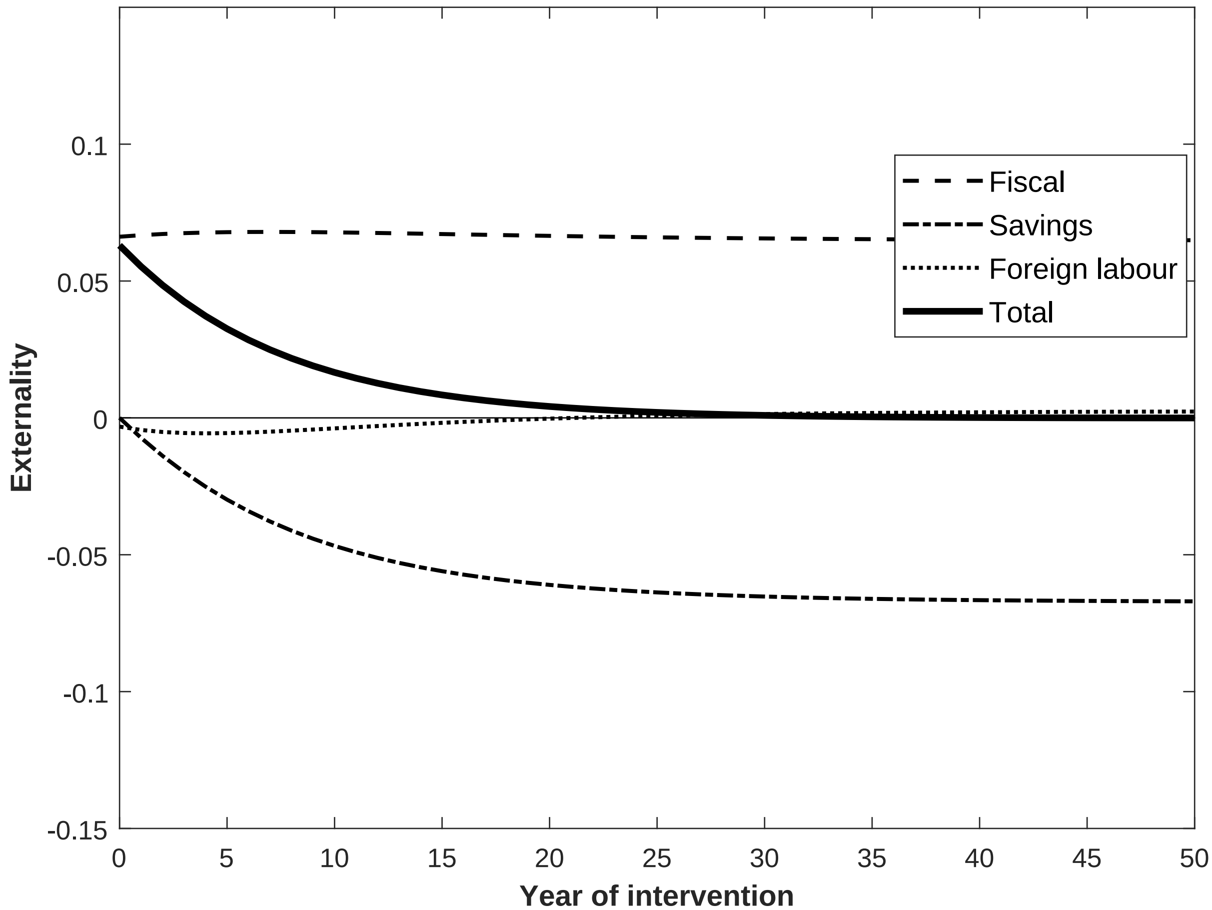


Figure 4: Capital taxes when the home country's initial asset position is stronger than the foreign country's

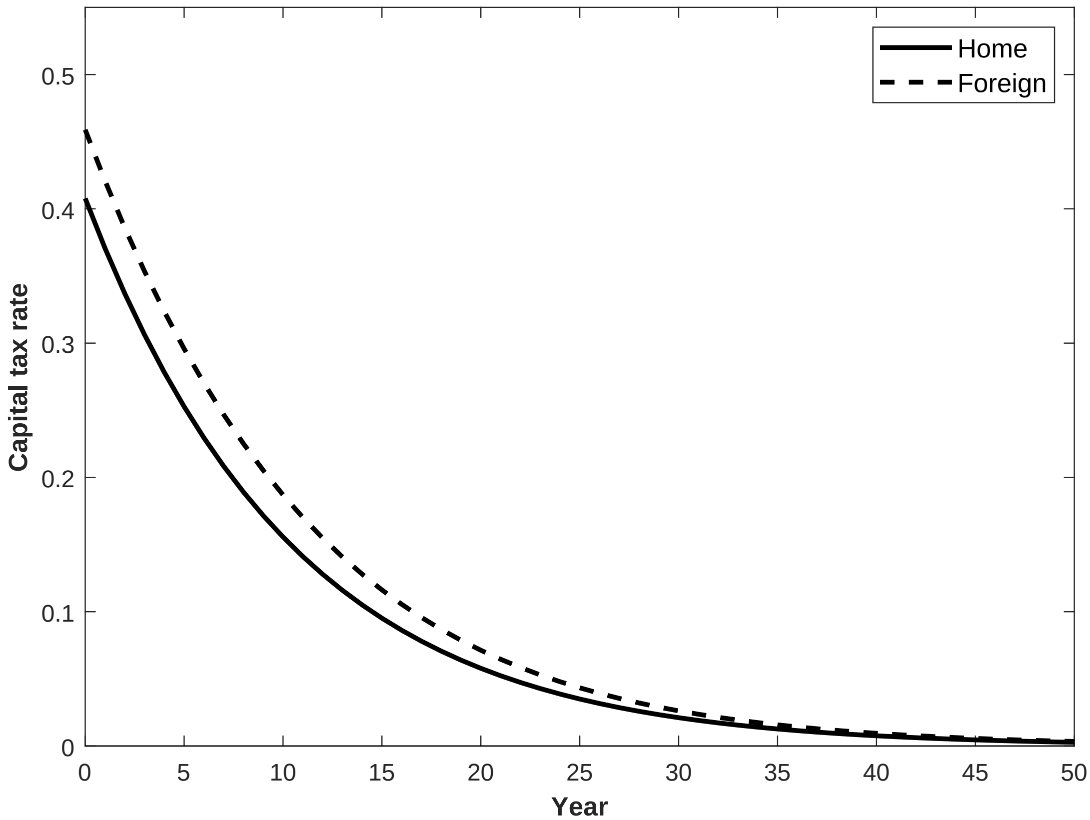


Figure 5: Capital tax externalities when the home country's initial asset position is stronger than the foreign country's

