Dynamic Optimal Fiscal Policy in a Transfer Union

Till Gross*

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Abstract

Transfers between regions within a federal or supranational entity are highly prevalent and may yield substantial benefits; however, such transfers are also likely to have an impact on the involved regions' incentives to tax and spend and thereby efficiency. This paper studies theoretically and quantitatively how the taxation of strategically-acting tax authorities affects their optimal fiscal policy in a dynamic model. Fiscal policy is composed of source-based capital taxes, labour taxes, government consumption, productive infrastructure, and bonds. The global capital stock evolves endogenously due to private agents' optimal savings decisions as in a neoclassical growth model. Labour taxes, government consumption, and infrastructure are all declining functions of the share of government revenues which are transferred. Capital taxes are surprisingly increasing in transfers in the short run, but unaffected in the long run. In the short run, capital taxes are too low and infrastructure spending is too high from a global welfare perspective in the absence of transfers, whereas both are at the efficient level in the long run. The dampened capital-tax and infrastructure competition during the transition means that economic efficiency and thus welfare paradoxically increase for low levels of transfers, even though there are no redistributive gains from transfers.

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1 Introduction

An important issue in federal countries – such as the United States, Canada, and Germany – or supra-national entities like the European Union is how the "taxation" of its members, which are

*Department of Economics, Carleton University, 1125 Colonel By Dr., Ottawa, ON, Canada, K1S 5B6. Tel: 613-520-3744, Fax: 613-520-3906. Email: till.gross@carleton.ca. I would like to thank participants at the 2016 Canadian Public Economics Group meeting, in particular Alex Armstrong, the 2016 annual conference of the International Institute of Public Finance, in particular Thiess Büttner, at the 2015 meetings of the Canadian Economic Association, in particular Constantine Angyridis, and seminar attendees at the University of Windsor, in particular Marcelo Arbex. I am grateful to the editor and anonymous referees for their comments. I also thank Richard Brecher for his helpful suggestions. All errors remain of course my own.

tax authorities themselves, affects efficiency and their incentives to tax and spend. In each of the aforementioned examples, the composing jurisdictions (the states, provinces, Länder, or EU member countries) set some taxes on their own, but transfer part of their revenues to each other, either directly or indirectly through the federal/supra-national level. For instance, in Canada there are equalization payments between provinces; in Germany there is the Länderfinanzausgleich; in the European Union each member state contributes a share of its gross national income and value-added tax revenues and receives in turn funding for agriculture, cohesion policies, research, and other projects. Moreover, in the aftermath of the recent European financial crisis, there have been calls for large automatic transfers between governments of the European Union. Such transfers could potentially have sizable benefits in terms of insurance or macroeconomic stabilization.[1] However, such a taxation of governments is likely to cause distortions, similar to the ones created when these same governments tax the private sector. This paper seeks to answer two related questions: First, how are governments' incentives to set fiscal policy affected by a transfer union, where every constituency has to pay a share of its tax revenues into a pool which then disburses the funds back to its members? Second, what are the rough efficiency costs of such inter-governmental transfers?

I adopt an optimal taxation approach, where each government optimally chooses its fiscal policy – capital and labour taxes, infrastructure, government consumption, and debt – taking into account how this influences the decisions of private agents.[2] I consider a one-shot game between governments, where each is able to commit perfectly.[3] Since the focus is on an international (or

[1] Evers (2012, 2015) considers fiscal transfers in a monetary union and finds that equalization schemes may actually lead to less stabilization and lower welfare, though.

[2] Personal-income taxes and social-security contributions each constituted roughly 25% of government revenues (on average for OECD countries in 2015), while corporate income taxes contribute about 9%. One can interpret the former two as mainly labour taxes (although there is certainly a capital-tax component to it), while the latter can be thought of as a capital tax. In the sensitivity analysis I also consider consumption taxes, which make up almost a third of government revenues (20% in the form of value-added taxes and the rest in other consumption taxes). Together these taxes thus comprise most of the government revenues in OECD countries. For federal countries, the central government levied 54% of all tax revenues, state or regional governments accounted for 17%, local governments for 7.5%, and at the supra-national level (i.e. the EU) 0.5%. See OECD (2017). Public investment is done largely at the subnational level, where approximately 70% of the spending takes place, according to OECD (2014). About 40% of all government expenditure happens at the subnational level (OECD, 2018), and this number tends to be substantially higher in federations and quasi-federations. Overall, it appears safe to say that taxation and spending at the subnational level are not insignificant. Several countries grant a large degree of fiscal autonomy to its constituent regions, also see the OECD Fiscal Decentralisation Database.

[3] This is mainly important in relation to private agents, in the sense of committing to not expropriate their wealth in the future, and not in relation to other governments. For repeated games between governments, one would have to consider imperfect commitment (I briefly discuss this in the conclusion). Even though the assumption of perfect commitment may not hold in practice, it provides a useful benchmark, which is important when considering welfare implications (i.e. whether taxes and allocations are efficient or not), as argued by Kydland and Prescott (1980). Repeated games and limited commitment could be interesting to study inter-governmental commitment problems of transfers, though. Akai and Sato (2008), for example, do this in a quasi-static model.

inter-jurisdictional) context with several interacting governments, optimal fiscal policy considers also the impact on foreign private agents' behavior and is contingent on the belief of foreign policy. I analyze equilibria where these beliefs are consistent with the actual foreign strategy. Capital is assumed to be mobile, whereas labour is not. Capital is accumulated through agents' optimal savings decisions. I consider a symmetric two-country economy, in which there are no distributional benefits from transfers in order to focus on the distortions for public policy (similar to a conventional representative-agent tax model in which tax revenues are rebated back in a lump-sum fashion). The model easily extends to any number of jurisdictions and almost any type of asymmetry, though, and most analytical (and concerning the number of countries, also numerical) results remain qualitatively unchanged.

Casual intuition would suggest that in the presence of intergovernmental transfers which are based on actual tax revenues (as in the German Länderfinanzausgleich), not some form of fiscal capacity (as in Canada), there is a positive externality emanating from taxes and productive public capital (which I use synonymously for infrastructure).[4] The benefits accruing to the home government decrease and the benefits to the other government increase in revenue sharing, so one would thus presume that taxes and infrastructure spending (and hence also government consumption) are a decreasing function of transfers. As Baretti, Huber, and Lichtblau (2002, p. 632) argue, transfers are effectively a tax on tax revenues and "Conventional economic theory suggests that [...] a state's level of [...] tax revenue will be lower the higher the marginal tax rate on its tax revenue." The welfare effects should then be negative.

This intuition is partially borne out in my model: Labour taxes and government consumption are lower the higher the transfers, and this constitutes an inefficiency. The reason is precisely that labour tax revenues are being taxed from the perspective of each country, while the benefits to the other country are not taken into account. The transfers from the other country on the other hand depend on the foreign labour tax rate, which is taken as given from the home country's perspective. With regard to government consumption, the marginal cost of public funds is increasing in transfers (because of the taxation of tax revenues) while the benefits remain the same, which implies that

[4] Also see Köthenbürger (2002) who considers Germany's Länderfinanzausgleich as an example of revenue-based transfers. It is difficult to classify real-world transfer schemes as either based on actual revenues or fiscal capacity, since these schemes are highly complicated. In Germany for instance, the transfers follow a non-linear formula, different states get different payments per inhabitant, and there are federal transfers on top of the direct transfers between the states. Baretti, Huber, and Lichtblau (2002) provide an excellent discussion. They argue that even though the states in Germany cannot set tax rates explicitly, they may do so implicitly by varying tax enforcement.

government consumption is decreasing in transfers.

Concerning capital taxes and infrastructure, this intuition is misleading, though. The initial capital stock is an endowment and should be taxed as much as possible in a closed economy (say at 100%), since taxing it is non-distortionary. [The same logic applies to the short run more generally, when the government sets capital taxes to 100%, which still taxes the initial capital stock indirectly.] In an open economy, each government has an incentive to lower capital taxes to attract capital from abroad, since the marginal social product of capital is higher than the private return to capital for foreign investors, creating a positive intratemporal externality for capital taxes. This leads to inefficient tax competition and a race to the bottom, which is a well-established result in the large literature on this subject.[5] Transfers diminish the benefits of attracting capital, as only a fraction of the wedge between capital's marginal product and the investor's private net return flows to the home government, while the rest goes abroad. Transfers thus reduce capital-tax competition.

Even though the marginal products of capital and infrastructure are equal to each other at all times (as in first best), this implies surprisingly an overprovision of infrastructure from a global perspective in the short run. Given that capital taxes are suboptimal in the short run, the marginal product of infrastructure should be higher than that of capital; in the long run, with efficient capital taxes, infrastructure provision is efficient, too. Intuitively, one could thus speak of "infrastructure competition" in the short run of an open economy without transfers; infrastructure attracts capital from abroad and due to the non-cooperative nature of the game, governments do not take this negative externality on the other country into account. Since transfers increase the cost of public funds and governments thus provide less infrastructure, transfers therefore reduce infrastructure competition. For higher levels of transfers (and in the long run), infrastructure is less than what would be efficient, though.

Besides the positive *intratemporal* externality of capital taxes an additional *intertemporal* negative externality exists, as Gross, Klein, and Makris (2017) show. Capital taxes reduce the incentive to save and thereby the global capital-stock. Since the capital stock is shared by all countries, this effect is not fully internalized. Similarly, higher infrastructure spending increases the returns to

[5]Zodrow and Mieszkowski (1986) and Wilson (1986) were the pioneering papers. Bucovetsky and Wilson (1991) is an example with multiple tax instruments. Griffith, Hines, and Sørensen (2010) provides an overview. If governments are not maximizing the welfare of their citizens, then capital-tax competition can discipline these leviathan governments and improve welfare, as Edwards and Keen (1996) and Eggert (2001) argue, so Wilson and Wildasin (2004) ask the question whether tax competition is a "Bane or Boon." In this paper I abstract from political-economy considerations and assume a benevolent government, although the results for infrastructure and long-run capital allocations are not affected by having self-interested governments.

capital and therefore encourages savings and expands the global capital stock. As I have argued above, the benefits of attracting capital are diminished by transfers, so the negative intertemporal externality of capital taxes is exacerbated by transfers; the costs of infrastructure increase in transfers, enlarging the positive intertemporal externality of infrastructure.

In steady state, capital taxes and infrastructure are at their efficient levels without transfers, when the intratemporal and intertemporal externality cancel each other out. In the long run lower capital taxes or higher infrastructure no longer attract capital from abroad, but instead create their own supply by encouraging savings. With perfect commitment and a complete tax system, long-run capital taxes are used to implement the efficient (first-best) capital allocation and not to raise revenues.[6] The long-run capital taxes in the present paper also implement the efficient capital allocation and since revenues are purely incidental, the fact that some of these revenues are transferred abroad is of no relevance. Transfers hence do not affect optimal capital taxes in steady state. However, for infrastructure the costs are in terms of public funds, which are higher with transfers – the long-run infrastructure allocation is therefore distorted downwards by transfers.

Considering welfare, it follows that relatively low transfers paradoxically increase welfare in the short run, due to reduced capital-tax and infrastructure competition. Higher transfers decrease welfare, though, since infrastructure spending and government consumption are too low. Since capital-tax and infrastructure competition are absent in the long run, transfers unambiguously reduce efficiency in the long run.

In terms of policy, the results suggest that (relatively small) transfers between jurisdictions, which might be beneficial in terms of macroeconomic stabilization, or for redistribution and insurance purposes, will have only small detrimental effects on efficiency or might even improve it. However, it is important to bear in mind that the analysis in this paper abstracts from political-economy considerations, limited commitment, government default, and many other important real-world aspects. Moreover, all the gains stem from the short run, whereas in the long run transfers decrease efficiency.

The remainder of the paper is organized as follows: In the rest of this section I discuss the

[6] I discuss this in detail in Gross (2015b). Optimal taxation aims to tax endowments. In the short run, capital taxes are used to tax (in)directly the initial asset endowment. In the long run, the capital stock does not contain any endowment component anymore and is an intertemporal intermediate good. Intermediate goods should be provided efficiently and if taxes are necessary to implement the efficient allocation of an intermediate good, then the revenues thus generated are purely incidental. In this paper, capital taxes tax away the firms' profits which go to capital owners. Capital taxes are thus similar to Pigouvian taxes, since capital would be over-provided without them. This logic carries over to open economies (Gross, 2014, 2015a).

related literature, in section 2 I present the economic environment and lay out the structure of the game between governments and agents. I analytically derive optimal policies in section 3, whereas section 4 contains the presentation of the numerical results. I discuss the intuition of both the analytical and numerical results in section 5. I perform sensitivity analysis regarding parameter robustness and modeling assumptions in section 6. The last section concludes and proposes avenues for future research. In the appendix I provide some proofs and show the results for the sensitivity analysis.

Related Literature Boadway (2004) provides an overview on transfers, stressing that equalizing transfers mostly occur when there is a federal government on top of the regional governments. It is thus strongly related to the theory of decentralization, also see Boadway (2001). Boadway distinguishes between gross equalization (with transfers from the federal level to the regions) and net equalization (with inter-regional direct transfers). The transfers in this paper can thus be classified as a net equalization scheme, since I do not include a federal level.

Transfers either take the form of revenue equalization (as in this paper) or tax-base equalization. Models of *tax-base equalization* in a static model have also found that transfers dampen tax competition: Smart (1998) and Büttner (2006) show that distortionary taxes may actually increase as a function of transfers and Köthenbürger (2002) and Bucovetsky and Smart (2006) argue that this may improve efficiency under tax competition.[7]

Static models of *revenue equalization* generally find the opposite: As Köthenbürger (2002, p. 402) states, a revenue-based transfer scheme "tends to reinforce the effects of tax competition." He studies a model where governments choose capital taxes and government consumption in a standard model of tax competition.[8] Hindriks, Peralta, and Weber (2008) find that without transfers there is undertaxation and underprovision of infrastructure and higher transfers leave taxes unchanged, but decrease infrastructure investment, leading to a welfare improvement. They assume that governments choose public infrastructure and capital taxes sequentially. Relatedly, Köthenbürger (2011) emphasizes that optimizing over taxes or expenditures for local governments may lead to different results. In their theoretical model, Baretti, Huber, and Lichtblau (2002) abstract from tax compe-

[7] Other authors reach these conclusions in somewhat different settings: Kotsogiannis (2010) and Silva (2017) study tax-base equalization in a federation, Wang, Kawachi, and Ogawa (2014) and Ogawa and Wang (2016) consider a repeated game, Köthenbürger (2005) assumes Leviathan instead of benevolent governments, and Wrede (2014) examines agglomeration economies.

[8] Gaigné and Riou (2007) find that revenue equalization may lead to a more efficient allocation, but in a context of trade and imperfect competition.

tition, so that output is produced from immobile labour alone. They show that transfers generally lead to lower effective taxes.

The literature on equalizing transfers does not, to the best of my knowledge, extend to a fully dynamic environment. The dissertation by Kim (2014) considers a dynamic economy with transfers similar to the one presented in this paper but does not show any analytical results. Moreover, the numerical implementation does not take into account the transition. Gong and Zou (2002) have a government maximize steady-state welfare subject only to steady-state constraints. There are two state governments and one federal government, but there is no capital mobility and no interaction between state governments. Ogawa and Yakita (2009) study a growth model with interregional transfers, but restrict fiscal policy to labour taxes. Local governments do not take into account how their taxes affect human and physical capital accumulation. Cyrenne and Pandey (2015) analyze a growth model where the government's single choice is the time-invariant share of tax revenues which goes to infrastructure vs. government consumption. They find that higher transfers likely lead to less infrastructure spending and more government consumption, but there is no strategic interaction between governments and no tax competition.

This paper also relates to and builds on the small literature in dynamic optimal taxation (with commitment) in open economies.[9] Correia (1996) extended the Chamley-Judd result of zero long-run capital taxes to a small open economy; Gross (2014) does the same for large open economies. Angyridis (2007) studies a stochastic small open economy. Gross, Klein, and Makris (2017) focus on a computational analysis of transition dynamics and cross-border externalities in a two-country model. Gross (2015a) shows that the long-run capital allocations and qualitative capital-tax conclusions derived in closed-economy models also apply to open economies.

The contribution of this paper is thus twofold: First, in comparison to the literature on intergovernmental transfers, this is the first paper to analyze the incentive and welfare consequences of transfers in a fully dynamic optimal taxation framework. The time dimension is important, because the results differ markedly in the short and long run. Moreover, I consider a relatively comprehensive set of fiscal-policy instruments, with debt, labour and capital taxes, and productive and unproductive government spending. As far as I am aware, the transfers literature has so far only considered subsets of this. Second, with regards to the works on optimal dynamic taxation in open

[9]Wildasin (2003), Köthenbürger and Lockwood (2010), and Hatfield (2015) all consider dynamics in small open economies, but not dynamic optimal taxation in the sense of allowing for time-varying taxes and for the taxation of labour income, while precluding lump-sum taxes.

economies (without transfers), this paper analyzes the case of endogenous government consumption and infrastructure, and establishes that there is infrastructure competition in the short, but not in the long run. In the sensitivity analysis, I also show how labour mobility can be included in dynamic tax competition models and that it does not play a quantitatively significant role – at least under the (fairly conventional) assumptions made here. Furthermore, this paper is the first to compare different equilibrium concepts in a dynamic open economy-framework numerically, and, conceptually, makes an argument why the benchmark concept is the preferred equilibrium notion.

There is relatively little empirical evidence on the effect of transfers on fiscal policy. Baretti, Huber, and Lichtblau (2002) find that transfers tend to reduce tax revenues of states in Germany. In my model tax revenues are decreasing in transfers. Even though capital tax competition is dampened in the short run, the negative impact of transfers on labour taxes outweighs this and the model is thus consistent with these empirical findings. The work by Smart (2007) suggests an increase in tax revenues through transfers for Canada, but this is a system of capacity-based transfers. Büttner (2006) and Egger, Köthenbürger, and Smart (2010) find that fiscal equalization leads to higher business tax rates of municipalities in Germany, in consonance with the short-run results of my model, but fiscal equalization in this context seems to be largely in terms of capacity.[10] For US and German states, the results by Potrafke and Reischmann (2015, p.975) "indicate that intergovernmental transfers have implicitly subsidized debts," in line with my findings that transfers lead to a higher path of government debt at any time period.[11] I am not aware of any research which studies the consequences of transfers on fiscal policy over time, so one cannot evaluate the dynamic component of the model. Overall, however, the (scant) evidence regarding the impact of (revenue-based) transfers on fiscal policy is in consonance with the results in this paper. As mentioned above, the model (necessarily) abstracts from some practically relevant issues, though. For instance, a benevolent government with perfect commitment is useful as a benchmark, but I am personally not convinced that governments actually do bahave in this way. While governments may or may not act as in my model, it is still useful for policy purposes, as it provides an idea what governments ought to do. The focus of this work is on understanding how the incentives to tax and spend are affected by transfers, rather than empirical predictions.

[10]Using a similar approach to Büttner (2006), Ferede (2017) finds a similar result for Canadian provinces, that equalization grants lead to higher business and personal income tax rates.

[11]The US system is better characterized by capacity-based transfers, however.

2 Economic Environment

The economy consists of two jurisdictions which are part of a transfer union, i.e. a certain fraction of tax revenues from each jurisdiction flows into a common pool which is then transferred back. Both jurisdictions are identical and populated by a representative agent; there is no outside world in this model. These simplifications allow me to focus on the different incentives created by the transfer union as opposed to the potential welfare gains from redistribution between asymmetric countries. The analytic results can be generalized to a model with any number of countries with almost any type of asymmetry.[12]

A fixed measure of perfectly competitive firms produce output in each country from labour and capital. There are constant returns to scale in these two private inputs and publicly-provided infrastructure, resulting in profits. These are returned to the firms' shareholders, which provide the capital; this is the reason why capital taxes are optimally positive in the long run.[13]

Capital investment stems from globally acting, perfectly competitive investment firms. They collect individuals' savings and invest them in government bonds and capital in both countries. Capital is perfectly mobile, while labour is immobile (I relax this assumption in Section 6.4). The government in each country aims to maximize the home agent's utility and chooses capital and labour taxes, as well as one-period bonds, to finance public consumption and infrastructure spending. Capital taxes are paid according to the territorial principle, i.e. they are paid where the capital is employed. The two governments engage in a one-shot game and each simultaneously announce a policy sequence at time zero, to which agents and firms then react. Governments can thus commit perfectly to their future actions.

[12]One can readily verify that the propositions do not depend on the specifics of the utility or production functions, so even if these differ across countries the results still apply. Adding more countries to the Lagrangian is similarly straightforward. I do require a common discount factor, otherwise a stable non-degenerate long run does not exist.

[13]This formulation allows for constant returns to scale in all production factors, but results would remain qualitatively unchanged if there were increasing returns to scale (however still assuming decreasing returns in accumulable factors, i.e. private and public capital, otherwise all capital could be attracted to only one country). It also does not matter qualitatively whether capital is optimally taxed in the long run or not.