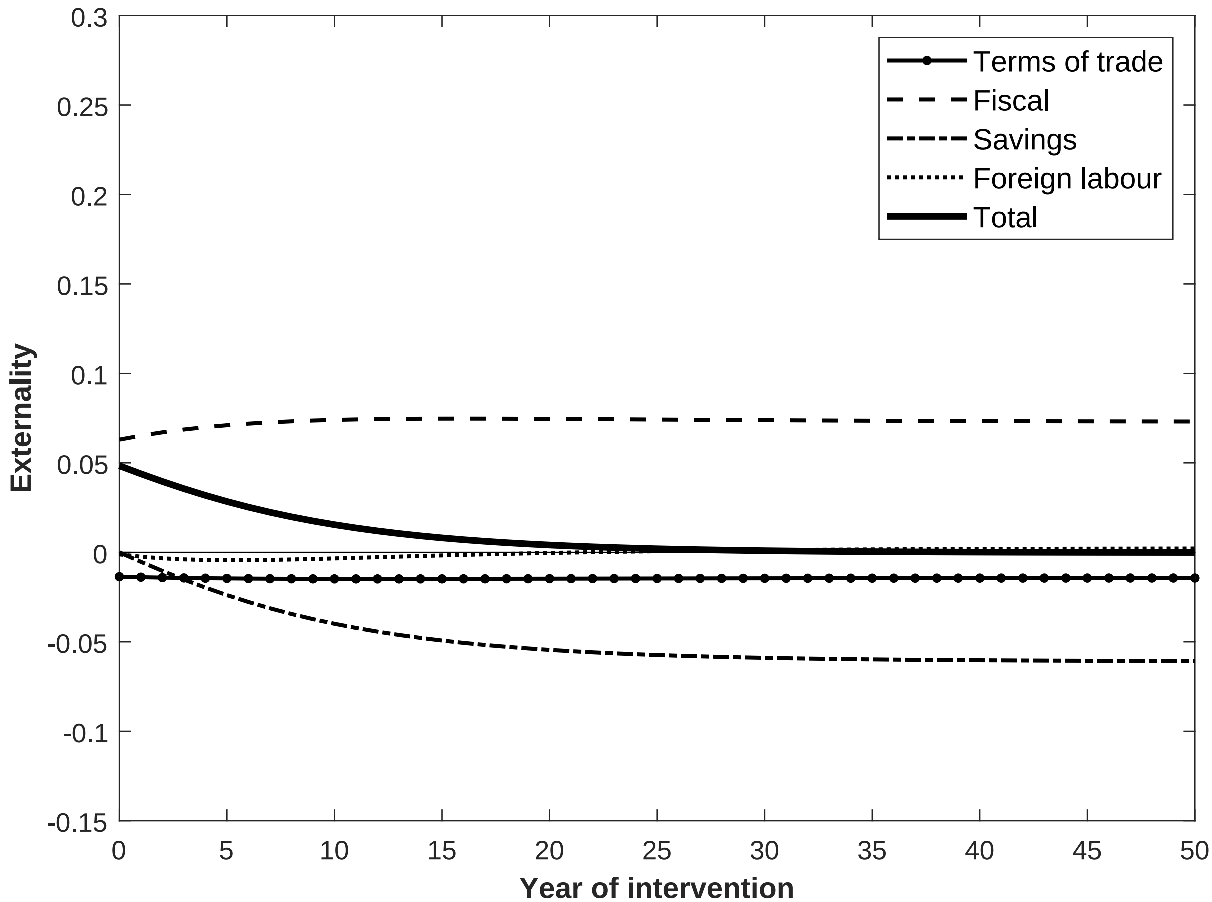


Figure 6: Capital taxes when the home country is twice as populous

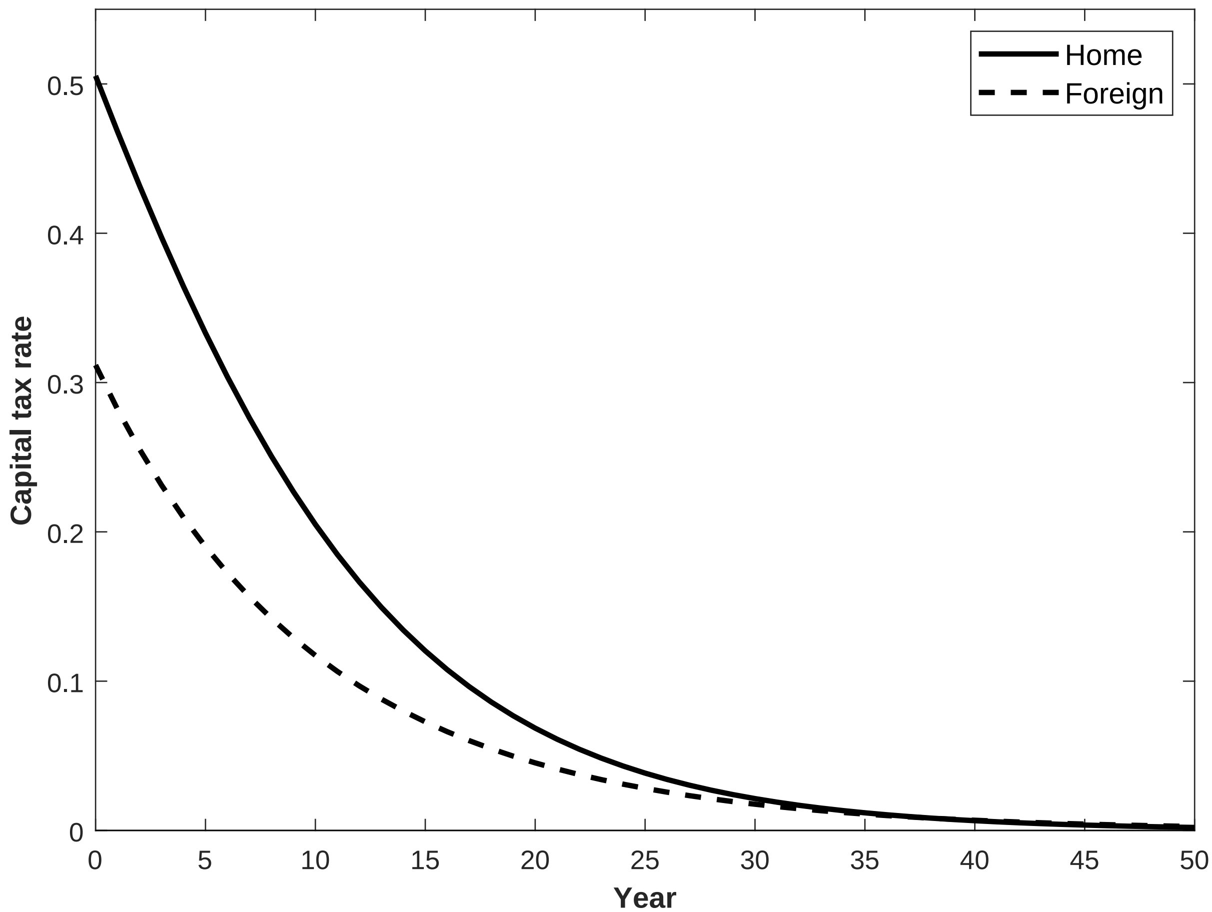


Figure 7: Capital tax externalities when the home country is twice as populous

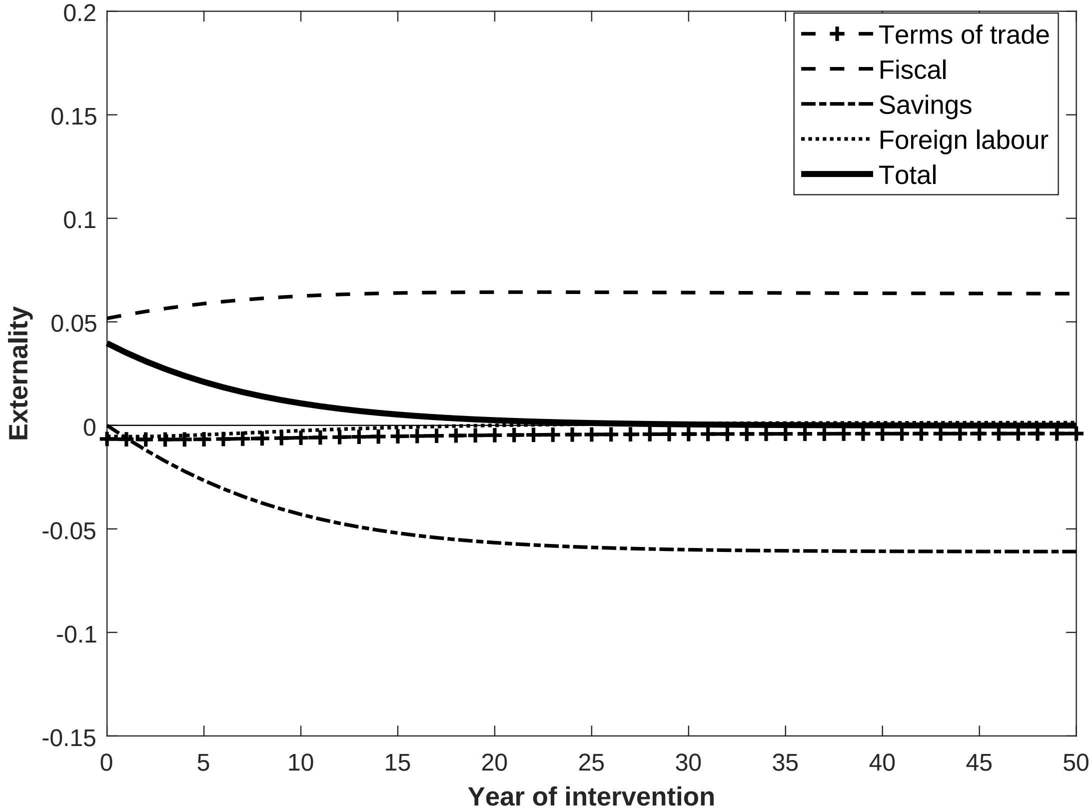


Figure 8: Capital taxes when the home country has no initial government debt

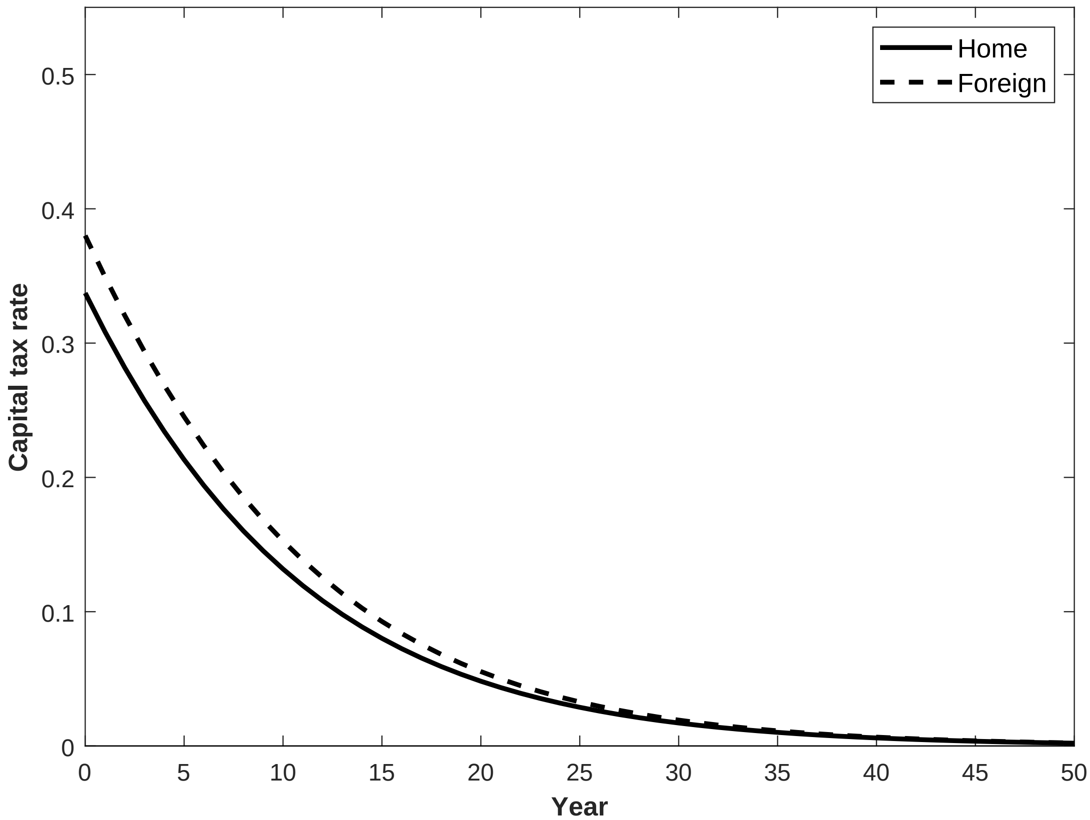


Figure 9: Capital tax externalities when the home country has no initial government debt

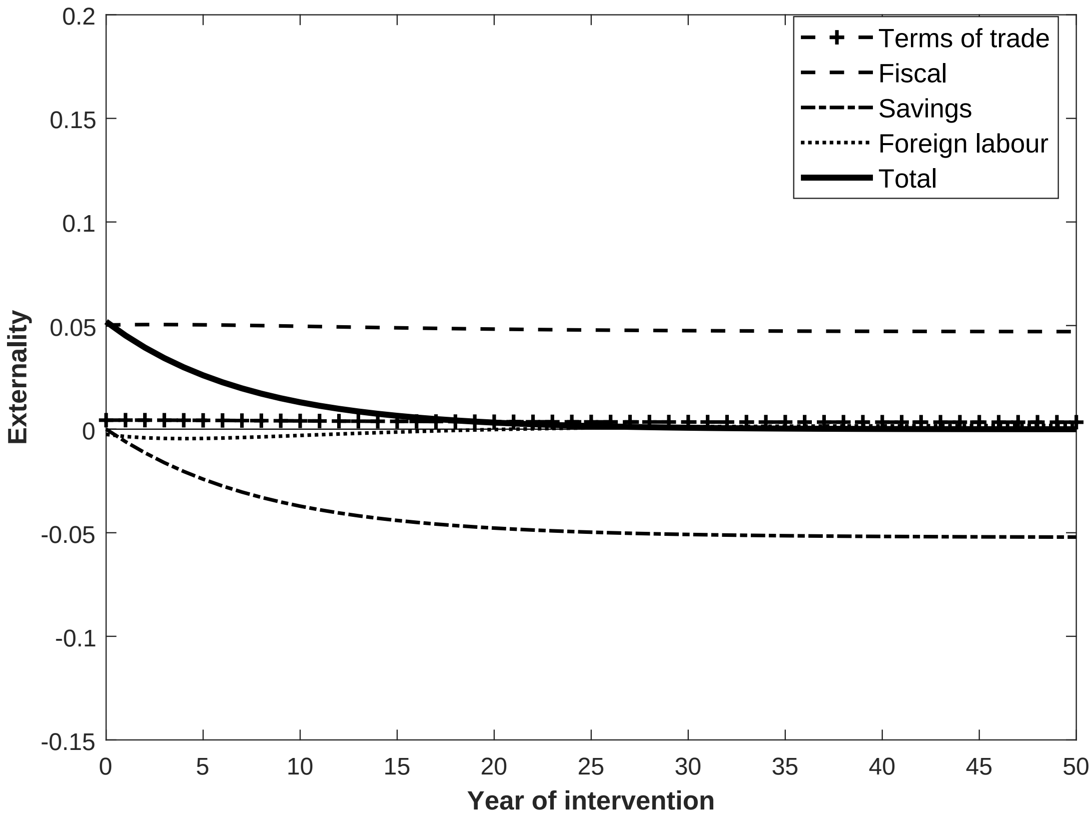


Figure 10: Capital and labour taxes when initial assets are asymmetric and policies are coordinated