2.1 The Representative Agent

There is a measure one of agents in each country, taking prices and taxes as given and maximizing lifetime utility:

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

c_t is private consumption, leisure is l_t, and government consumption is G_t (all terms here are in per-capita terms, which is equal to the aggregate, since the population size is unitized). $\beta \in (0, 1)$ is the discount factor. I assume that preferences are consistent with balanced growth, as outlined by King, Plosser, and Rebelo (2002), for two reasons: First, it implies that the model could easily be extended to feature exogenous growth, and second, it allows me to derive some results for the transition path as in Atkeson, Chari, and Kehoe (1999). Preferences are

$$\begin{aligned} u(c_t, l_t, G_t) &= \frac{c_t^{1-\sigma}}{1-\sigma} v(l_t) + g \frac{G_t^{1-\sigma}}{1-\sigma} \qquad \text{if} \quad 0 < \sigma < 1 \quad \text{or} \quad \sigma > 1 \\ u(c_t, l_t, G_t) &= \log(c_t) + v(l_t) + g \log(G_t) \quad \text{if} \quad \sigma = 1 \end{aligned}$$

The restrictions on $v(l_t)$ are as in King, Plosser, and Rebelo (2002, p.95). The household divides up its total unitized time between labour N_t and leisure. The per-period budget constraint is:

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

w_t is the domestic wage, τ_t^n are labour taxes, a_t are asset holdings, and R_t is the international net rate of return. Initial asset holdings a_0 are exogenously given.

Utility maximization implies the familiar labour-leisure trade-off and an Euler equation concerning the trade-off between consumption today versus tomorrow (subscripts denote derivatives, e.g. $u_c(t) = \partial u(c_t, l_t, G_t)/\partial c_t$):

$$u_l(t) = u_c(t)(1 - \tau_t^n) w_t \tag{3}$$

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

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

2.2 Firms and Production

There is a continuum of identical firms of measure one. Since they are perfectly competitive, I focus on a representative firm, which produces output used for private and public consumption and investment. To obtain an analytical expression for optimal capital taxes in the long run (and since a functional form has to be chosen anyway to run simulations), I assume the following Cobb-Douglas production function:[14]

$$F(K_t, I_t, N_t) = ZK_t^{\alpha} I_t^{\iota} N_t^{1-\alpha-\iota}. \tag{5}$$

Z is the firm's productivity, K_t is the firm's capital, I_t is the country's infrastructure, and N_t the amount of labour the firm hires.

Firms are lent capital K_t by investors and aim to maximize total dividends, $r_t K_t$, where r_t is the dividend (or rate of return) per unit of capital, by choosing labour input N_t:

$$\begin{aligned} \max_{N_t, r_t} \quad & r_t K_t \\ \text{s.t.} \quad & F(K_t, I_t, N_t) - w_t N_t \geq r_t K_t. \end{aligned} \tag{6}$$

It can be readily shown that this dividend maximization is equivalent to standard profit maximization when profits accrue to capital owners.

The wage and rate of return on capital are thus determined by

$$w_t = (1 - \alpha - \iota) F(K_t, I_t, N_t)/N_t \tag{7}$$

$$r_t = (\alpha + \iota) F(K_t, I_t, N_t)/K_t. \tag{8}$$

2.3 The Government

Each government decides its spending on government consumption G_t and the infrastructure level I_t, as well as taxes on capital and labour income, to maximize the discounted life-time utility of its citizens. It may also issue government bonds B_{t+1} at an interest rate $\tilde{r}$, with initial debt B_0 exogenously given. I assume that infrastructure is rented from capital markets, and its cost is $\hat{r}_t$.[15]

[14] This specification is of course also consistent with balanced growth. The analytical results remain qualitatively unchanged for any well-behaved production function with decreasing returns in reproducible inputs, i.e. capital and infrastructure. Capital depreciation is included in the investors' problem below.

[15] Assuming that infrastructure is a stock which is owned by the government does not change the analytic results. I differentiate between productive and unproductive government spending, I_t and G_t, in order to evaluate how

The government's per-period budget constraint can be written as

$$G_t + I_t\hat{r}_t + B_t(1+\tilde{r}_t) = \tag{9}$$
$$(1-T)[\tau_t^k r_t K_t + \tau_t^n w_t N_t] + TH[\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*] + B_{t+1}.$$

$0 \leq T < 1$ is the fraction of government revenues which is channeled into the common pool and $0 < H \leq 1$ is the share of the funds in this pool which are given back to the home country (in the symmetric case considered here, $H = 1/2$). I assume that capital taxes are bounded above by 1, but since this constraint is only relevant for the closed-economy benchmark, I generally suppress mentioning it.

2.4 Investors

Investors allocate savings from agents into firm capital, infrastructure, and government bonds to maximize their profits (which are zero in equilibrium). Capital returns are taxed at source in each country and both private and public capital depreciate at the same rate δ. Capital depreciation is not tax-deductible in order to generate a simple formula for optimal capital taxes. This does not affect results qualitatively, though. I evaluate the quantitative relevance of this assumption in Section 6.3.[16] The representative investor's profit maximization problem is

$$\max_{K_t,K_t^*,I_t,I_t^*,B_t,B_t^*,a_t,a_t^*} [r_t(1-\tau_t^k)-\delta]K_t + [r_t^*(1-\tau_t^{k*})-\delta]K_t^* + [\hat{r}_t-\delta]I_t + [\hat{r}_t^*-\delta]I_t^* \tag{10}$$
$$+ B_t\tilde{r}_t + B_t^*\tilde{r}_t^* - (a_t + a_t^*)R_t$$
$$\text{s.t. } a_t + a_t^* = K_t + K_t^* + I_t + I_t^* + B_t + B_t^*. \tag{11}$$

Foreign prices and allocations are denoted by an asterisk. The constraint is the familiar capital-market clearing condition: the global supply of assets is equal to the total use of assets (for capital, infrastructure, and bonds). The first-order conditions are the common no-arbitrage conditions. The

transfers may affect these types of spending differently. In Section 6.2 I also include consumption taxes.

[16] I also abstract from variable capacity utilization and adjustment costs; the former would reduce the incentives to use capital taxes in the short run, while the latter would strengthen these incentives. While variable capacity utilization and adjustment costs may be useful in adding realism to government responses to short-term shocks, for instance, these factors would unnecessarily complicate the analysis of this paper. I implicitly assume that returns on government bonds, and thus infrastructure lending, are not taxed. As shown below, no-arbitrage requires that returns on government bonds have to be equal to dividends from firms. It therefore does not matter whether bond returns are taxed or not.

net returns on each asset have to be equal to each other and the international rate of return:

$$R_t = r_t(1 - \tau_t^k) - \delta \tag{12}$$

$$\begin{aligned} R_t &= r_t^*(1 - \tau_t^{k*}) - \delta \qquad (13) \\ &= \hat{r}_t - \delta \\ &= \hat{r}_t^* - \delta \\ &= \tilde{r}_t \\ &= \tilde{r}_t^*. \end{aligned}$$

From here on I will replace $\hat{r}_t$ and $\hat{r}_t^*$ by $R_t + \delta$ and $\tilde{r}_t$ and $\tilde{r}_t^*$ by R_t. It follows that governments can issue (any) amount of government debt at the market rate R_t.[17]

2.5 Game Structure

Governments are able to commit perfectly and announce their policies simultaneously at time zero for the infinite future. With internationally involved governments, perfect commitment corresponds to a one-shot game between governments and repeated games correspond to imperfect commitment. Perfect commitment is a benchmark to which one can compare the case of imperfect commitment; I discuss this in the conclusion.

Households, firms, and investors react optimally to the announced policies. Incorporating their optimality conditions as constraints allows the government to directly use all of the private sector's choice variables as its own control variables. The other government is a strategic actor and chooses its policy at the same time. The foreign policy can therefore not be chosen by the home government. For any belief of foreign policy, the home government determines its best-response. This is a generalized game, as in Debreu (1952) and Arrow and Debreu (1954), where the equilibrium is feasible, but off-equilibrium behavior is generally not (that is, the worldwide resource constraint will hold only in equilibrium). I analyze alternative equilibrium concepts in Section 6.5. The constraint that capital taxes are less than 100% is never binding in equilibrium, so I do not show

[17] This is of course subject to a no-Ponzi condition, which I do not write down explicitly. Moreover, it is clear that for given asset levels, the amount of debt that can be issued is finite, since the rate of return goes to infinity as B_t approaches $a_t + a_t^* - (I_t + I_t^* + B_t^*)$. Similarly, the government can rent any amount of infrastructure capital within these endogenous bounds of the model.

it here (similar to the non-negativity constraints for all quantities).[18] The domestic government's Lagrangian is

$$
\begin{aligned}
\mathcal{L} = &\sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t, G_t) \qquad (14) \\
&+\psi_t[(1-T)(\tau_t^k r_t K_t + \tau_t^n w_t N_t) + TH(\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*) + \\
&\quad B_{t+1} - G_t - I_t(R_t + \delta) - B_t(1 + R_t)] \\
&+\theta_t[(1-\tau_t^n) w_t N_t + (1+R_t) a_t - a_{t+1} - c_t] \\
&+\mu_t[(1-\tau_t^n) w_t u_c(t) - u_l(t)] \\
&+\zeta_t[\beta u_c(t+1)(1+R_{t+1}) - u_c(t)] \\
&+\theta_t^*[(1-\tau_t^{n*}) w_t^* N_t^* + (1+R_t) a_t^* - a_{t+1}^* - c_t^*] \\
&+\mu_t^*[(1-\tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t)] \\
&+\zeta_t^*[\beta u_c^*(t+1)(1+R_{t+1}) - u_c^*(t)] \\
&+\gamma_t[r_t(1-\tau_t^k) - \delta - R_t] \\
&+\gamma_t^*[r_t^*(1-\tau_t^{k*}) - \delta - R_t] \\
&+\omega_t[a_t + a_t^* - (K_t + K_t^* + I_t + I_t^* + B_t + B_t^*)]\},
\end{aligned}
$$

where w_t and r_t are functions of K_t and N_t as described in equations (7) and (8) and $l_t = 1 - N_t$ (and similarly for abroad). The set of control variables is

$$X = \{c_t, c_t^*, N_t, N_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*, B_{t+1}, \tau_t^k, \tau_t^n, G_t, I_t, R_t\}_{t=0}^{\infty}. \qquad (15)$$

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

1. *agents at home and abroad choose consumption, labour supply, and asset holdings to maximize*

[18] If capital taxes in one country were at 100%, the other country could attract all of the capital by setting any tax rate below 100%. This would leave the first country with no production and the second country would benefit, since capital's marginal product is higher than the private rate of return.

their utility subject to their budget constraint, taking prices and taxes as given;

2. *firms at home and abroad choose labour to maximize dividends, taking capital and wages as given;*

3. *investors choose asset borrowing and bond, infrastructure, and capital lending at home and abroad to maximize profits, taking prices and taxes as given.*

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

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

If an equilibrium exists (and numerically there was no indication of non-existence problems or multiple equilibria), it satisfies the worldwide resource constraint. In an equilibrium, each country plays an optimal response to the other country's policy; thus, each country's government budget constraint has to hold. Moreover, the budget constraints of both households and the capital market clearing condition (with Lagrange multiplier ω_t) also hold. Combining these equations and using the fact that $w_t N_t + r_t K_t = F(K_t, I_t, N_t)$, yields the worldwide resource constraint:

$$\begin{aligned} &F(K_t, I_t, N_t) + K_t(1-\delta) - K_{t+1} + I_t(1-\delta) - I_{t+1} - c_t - G_t + \\ &F^*(K_t^*, I_t^*, N_t^*) + K_t^*(1-\delta) - K_{t+1}^* + I_t^*(1-\delta) - I_{t+1}^* - c_t^* - G_t^* = 0. \end{aligned} \tag{16}$$

This worldwide resource constraint also illustrates that infrastructure is a stock just like capital, even though it is modeled somewhat unconventionally in that it is rented by governments from capital markets.

3 Optimal Fiscal Policy

In this section I characterize optimal fiscal policy. I first define a closed-economy benchmark and then show results for the open-economy setting. I focus here on capital (taxes) and infrastructure, since one cannot derive cleanly interpretable results for the other variables (as is usual in optimal dynamic taxation). Moreover, one can analytically prove (most) results only in steady state. To illustrate optimal policy in general, I use numerical simulations in the next section, while Section 6 contains an extensive sensitivity analysis.[19] I discuss the intuition in section 5, in order to be able to cover both the analytic and numerical results.

3.1 Closed-economy Benchmark

It is useful to define a closed economy as a benchmark, where the government does not have to deal with strategic issues between countries. Since I assume symmetry, this also corresponds to the coordinated solution in an open economy (with equal bargaining weights for each country). In technical terms, one can still use the previous Lagrangian, equation (14), by simply setting all variables with an asterisk to zero and excluding them as choice variables where applicable; the transfers T are obviously zero in this case. In a closed economy the constraint $\tau_t^k \leq 1$ is potentially binding, so it has to be added; I assign a Lagrange multiplier ϕ_t to this constraint.

Proposition 1. *In a closed economy, the optimal steady-state capital and infrastructure allocations are characterized by* $1-\delta+F_K(K_{SS}, I_{SS}, N_{SS}) = 1/\beta$ *and* $F_I(K_{SS}, I_{SS}, N_{SS}) = F_K(K_{SS}, I_{SS}, N_{SS})$*, respectively. The optimal capital tax is* $\tau_{SS}^k = \iota/(\alpha+\iota)$.

The proof is in the appendix. This is a simple extension of the work by Chamley (1986) and Judd (1999).[20] The capital and infrastructure allocations follow the modified golden rule and capital taxes are used to implement this by reducing the super-returns of capital to its marginal product. Capital tax revenues are therefore purely incidental. In the long run, the capital stock is determined endogenously (unlike the initial capital endowment) and public and private capital are thus intertemporal intermediate goods. These are provided without distortions, even when the public capital has to be paid for through distortionary taxes. This corresponds to the first-best efficient infrastructure allocation when the government has access to lump-sum taxes (note that government consumption is *not* at its first-best level, though).

[19] Some of the derivations are in the appendix, but I have left the most important ones in the paper, as the proofs help build intuition and understand the results. I do not show the derivations at all when they are not helpful in building intuition. For instance, there is no simple Samuelson rule for government consumption, so I only display the numerical results for this.

[20] For the long run I focus on steady states, but the qualitative results also apply on average to any stable non-degenerate long run: see Judd (1999) for a closed economy and Gross (2014, 2015a) for open economies.

Following Atkeson, Chari, and Kehoe (1999), one can readily show that the maximum-capital tax constraint binds for a finite number of periods $\mathbf{t}$, i.e. $\tau_t^k = 1$ for $t < \mathbf{t}$, that capital taxes take on an intermediate value for one period, i.e. $\tau_{SS}^k \leq \tau_{\mathbf{t}}^k < 1$, and that capital taxes are at their steady-state level subsequently, i.e. $\tau_t^k = \tau_{SS}^k$ for $t > \mathbf{t}$.

Now I turn to the optimal infrastructure provision.

Proposition 2. *In a closed economy, where the limit on capital taxes is $\tau_{max}^k = 1$, the optimal infrastructure allocation is characterized by $F_I(K_t, I_t, N_t) = F_K(K_t, I_t, N_t)\, \forall\, t$.*

The proof is in the appendix. As mentioned above, the government seeks to implement the efficient allocation of infrastructure, but in the short run (while the constraint on maximal taxes is binding) the value of assets, and therefore infrastructure, is determined by the initial endowment. Then the fiscal costs of public capital (infrastructure) compared to private capital matter and the marginal product of infrastructure is higher than that of capital, i.e. infrastructure is at less than the first-best level. However, when the net return to capital is driven down to zero, i.e. $\tau_{max}^k = 1$, the cost of infrastructure is equal to the opportunity cost of having less capital and hence the marginal products should be equalized – even in the short run.

Corollary 1. *In a closed economy, where the limit on capital taxes is $\tau_{max}^k < 1$, then the optimal infrastructure allocation satisfies $F_I(K_t, I_t, N_t) > F_K(K_t, I_t, N_t)$ when $\tau_t^k = \tau_{max}^k$ and $F_I(K_t, I_t, N_t) = F_K(K_t, I_t, N_t)$ when $\tau_t^k < \tau_{max}^k$.*

The proof is in the appendix. This is an example of the general theory of the second best (Lipsey and Lancaster, 1956): it is no longer optimal for the infrastructure allocation to be at the first best level if there are other distortions. When the constraint ceases to bind, i.e. $\tau_t^k < \tau_{max}^k$, then the initial capital endowment no longer matters and the long-run logic applies.

3.2 Open Economy

I now present the analytic results for an open economy, which help to understand the numerical exercises. In the short run, transfers increase capital taxes and reduce infrastructure provision; without transfers, non-cooperative capital taxes are lower and infrastructure provision (given these taxes) is higher than with cooperation. In the long run, transfers leave capital taxes unchanged, but reduce infrastructure provision; without transfers, non-cooperative capital taxes and infrastructure follow the same rule as with cooperation.

The first-order conditions with respect to capital, infrastructure, and labour and capital taxes are

$$
\begin{aligned}
K_t:\ & \psi_t[1-T(1-H)]\left[\tau_t^k r_t + \tau_t^k K_t \frac{\partial r_t}{\partial K_t} + \tau_t^n N_t \frac{\partial w_t}{\partial K_t}\right] + \theta_t(1-\tau_t^n)N_t \frac{\partial w_t}{\partial K_t} && (17)\\
& + \mu_t u_c(t)(1-\tau_t^n)\frac{\partial w_t}{\partial K_t} + \gamma_t(1-\tau_t^k)\frac{\partial r_t}{\partial K_t} = \omega_t, \\
I_t:\ & \psi_t[1-T(1-H)]\left[\tau_t^k K_t \frac{\partial r_t}{\partial I_t} + \tau_t^n N_t \frac{\partial w_t}{\partial I_t}\right] + \theta_t(1-\tau_t^n)N_t \frac{\partial w_t}{\partial I_t} && (18)\\
& + \mu_t u_c(t)(1-\tau_t^n)\frac{\partial w_t}{\partial I_t} + \gamma_t(1-\tau_t^k)\frac{\partial r_t}{\partial I_t} = \omega_t + \psi_t(R_t+\delta), \\
\tau_t^n:\ & \psi_t[1-T(1-H)]N_t w_t = \theta_t N_t w_t + \mu_t u_c(t) w_t, && (19)\\
\tau_t^k:\ & \psi_t[1-T(1-H)]K_t r_t = \gamma_t r_t. && (20)
\end{aligned}
$$

Inserting equations (19) and (20) into equations (17) and (18) yields

$$
\psi_t[1-T(1-H)]\left[\tau_t^k r_t + K_t \frac{\partial r_t}{\partial K_t} + N_t \frac{\partial w_t}{\partial K_t}\right] = \omega_t \tag{21}
$$

$$
\psi_t[1-T(1-H)]\left[K_t \frac{\partial r_t}{\partial I_t} + n_t \frac{\partial w_t}{\partial I_t}\right] = \omega_t + \psi_t(R_t+\delta). \tag{22}
$$

Furthermore, total production has to equal total factor remuneration, so $F(K_t, I_t, N_t) = K_t r_t + N_t w_t$. Differentiating this identity with respect to capital leads to $F_K(t) = K_t(\partial r_t)/(\partial K_t) + r_t + N_t(\partial w_t)/(\partial K_t)$. Equation (21) then becomes

$$
\psi_t[1-T(1-H)][F_K(t) - \delta - R_t] = \omega_t. \tag{23}
$$

Equation (23) shows the benefits from an additional unit of capital on the left and the costs on the right. The benefits are expressed (using the optimality of taxes) in terms of fiscal gains. $F_K(t) - \delta - R_t$ is the capital wedge, i.e. the difference between social and private returns to capital, $F_K(t) - \delta$ and R_t respectively. At the optimum, the value of the wedge (its size multiplied by the value per unit, $\psi_t[1-T(1-H)]$) is equal to the shadow value of one unit of the stock of global assets ω_t. This implies somewhat paradoxically that a higher $T(1-H)$ should result in a larger capital wedge – as long as $\omega_t > 0$, which is true during the transition, but not in steady state, as shown below. The Lagrange multipliers ψ_t and ω_t are of course also changing with transfers, but as the numerical simulations below confirm, the direct effect is always stronger than the indirect effects through the Lagrange multipliers (in fact, both ψ_t and ω_t are increasing in T, so they pull in opposite directions). Optimal capital taxes can be expressed as

$$\tau_t^k = \frac{\iota}{\alpha + \iota} + \frac{\omega_t}{\psi_t[1 - T(1-H)]} \frac{1}{r_t}. \tag{24}$$

The first term on the right in equation (24) is the efficient first-best capital tax. The second term is larger the more the home government can influence the global rate of return, since ω_t is decreasing in the size of a country compared to the rest of the world. In the limit of a small open economy, the relative size of the global asset stock is infinite, so $\omega_t = 0 \, \forall \, t$. As explained above for the capital wedge, capital taxes are higher the larger the revenue sharing while $\omega_t > 0$.