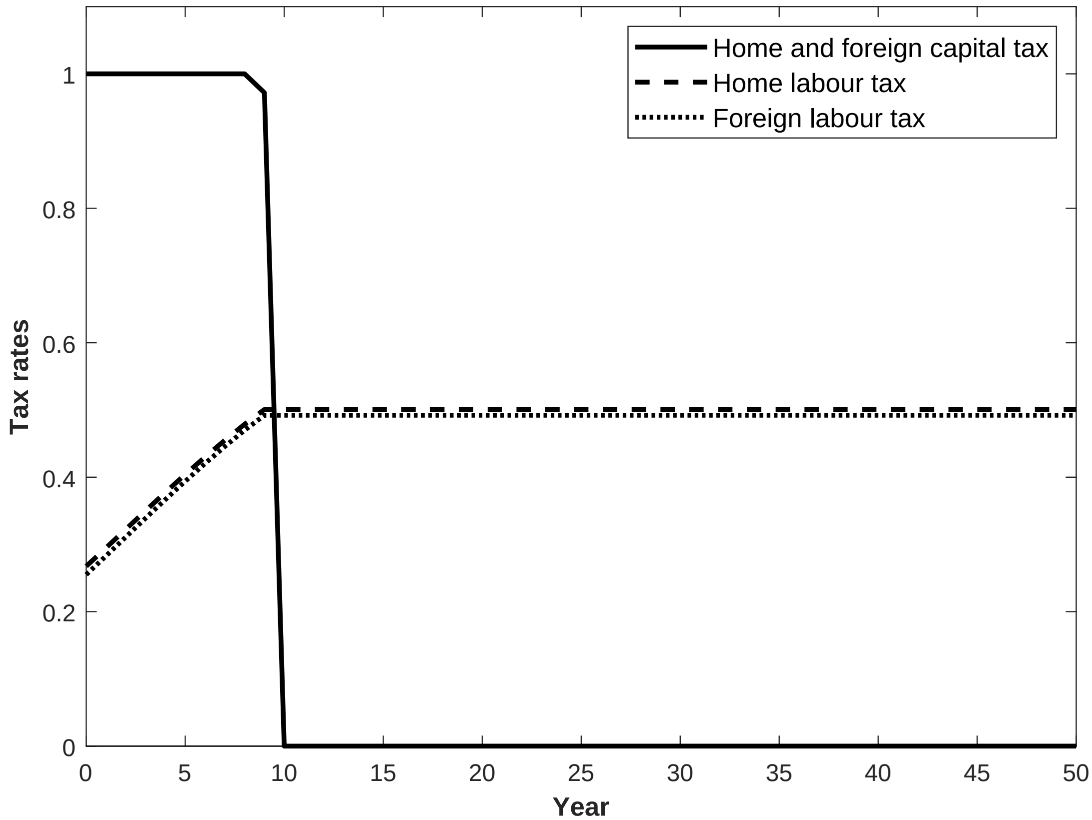


Figure 11: Capital taxes in the UK and continental Europe

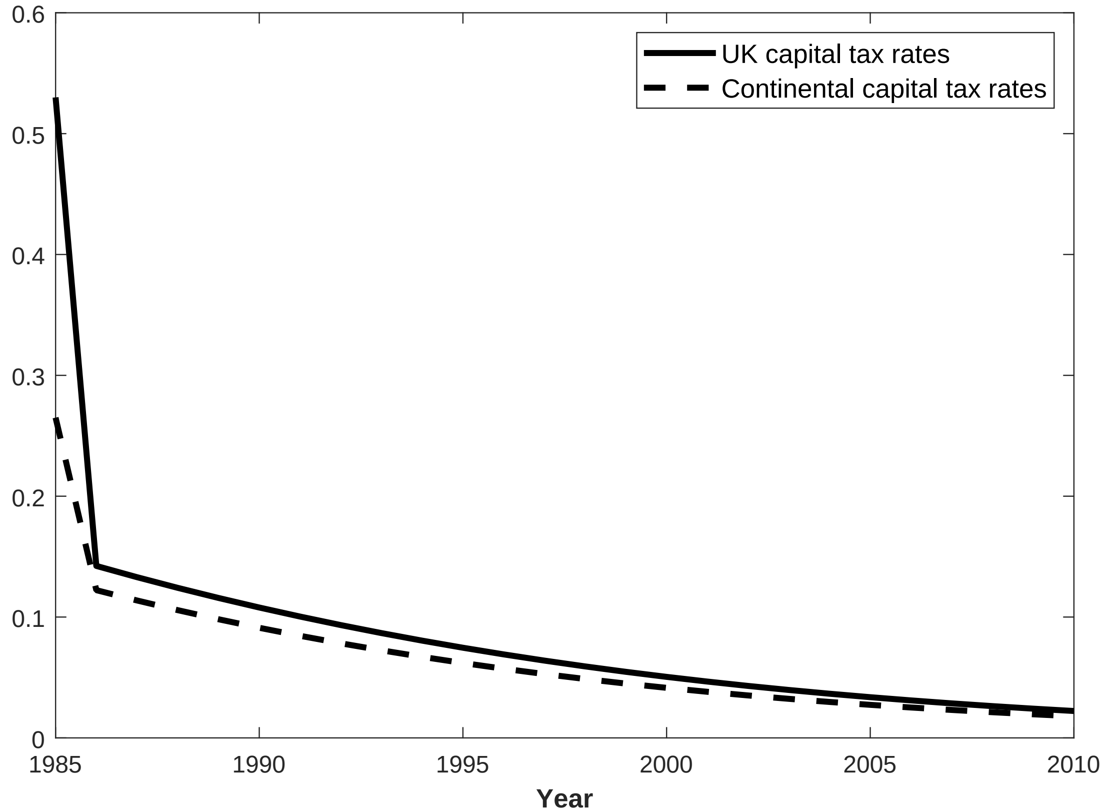


Figure 12: Capital tax externalities from the point of view of the UK

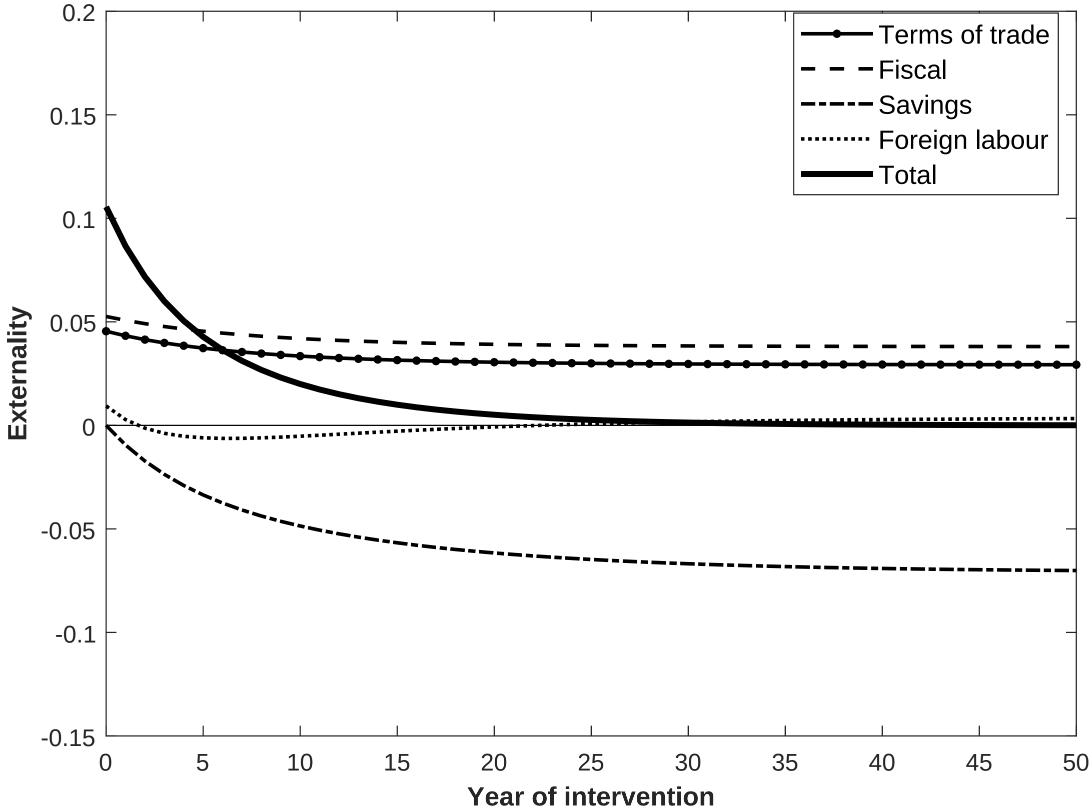


Figure 13: Capital taxes when countries are symmetric and $\omega = 0.03$ (capital adjustment costs)

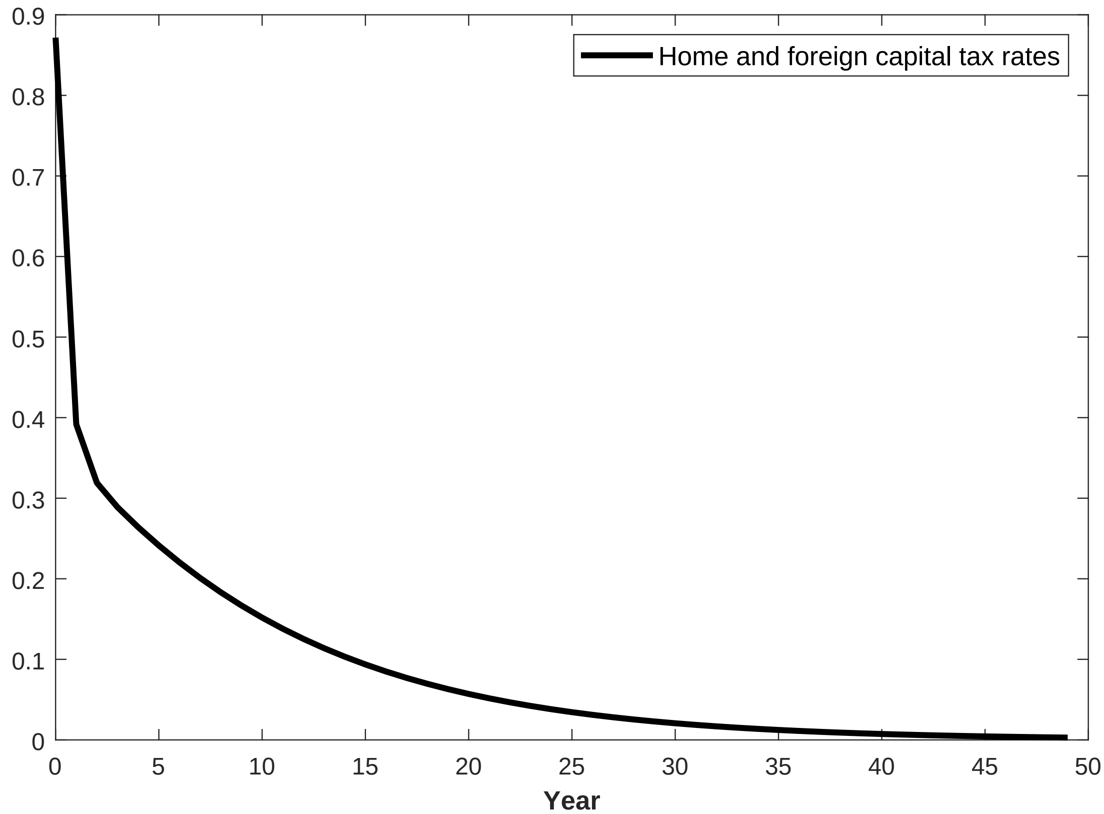
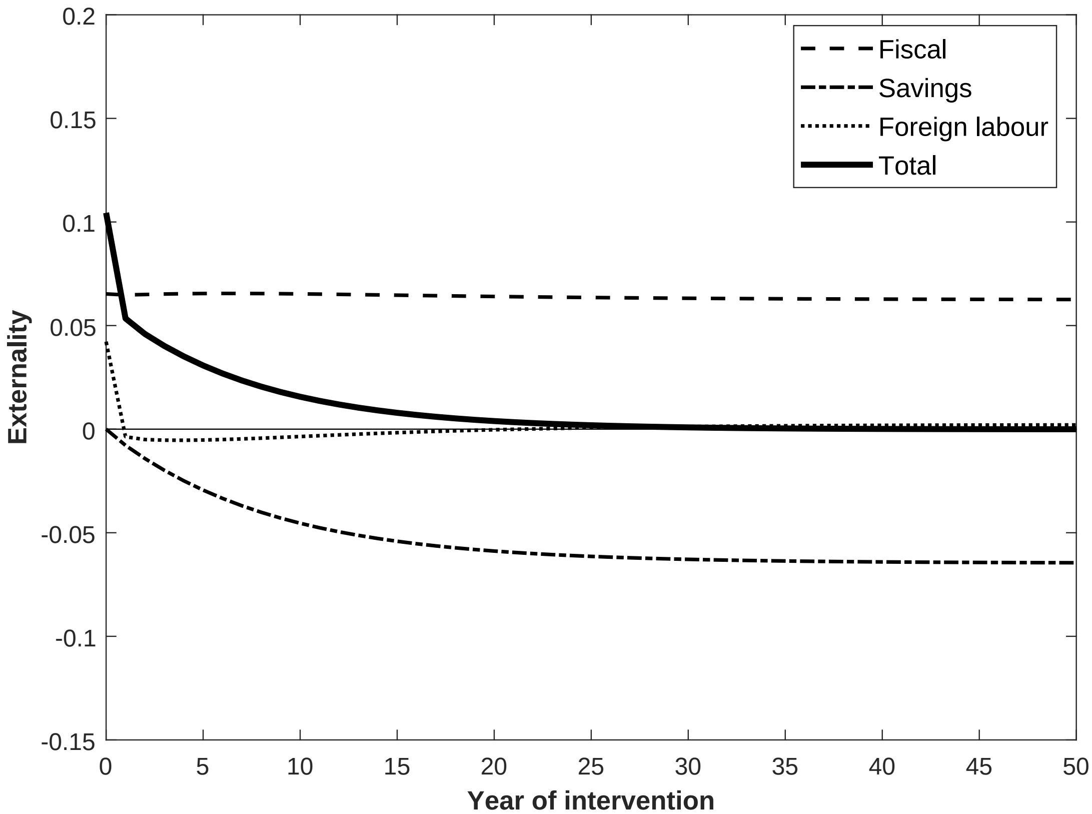


Figure 14: Capital tax externalities when countries are symmetric and $\omega = 0.03$ (capital adjustment costs)



Appendix A: Derivation of the equilibrium conditions

In this Appendix we characterize the equilibrium in detail. Associating the Lagrange multipliers $\lambda_{1,t} - \lambda_{9,t}$ to the constraints (1)-(9), we have the following domestic Lagrangian:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \{[u(c_t, h_t) + v(g_t)] +$$

$$\lambda_{1,t} [u_{c,t}(1 - \tau_t) w_t + u_{h,t}] +$$

$$\lambda_{2,t} [u_{c^*,t}(1 - \tau_t^*) w_t^* + u_{h^*,t}] +$$

$$\lambda_{3,t} [\beta u_{c,t+1}[1 + r_{t+1}(1 - \theta_{t+1})] - u_{c,t}] +$$

$$\lambda_{4,t}\left[\beta u_{c^*,t+1}[1+r^*_{t+1}(1-\theta^*_{t+1})]-u_{c^*,t}\right]+$$

$$\lambda_{5,t}\left[(1-\theta_t)r_t-(1-\theta^*_t)r^*_t\right]+$$

$$\lambda_{6,t}\left[J_t+J^*_t-(B_t+B^*_t+K_t+K^*_t)\right]+$$

$$\lambda_{7,t}\left[(1-\tau_t)w_t h_t+[1+r_t(1-\theta_t)]j_t-c_t-j_{t+1}\right]+$$

$$\lambda_{8,t}\left[B_{t+1}-[1+r_t(1-\theta_t)]B_t+\tau_t w_t L_t+\theta_t r_t K_t-\mathbb{T}_t-G_t\right]+$$

$$\lambda_{9,t}n^*\left[(1-\tau^*_t)w^*_t h^*_t+[1+r^*_t(1-\theta^*_t)]j^*_t-c^*_t-j^*_{t+1}\right]\}$$