For the optimal infrastructure decision, one can substitute $F_I(t)$ for $K_t(\partial r_t)/(\partial I_t) + N_t(\partial w_t)/(\partial I_t)$ and from equation (23) $\psi_t[1 - T(1-H)][F_K(t) - \delta - R_t]$ for ω_t into equation (22) to obtain

$$F_I(K_t, I_t, N_t) = F_K(K_t, I_t, N_t) + r_t(1 - \tau_t^k)\frac{T(1-H)}{1 - T(1-H)}. \tag{25}$$

In equation (25), the first term on the right is how infrastructure is provided in first-best, i.e. where the marginal product of public infrastructure is equal to the marginal product of capital. The second term captures how revenue-sharing influences infrastructure provision: the higher $T(1-H)$, the larger the term (the interest rate net of taxes $r(1-\tau^k)$ is also a function of $T(1-H)$, but the numerical results show again that these indirect effects do not outweigh the direct effects). We can thus conclude that the higher the revenue-sharing, the higher the marginal product of infrastructure relative to the marginal product of capital and thus the lower the level of infrastructure. Note that this does not depend on the value of ω_t.

Comparing these results, when transfers are zero, to the second-best solution in a closed economy, it becomes apparent that in the short run capital taxes are lower in an open economy and that given these capital taxes, infrastructure provision is higher. In a closed economy, capital taxes are equal to 100% in the short run, whereas they are below this level in an open economy, as explained in section 2.5.

As shown in the previous subsection, if capital taxes are restricted to be less than 100% in the short run, then infrastructure's marginal product is higher than capital's in a closed economy. Therefore, infrastructure provision in an open economy without transfers (where capital taxes are less than 100%) is "too high" in the short run in the sense that $F_I(t) = F_K(t)$.[21]

I now turn to the long-run results. As I have shown in previous work without revenue transfers (Gross, 2014, 2015a), capital is provided efficiently in the long run when governments pursue uncooperative policies (and when they do cooperate); the externality of a common capital market disappears in the long run and capital taxes in a closed and an open economy are equal to each other. Surprisingly, this also holds in the presence of revenue-sharing:

Proposition 3. *The optimal steady-state capital taxes are independent of the degree of revenue-sharing and identical to a closed economy; the steady-state allocation of private capital follows the modified golden rule.*

Proof. The first-order condition for next-period government bonds is

$$\psi_{t+1}(1 + R_{t+1}) + \omega_{t+1} = \psi_t/\beta. \tag{26}$$

For an interior steady-state, the Lagrange multiplier ψ_t is equal across time periods (from the first-order condition with respect to G_t, that $u_G(t) = \psi_t$) and I thus suppress time subscripts and replace them with SS. From the household's Euler equation (4) it follows that $1 + R_{SS} = 1/\beta$ and the equation above hence implies that $\omega_{SS} = 0$. Equation (24) then shows that the optimal steady-state tax is the same as in a closed economy:

$$\tau^k_{SS} = \frac{\iota}{\alpha + \iota} \tag{27}$$

It follows that $R_{SS} = F_K(SS) - \delta$. Using again the Euler equation leads to the modified golden rule:

$$1 - \delta_K + F_K(SS) = 1/\beta. \tag{28}$$

□

Concerning infrastructure on the other hand, results align with the short run in the sense that infrastructure provision is a decreasing function of transfers. At the same time, without transfers

[21] In general one cannot compare the levels of spending and taxes between an open and a closed economy separately, since the entire fiscal policy matters. If one compares element by element the components of fiscal policy, then one would conclude that infrastructure spending is always at the efficient level in an open economy without transfers, while this is in fact not the case. The numerical simulations indeed show that both countries gain by mutually decreasing infrastructure spending.

steady-state infrastructure is at the efficient level – following the same modified golden rule as in a closed economy – whereas in the short run, it is inefficiently high:

Proposition 4. *Infrastructure provision follows the modified golden rule in steady state in the absence of revenue sharing. Otherwise infrastructure is provided inefficiently, the more so the higher the revenue sharing.*

Proof. Using the result above that $R_{SS} = F_K(SS) - \delta$ and substituting this into equation (25) yields

$$F_I(SS) = \frac{F_K(SS)}{1 - T(1-H)}. \tag{29}$$

It follows that if there is no revenue sharing and $T = 0$, then infrastructure provision is efficient (and follows the same modified golden rule rule as in a closed economy), whereas it is inefficient and a decreasing function of T otherwise (since $r_{SS}(1-\tau^k_{SS})$ is a constant, independent of T). □

4 Quantitative Assessment

In this section I present the results for simulations of open economies with different degrees of revenue sharing. The economy starts in a steady state of an economy without transfers and an exogenously-determined level of debt (which is indeterminate in steady state, as it depends on the initial conditions). Due to the assumption of symmetry, this could either be an open or closed economy, both share the same steady-state characteristics for a given debt level. Then the game as specified above starts and I solve for the equilibrium time paths, including both the transition and new steady state, which depend on the level of transfers between governments.[22] I proceed by first describing the parametrization procedure, and then show the results. The next section discusses both the analytical and numerical results. I conduct a sensitivity analysis in Section 6.

[22]Specifically, I hypothesize that the economy will approximately converge to a steady state until some date $\mathbf{T}$. I create a system of equations consisting of all the government's first-order conditions (including the constraints) in each time period until time $\mathbf{T}$, for a given foreign policy. Variables at time $\mathbf{T}+1$ are forced to take the same value as at time $\mathbf{T}$. Using fsolve in Matlab (which in turn relies on a Levinson-Marquardt algorithm), I solve this system of equations, forcing in each iteration the foreign policy to be equal to the domestic policy. This corresponds to a fixed point of best responses by each government, see appendix B for further details. I then check the solution to see whether the variables change (up to 10^{-4}) in the last 10 periods before $\mathbf{T}$; if they do, I increase the time horizon $\mathbf{T}$ and start again. I repeat this procedure for every value of transfers T.

4.1 Parametrization

For the parametrization I use the steady state of an economy, open or closed, where the government's optimality conditions hold as above, with the exception of government debt. Productivity is normalized to one. I set the capital coefficient in the production function to $\alpha = 0.3$ and the infrastructure one to $\iota = 0.05$. This results in a share of roughly 1/3 of total income going to capital owners, which is a common estimate. The infrastructure share is in line with results for the United States from a meta study by Bom and Ligthart (2014). One time period corresponds to one year. The depreciation rate is $\delta = 0.08$, which is also standard. The intertemporal elasticity of substitution is $1/\sigma = 1$, a commonly used value. The disutility from labour takes the form $v(l) = -e(1-l)^{\eta}$, as in Gross, Klein, and Makris (2017). I calibrate $\eta = 3$ and $e = 6.1271$ such that time worked equals one third and the Frisch labour-supply elasticity is $1/(\eta - 1) = 0.5$, in line with microeconomic estimates. I set $\beta = 0.9615$ to obtain a steady-state net rate of return on capital of 4%.[23]

Unlike Gomes and Pouget (2008) I do not include infrastructure in the utility function, so as to be able to cleanly separate the implications of transfers for the provision of a government consumption good versus public capital. Government debt is set to 60% of output. The parameter for government consumption $g = 0.7398$ is calibrated so that total government revenues are 40% of output.[24] The initial asset endowment is $a_0 = 1.6727$, a value that is determined by the rest of the calibration procedure. Since there are two symmetric governments, $H = 0.5$.

4.2 Numerical results

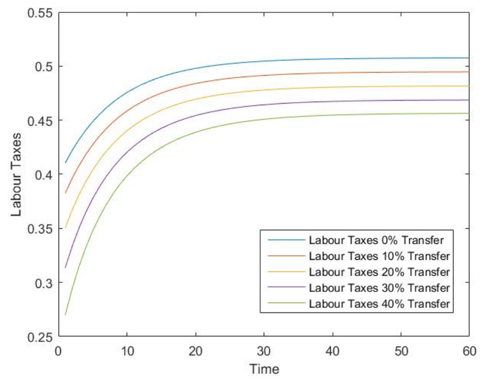
The numerical results show that labour taxes, government spending, and infrastructure are lower at any moment in time when transfers are higher, see panels (a), (b), and (c) of figure 1.[25] The

[23]It is well understood that the parameters are calibrated jointly and that one cannot necessarily attribute meeting one target to one specific parameter; I still portray it in such a way to illustrate what the calibration goals were and which parameters influence which target the most. Also, while one cannot establish uniqueness of the equilibrium, I have found no indication of the existence of alternative equilibrium solutions.

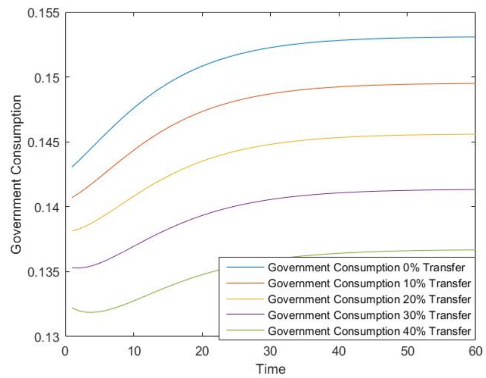
[24]This implies that government consumption G in my model corresponds to both actual consumption and transfers to citizens in reality. Since the model features a representative agent, the government would never choose to use positive transfers to this agent. In order to keep the model relatively simple, I abstract from such transfers and include them in government consumption. Moreover, since I already use inter-governmental transfers, I want to avoid confusion with transfers from governments to private agents.

[25]One might think that it is more informative to report the wedges associated with these policy variables, for instance to report F_K/F_I instead of I. However, this would be misleading. The wedge for infrastructure without transfers is always zero, as shown above, but welfare would still improve if both countries agreed to reduce their infrastructure spending in the short run. Thus, when a wedge appears with transfers, this improves welfare at first

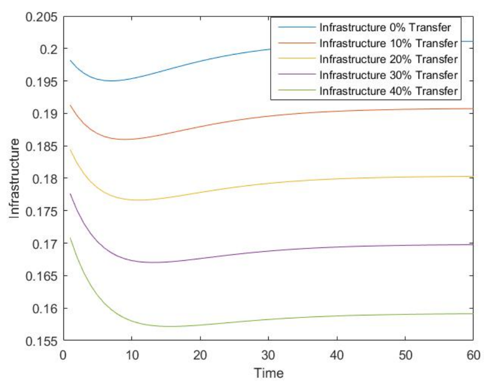
time path of public debt is higher the bigger the transfers, as seen in panel (d).



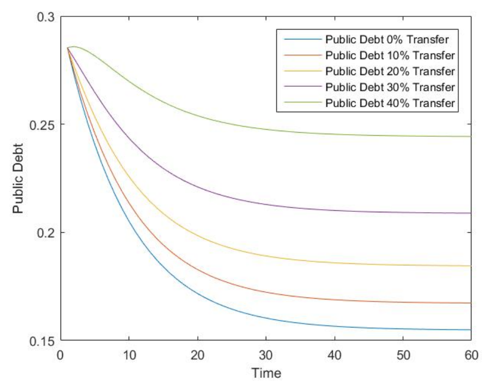
(a) Labour Taxes



(b) Government Consumption



(c) Infrastructure



(d) Debt

Figure 1: Optimal Dynamic Fiscal Policy

Figure 2 shows that capital taxes during the transition are higher the larger the transfers, while always converging to the same efficient steady-state solution, as predicted by theory.[26]

and does not reduce it. Similarly, the intertemporal wedge (i.e. capital taxes) is larger with transfers, but this still improves welfare.

[26]One may wonder whether governments are on the "wrong side of the Laffer curve." (It should be noted that there is a Laffer curve for each tax rate at each time period in this model.) Since governments are optimizing, they will never choose a tax rate which yields less revenues than a lower tax rate with fewer distortions. Also, fiscal solvency is not an issue since all government expenditures are optimally chosen.

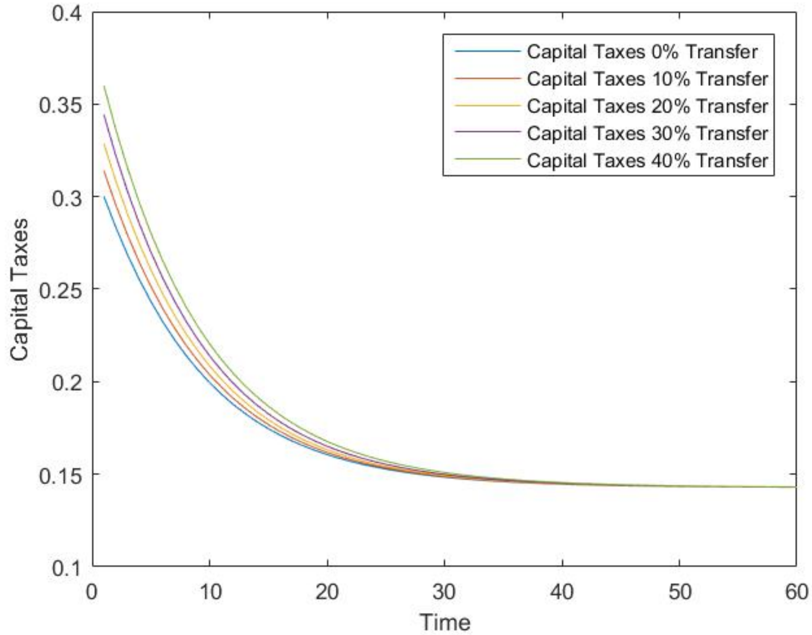


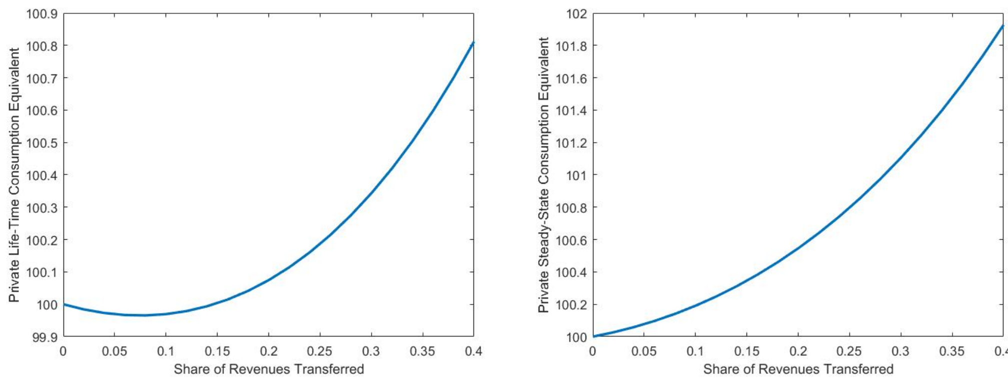
Figure 2: Optimal Capital Taxes over Time as a function of Transfers

As is common in dynamic optimal taxation, capital taxes are initially high and labour taxes are low, with a corresponding decumulation of debt (or an accumulation of assets). Government consumption rises during the transition, reflecting a relatively high cost of public funds in the beginning. For infrastructure, one can observe an initial decline and a subsequent rise. This mirrors the decumulation of private assets in the early periods due to high capital taxation, which is followed by an increase in assets (not shown) once capital taxes have fallen.

Welfare is at first, for low levels of transfers, an increasing function of the size of transfers but then decreases. This is illustrated in panel (a) of figure 3, where I plot the lifetime consumption equivalent. It is defined as the percentage of private consumption that is needed to achieve the same utility as in an open economy without transfers.[27] A lower consumption equivalent thus implies higher welfare. While it may come as a surprise that transfers can increase welfare, it is also interesting to note that the welfare costs remain relatively low even for higher levels of

[27]Formally, I define the consumption equivalent $x_{(T=y)}$ for transfer level $T = y$ implicitly as the x that solves $U_{T=0} = \sum_{t=0}^{\infty} \beta^t [ln(C_{T=y}(t)x_{T=y}) - e(1 - l_{T=y}(t))^\eta + gln(G_{T=y}(t)]$, which can then be simplified to $x_{T=y} = \exp((1-\beta)(U_{T=0} - U_{T=y}))$. To obtain a percentage, I multiply this by 100.

transfers. For example, for 40% of revenues transferred (which appears very high) the welfare costs are still below 1% of private consumption. However, the gains are restricted to the transition, as a comparison to panel (b) makes clear, which shows the consumption equivalent for steady state only. There are no gains in the long run from transfers and the welfare costs approach almost 2% of private consumption when transfers are at 40%.



(a) Transition and Steady State

(b) Steady State Only

Figure 3: Lifetime Consumption Equivalents as a function of Transfers

5 Discussion

The shared asset (or capital) market is what links open economies. In the initial period, and to a lesser extent in the short run more generally, the asset endowment is fixed and a tax on capital indirectly taxes the initial asset endowment. It is globally optimal to tax this endowment at 100%, since it amounts to a lump-sum tax, and other tax instruments, such as labour taxes, are distortionary. The ability to tax this endowment is reduced by international capital mobility and in an uncooperative Nash game capital taxes are inefficiently low. This has been shown by the large tax-competition literature, starting with Zodrow and Mieszkowski (1986) and Wilson (1986). The idea is that each country aims to attract foreign capital, since the marginal product of capital is higher than the net return to the investor; the tools to attract capital are lower capital taxes. Capital taxes thus have an intratemporal positive externality. In terms of the equations set out above, the Lagrange multiplier of the capital-market clearing equation, ω_t, decreases as the size of the home economy compared to the rest of the world decreases.[28] Each government takes into account how attracting capital from global markets affects itself, but not that it imposes a cost on other governments. With transfers, the benefits of attracting capital are lower than without transfers, since some of the gained resources are sent abroad. The difference between the social marginal product of capital and its cost is thus smaller: in equation (23), $\psi_t[1 - T(1 - H)]$ is decreasing in T. Hence, capital taxes are higher the larger the transfers and tax competition is dampened; this effect leads to higher welfare.

In the short run, there is also infrastructure competition, in consonance with Keen and Marchand (1997):[29] in order to attract scarce capital from abroad, governments spend more on infrastructure in an open economy than they would in a closed economy (holding fixed the capital tax rate). Using public capital draws from the common asset market and individual governments do not take into account how this negatively affects the other country (again, the value of the Lagrange multiplier ω_t is smaller the more countries there are and this reflects the capital market externality). Infrastructure thus has an intratemporal negative externality. With transfers, the marginal cost of infrastructure is higher, since it is paid through public funds: For one dollar spent on infrastructure, $1/(1 - T(1 - H))$ dollars have to be raised in tax revenues. To see this, note that equations (21) and (22) can be rewritten as

$$\begin{aligned} F_K(t) &= \frac{\omega_t}{\psi_t[1 - T(1 - H)]} + R_t + \delta \\ F_I(t) &= \frac{\omega_t}{\psi_t[1 - T(1 - H)]} + \frac{R_t + \delta}{[1 - T(1 - H)]} \end{aligned}$$

Therefore, at lower levels of transfers, infrastructure competition is dampened ($\frac{\omega_t}{\psi_t[1-T(1-H)]}$ increases in T), which leads to higher welfare; however, at higher levels of transfers, infrastructure provision is below what it would be in a closed economy with the same capital taxes (since $\frac{R_t+\delta}{[1-T(1-H)]}$ is also increasing in T), leading to a decline in welfare.

[28] It can be instructive to consider a small open economy, which perceives that it has no impact on global asset markets, and so ω_t is zero. The model easily extends to any number of countries, where one may simply conceive all variables with an asterisk as a vector with the number of foreign countries M as its length. In the government budget constraint, the terms $\tau_t^{*k} r_t^* K_t^* + \tau_t^{*n} w_t^* N_t^*$ would have to be the sum of all government revenues in all countries. The share of revenues which gets reimbursed would be $H = 1/(1+M)$. A small open economy is then the case where the number of countries M tends to infinity. The cost of attracting capital is thus zero, and the fact that transfers diminish *multiplicatively* the value of the benefits of attracting capital is therefore not relevant anymore.

[29] They consider static small open economies without transfers, where infrastructure is provided according to the first-best rule when profits can be fully taxed. The modeling assumptions differ somehow, though: “their” infrastructure is produced from output, whereas “my” infrastructure uses the capital stock.

Beyond the *intratemporal* externalities mentioned above, there is an opposing *intertemporal* externality for both capital taxes and infrastructure: while lower capital taxes and higher infrastructure hurt the other country by attracting capital from there, they also encourage capital formation and thus benefit the other country in the future. This can be immediately seen from equations (12) and (13), where a lower τ_t^k and a higher I_t lead to a higher global rate of return R_t, which in turn encourages capital accumulation through the household's Euler equation (4). As time progresses, the importance of the initial capital stock decreases and therefore the intertemporal externality becomes stronger; in the long run, the intratemporal and intertemporal externalities cancel each other out (ω_t goes to zero in steady state). Gross, Klein, and Makris (2017) point this out for capital taxes, but it also applies to infrastructure.