As a reminder, we defined $\lambda_{i,t}=0$ for $i\in\{1,\ldots,9\}$. We define $w^*_{K,t}\equiv\partial w^*_t/\partial K^*_t$ and similarly for the other derivatives. Differentiating with respect to all of the domestic government's choice variables, the first order conditions for the home country are given by:

$$u_{c,t}+\lambda_{1,t}u_{cc,t}(1-\tau_t)w_t+\beta\lambda_{3,t-1}u_{cc,t}[1+r_t(1-\theta_t)]- \\ \lambda_{3,t}u_{cc,t}-\lambda_{7,t}=0 \tag{c}$$

$$u_{h,t}+\beta\lambda_{3,t-1}u_{c,t}(1-\theta_t)r_{L,t}+ \\ \lambda_{1,t}\{u_{c,t}(1-\tau_t)w_{L,t}+u_{hh,t}\}+\lambda_{5,t}(1-\theta_t)r_{L,t}+ \\ \lambda_{7,t}\{(1-\tau_t)[w_{L,t}L_t+w_t]+(1-\theta_t)r_{L,t}j_t\}+ \\ \lambda_{8,t}\{\tau_t[w_{L,t}L_t+w_t]+r_{L,t}[\theta_t K_t-(1-\theta_t)B_t]\}=0 \tag{h}$$

$$\beta\lambda_{3,t-1}u_{c,t}(1-\theta_t)r_{K,t}+ \\ \lambda_{1,t}u_{c,t}(1-\tau_t)w_{K,t}+\lambda_{5,t}(1-\theta_t)r_{K,t}-\lambda_{6,t}+ \\ \lambda_{7,t}\{(1-\tau_t)w_{K,t}L_t+(1-\theta_t)r_{K,t}j_t\}+ \\ \lambda_{8,t}\{\tau_t w_{K,t}h_t+\theta_t[r_{K,t}K_t+r_t]-(1-\theta_t)r_{K,t}B_t\}=0 \tag{K}$$

$$-\lambda_{1,t}u_{c,t} - \lambda_{7,t}L_t + \lambda_{8,t}L_t = 0 \tag{τ}$$

$$-\beta\lambda_{3,t-1}u_{c,t} - \lambda_{7,t}J_t + \lambda_{8,t}(K_t + B_t) - \lambda_{5,t} = 0 \tag{θ}$$

$$\nu_{g,t} - \lambda_{8,t} = 0 \tag{G}$$

$$\begin{gathered}\lambda_{2,t}u_{cc^*,t}(1-\tau_t^*)w_t^* + \beta\lambda_{4,t-1}u_{cc^*,t}[1 + r_t^*(1-\theta_t^*)] - \\ \lambda_{4,t}u_{cc^*,t} - \lambda_{9,t}n^* = 0\end{gathered} \tag{c^*}$$

$$\begin{gathered}\beta\lambda_{4,t-1}u_{c^*,t}(1-\theta_t^*)r_{L,t}^* + \\ \lambda_{2,t}\{u_{c^*,t}(1-\tau_t^*)w_{L,t}^* + u_{hh^*,t}/n^*\} - \lambda_{5,t}(1-\theta_t^*)r_{L,t}^* + \\ \lambda_{9,t}\{(1-\tau_t^*)[w_{L,t}^*L_t^* + w_t^*] + (1-\theta_t^*)r_{L,t}^*J_t^*\} = 0\end{gathered} \tag{h^*}$$

$$\begin{gathered}\beta\lambda_{4,t-1}u_{c^*,t}(1-\theta_t^*)r_{K,t}^* + \\ \lambda_{2,t}u_{c^*,t}(1-\tau_t^*)w_{K,t}^* - \lambda_{5,t}(1-\theta_t^*)r_{K,t}^* - \lambda_{6,t} + \\ \lambda_{9,t}\{(1-\tau_t^*)w_{K,t}^*L_t^* + (1-\theta_t^*)r_{K,t}^*J_t^*\} = 0\end{gathered} \tag{K^*}$$

and only for $t > 0$

$$\lambda_{8,t-1}/\beta - \lambda_{6,t} - \lambda_{8,t}[1 + r_t(1-\theta_t)] = 0 \tag{B}$$

$$-\lambda_{7,t-1}/\beta + \lambda_{6,t} + \lambda_{7,t}[1 + r_t(1-\theta_t)] = 0 \tag{j}$$

$$-\lambda_{9,t-1}/\beta + \lambda_{6,t} + \lambda_{9,t}[1 + r_t^*(1 - \theta_t^*)] = 0 \qquad (j^*)$$

Appendix B: Further tables

Table B1: Robustness check with respect to intertemporal elasticity of substitution

	IES = 2/3				IES = 3/2			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.36	0.42	0.30	0.59	0.41	0.43	0.29	0.58
1	0.33	0.43	0.30	0.59	0.37	0.44	0.30	0.56
2	0.31	0.43	0.30	0.58	0.34	0.45	0.30	0.54
3	0.29	0.44	0.30	0.58	0.31	0.46	0.30	0.52
4	0.27	0.45	0.30	0.57	0.28	0.46	0.30	0.50
5	0.25	0.45	0.30	0.57	0.25	0.47	0.30	0.49
6	0.23	0.46	0.30	0.57	0.22	0.47	0.30	0.47
7	0.21	0.46	0.30	0.56	0.20	0.48	0.30	0.46
8	0.20	0.47	0.30	0.56	0.18	0.48	0.30	0.44
9	0.18	0.47	0.30	0.55	0.16	0.49	0.30	0.43
10	0.17	0.47	0.31	0.55	0.14	0.49	0.31	0.42
11	0.16	0.48	0.31	0.55	0.12	0.49	0.31	0.41
12	0.15	0.48	0.31	0.54	0.11	0.49	0.31	0.40
13	0.13	0.48	0.31	0.54	0.10	0.50	0.31	0.40
14	0.13	0.49	0.31	0.53	0.09	0.50	0.31	0.39
15	0.12	0.49	0.31	0.53	0.08	0.50	0.31	0.38
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.04	0.51	0.31	0.53	0.01	0.51	0.31	0.34
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.01	0.52	0.32	0.49	0.00	0.51	0.31	0.34
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.00	0.52	0.32	0.48	0.00	0.51	0.31	0.34

Note: θ is the capital tax rate, τ is the labour tax rate. G/Y is government spending as a fraction of GDP. B/Y is government debt as a fraction of GDP.

Table B2: Robustness check with respect to the subjective discount factor

	$\beta = 0.95$				$\beta = 0.97$			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.35	0.42	0.29	0.58	0.44	0.43	0.30	0.59
1	0.32	0.43	0.29	0.57	0.41	0.44	0.30	0.58
2	0.29	0.44	0.29	0.56	0.38	0.44	0.30	0.56
3	0.26	0.44	0.29	0.55	0.36	0.45	0.30	0.55
4	0.24	0.45	0.29	0.53	0.33	0.46	0.30	0.54
5	0.22	0.46	0.29	0.52	0.31	0.46	0.31	0.53
6	0.19	0.46	0.30	0.51	0.28	0.47	0.31	0.52
7	0.18	0.47	0.30	0.50	0.26	0.47	0.31	0.51
8	0.16	0.47	0.30	0.49	0.24	0.47	0.31	0.50
9	0.14	0.48	0.30	0.48	0.22	0.48	0.31	0.49
10	0.13	0.48	0.30	0.48	0.20	0.48	0.31	0.48
11	0.12	0.48	0.30	0.47	0.19	0.48	0.31	0.48
12	0.10	0.48	0.30	0.46	0.17	0.49	0.31	0.47
13	0.09	0.49	0.30	0.46	0.16	0.49	0.31	0.46
14	0.08	0.49	0.30	0.45	0.15	0.49	0.31	0.46
15	0.08	0.49	0.30	0.45	0.13	0.49	0.31	0.45
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.01	0.50	0.31	0.45	0.03	0.51	0.32	0.40
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.00	0.51	0.31	0.40	0.01	0.52	0.32	0.38
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.00	0.51	0.31	0.40	0.00	0.52	0.32	0.38

Note: θ *is the capital tax rate,* τ *is the labour tax rate.* G/Y *is government spending as a fraction of GDP.* B/Y *is government debt as a fraction of GDP.*

Table B3: Robustness check with respect to Frisch elasticity

	$\varepsilon = 0.3$				$\varepsilon = 0.7$			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.31	0.45	0.30	0.59	0.44	0.40	0.29	0.58
1	0.28	0.46	0.30	0.58	0.40	0.41	0.29	0.57
2	0.26	0.47	0.30	0.57	0.37	0.42	0.29	0.55
3	0.23	0.47	0.31	0.56	0.34	0.43	0.29	0.54
4	0.21	0.48	0.31	0.55	0.31	0.44	0.29	0.53
5	0.20	0.48	0.31	0.54	0.29	0.44	0.29	0.51
6	0.18	0.48	0.31	0.53	0.26	0.45	0.29	0.50
7	0.16	0.49	0.31	0.53	0.24	0.46	0.29	0.49
8	0.15	0.49	0.31	0.52	0.22	0.46	0.30	0.48
9	0.13	0.49	0.31	0.51	0.20	0.47	0.30	0.47
10	0.12	0.49	0.31	0.50	0.18	0.47	0.30	0.46
11	0.11	0.50	0.31	0.50	0.17	0.47	0.30	0.45
12	0.10	0.50	0.31	0.49	0.15	0.48	0.30	0.45
13	0.09	0.50	0.31	0.49	0.14	0.48	0.30	0.44
14	0.08	0.50	0.31	0.48	0.12	0.48	0.30	0.43
15	0.08	0.50	0.31	0.48	0.11	0.48	0.30	0.43
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
30	0.02	0.52	0.32	0.48	0.03	0.50	0.31	0.38
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
50	0.00	0.52	0.32	0.43	0.00	0.51	0.31	0.36
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
100	0.00	0.52	0.32	0.43	0.00	0.51	0.31	0.36

Note: θ *is the capital tax rate,* τ *is the labour tax rate.* G/Y *is government spending as a fraction of GDP.* B/Y *is government debt as a fraction of GDP.*

Table B4: Robustness check with respect to the capital share

	$\alpha = 0.3$				$\alpha = 0.4$			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.40	0.41	0.30	0.59	0.38	0.44	0.29	0.58
1	0.36	0.41	0.30	0.58	0.35	0.45	0.29	0.57
2	0.32	0.42	0.30	0.57	0.33	0.46	0.29	0.55
3	0.29	0.43	0.30	0.56	0.30	0.47	0.29	0.53
4	0.26	0.43	0.31	0.55	0.28	0.47	0.29	0.52
5	0.24	0.44	0.31	0.54	0.26	0.48	0.29	0.51
6	0.21	0.45	0.31	0.54	0.24	0.48	0.29	0.49
7	0.19	0.45	0.31	0.53	0.23	0.49	0.29	0.48
8	0.17	0.45	0.31	0.52	0.21	0.49	0.29	0.47
9	0.15	0.46	0.31	0.52	0.20	0.50	0.30	0.46
10	0.13	0.46	0.31	0.51	0.18	0.50	0.30	0.44
11	0.12	0.46	0.31	0.50	0.17	0.50	0.30	0.43
12	0.11	0.46	0.31	0.50	0.16	0.51	0.30	0.42
13	0.09	0.47	0.31	0.49	0.14	0.51	0.30	0.42
14	0.08	0.47	0.31	0.49	0.13	0.51	0.30	0.41
15	0.07	0.47	0.31	0.49	0.12	0.52	0.30	0.40
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.01	0.48	0.32	0.49	0.04	0.54	0.31	0.33
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.00	0.48	0.32	0.46	0.01	0.54	0.31	0.30
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.00	0.48	0.32	0.46	0.00	0.54	0.31	0.30

Note: θ is the capital tax rate, τ is the labour tax rate. G/Y is government spending as a fraction of GDP. B/Y is government debt as a fraction of GDP.

Table B5: Robustness check with respect to the depreciation rate

	$\delta = 0.06$				$\delta = 0.10$			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.33	0.42	0.29	0.58	0.43	0.43	0.29	0.59
1	0.31	0.43	0.29	0.57	0.40	0.44	0.30	0.57
2	0.29	0.43	0.29	0.56	0.36	0.44	0.30	0.56
3	0.27	0.44	0.30	0.55	0.33	0.45	0.30	0.55
4	0.25	0.45	0.30	0.54	0.30	0.46	0.30	0.54
5	0.23	0.45	0.30	0.53	0.27	0.47	0.30	0.53
6	0.21	0.46	0.30	0.52	0.24	0.47	0.30	0.52
7	0.20	0.46	0.30	0.51	0.22	0.48	0.30	0.51
8	0.18	0.46	0.30	0.50	0.20	0.48	0.30	0.50
9	0.17	0.47	0.30	0.49	0.18	0.48	0.30	0.49
10	0.15	0.47	0.30	0.48	0.16	0.49	0.30	0.48
11	0.14	0.47	0.30	0.47	0.14	0.49	0.31	0.47
12	0.13	0.48	0.31	0.46	0.13	0.49	0.31	0.47
13	0.12	0.48	0.31	0.46	0.12	0.49	0.31	0.46
14	0.11	0.48	0.31	0.45	0.10	0.50	0.31	0.45
15	0.10	0.48	0.31	0.44	0.09	0.50	0.31	0.45
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.03	0.50	0.31	0.44	0.02	0.51	0.31	0.42
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.01	0.51	0.32	0.37	0.00	0.51	0.31	0.41
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.00	0.51	0.32	0.36	0.00	0.51	0.31	0.41

Note: θ is the capital tax rate, τ is the labour tax rate. G/Y is government spending as a fraction of GDP. B/Y is government debt as a fraction of GDP.

Table B6: Robustness check with respect to the weight of gov't consumption in the utility function

	$\gamma = 0.36$				$\gamma = 0.49$			
Period	θ	τ	G/Y	B/Y	θ	τ	G/Y	B/Y
0	0.34	0.37	0.25	0.59	0.43	0.48	0.33	0.58
1	0.31	0.38	0.26	0.58	0.40	0.48	0.33	0.56
2	0.28	0.38	0.26	0.57	0.37	0.49	0.33	0.55
3	0.25	0.39	0.26	0.56	0.35	0.50	0.33	0.53
4	0.23	0.40	0.26	0.56	0.32	0.51	0.34	0.51
5	0.21	0.40	0.26	0.55	0.30	0.51	0.34	0.50
6	0.19	0.41	0.26	0.54	0.28	0.52	0.34	0.48
7	0.17	0.41	0.26	0.53	0.25	0.52	0.34	0.47
8	0.15	0.41	0.26	0.53	0.23	0.53	0.34	0.46
9	0.14	0.42	0.26	0.52	0.22	0.53	0.34	0.44
10	0.12	0.42	0.26	0.52	0.20	0.54	0.34	0.43
11	0.11	0.42	0.26	0.51	0.18	0.54	0.34	0.42
12	0.10	0.42	0.26	0.51	0.17	0.54	0.34	0.41
13	0.09	0.43	0.26	0.50	0.16	0.55	0.35	0.40
14	0.08	0.43	0.27	0.50	0.14	0.55	0.35	0.39
15	0.07	0.43	0.27	0.49	0.13	0.55	0.35	0.38
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	0.01	0.44	0.27	0.49	0.03	0.57	0.35	0.32
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	0.00	0.44	0.27	0.46	0.01	0.57	0.36	0.30
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	0.00	0.44	0.27	0.46	0.00	0.58	0.36	0.29

Note: θ *is the capital tax rate,* τ *is the labour tax rate.* G/Y *is government spending as a fraction of GDP.* B/Y *is government debt as a fraction of GDP.*

References

Arrow, K. J. and G. Debreu (1954). Existence of an equilibrium for a competitive economy. *Econometrica 22*(3), 265–290.

Atkeson, A., V. Chari, and P. J. Kehoe (1999). Taxing capital income: A bad idea. *Quarterly Review 23*(3), 3–17.

Auray, S., A. Eyquem, and P. Gomme (2018). Ramsey-optimal tax reforms and real exchange rate dynamics. *Journal of International Economics 115*, 159 – 169.