The intuition is that in the long run, countries are no longer competing for a fixed capital stock: if one country lowers its steady-state capital-tax rate (or increases infrastructure), it does not "steal" the capital from abroad, but new capital is instead generated through savings. It follows that without transfers capital is provided efficiently in the long run – according to the modified golden rule – and capital taxes implement this allocation, while revenues are purely incidental, in consonance with my previous findings in Gross (2014, 2015a). The last point is crucial to understand why transfers do not affect the long-run capital allocation and taxes. Capital is privately provided and its costs are therefore not affected by transfers; since revenues are purely incidental, the fact that part of these revenues are transferred abroad is irrelevant. Infrastructure provision in the long run is also efficient in an open economy without transfers. However, the costs of infrastructure are covered by tax dollars, so in the presence of transfers $1/(1 - T(1 - H))$ dollars have to be raised in tax revenues for one dollar of spending. Therefore, infrastructure provision in the long run is below what it would be in a closed economy, leading to a decline in welfare.

Public consumption, and by the same token labour taxes, are always negatively affected by revenue sharing, since the marginal cost of public funds is higher the bigger the proportion of revenues transferred.[30] This effect naturally implies a lower welfare. Government debt is increasing in transfers, since debt crowds out capital in the short run, and the value of capital from the government's perspective is lower with transfers. To see this, note that the costs of issuing government debt include the marginal value of more global assets ω_t, on the left-hand side in equation (26). As

[30] For example, the first-order condition with respect to government spending is $u_G(t) = \psi_t$. As mentioned before, the marginal value of government funds ψ_t is naturally increasing in transfers, so government consumption is decreasing in transfers.

indicated by equation (23), this Lagrange multiplier is decreasing in transfers.

Taken together, there are potential benefits from transfers in the short run due to dampened capital tax competition and, to a certain degree, infrastructure competition; there are costs of inefficiently low infrastructure provision in the long run, as well as inefficiently low government consumption (and inefficiently high debt) at all times. This explains the U-shaped lifetime welfare effects: for lower levels of transfers, welfare increases, but then decreases in transfers.[31] Since there are no welfare benefits but only costs in the long-run, steady-state welfare is monotonically decreasing in transfers.

Number of Countries What happens as the number of foreign countries M participating in a transfer union increases? The effective transfer rate $T(1-H)$ is increasing in M, since $H = 1/(1+M)$ is decreasing in M. In this sense, a transfer rate of 40% with two countries (one home and one foreign as in the analysis above) is equivalent to a transfer rate of 30% with three countries ($M = 2$ foreign countries). Tax (and infrastructure) competition in the short run is fiercer the more countries there are, so transfers may be more beneficial in reducing it. At the same time, since in a small open economy tax competition is no longer mitigated by transfers, one may expect that the benefits of transfers are smaller (or the costs larger) the more countries participate in a transfer union. Numerically, I find that transfers indeed do worse when there are more countries (detailed results are available on request). For example, the welfare costs of 40% transfers with one foreign country are 0.8% of lifetime private consumption, whereas they grow to 3.1% with four foreign countries; the steady state welfare costs go from 1.9% to 4.7%.[32] Even with a fairly large number of jurisdictions (fifty), there were still (small) welfare gains for low levels of transfers, though.

6 Sensitivity Analysis

In this section, I explore the sensitivity of the results regarding different parameter specifications and modelling assumptions, notably including consumption taxes, a capital depreciation tax deduction,

[31] Unlike in the taxation of individuals, a tax rate of 100% for governments (i.e. $T = 1$) would not lead to a complete breakdown of government services, as governments are strategic and take into account that they receive a fraction H of it back. Of course this would change if the number of symmetric countries went to infinity or more generally if the relative size of an individual country compared to the transfer union went to zero.

[32] However, if one compares effective transfer rates, then the picture looks different. 40% transfers with one foreign country is equivalent to 20% effective transfers, which would be the same as 25% nominal transfers with four foreign countries. The welfare costs in the former case are still 0.8% (1.9% in steady state), in the latter case they are 0.9% (1.8% in steady state).

interjurisdictional labour mobility, and alternative equilibrium concepts.

6.1 Parameter Robustness

For all parameter robustness checks I have considered, the results remain qualitatively unchanged, but some quantitative differences naturally occur. In each scenario, I change one parameter or calibration target and recalibrate the rest as outlined above. All parameter values are reported in table 1, while the results are in appendix G. In the following, I briefly discuss how the different parameters change the results.

Table 1: Alternative Parametrizations

Parametrization	α	ι	e	η	σ	g	b_0	a_0
Baseline	0.3	0.05	6.13	3	1	0.74	0.29	1.67
High Infrastructure Share	0.25	0.1	6.42	3	1	0.56	0.26	1.51
High Government Debt	0.3	0.05	5.96	3	1	0.69	0.43	1.82
Low Government Debt	0.3	0.05	6.30	3	1	0.79	0.14	1.53
High Government Share	0.3	0.05	5.28	3	1	1.25	0.29	1.67
Low Government Share	0.3	0.05	6.66	3	1	0.42	0.29	1.67
High Frisch Elasticity	0.3	0.05	4.25	2.5	1	0.74	0.29	1.67
Low Frisch Elasticity	0.3	0.05	13.8	4	1	0.74	0.29	1.67
High Intertemporal Elasticity	0.3	0.05	13.4	3	0.67	1.39	0.29	1.67
Low Intertemporal Elasticity	0.3	0.05	2.81	3	2	0.44	0.29	1.67
Cobb-Douglas Utility	0.3	0.05	1.36	–	1	0.74	0.29	1.67
GHH Utility	0.3	0.05	1.28	3	1	1.46	0.29	1.67

α is the exponent of capital in the production function, ι is the exponent of infrastructure in the production function, e multiplies the disutility from labour in the utility function, $1/(\eta-1)$ is the Frisch labour-supply elasticity (except in the Cobb-Douglas case), $1/\sigma$ is the intertemporal elasticity of substitution, g multiplies the logarithm of government consumption in the utility function, b_0 is the initial public debt position, and a_0 is the initial total asset position of the private household. The depreciation of capital and infrastructure is $\delta = 0.08$ and the discount factor is $\beta = 0.96$ in all specifications.

When the infrastructure share in the production function is $\iota = 0.1$ and the capital share is $\alpha = 0.25$, infrastructure spending and capital taxes are of course higher than in the benchmark (and labour taxes and government consumption lower), but the shape of the time paths and the effect of transfers on optimal policy and welfare are very similar.

Increasing (decreasing) the debt to output ratio to 90% (to 30%) in the initial steady state obviously leads to a higher (lower) level of debt during the transition and in the new steady state, but has otherwise very little impact on the results. The welfare losses due to transfers are somewhat smaller when debt is higher, because the calibrated taste for government consumption is lower.

Changing the government share (to 30% or 50% of gross output) in the initial steady state results in slightly more important changes. Naturally, the magnitude of the welfare effects of transfers are increasing in government size. In the short run, the gains from limited capital-tax (and infrastructure) competition are larger, since the value of public funds is higher when government spending is higher. In the long run, the underprovision of government consumption constitutes one of the main costs of transfers, which is amplified when government consumption is relatively large.

The Frisch labour-supply elasticity, on the other hand, does not affect results in any sizeable way: calibrating it to 1/3 or 2/3 (instead of 1/2 in the baseline) pushes short-run capital taxes for instance slightly down and up, respectively, and welfare costs are slightly higher (for an elasticity of 1/3) or lower (for an elasticity of 2/3).

Finally, I also consider a different type of utility function. In this case, the analytical result from the closed-economy benchmark – that capital taxes are at 100% for a finite time, with one intermediate period, and then at the long-run efficient level – no longer applies. When I change the intertemporal elasticity of substitution (IES), I consider the functional form $u(c_t, l_t, G_t) = c_t^{1-\sigma}/(1-\sigma) - e(1-l_t)^\eta + g\log(G_t)$ and use the values $\sigma = 0.5$ for a high IES (which is equal to $1/\sigma = 2$) and $\sigma = 1.5$ for a low IES (which is equal to $1/\sigma = 2/3$). The lower the IES, the higher the welfare costs of transfers.

The Cobb-Douglas utility function takes the form $u(c_t, l_t, G_t) = \log(c_t) + e\log(l_t) + g\log(G_t)$, which implies that the Frisch labour-supply elasticity is given by $(1/n_t - 1)^{-1}$; it is no longer constant and takes the value of 2 in the initial steady state. A utility function of the Greenwood-Hercowitz-Huffman (GHH) type is given by $u(c_t, l_t, G_t) = \log(c_t - e(1-l_t)^\eta) + g\log(G_t)$, where the Frisch labour-supply elasticity is the same as in the benchmark, i.e. $(\eta - 1)^{-1}$. Results remain qualitatively the same, but in the Cobb-Douglas case the short-run capital taxes most notably are higher than in the benchmark, and the welfare costs are lower; for example, when $T = 0.4$ the welfare costs are the equivalent of about 0.5% of private consumption as compared to 0.8% in the benchmark. With GHH preferences, the transition to steady state takes longer, and debt and labour taxes are lower, but overall the results are highly similar. What stands out is the welfare cost of transfers in private consumption equivalents, which is much smaller in magnitude compared to the benchmark. This is due to the fact that the marginal utility of consumption depends on the marginal utility from leisure, so it is difficult to compare these numbers across such different specifications.[33]

6.2 Consumption Taxes

Consumption taxes play an important role in the public finances of many countries. I therefore consider in this section how the presence of consumption taxes, such as a VAT, would affect the analysis. The constraints that change are the household's optimality conditions

$$c_t(1+\tau_t^c) = (1-\tau_t^n)w_t N_t + (1+R_t)a_t - a_{t+1} \tag{30}$$

$$u_l(t) = u_c(t)(1-\tau_t^n)w_t/(1+\tau_t^c) \tag{31}$$

$$u_c(t)/(1+\tau_t^c) = \beta u_c(t+1)(1+R_{t+1})/(1+\tau_{t+1}^c) \tag{32}$$

as well as the government budget constraint

$$\begin{aligned} &G_t + I_t R_t + B_t(1+R_t) = \\ &B_{t+1} + (1-T(1-H))[\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^c c_t] + TH[\tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^* + \tau_t^{c*} c_t^*]. \end{aligned} \tag{33}$$

In a closed economy, consumption taxes are redundant as long as the effective constraint on capital taxes remains the same. Intuitively, consumption taxes at time t reduce the value of working at time t, just like labour taxes (as is clear from the optimal labour-leisure tradeoff); increasing consumption taxes across time periods decrease the value of savings, just like capital taxes (as is clear from the optimal intertemporal tradeoff). In an open economy, this redundancy of consumption taxes no longer holds: the capital taxes are modeled as source-based capital taxes, whereas consumption taxes are in this respect more akin to residence-based capital taxes. That is, consumption taxes affect the accumulation of assets in a country, but do not affect the allocation of capital across countries. Most of the tax-competition literature assumes that residence-based capital taxes are

[33] However, the welfare results in terms of *government consumption equivalents* are of the same order of magnitude across all specifications (since government consumption always enters per-period utility in the same way), albeit still of different size. In the baseline case, welfare losses at $T = 0.4$ are about 1.1% of government consumption equivalents, compared to roughly 0.4% with GHH preferences.

not feasible due to information requirements, as it eliminates tax competition. Examples of works that do study residence-based capital taxes are Bucovetsky and Wilson (1991) and Eggert and Haufler (1999) in a two-period model and Gross, Klein, and Makris (2018) with an infinite-horizon framework.

To facilitate comparison with previous work on transfers and tax competition, I limit the government's tax choices to labour taxes and source-based capital taxes, while consumption taxes are exogenously determined. One can easily see that the analytical derivations remain unchanged, but the quantitative results may be affected. In order to evaluate this, I set τ^c to a time-invariant 19%, conforming to the OECD average in 2016. The results align very closely with those in the benchmark model, except for the (obviously) lower labour and capital tax rates. When I allow governments to optimally choose consumption taxes, I have to impose an upper limit (otherwise the government is able to completely expropriate the initial asset base of the private households).[34] See appendix C for the Lagrangian and the choice set, and a more detailed discussion of the numerical results. In my numerical simulations, the government optimally chooses consumption taxes at the maximum (I have considered maximum values up to 100%), so the results are the same as for an exogenous consumption tax. Even for a consumption tax of 100% the results are qualitatively the same as without consumption taxes, though. At the same time, capital tax competition is not affected as much by transfers when consumption taxes are high, so the welfare costs of transfers are larger.

6.3 Capital Depreciation Deduction

In the benchmark model I assume that capital depreciation is not tax-deductible, in order to obtain an analytically convenient solution. While this assumption does not change the qualitative nature of the results, a natural question to ask is what the quantitative consequences are. Specifically, the relevant change in equations is in the no-arbitrage condition which now becomes

$$(r_t - \delta)(1 - \tau_t^k) = R_t \tag{34}$$

[34] In order to meaningfully study consumption taxes as a choice variable without an exogenous upper limit, one would presumably have to incorporate cross-border shopping into the model, as for example in Kanbur and Keen (1993). Moreover, distributional concerns matter, too, so a model with agent heterogeneity and progressive labour taxes would appear warranted. This is beyond the scope of this paper, though.

and similarly for capital abroad. The optimal steady-state capital taxes are now given by

$$\tau^k = \frac{\iota F(\cdot) - \delta K}{(\alpha + \iota)F(\cdot) - \delta K}. \tag{35}$$

In a closed economy, this is the only change compared to the situation where capital depreciation is not tax-deductible (as long as the effective upper bound on capital taxes remains the same). All allocations are exactly the same. Intuitively, the government can choose the net rate of return R_t through capital taxes; if R_t is chosen optimally, then it does not matter whether it equals $(r_t - \delta)(1 - \tau_t^k)$ or $r_t(1 - \tau_t^k) - \delta$ except for the value of τ_t^k. In an open economy, the government cannot freely choose R_t as it cannot control foreign capital taxes, so the depreciation allowance does influence results. The differences are barely visible, though, with the obvious exception of the capital-tax rate itself, so I show the results, but do not discuss them further, in appendix D.

6.4 Labour Mobility

In line with most of the literature on tax competition and intergovernmental transfers, I have assumed that capital is (perfectly) mobile, whereas labour is (perfectly) immobile.[35] While one can readily argue that capital is more mobile than labour, labour may also exhibit some degree of mobility between countries. This complicates the analysis in several ways. Obviously, a labour-mobility constraint needs to be incorporated into the government problem, and country size has to be added as a choice variable (even though in a symmetric equilibrium it will remain constant). Second, it is not clear what the government's objective function should be, given that the population may change. Third, if the costs to labour mobility are low enough, the equilibrium outcome may be for only one country to exist, while the other is depopulated.

In order to keep the model tractable, I make the following assumptions: The government maximizes the per-capita period utility of agents who live in that country in that period, for each period over the entire infinite time horizon. Agents are heterogeneous in their preferences regarding the country they would like to live in, and that initially all agents live in the country they prefer to live in. Agents may move costlessly and as many times as they wish and only take into account per-period utility for their moving decisions. The per-period utility in the home country is multi-

[35]There are studies on fiscal equalization with labour mobility. For instance, Albouy (2012) characterizes an optimal transfer system with labour mobility, but in a static model. Moreover, he does not consider the impact of transfers on regional decision-making.

plied by $(1+x)^s$, where $s>0$ is a parameter, while the utility in the foreign country is multiplied by $(1-x)^s$.[36] I assume that the total mass of agents is two, and the preference parameter x is uniformly distributed over the interval $[-1,1]$. A person with $x=1$ thus always prefers to stay in the home country, no matter what the difference in utility is; a person with $x=-1$ always prefers the foreign country; a person with $x=0$ always prefers the country with the higher utility, no matter how small the difference is. The additional constraint in the government's optimization problem is therefore

$$(2-\chi_t)^s u(c_t, l_t, G_t) = \chi_t^s u(c_t^*, l_t^*, G_t^*), \tag{36}$$

where χ_t is the home country population size at time t and $2-\chi_t$ is the foreign country's size. The larger s, the more the agents' preferences towards one country matter compared to the utility they obtain in each country. As $s \to \infty$, the model is identical to the baseline model with perfectly immobile labour; as $s \to 0$, the model is one of perfect labour mobility.[37]

Since all the variables and constraints are written in per-capita terms, the only changes to the government's problem are in the government budget constraint and in the capital-market clearing condition:

$$\begin{aligned} &\chi_t G_t + \chi_t I_t R_t + B_t(1+R_t) = && (37)\\ &B_{t+1} + (1-T(1-H))\chi_t[\tau_t^k r_t K_t + \tau_t^n w_t N_t] + TH(2-\chi_t)[\tau_t^{*k} r_t^* K_t^* + \tau_t^{*n} w_t^* N_t^*] \\ &\chi_t(a_t - K_t - I_t) - B_t + (2-\chi_t)(a_t^* - K_t^* - I_t^*) - B_t^* = 0. && (38) \end{aligned}$$

Bonds B_t are no longer expressed in per-capita terms, since government debt remains the same even if people move from one country to the other (for infrastructure this problem does not arise, since I model it as a flow rented from capital markets, and not a stock). For the complete Lagrangian and choice set, see appendix E. The qualitative results remain intact, as one can readily verify.

Numerically, I set $s=0.5$, which implies that a one-percent difference in utility levels would roughly lead to one percent of the population moving from one country to another. The relationship is of course not linear: if the foreign utility level were 100% higher than at home, then 60% of the

[36] I assume here positive utility in each country, for negative utility it is the inverse. The setup is ill suited if utility is positive in one country and negative in the other, but that is of no importance in the present paper, as countries are symmetric. Ideally agents would take into account their discounted lifetime utility for their moving decisions, but that becomes intractable.

[37] This would lead to stability issues, though: With constant returns to scale and positive initial government debt, all agents would have an incentive to move to the same country.

home country population would move abroad. I believe that this is a fairly high degree of labour mobility.[38] Nonetheless, the results are remarkably similar to the baseline case.

Somewhat surprisingly, even a relatively large degree of labour mobility does not change results substantively. In appendix E I show the results and also discuss them in more detail. In order to make sense of this, it is important to understand why governments may want to attract foreign workers. With constant returns to scale, a public-goods consumption which is perfectly rivalrous, and a per-capita objective function (as I have assumed in this paper), governments only have an incentive to attract immigrants to reduce the burden of public debt (as long as it is positive). The externality from competition over internationally mobile labour is thus relatively minor compared to the externalities from competition over internationally mobile capital. If there were increasing returns to scale at the national level, imperfectly rivalrous government consumption, or different types of agents, then "labour competition" might play a more important role. Investigating this is beyond the scope of this paper, though.

6.5 Alternative Equilibrium Definition

The equilibrium definition chosen in the benchmark model appears natural to me, since it comes closest to the spirit of a Nash equilibrium, where each player cannot directly influence any component of the other player's strategy. This "Social Equilibrium" of a "Generalized Game" also has a long-standing tradition in economic theory, being put forth by Debreu (1952) and applied in Arrow and Debreu (1954). However, a valid criticism of this approach is that off-equilibrium behavior is generally not feasible (as discussed above). An alternative equilibrium definition, which I have discussed in earlier work, Gross (2014), uses one of the instruments of fiscal policy at each t as a residual to satisfy the government budget constraint. This could be either τ_t^n and τ_t^{n*}, τ_t^k and τ_t^{k*}, G_t and G_t^*, or I_t and I_t^*, each representing a different game between governments. Using government debt B_{t+1} and B_{t+1}^* is not an option, since that would not be sufficient for the government's intertemporal budget constraint to hold. As I discuss below, there are many more options, though, which partially involve government debt as the adjusting variable.

Under the alternative equilibrium definition, both governments do not commit to their entire fiscal policies at the beginning of the game; instead, one fiscal policy variable in each time period

[38] It corresponds to an elasticity of 1 at the equilibrium level. This is much higher than what Lehmann, Simula, and Trannoy (2014), for example, use in their study of optimal non-linear income taxation. Obviously, the lower the elasticity, the lower is the impact of labour mobility.

is left to adjust so that the government budget constraint holds. For the sake of concreteness, take the case where government spending G_t (and G_t^*) adjusts. Then, at the beginning of the game, the home government chooses a policy $\hat{X} = \{B_{t+1}, \tau_t^k, \tau_t^n, I_t\}_{t=0}^{\infty}$ to maximize discounted household utility; this depends on its belief of foreign fiscal policy, $\hat{X}^*$. Note that there is no belief on G_t^*, since foreign government spending is not chosen at the same time as $\hat{X}$ and $\hat{X}^*$. In fact, it is a reaction function to both $\hat{X}$ and $\hat{X}^*$ (similarly to c_t, c_t^*, etc.). G_t is also not chosen initially by the home government, as it is a reaction function, too. The government knows how these variables will react to policy, though, and can influence them. This implies that the home government can use G_t and G_t^* as choice variables, as long as it incorporates the corresponding constraints (the domestic and foreign government budget constraints, respectively). Note that this is equivalent to the government "choosing" private consumption c_t, leisure l_t, and next-period assets a_{t+1}, as long as it incorporates the private-sector optimality conditions, equations (2) - (4). For the complete Lagrangian and choice set, see appendix F.