Batina, R. (2009). Local capital tax competition and coordinated tax reform in an overlapping generations economy. *Regional Science and Urban Economics 39*, 472–478.

Becker, D. and M. Rauscher (2007). Fiscal competition in space and time: An endogenous-growth approach. CESifo Working Paper No. 2048.

Bénassy-Quéré, A., N. Gobalraja, and A. Trannoy (2007). Tax and public input competition. *Economic Policy 22*, 385–430.

Bucovetsky, S. and J. D. Wilson (1991). Tax competition with two tax instruments. *Regional Science and Urban Economics 21*, 333–350.

Buettner, T. (2003). Tax base effects and fiscal externalities of local capital taxation: evidence from a panel of German jurisdictions. *Journal of Urban Economics 54*(1), 110–128.

Chamley, C. (1986). Optimal taxation of capital income in general equilibrium with infinite lives. *Econometrica 54*, 607–22.

Coates, D. (1993). Property tax competition in a repeated game. *Regional Science and Urban Economics 23*, 111–19.

Correia, I. H. (1996, April). Dynamic optimal taxation in small open economies. *Journal of Economic Dynamics and Control 20*(4), 691–708.

Dasgupta, P. S. and E. S. Maskin (2015). Debreu's social equilibrium existence theorem. *Proceedings of the National Academy of Sciences 112*(52), 15769–15770.

De Pater, J. and G. Myers (1994). Strategic capital tax competition: A pecuniary externality and a corrective device. *Journal of Urban Economics 36*, 66–78.

Debreu, G. (1952). A social equilibrium existence theorem. *Proceedings of the National Academy of Sciences of the United States of America 38*(10), pp. 886–893.

Devereux, M. P., B. Lockwood, and M. Redoano (2008, June). Do countries compete over corporate tax rates? *Journal of Public Economics 92*(5-6), 1210–1235.

European Commission (2001). Company taxation in the internal market. Commission of the European Communities, Commission Staff Working Paper - SEC(2001) 1681.

European Union (2003). Council directive 2003/48/EC of June 2003 on taxation of savings income in the form of interest payments. *Official Journal of the European Union* L 157/38, 26.6.2003.

Fair, R. C. and J. B. Taylor (1983, July). Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models. *Econometrica 51*(4), 1169–1185.

Fischer, S. (1980). Dynamic inconsistency, cooperation and the benevolent dissembling government. *Journal of Economic Dynamics and Control 2*, 93–107.

Gervais, M. and A. Mennuni (2015). Optimal fiscal policy in the neoclassical growth model revisited. *European Economic Review 73*, 1 – 17.

Gross, T. (2014). Equilibrium capital taxation in open economies under commitment. *European Economic Review 70*(0), 75 – 87.

Gross, T. (2018). Dynamic optimal fiscal policy in a transfer union. Carleton University Working Paper.

Holehouse, M. and C. Williams (2015). *The Telegraph*, May 26, 2015. Available at: http://www.telegraph.co.uk/news/worldnews/europe/eu/11630468/France-and-Germany-behind-plans-for-common-EU-corporation-tax.html[Last accessed: May12, 2016].

IMF (2020). Historical public debt database. `https://www.imf.org/external/datamapper/DEBT1@DEBT/FAD_G20Adv/FAD_G20Emg/FAD_LIC/`, accessed on 23 December 2020.

Keen, M. and D. Wildasin (2004). Pareto-efficient international taxation. *American Economic Review 94*(1), 259–275.

Keen, M. J. and C. Kotsogiannis (2002). Does federalism lead to excessively high taxes? *American Economic Review 92*, 363–70.

Kehoe, P. J. (1989). Policy coordination among benevolent governments may be undesirable. *Review of Economic Studies 56*, 289–296.

Kessler, A. S., C. Lülfesmann, and G. M. Myers (2002). Redistribution, fiscal competition, and the politics of economic integration. *Review of Economic Studies 69*, 899–923.

Klein, P., V. Quadrini, and J.-V. Ríos-Rull (2005). Optimal time-consistent taxation with international mobility of capital. *Advances in Macroeconomics 5*(1), 1–36.

Koethenbuerger, M. and B. Lockwood (2010). Does tax competition really promote growth? *Journal of Economic Dynamics and Control 34*(2), 191–206.

Kotsogiannis, C. and M. Makris (2002). On production efficiency in federal systems. *Economics Letters 76*(2), 281–287.

Lejour, A. M. and H. A. A. Verbon (1997). Tax competition and redistribution in a two-country endogenous growth model. *International Tax and Public Finance 4*, 485–497.

Lockwood, B. and M. Makris (2006). Tax incidence, majority voting, and capital market integration. *Journal of Public Economics 90*, 1007–1025.

Lynch, S. (2015). *The Irish Times*, June 17, 2015.
Available at: http://www.irishtimes.com/business/economy/eu-commissioner-calls-on-ireland-to-engage-with-tax-harmonisation-1.2252950 [Last accessed: May 12, 2016].

Makris, M. (2006). Capital tax competition under a common currency. *Journal of Urban Economics 59*(1), 54–74.

Mendoza, E. G. and L. L. Tesar (2005, January). Why hasn't tax competition triggered a race to the bottom? Some quantitative lessons from the EU. *Journal of Monetary Economics 52*(1), 163–204.

Nash, J. F. (1950). Equilibrium points in N-person games. *Proceeding of the National Academy of Sciences USA 36*, 48–49.

Nicodème, G. (2006). Corporate tax competition and coordination in the European Union: What do we know? Where do we stand? European Commission, European Economy, Economic Papers 250.

Norman, P. (2000a). Portugal pledges to resolve tax deadlock. *The Financial Times*, 7 January 2000.

Norman, P. (2000b). UK to offer withholding tax. *The Financial Times*, 25 February 2000.

OECD (1998). Harmful tax competition: An emerging global issue. Paris: OECD Publications.

OECD (1999). OECD corporate income tax rates 1981-1999. `http://www.oecd.org/tax/tax-policy/tax-database/Table-II.1_1981-1999.xls` (accessed on 18 March 2021).

OECD (2020a). Central government debt. `https://stats.oecd.org/Index.aspx?DataSetCode=GOV_DEBT` (accessed on 23 December 2020).

OECD (2020b). Tax revenue (indicator). https://doi.org/10.1787/d98b8cf5-en (accessed on 23 December 2020).

Quadrini, V. (2005). Policy commitment and the welfare gains from capital market liberalization. *European Economic Review 49*(8), 1927 – 1951.

Sørensen, P. B. (2004). International tax coordination: regionalism versus globalism. *Journal of Public Economics 88*(6), 1187–1214.

Sørensen, P. B. (2004, June). International tax coordination: regionalism versus globalism. *Journal of Public Economics 88*(6), 1187–1214.

Wildasin, D. (2011). Fiscal competition for imperfectly-mobile labor and capital: A comparative dynamic analysis. *Journal of Public Economics 95*(11), 1312–1321.

Wildasin, D. E. (2003). Fiscal competition in space and time. *Journal of Public Economics 87*, 2571–88.

Wilson, J. D. (1986). A theory of interregional tax competition. *Journal of Urban Economics 19*, 296–315.

Wilson, J. D. (1991). Tax competition with interregional differences in factor endowments. *Regional Science and Urban Economics 21*(3), 423 – 451.

Wilson, J. D. (1999). Theories of tax competition. *National Tax Journal 52*(2), 269–304.

Wilson, J. D. and D. E. Wildasin (2004). Capital tax competition: Bane or boon. *Journal of Public Economics 88*, 1065–91.

Wooders, M., B. Zissimos, and A. Dhillon (2007). Tax competition reconsidered. *Journal of Public Economic Theory 9*, 391–423.

Wrede, M. (1999). Tragedy of the fiscal common?: Fiscal stock externalities in a Leviathan model of federalism. *Public Choice 101*, 177–93.

Zodrow, G. R. and P. Mieszkowski (1986). Pigou, Tiebout, property taxation, and the underprovision of local public goods. *Journal of Urban Economics 19*, 356–70.