The analytical results remain, mutatis mutandis, very close to the benchmark results. Equations (24) and (25) now become

$$\tau_t^k = \frac{\iota}{\alpha + \iota} + \frac{\omega_t}{\psi_t[1 - T(1-H)] + \psi_t^* TH} \frac{1}{r_t} \tag{39}$$

$$F_I(K_t, I_t, N_t) = F_K(K_t, I_t, N_t) + r_t(1 - \tau_t^k) \frac{\psi_t T(1-H) + \psi_t^* TH}{\psi_t[1 - T(1-H)] + \psi_t^* TH}. \tag{40}$$

It is immediately apparent that the long-run results (when ω converges to zero) are unaffected: (i) Capital taxes are efficient and implement the optimal capital allocation, independent of transfers; and (ii) the infrastructure allocation is efficient in the absence of transfers. With transfers, infrastructure is chosen sub-optimally, i.e. its marginal product is higher than capital's, as long as the direct positive impact of T on the term $r_t(1 - \tau_t^k) \frac{\psi_t T(1-H) + \psi_t^* TH}{\psi_t[1-T(1-H)] + \psi_t^* TH}$ is not offset by the indirect impact on that term through ψ_t and ψ_t^*.[39] Numerically, I find that the difference between the marginal products of infrastructure and capital is indeed increasing in T in all cases.

Quantitatively, and along the transition qualitatively, there are potentially some important differences, though. These depend on the adjusting fiscal policy variable. In appendix F I show results for some possibilities of an adjusting fiscal policy variable.

[39] Naturally $\psi_t > \psi_t^*$: the home government values an additional dollar in home tax revenues more than a dollar in foreign tax revenues. Moreover, in the long run, $r_t(1 - \tau_t^k)$ converges to a constant, $1/\beta - (1 - \delta)$, irrespective of transfers.

I will start with the case of adjusting labour taxes. In this case, equilibrium capital taxes are now decreasing in transfers. Moreover, there are no welfare gains from low transfers, and overall the welfare costs of transfers are higher. What explains this? I first consider the case without transfers. Under the alternative equilibrium concept the home government takes into account how an increase in its capital taxes leads to a larger tax base in the foreign country (through an inflow of capital), thus resulting in a lower foreign labour tax and a higher foreign labour supply. This may in sum be beneficial or detrimental for the home country. There are benefits because the global returns to capital are higher, but it suffers, because the foreign country can attract more capital.[40] Numerically, I consistently find that the overall effect is initially positive and then negative; technically, μ_t^* and/or ψ_t^* are positive for a couple of periods and then turn negative. Under the alternative equilibrium concept, tax competition without transfers is thus dampened compared to the baseline equilibrium.

In an economy with transfers, there is an additional negative effect from lower foreign labour taxes: the foreign government transfers less tax revenues back to the home country. When a unit of capital flows into the foreign country, then the home country no longer benefits from this in terms of receiving larger transfers from abroad. The reason is that the foreign government offsets the tax revenue increases from a broadened tax base (a higher K_t^*) by lowering τ_t^{*n}. This is reflected in a value of ω_t (the Lagrange multiplier on the capital-market clearing constraint) which is decreasing in T. In the benchmark equilibrium, it is precisely the opposite: ω_t is increasing in T, since a larger capital stock abroad results in higher transfers from abroad, holding taxes abroad constant. In consequence, I find numerically that τ_t^k is a declining function of transfers in the alternative equilibrium. The term $1/((\psi_t[1-T(1-H)]+\psi_t^* TH)r_t)$ is still increasing in transfers (as in the baseline case), but the decline in ω_t more than offsets it. It is thus not surprising that welfare is always decreasing in transfers if tax competition is aggravated by transfers. Naturally, overall welfare costs are thus higher under the alternative equilibrium concept than in the baseline scenario.

Now I turn to the case where foreign government consumption adjusts in each period.[41] The results are *identical* to the baseline scenario, since the Lagrange multiplier of the foreign government budget constraint is zero. This follows immediately from taking the derivative of the home government's Lagrangian with respect to G_t^*. I thus do not show the results of this case in the

[40] A higher foreign labour supply equates ceteris paribus to a higher marginal product of capital abroad, so for returns to equalize across countries, capital needs to flow into the foreign country.

[41] In this case, as when infrastructure spending adjusts, there is a non-negativity constraint for G_t^* (or I_t^*).

appendix.

When foreign capital taxes in each period adjust, then tax competition in the absence of transfers is more severe than in the benchmark, the levels of capital taxes are substantially lower. The reasoning is straight-forward: Higher capital taxes in the home country lead to an outflow of capital, and hence a larger tax base abroad, so that foreign capital taxes have to decrease to satisfy the foreign budget constraint. The costs of raising revenues through capital taxes are thus heightened. Furthermore, transfers aggravate the problems from tax competition for reasons similar to the case when labour taxes are adjusting, although the decreases in capital taxes are fairly small as transfers increase. However, labour taxes, infrastructure, and government consumption decrease substantially in transfers. The welfare effects of transfers are qualitatively the same as with adjusting labour taxes.

When foreign infrastructure is adjusting in each period, tax competition without transfers is fiercer than in the benchmark, as higher infrastructure spending attracts further capital from abroad. The impact of transfers is to dampen tax competition, though, and more strongly than with the baseline equilibrium concept – only at about 30% transfers does the welfare effect start to turn negative. The reason is that when the home government increases its capital taxes, then capital moves abroad and widens the tax base there, leading to higher infrastructure spending. This would raise the foreign rate of return, resulting in further capital flows abroad and an even larger tax base. With transfers, an increase in the tax base abroad is partly enjoyed by the home government, so that the positive externality of increasing capital taxes is partially internalized.

Besides these four different obvious alternative equilibrium concepts, one could also assume that government debt at each t and one of the other policy instruments in some time period $\hat{t}$ adjust. Or that labour taxes adjust in periods $1, 5, 9 \ldots$, capital taxes in periods, $2, 6, 10, \ldots$, government consumption in periods $3, 7, 11, \ldots$, and infrastructure in periods $4, 8, 12, \ldots$. There are infinitely many different ways in which government policy can adjust; while some are perhaps more natural than others, it remains an arbitrary choice. This highlights the importance of the equilibrium concept, which to the best of my knowledge has not been studied before in this context: Even though the long-run analytical results may be the same – as in Gross (2014) – the entire solution may depend in important ways on the choice of the equilibrium concept.

It should be noted that while off-equilibrium behavior is generally infeasible in the benchmark, some but not all off-equilibrium behavior is feasible under the alternative equilibrium concept. I think it is immediately clear that if for instance labour taxes in period 0 and bonds in all other periods adjust, then this may not be sufficient to satisfy revenue requirements if the other country sets very low (or negative) capital taxes. But even if labour taxes in each period adjust, the home government may hit the peak of the (intertemporal) Laffer curve before it meets its revenue requirements. When capital taxes or infrastructure adjust, this problem becomes even more severe (since higher capital taxes and lower infrastructure lead to capital flight and lower productivity). When government spending adjusts, this issue should be least problematic (since lower government spending does not reduce the tax base), but even then not all off-equilibrium behavior is feasible.[42]

The benchmark thus remains my favorite equilibrium concept: 1) It is closest in spirit to a Nash equilibrium, where the entire fiscal policy is determined simultaneously. It also has a long-standing history in economic theory, as this type of equilibrium concept was proposed by Debreu (1952) and applied in the seminal work by Arrow and Debreu (1954). 2) The benchmark results do not depend on an arbitrary choice of adjusting fiscal variables. 3) Although off-equilibrium beliefs in the benchmark specification would result in an infeasible allocation, equilibrium is always feasible. 4) Even with the alternative equilibrium concept, not all off-equilibrium beliefs would result in a feasible allocation. 5) The alternative equilibrium concept which presumably does best on the dimension of feasible allocations with off-equilibrium beliefs, that of an adjusting government consumption, leads to identical results as the benchmark.

7 Conclusion

In this paper I develop a model of dynamic optimal fiscal policy with capital mobility and transfers between governments. I show that government consumption and labour taxes are decreasing functions of transfers, which represents a negative welfare effect. The short-run incentives to attract capital from abroad by lowering capital taxes or providing infrastructure – traditionally referred to as capital-tax and infrastructure competition – are dampened and this positively affects welfare (up to a certain degree). In the long run, capital is provided efficiently; since capital taxes are then only

[42] There are some obviously non-sensical foreign policies which are never feasible, for instance when bonds and infrastructure in one country are higher than the available world-wide assets. Even apart from that, one can always construct an off-equilibrium strategy which results in an infeasible allocation, for instance when the non-negativity constraint on G_t or G_t^* becomes binding. It is not clear how to limit the beliefs to something "sensible" beyond equilibrium strategies. The game-theoretic problem is what payoff to assign both players when feasibility is violated. One may set the payoff for the violating player to negative infinity, but the non-violating player will still have an undefined payoff.

used to implement this efficient capital allocation and not to raise revenues, they are independent of transfers. The long-run infrastructure provision is efficient without transfers and inefficiently low with them. The reason why (private) capital and (public) infrastructure are affected differently is due to the fact that intergovernmental transfers increase the cost of public funds and thus of public capital, while the cost of private capital remains unchanged.

Taking all these effects together, transfers may thus paradoxically increase welfare due to improved efficiency in the short run. In the long run, the welfare effects of transfers are unambiguously negative, though. Numerically, I find that the efficiency costs of transfers are small: when transfers are at 10% of tax revenues, there are still efficiency gains, and when transfers reach 20% of tax revenues the efficiency costs are 0.075% of private lifetime consumption, according to the (admittedly stylized) model. This suggests that if there are substantial benefits from transfers, for instance due to macroeconomic stabilization, then the efficiency costs of transfers are unlikely to outweigh these benefits. It is important to bear in mind, though, that the costs of transfers are increasing in the number of countries participating in the transfer union, and are substantially higher in the long run. Moreover, the analysis in this paper abstracts from political-economy considerations, limited commitment, government default, and many other important real-world aspects, which might increase the costs of transfers.

For instance, it is well-known that with imperfect commitment equilibrium capital taxes are too high.[43] The reason is that governments take the current capital stock as given, but it is determined endogenously through agents' rational expectations of taxes. That is, governments perceive capital to be an endowment whereas it is accumulated endogenously. Tax competition is then welfare-improving, as it drives capital-tax rates down towards the efficient level, see Quadrini (2005). Therefore, with imperfect commitment transfers would appear to clearly affect welfare (in the long-run equilibrium) in a negative way: first, through the distortion of incentives to provide infrastructure and government consumption, and second through the dampened tax competition, which produces higher rates of inefficient capital taxes.

I believe there are many interesting avenues for future research on this subject: One would be to investigate how transfers affect government consumption, labour taxes, and short-run capital taxes differently when countries are asymmetric; in that case, transfers will serve as a vehicle to shift resources from richer to poorer jurisdictions (which Bargain, Dolls, Fuest, Neumann, Peichl,

[43]This relates to the famous time-inconsistency problem first established by Kydland and Prescott (1977).

Pestel, and Siegloch (2013) studied in a static context and without optimal taxation). Moreover, transfers could also be used as some sort of insurance device, for instance if productivity were not deterministic as in the present model, but stochastic as in Chari, Christiano, and Kehoe (1994). This is computationally difficult, though. It could also be interesting to compute the welfare costs of transfers in a repeated game with imperfect commitment. Modeling countries outside of the transfer union does not affect the analytical results presented in this paper, but does of course change equilibrium values. Comparing policies within and outside the union and finding the optimal transfer rate, similar in spirit to Becker and Fuest (2010), could yield interesting insights. One could also contrast equalization schemes based on capacity vs. actual revenues – similar to Köthenbürger (2002) – or investigate what an optimal equalization scheme might look like, akin to Bucovetsky and Smart (2006). Considering transfers in a federation would allow one to study the different incentive effects on a horizontal and vertical level. This adds an additional player to the game, and thus greatly increases the level of complexity.

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A Appendix: Proofs

Claim. In a closed economy, the optimal steady-state capital and infrastructure allocations are characterized by $1 - \delta + F_K(K_{SS}, I_{SS}, N_{SS}) = 1/\beta$ and $F_I(K_{SS}, I_{SS}, N_{SS}) = F_K(K_{SS}, I_{SS}, N_{SS})$, respectively. The optimal capital tax is $\tau^k_{SS} = \iota/(\alpha + \iota)$.

Proof. The first-order conditions with respect to capital, infrastructure, and labour taxes are similar to those in the main part of the paper:

$$K_t\colon\ \psi_t\left[\tau_t^k r_t + \tau_t^k K_t \frac{\partial r_t}{\partial K_t} + \tau_t^n N_t \frac{\partial w_t}{\partial K_t}\right] + \theta_t(1-\tau_t^n)N_t\frac{\partial w_t}{\partial K_t} \tag{A.1}$$
$$+ \mu_t u_c(t)(1-\tau_t^n)\frac{\partial w_t}{\partial K_t} + \gamma_t(1-\tau_t^k)\frac{\partial r_t}{\partial K_t} = \omega_t,$$
$$I_t\colon\ \psi_t\left[\tau_t^k K_t \frac{\partial r_t}{\partial I_t} + \tau_t^n N_t \frac{\partial w_t}{\partial I_t}\right] + \theta_t(1-\tau_t^n)N_t\frac{\partial w_t}{\partial I_t} \tag{A.2}$$
$$+ \mu_t u_c(t)(1-\tau_t^n)\frac{\partial w_t}{\partial I_t} + \gamma_t(1-\tau_t^k)\frac{\partial r_t}{\partial I_t} = \omega_t + \psi_t(R_t+\delta),$$
$$\tau_t^n\colon\ \psi_t N_t w_t = \theta_t N_t w_t + \mu_t u_c(t) w_t, \tag{A.3}$$

Note that $R_t = r_t(1-\tau_t^k)-\delta$. Using $K_t(\partial r_t)/(\partial K_t)+N_t(\partial w_t)/(\partial K_t) = F_K(t)-r_t$ and $K_t(\partial r_t)/(\partial I_t)+N_t(\partial w_t)/(\partial I_t) = F_I(t)$ and inserting equation (A.3) into equations (A.1) and (A.2) yields

$$\psi_t F_K(t) - (1-\tau_t^k)\left[\psi_t r_t + \psi_t K_t\frac{\partial r_t}{\partial K_t} - \gamma_t\frac{\partial r_t}{\partial K_t}\right] = \omega_t \tag{A.4}$$
$$\psi_t F_I(t) - (1-\tau_t^k)\left[\psi_t r_t + \psi_t K_t\frac{\partial r_t}{\partial I_t} - \gamma_t\frac{\partial r_t}{\partial I_t}\right] = \omega_t. \tag{A.5}$$

The first-order condition with respect to capital taxes at time t is

$$\psi_t K_t r_t - \gamma_t r_t - \phi_t = 0. \tag{A.6}$$

Since $r_t > 0$ and the constraint on capital taxes cannot bind in a non-degenerate steady state, $\psi_t K_t = \gamma_t$ in steady state. Therefore equation (A.4) leads to $\psi_t[F_K(t) - (1-\tau_t^k)r_t] = \omega_t$. The first-order conditions for B_{t+1} and G_t are

$$\psi_{t+1}(1+R_{t+1})+\omega_{t+1}=\psi_t/\beta \tag{A.7}$$

$$\psi_t=u_G(t). \tag{A.8}$$

In steady state, $G_t=G_{t+1}$ and Lagrange multipliers for the government budget constraint are thus equal across time periods, $\psi_t=\psi_{t+1}$. The household's Euler equation in steady state implies that $1+R_{SS}=1/\beta$ and hence $\omega_{SS}=0$. It follows that $F_K(SS)=(1-\tau^k_{SS})r_{SS}$, which is equivalent to $R_{SS}=F_K(SS)-\delta$ and thus $1-\delta+F_K(SS)=1/\beta$. Simple algebraic manipulations show that $F_K(SS)=(1-\tau^k_{SS})r_{SS}$ implies that $\tau^k_{SS}=\iota/(\alpha+\iota)$.

Concerning infrastructure, combining equations (A.4) and (A.5) yields

$$\psi_t[F_K(t)-F_I(t)]=(1-\tau^k_t)[\psi_tK_t-\gamma_t]\,[(\partial r_t)/(\partial I_t)-(\partial r_t)/(\partial K_t)] \tag{A.9}$$

As argued above, $\phi_t=0$ and hence $\psi_tK_t=\gamma_t$ in steady state, so $F_I(SS)=F_K(SS)$. □

Claim. In a closed economy, where the limit on capital taxes is $\tau^k_{max}=1$, the optimal infrastructure allocation is characterized by $F_I(K_t,I_t,N_t)=F_K(K_t,I_t,N_t)\,\forall\,t$.

Proof. Using equation (A.9), it follows that when the constraint $\tau^k_t\le 1$ is binding, then the right-hand side is zero, because $1-\tau^k_t=0$; when the constraint is not binding, then $\phi_t=0$ and from equation (A.6) $\psi_tK_t-\gamma_t=0$. □

Claim. In a closed economy, where the limit on capital taxes is $\tau^k_{max}<1$, then the optimal infrastructure allocation satisfies $F_I(K_t,I_t,N_t)>F_K(K_t,I_t,N_t)$ when $\tau^k_t=\tau^k_{max}$ and $F_I(K_t,I_t,N_t)=F_K(K_t,I_t,N_t)$ when $\tau^k_t<\tau^k_{max}$.

Proof. When the constraint that $\tau^k_t\le\tau^k_{max}<1$ is binding, then $1-\tau^k_t>0$ and $\psi_tK_t>\gamma_t$ because $\psi_tK_t=\gamma_t+\phi_t/r_t$ and $\phi_t>0$. Moreover, $\frac{\partial r_t}{\partial I_t}=(\alpha+\iota)\iota F(t)/(K_tI_t)>0$ and $\frac{\partial r_t}{\partial K_t}=-(\alpha+\iota)(1-\alpha)F(t)/K_t^2<0$. It follows from equation (A.9) that $F_I(t)>F_K(t)$. When the constraint is not binding, $\phi_t=0$ and $\psi_tK_t=\gamma_t$, which implies that $F_I(t)=F_K(t)$. □

B Appendix: Computational Procedure

From the Lagrangian specified in equation (14) one can derive the "home" government's best response to a belief of the "foreign" government's fiscal policy. In particular, this belief of foreign fiscal policy consists (in the benchmark equilibrium) of the entire set of foreign fiscal choice variables, $\tilde{X}^* = \{B^*_{t+1}, \tau^{k*}_t, \tau^{n*}_t, G^*_t, I^*_t\}_{t=0}^{\infty}$. Equilibrium is defined so that each government's fiscal policy is a best response to the other government's fiscal policy (and beliefs equal actual policy). In order to find this equilibrium, one can compute the best response $\tilde{X}_0$ of the home government for some belief of the foreign government's policy, $\tilde{X}^*_0$. Then one can proceed to compute the foreign government's best response to $\tilde{X}_0$, which I call $\tilde{X}^*_1$. After that, one can find the best response $\tilde{X}_1$ of the home government to $\tilde{X}^*_1$, and so forth. An equilibrium is approximately reached when the distance (by some predefined metric) between $\tilde{X}_n$ and $\tilde{X}_{n-1}$, as well as between $\tilde{X}^*_n$ and $\tilde{X}^*_{n-1}$ is below a pre-defined threshold, i.e. when the sequences $\{\tilde{X}_i\}_{i=0}^n$ and $\{\tilde{X}^*_i\}_{i=0}^n$ converge, or a fixed point is reached.[44] At each iteration, I solve a system of equations, which consists of the ten constraints – as seen in the Lagrangian, equation (14) – as well as the fourteen first-order conditions in each time period $t \leq \mathbf{T}$, one for each control variable in X as specified in equation (15). The variables in this system of equations are the fourteen control variables and ten Lagrange multipliers for each time period. It is a system of $\mathbf{T}$ times 24 equations and unknowns.

This is the numerical approach I had initially taken (I call it "iterative procedure"), and it yields the same results as my current approach (which I call "simultaneous procedure"). The downside of the very intuitive iterative procedure is that one computes many best responses to beliefs of off-equilibrium policies. These best repsonses are neither of particular interest, nor necessary to find the equilibrium strategy. To reduce the computational burden, I therefore only compute the *equilibrium* best responses. This can be achieved by *simultaneously* solving for both the foreign and the domestic government's best response. To do so, I solve a system of equations and unknowns, consisting of each government's ten constraints and fourteen first-order conditions in each time period. Since nine of the constraints (all except the government budget constraints) appear in both governments' optimization problems and nine of the control variables are identical $(c_t, c^*_t, N_t, N^*_t, K_t, K^*_t, a_{t+1}, a^*_{t+1}, R_t)$, there are $\mathbf{T} \cdot (2 \cdot 24 - 9)$ independent equations and unknowns.

[44] When countries are symmetric, one can exploit the symmetry by simply setting $\tilde{X}^*_i = \tilde{X}_i$ (for $i > 0$) instead of computing the foreign government's best response. In that case, one does not need to write an additional file which computes the foreign government's best response, but it does not result in a relevant improvement in computing time.

This is considerably faster and numerically more precise than the iterative procedure, but yields the same equilibrium policies, since equilibrium requires each government's equilibrium policy to be a best response to the other government's policy (which is what the outcome of this approach is).[45]

With the simultaneous approach, one can further simplify the problem by making use of the symmetry of each country. In particular, one can solve the problem of only one country and force the other country's policy to be the same as the home government's, i.e. to set $\tilde{X}^* = \tilde{X}$. This reduces the problem again to $\mathbf{T}$ times 24 equations and unknowns. Moreover, it also allows me to vary the number of (symmetric) countries, as discussed at the end of section 5, without increasing the computational burden. All that needs to be done is to make the following adjustments: foreign tax revenues in the government budget constraint and foreign variables in the capital-market clearing condition need to be multiplied by the number M of foreign countries, and the first-order conditions change accordingly.[46]

Using the alternative equilibrium definition does not have any direct impact on the choice of the computational approach, and does not significantly increase the computational burden. It merely adds two variables and two equations per period. In a symmetric environment, these are the adjusting foreign fiscal policy variable and the Lagrange multiplier for the foreign government budget constraint (as unknowns), and the first-order condition for the adjusting foreign fiscal policy variable and the foreign government budget constraint (as equations). In an asymmetric environment, these are the Lagrange multipliers for the other government's budget constraint for both governments (as unknowns), and the first-order condition for the adjusting other government's fiscal policy variable (as equations); the foreign government budget constraint and all foreign fiscal policy variables are already part of the set of unknowns and equations.

[45]This is true under the assumption that there is a unique equilibrium. I cannot prove uniqueness for a problem of this complexity, but I also have not found any numerical indications that there are multiple equilibria. Moreover, I have employed both procedures, with the same result.

[46]The Lagrange multiplier on the "foreign" private agent's budget constraint θ_t^* is in this case in fact the sum of all the Lagrange multipliers on all the foreign agents' budget constraints, or M times the Lagrange multiplier on one foreign country's private agent's budget constraint (and similarly for μ_t^*, ζ_t^*, and γ_t^*).

C Appendix: Consumption Taxes

When the government may also use consumption taxes and chooses them optimally, then the Lagrangian is

$$
\begin{aligned}
\mathcal{L} = & \sum_{t=0}^{\infty} \beta^t \{ u(c_t, l_t, G_t) \qquad \text{(C.1)} \\
& + \psi_t [(1-T)(\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^c c_t) + TH(\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^c c_t + \tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^* + \tau_t^{c*} c_t^*) + \\
& \quad B_{t+1} - G_t - I_t(R_t + \delta) - B_t(1+R_t)] \\
& + \theta_t [(1-\tau_t^n) w_t N_t + (1+R_t) a_t - a_{t+1} - c_t(1+\tau_t^c)] \\
& + \mu_t [(1-\tau_t^n) w_t u_c(t)/(1+\tau_t^c) - u_l(t)] \\
& + \zeta_t [\beta u_c(t+1)(1+R_{t+1})/(1+\tau_{t+1}^c) - u_c(t)/(1+\tau_t^c)] \\
& + \theta_t^* [(1-\tau_t^{n*}) w_t^* N_t^* + (1+R_t) a_t^* - a_{t+1}^* - c_t^*(1+\tau_t^{c*})] \\
& + \mu_t^* [(1-\tau_t^{n*}) w_t^* u_c^*(t)/(1+\tau_t^{c*}) - u_l^*(t)] \\
& + \zeta_t^* [\beta u_c^*(t+1)(1+R_{t+1})/(1+\tau_{t+1}^{c*}) - u_c^*(t)/(1+\tau_t^{c*})] \\
& + \gamma_t [r_t(1-\tau_t^k) - \delta - R_t] \\
& + \gamma_t^* [r_t^*(1-\tau_t^{k*}) - \delta - R_t] \\
& + \omega_t [a_t + a_t^* - (K_t + K_t^* + I_t + I_t^* + B_t + B_t^*)] \\
& + \phi_t [\tau_t^c - \tau_{max}^c] \}.
\end{aligned}
$$

The set of control variables is

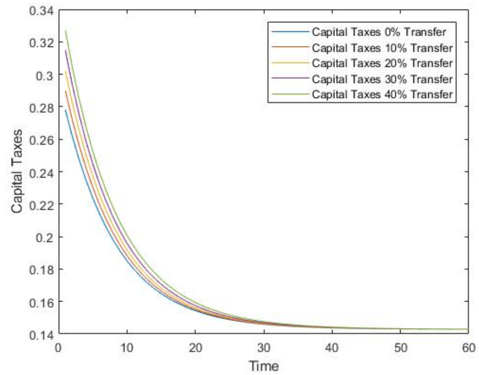
$$X^C = \{c_t, c_t^*, N_t, N_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*, B_{t+1}, \tau_t^k, \tau_t^n, \tau_t^c, G_t, I_t, R_t\}_{t=0}^{\infty}. \qquad \text{(C.2)}$$

Naturally, for constant expenditures, having consumption taxes results in lower taxes on labour (both taxes affect the labour-leisure tradeoff). Since consumption taxes also tax the household's initial assets, capital taxes are also lower with consumption taxes. Government consumption on the other hand is higher, as the distortions from raising public funds are lower. The capital stock is larger with consumption taxes than without, so that in order to keep a constant capital/infrastructure ratio – as required by equation (29) – steady-state infrastructure spending needs to be higher.

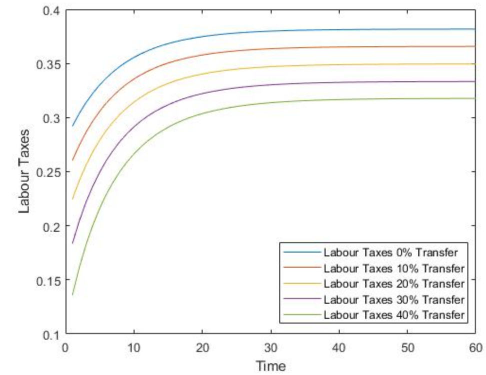
The outcome with endogenous consumption taxes is the same as with exogenous consumption taxes: The government chooses to optimally set consumption taxes at the highest possible level, that is the constraint $\tau_t^c \leq \tau_{\max}^c$ is always binding. The intuition behind this result is the following. In optimal taxation, governments seek to tax endowments, which are in this framework the initial asset endowment and the time endowment in each period. Labour and consumption taxes both tax the time endowment indirectly, but more directly than capital taxes. This can be seen from the leisure-consumption trade-off, $u_l(t) = u_c(t)(1-\tau_t^n)w_t/(1+\tau_t^c)$. The initial asset endowment can be taxed most directly either via consumption or capital taxes, in particular at time zero, when taxing the initial assets is a lump-sum tax. This can be seen best from the well-known implementability condition in a closed economy:

$$\frac{a_0(1+r_0(1-\tau_0^k))}{1+\tau_0^c} = \sum_{t=0}^{\infty} \beta^t \left[u_c(t)c_t + u_n(t)n_t \right].$$

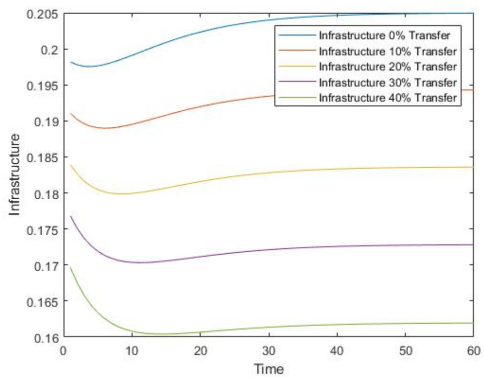
In an open economy (with or without transfers), source-based capital taxes, even at time zero, are an imperfect tax on initial assets, since capital is mobile and will move out of the country in response to higher capital taxes. Consumption taxes do not suffer from this, as they do not affect the spatial allocation of capital. It thus follows that constant consumption taxes act as a lump-sum tax on initial assets even in an open economy, and the taxation of the time endowment in each period can then be achieved through appropriately choosing labour taxes. If consumption taxes are not capped (and the initial capital stock is large enough), a first-best solution can thus be achieved in a closed economy, and when there is a cap, it will be binding. In terms of other taxes in my model, the higher the cap, the lower are source-based capital taxes, and the lower are labour taxes (they may in fact become negative).



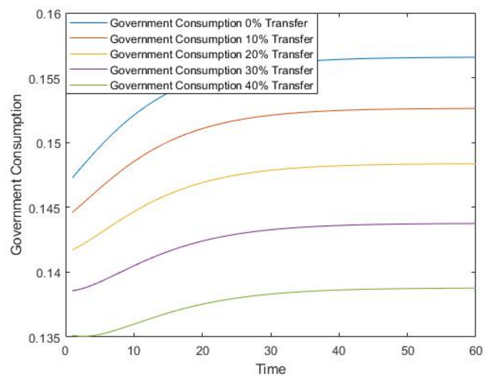
(a) Capital Taxes



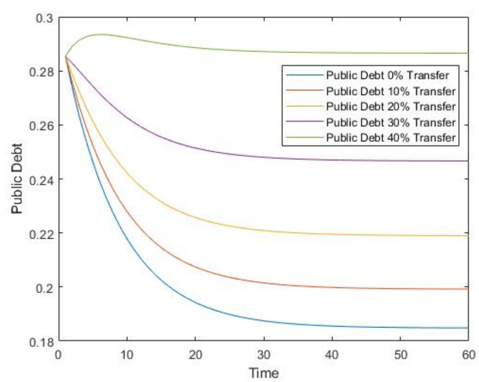
(b) Labour Taxes



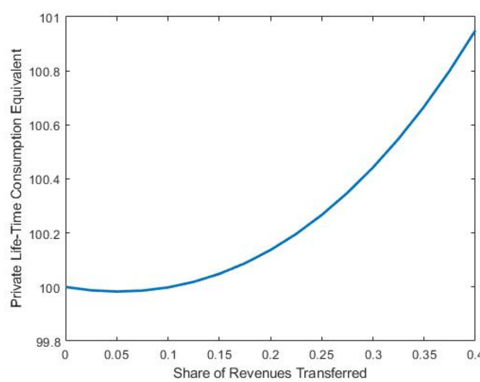
(c) Infrastructure



(d) Government Consumption



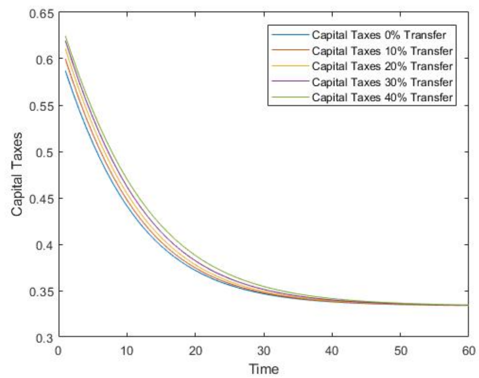
(e) Debt



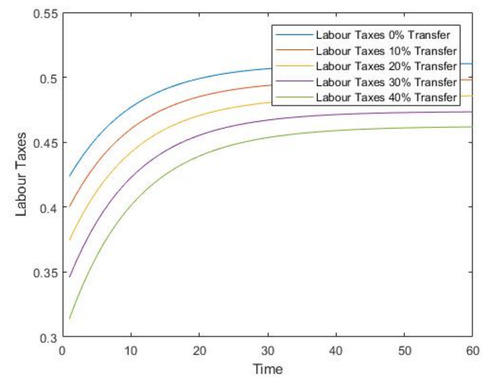
(f) Welfare

Figure C.1: Policy and Welfare with “Consumption Taxes”

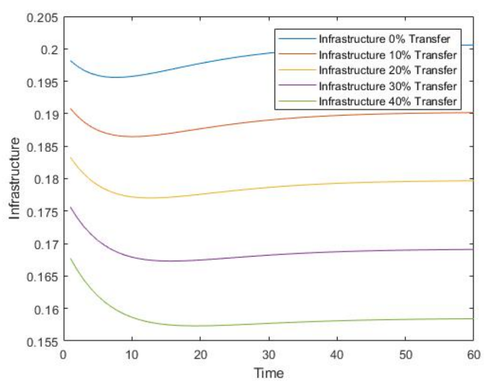
D Appendix: Capital Depreciation Deduction



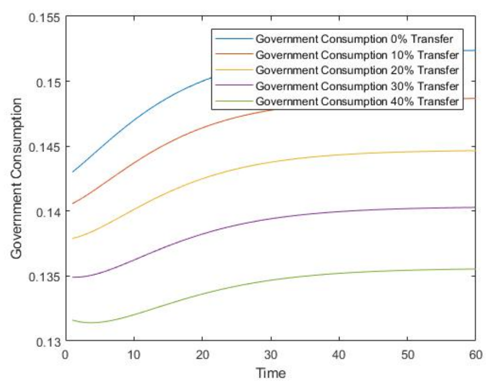
(a) Capital Taxes



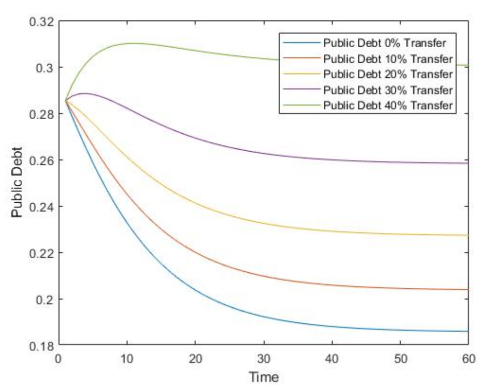
(b) Labour Taxes



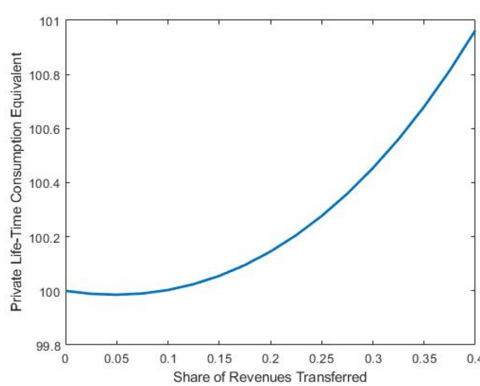
(c) Infrastructure



(d) Government Consumption



(e) Debt



(f) Welfare

Figure D.1: Policy and Welfare with “Capital Depreciation Deduction”

E Appendix: Labour Mobility

When labour is imperfectly mobile, then the Lagrangian is

$$\begin{aligned}
\mathcal{L} = &\sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t, G_t) \qquad \text{(E.1)}\\
&+\psi_t[(1 - T(1 - H))\chi_t(\tau_t^k r_t K_t + \tau_t^n w_t N_t) + TH(2 - \chi_t)(\tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*] + \\
&\quad B_{t+1} - \chi_t G_t - \chi_t I_t(R_t + \delta) - B_t(1 + R_t)]\\
&+\theta_t[(1 - \tau_t^n) w_t N_t + (1 + R_t) a_t - a_{t+1} - c_t]\\
&+\mu_t[(1 - \tau_t^n) w_t u_c(t) - u_l(t)]\\
&+\zeta_t[\beta u_c(t + 1)(1 + R_{t+1}) - u_c(t)]\\
&+\theta_t^*[(1 - \tau_t^{n*}) w_t^* N_t^* + (1 + R_t) a_t^* - a_{t+1}^* - c_t^*]\\
&+\mu_t^*[(1 - \tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t)]\\
&+\zeta_t^*[\beta u_c^*(t + 1)(1 + R_{t+1}) - u_c^*(t)]\\
&+\gamma_t[r_t(1 - \tau_t^k) - \delta - R_t]\\
&+\gamma_t^*[r_t^*(1 - \tau_t^{k*}) - \delta - R_t]\\
&+\omega_t[\chi_t(a_t - K_t - I_t) - B_t + (2 - \chi_t)(a_t^* - K_t^* - I_t^*) - B_t^*]\\
&+\Omega_t[(2 - \chi_t)^s u(c_t, l_t, G_t) - \chi_t^s u(c_t^*, l_t^*, G_t^*)]\},
\end{aligned}$$

The set of control variables is

$$X^{\chi} = \{c_t, c_t^*, N_t, N_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*, B_{t+1}, \tau_t^k, \tau_t^n, G_t, I_t, R_t, \chi_t\}_{t=0}^{\infty}. \qquad \text{(E.2)}$$

As discussed in the main text, labour mobility does not play an important role for optimal fiscal policy in this model. In fact, in many of the graphs it is difficult to see the difference. In other models, such as Lehmann, Simula, and Trannoy (2014), it has a significant impact. To better understand the mechanics of this result, it bears repeating the main underlying assumptions. The production function is constant returns to scale, which implies that a larger workforce (keeping capital per capita at the same level) does not have an impact on the rest of production in a country with immigration or emigration. Since capital is perfectly mobile, the capital per capita will remain the same in both countries, so in some sense the migrating worker takes the capital with him/her. Moreover, since I assume that countries are symmetric, the productivity per worker and capital per worker is identical across countries.

There are thus no immediate changes to the marginal product of capital and labour in either country, but naturally the receiving country will have higher tax receipts, while the country of origin will have less tax revenue (both from labour and capital taxes). If we abstract from debt for the moment, then this does not have any benefit or cost for either country, though: (i) again because of constant returns to scale, infrastructure spending has to increase proportionally to tax revenues, to keep infrastructure per capita at the same optimal level as before; (ii) public-sector consumption is perfectly rivalrous, so an increase in the population requires a proportionate increase in government consumption in order to keep spending per capita constant (at the previous, pre-immigration level that is optimal). Therefore, in the absence of government debt, neither country has any incentive to attract workers from abroad, and the "migration constraint" with Lagrange multiplier Ω_t would be slack.

Once there is government debt, however, the picture changes somewhat. In particular, if debt is positive, then immigration dilutes the existing amount of debt per capita, while it is the opposite in the country with emigration. As an example, if the workforce and therefore tax revenues increase by one percent, then spending on infrastructure and public consumption would also increase by one percent, but since there are debt payments, $\tau_t^k r_t K_t + \tau_t^n w_t N_t > G_t + I_t(R_t + \delta)$. This implies a better fiscal position of the receiving country, and the additional money can be used for lower taxes (and thus higher private consumption) and higher public consumption. It follows that with positive debt (in all periods) immigration is beneficial (and $\Omega_t > 0$), while negative debt (in all periods) implies that citizens are better off with emigration (and $\Omega_t < 0$). If debt is positive in some periods and negative in others, then in some periods debt may be positive but $\Omega_t < 0$ (and vice versa), because governments take into account that debt levels in all periods matter, and not just in the current period.

With transfers, a country with higher tax revenues has to transfer more into the common pool, but the share of tax revenues received from the common pool is also higher, since I defined it as $H = \chi_h/(\chi_h + \chi_f)$, which is in the case of labour mobility, $H = \chi_t/2$. The two effects exactly cancel out in a symmetric environment. To see this, call GR a government's total revenues and TR

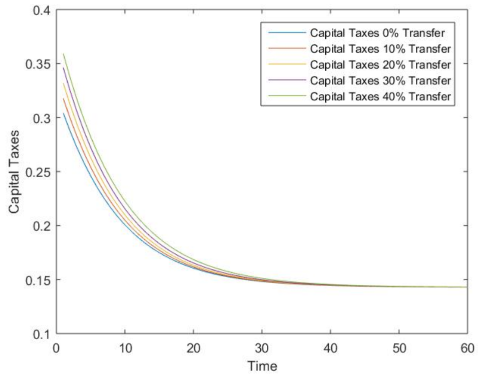
its tax revenues per capita:

$$GR = \chi TR(1 - T(1 - H)) + (2 - \chi)TR^{*}TH \tag{E.3}$$

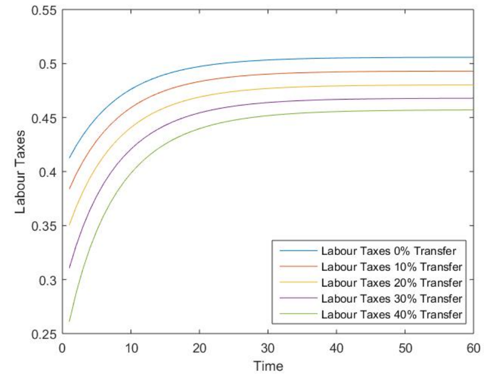
Then the derivative with respect to χ is

$$\frac{\partial GR}{\partial \chi} = TR(1 - T(1 - H)) - \chi TR^{*}TH + \chi TRT\frac{\partial H}{\partial \chi} + (2 - \chi)TR^{*}T\frac{\partial H}{\partial \chi}. \tag{E.4}$$

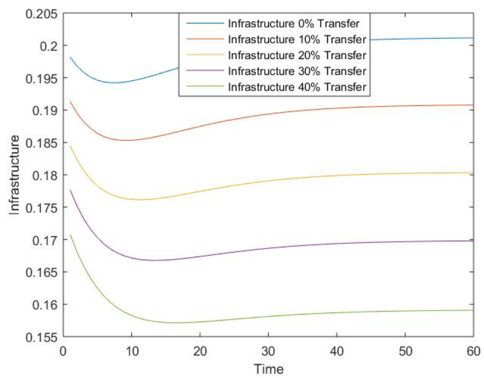
Since $H = \chi_t/2$, it follows that $\frac{\partial H}{\partial \chi} = 1/2$, and from symmetry $TR^{*} = TR$, so $\frac{\partial GR}{\partial \chi} = TR$. Therefore transfers do not affect the logic above. How the paths of fiscal policy are affected by labour mobility may differ by the level of transfers, though, since all endogenous variables are different.



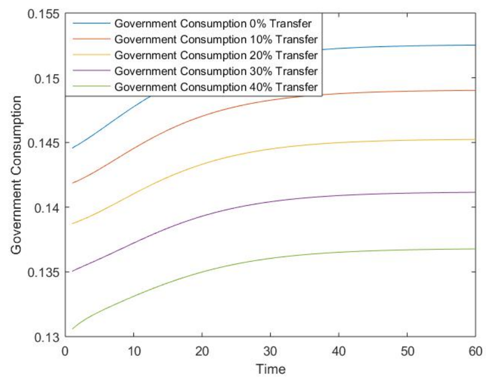
(a) Capital Taxes



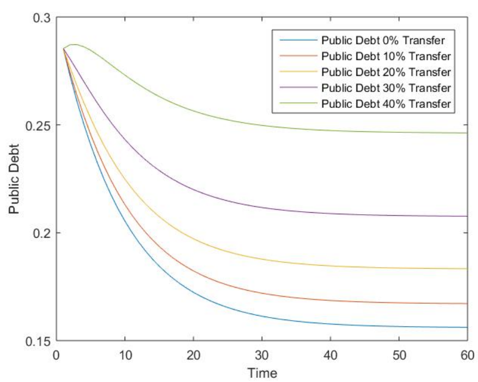
(b) Labour Taxes



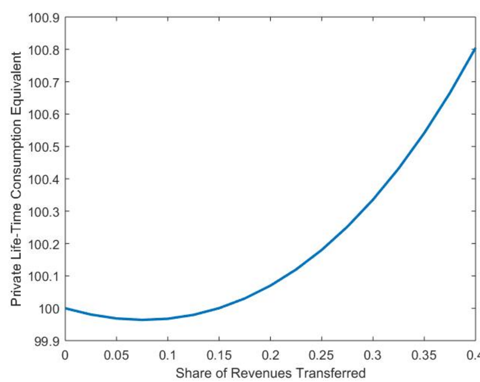
(c) Infrastructure



(d) Government Consumption



(e) Debt



(f) Welfare

Figure E.1: Policy and Welfare with "Labour Mobility"

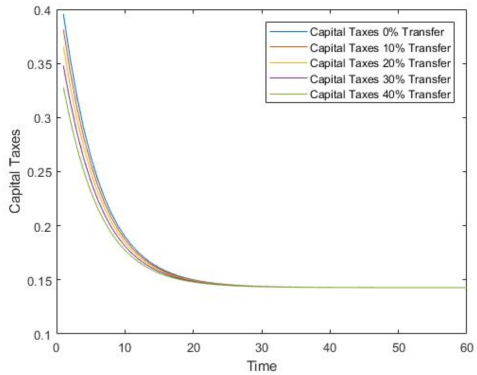
F Appendix: Alternative Equilibrium Definition

Under the assumption that each government initially chooses only part of its fiscal policy, and that one fiscal policy variable $\Theta_t \in \{B_{t+1}, \tau_t^k, \tau_t^n, G_t, I_t\}$ adjusts in each period (and $\Theta_t \neq \{B_{t+1}$ for some t), the Lagrangian is

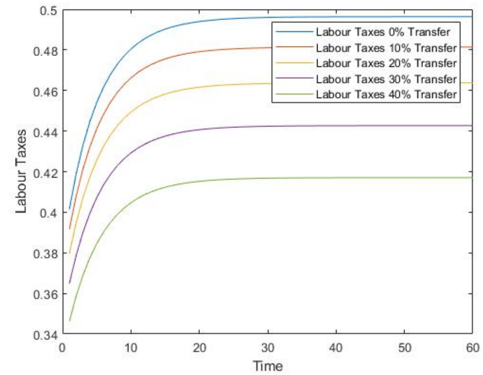
$$
\begin{aligned}
\mathcal{L} = & \sum_{t=0}^{\infty} \beta^t \{u(c_t, l_t, G_t) \qquad \text{(F.1)} \\
& + \psi_t[(1-T)(\tau_t^k r_t K_t + \tau_t^n w_t N_t) + TH(\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*) + \\
& \quad B_{t+1} - G_t - I_t(R_t + \delta) - B_t(1 + R_t)] \\
& + \psi_t^*[(1-T)(\tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*) + T(1-H)(\tau_t^k r_t K_t + \tau_t^n w_t N_t + \tau_t^{k*} r_t^* K_t^* + \tau_t^{n*} w_t^* N_t^*) + \\
& \quad B_{t+1}^* - G_t^* - I_t^*(R_t + \delta) - B_t^*(1 + R_t)] \\
& + \theta_t[(1 - \tau_t^n) w_t N_t + (1 + R_t) a_t - a_{t+1} - c_t] \\
& + \mu_t[(1 - \tau_t^n) w_t u_c(t) - u_l(t)] \\
& + \zeta_t[\beta u_c(t+1)(1 + R_{t+1}) - u_c(t)] \\
& + \theta_t^*[(1 - \tau_t^{n*}) w_t^* N_t^* + (1 + R_t) a_t^* - a_{t+1}^* - c_t^*] \\
& + \mu_t^*[(1 - \tau_t^{n*}) w_t^* u_c^*(t) - u_l^*(t)] \\
& + \zeta_t^*[\beta u_c^*(t+1)(1 + R_{t+1}) - u_c^*(t)] \\
& + \gamma_t[r_t(1 - \tau_t^k) - \delta - R_t] \\
& + \gamma_t^*[r_t^*(1 - \tau_t^{k*}) - \delta - R_t] \\
& + \omega_t[a_t + a_t^* - (K_t + K_t^* + I_t + I_t^* + B_t + B_t^*)]\}.
\end{aligned}
$$

The set of control variables (with Θ_t^* as the adjusting foreign fiscal-policy variable) is

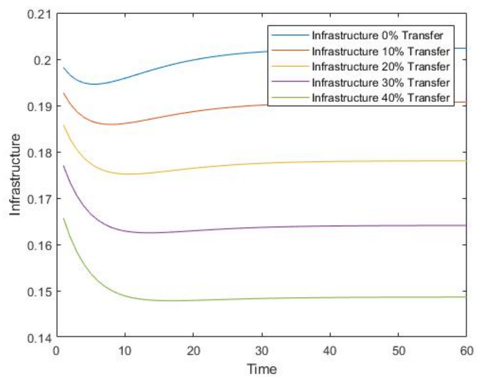
$$
X^{Alt} = \{c_t, c_t^*, N_t, N_t^*, K_t, K_t^*, a_{t+1}, a_{t+1}^*, B_{t+1}, \tau_t^k, \tau_t^n, G_t, \Theta_t^*, I_t, R_t\}_{t=0}^{\infty}. \qquad \text{(F.2)}
$$



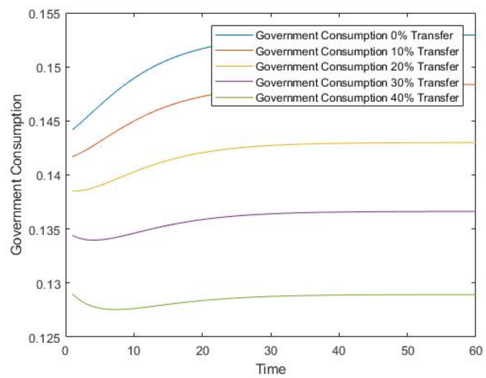
(a) Capital Taxes



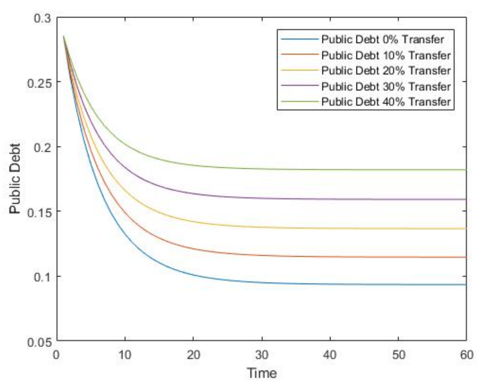
(b) Labour Taxes



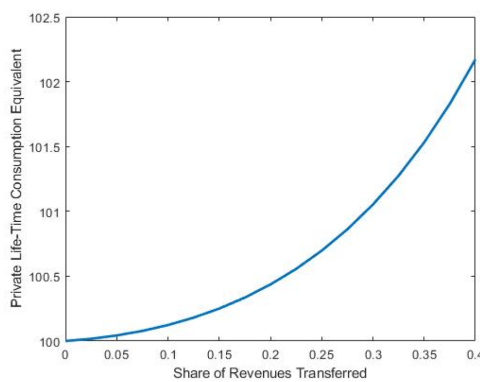
(c) Infrastructure



(d) Government Consumption

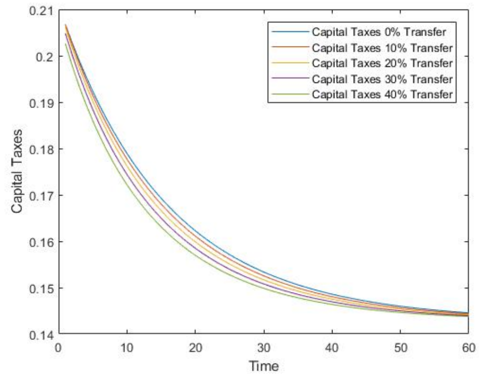


(e) Debt

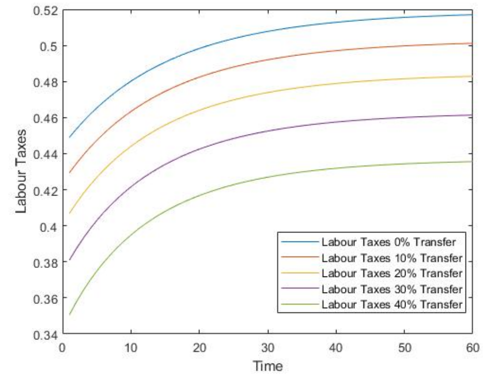


(f) Welfare

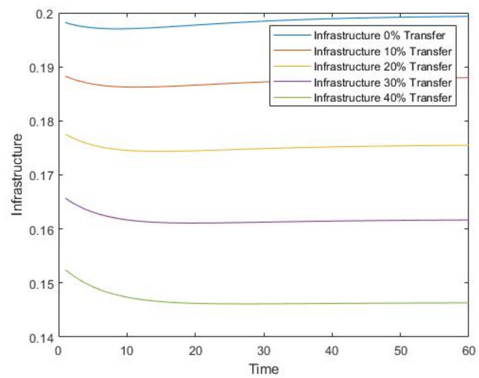
Figure F.1: Policy and Welfare with "Alternative Equilibrium Definition: Labour Taxes"



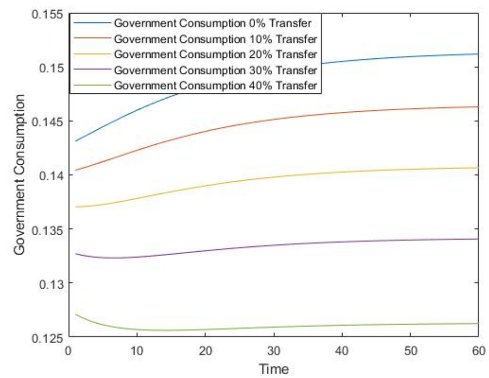
(a) Capital Taxes



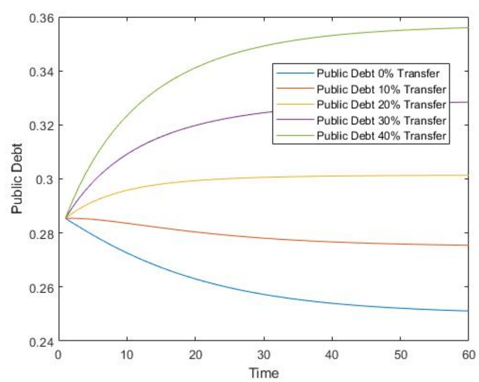
(b) Labour Taxes



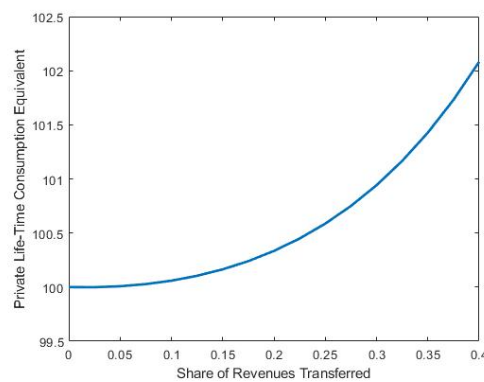
(c) Infrastructure



(d) Government Consumption

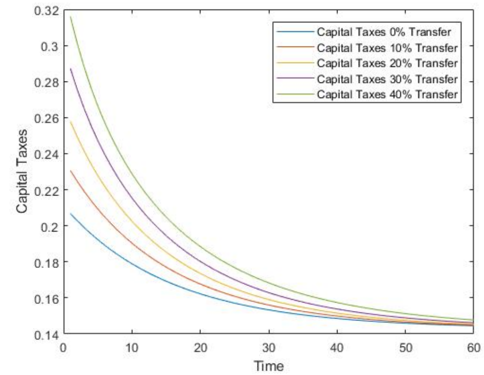


(e) Debt

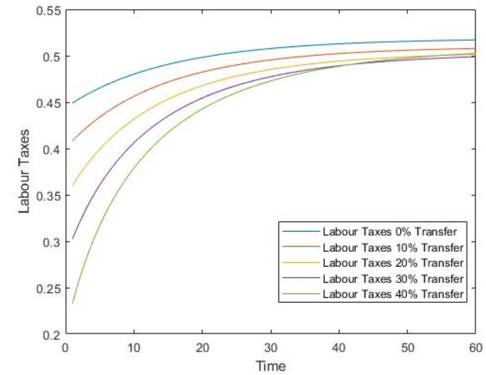


(f) Welfare

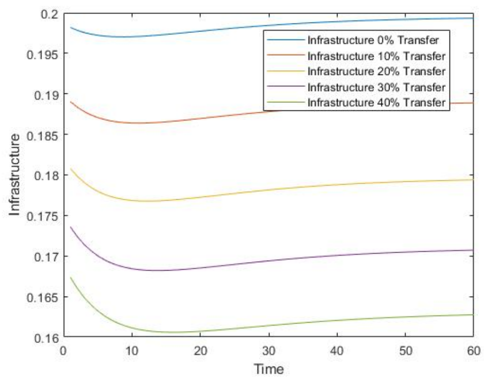
Figure F.2: Policy and Welfare with “Alternative Equilibrium Definition: Capital Taxes”



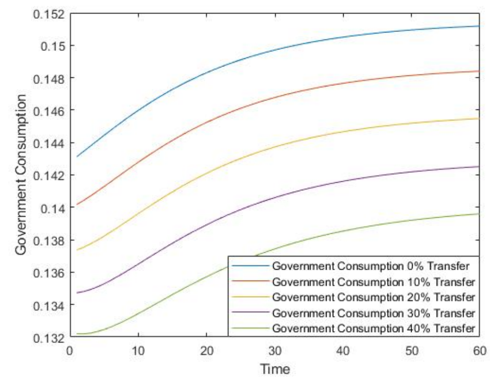
(a) Capital Taxes



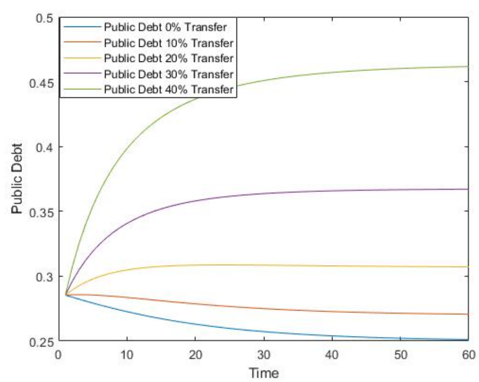
(b) Labour Taxes



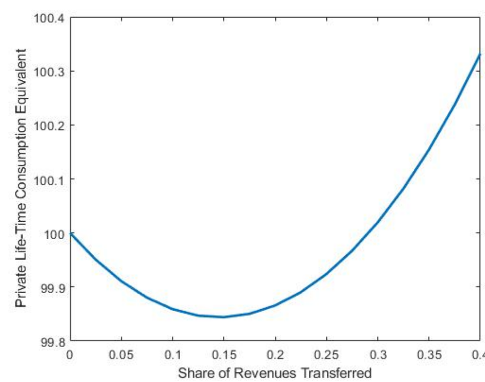
(c) Infrastructure



(d) Government Consumption



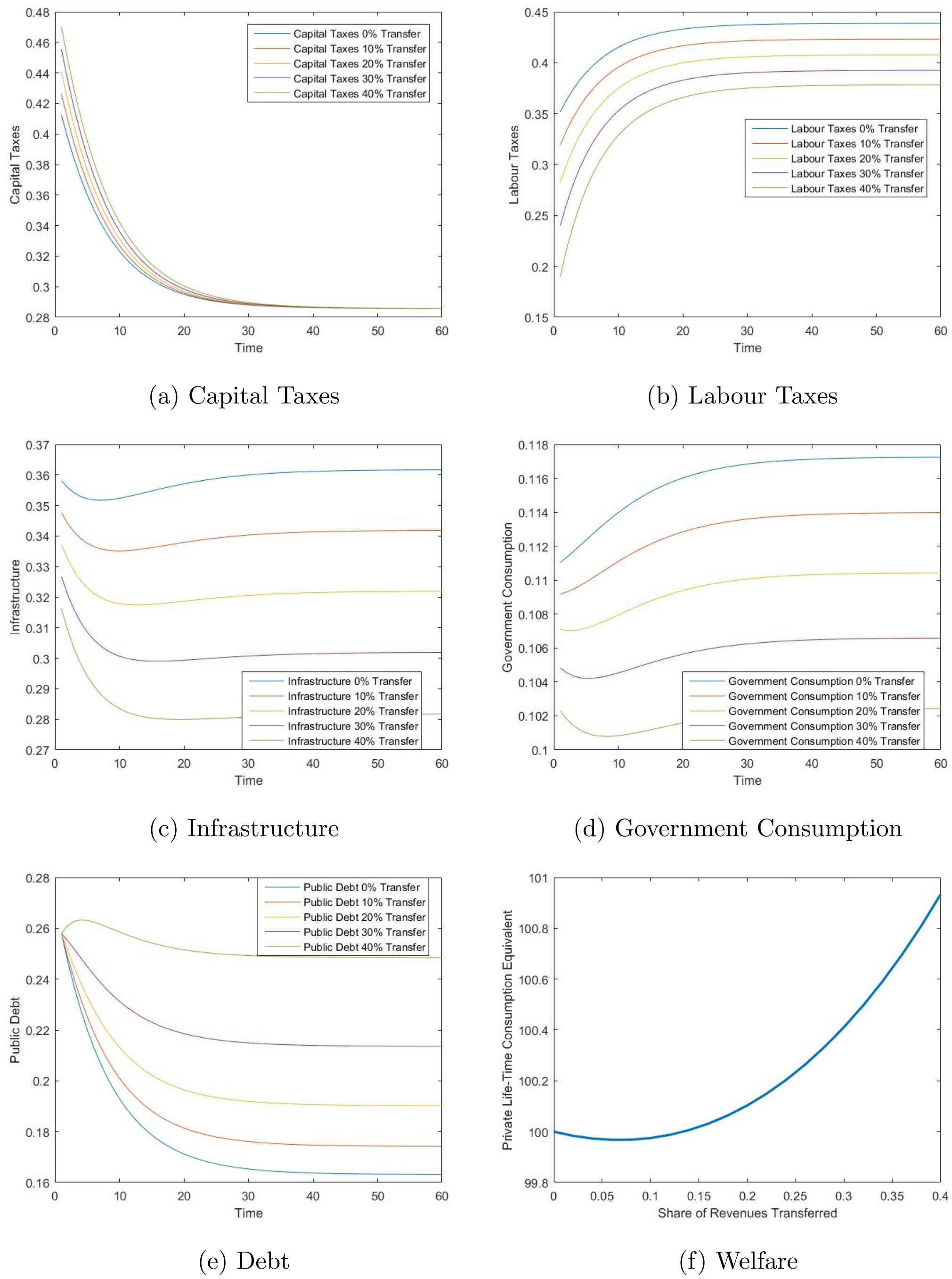
(e) Debt



(f) Welfare

Figure F.3: Policy and Welfare with “Alternative Equilibrium Definition: Infrastructure”

G Appendix: Results from Parameter Robustness Checks



(a) Capital Taxes

(b) Labour Taxes

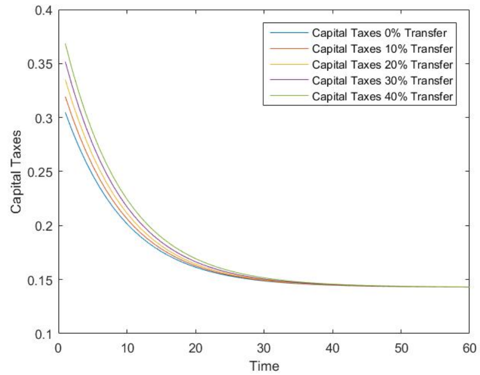
(c) Infrastructure

(d) Government Consumption

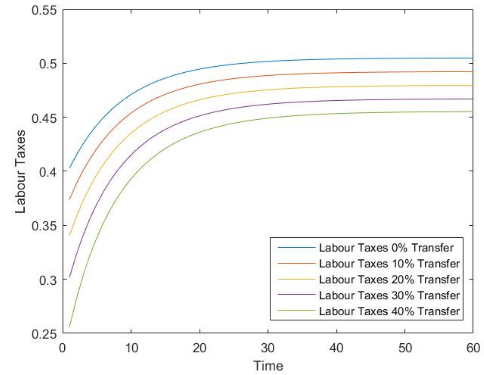
(e) Debt

(f) Welfare

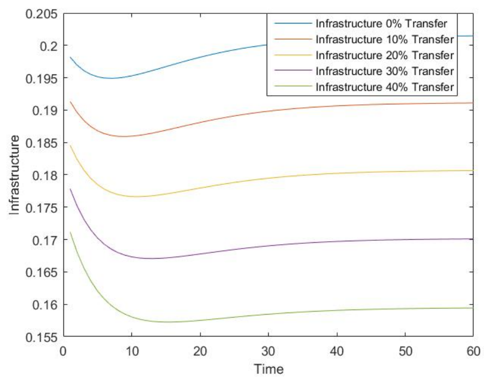
Figure G.1: Policy and Welfare under “High Infrastructure Share”



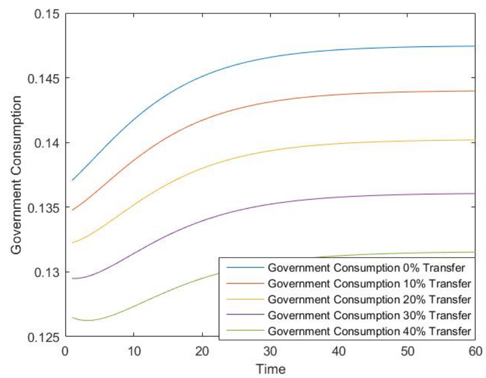
(a) Capital Taxes



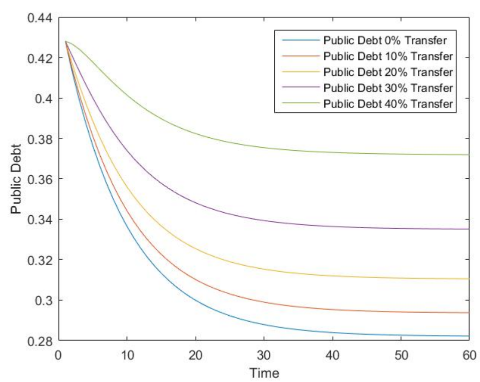
(b) Labour Taxes



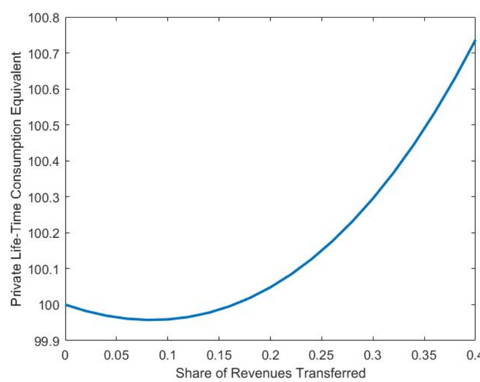
(c) Infrastructure



(d) Government Consumption

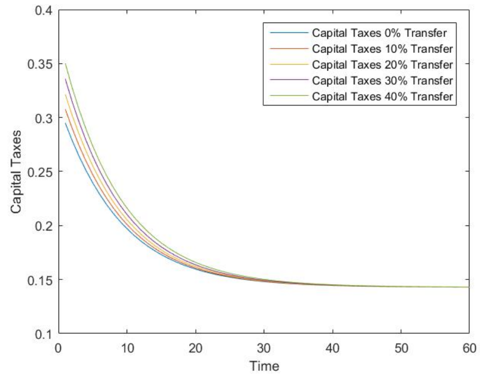


(e) Debt

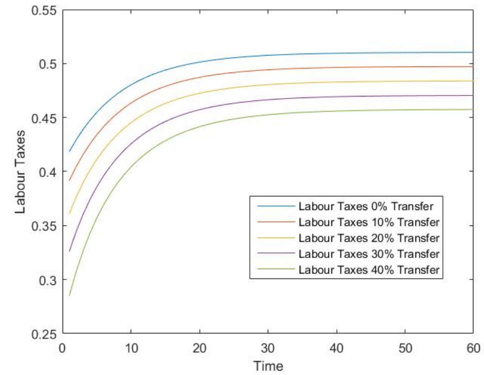


(f) Welfare

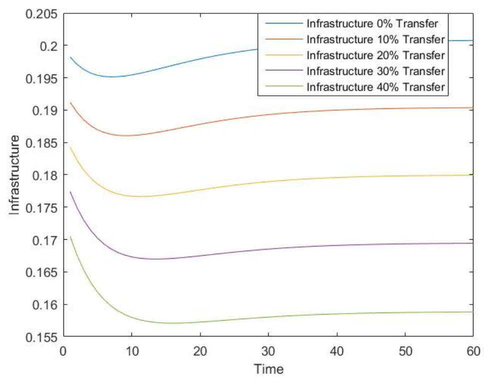
Figure G.2: Policy and Welfare under "High Government Debt"



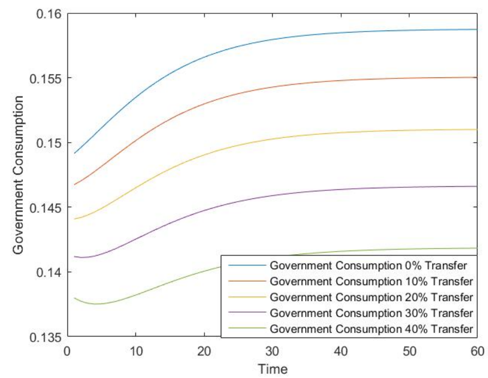
(a) Capital Taxes



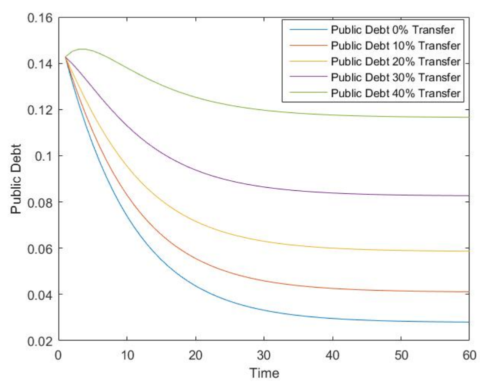
(b) Labour Taxes



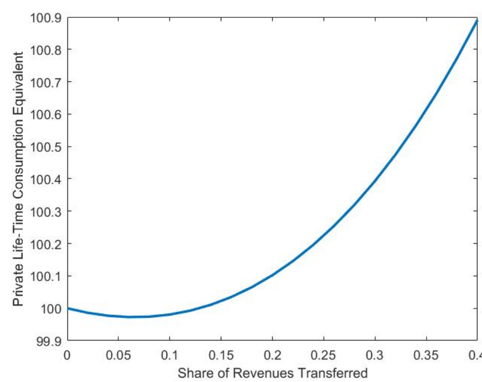
(c) Infrastructure



(d) Government Consumption

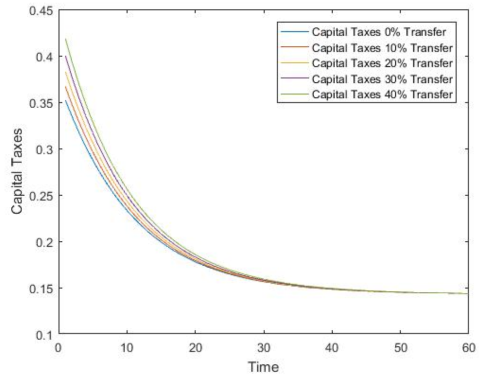


(e) Debt

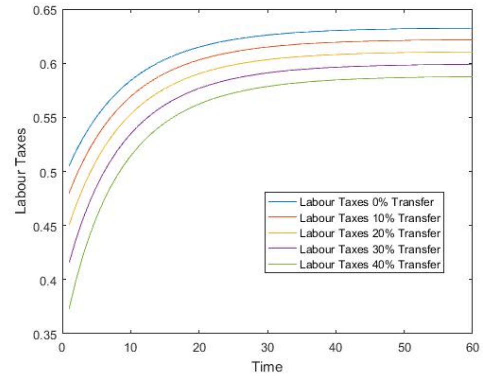


(f) Welfare

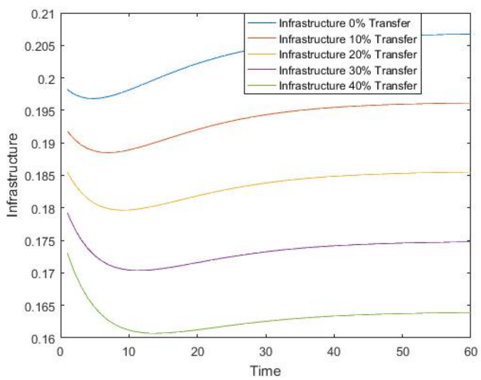
Figure G.3: Policy and Welfare under “Low Government Debt”



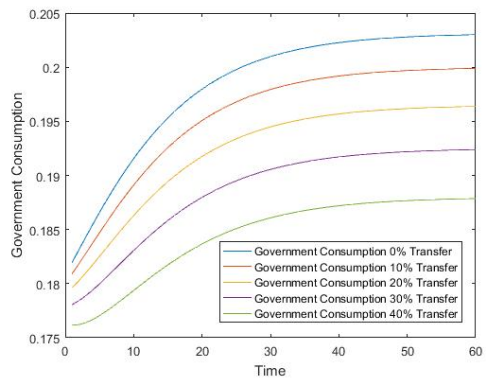
(a) Capital Taxes



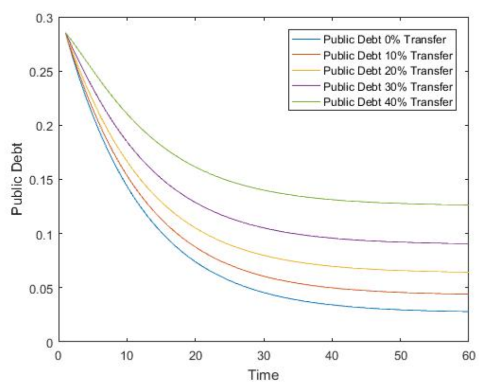
(b) Labour Taxes



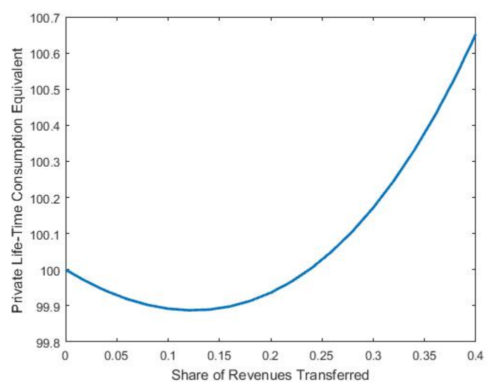
(c) Infrastructure



(d) Government Consumption

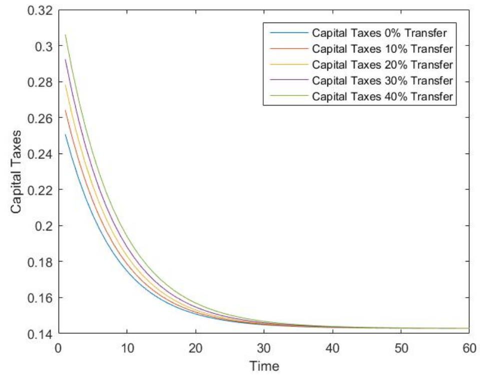


(e) Debt

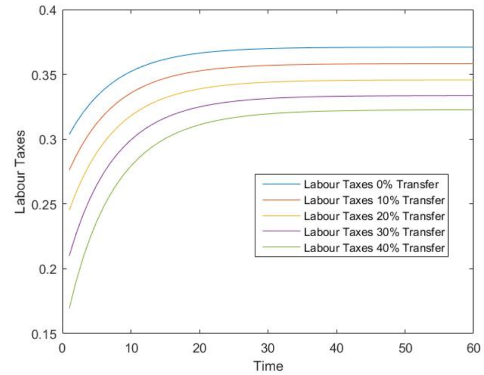


(f) Welfare

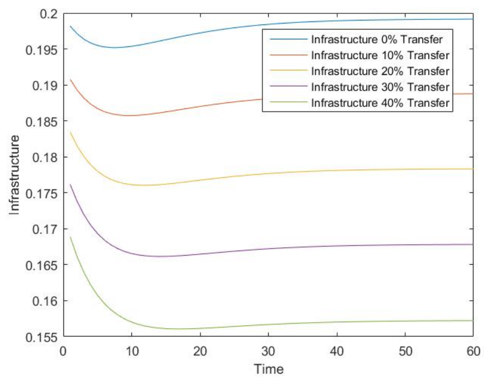
Figure G.4: Policy and Welfare under “High Government Share”



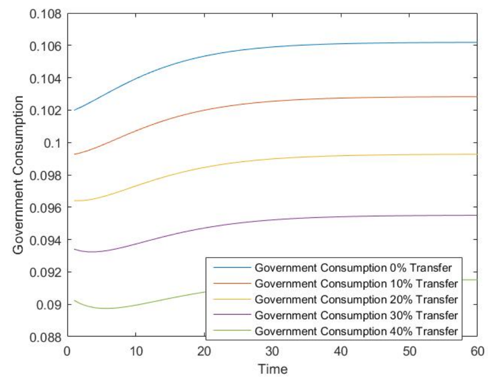
(a) Capital Taxes



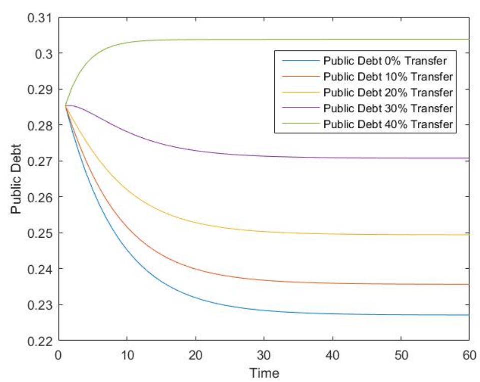
(b) Labour Taxes



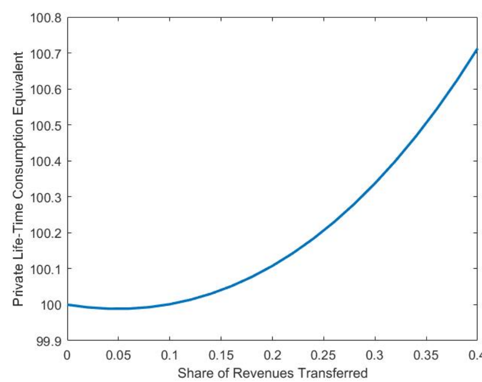
(c) Infrastructure



(d) Government Consumption

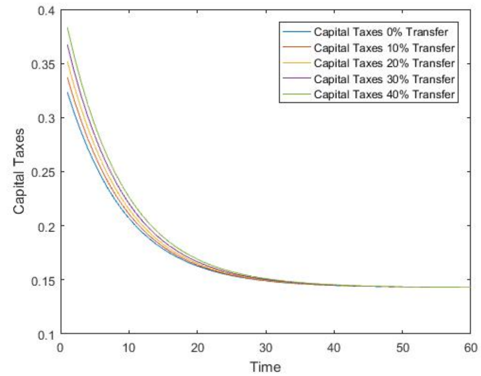


(e) Debt

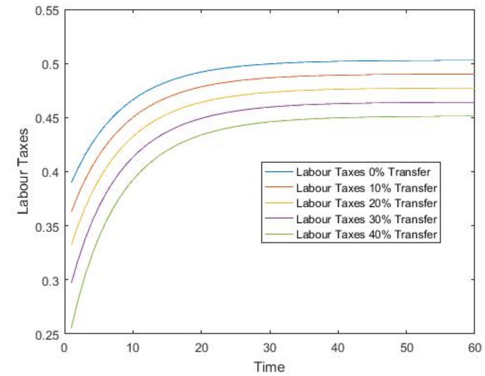


(f) Welfare

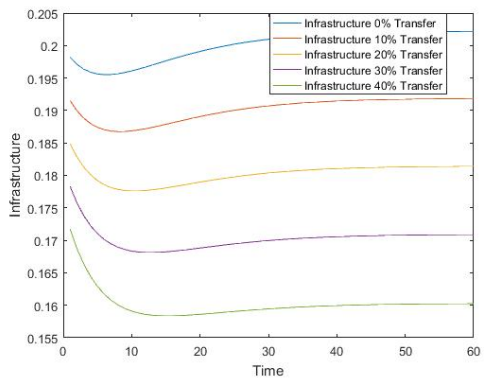
Figure G.5: Policy and Welfare under "Low Government Share"



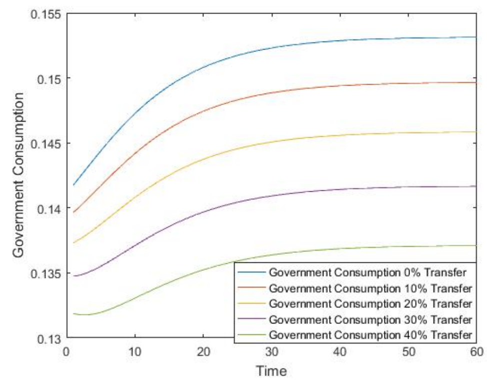
(a) Capital Taxes



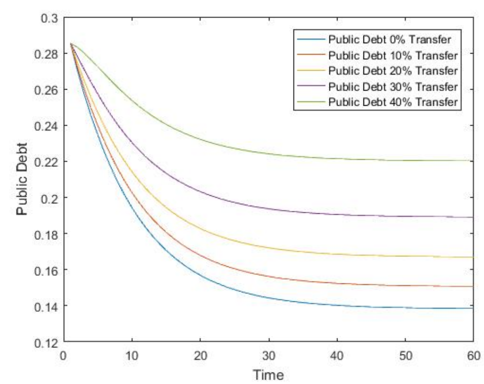
(b) Labour Taxes



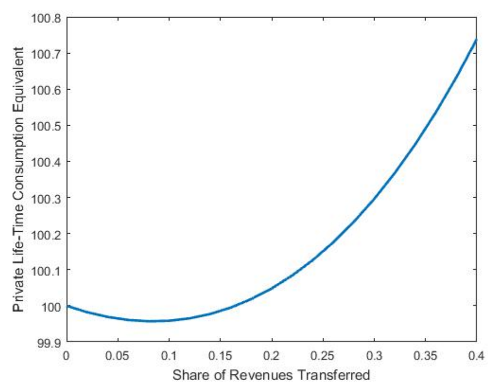
(c) Infrastructure



(d) Government Consumption

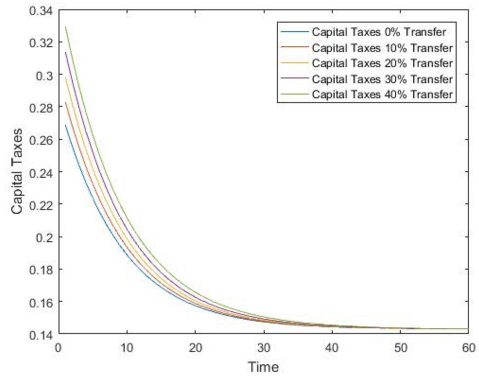


(e) Debt

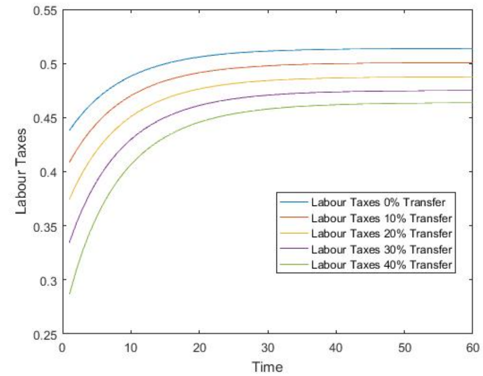


(f) Welfare

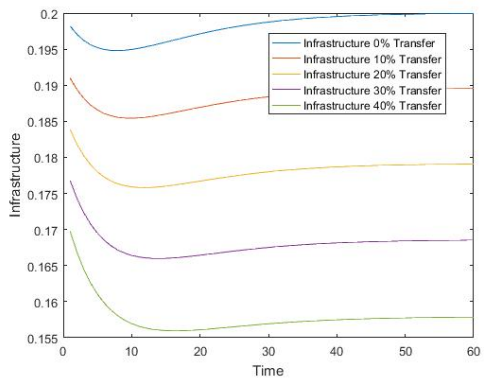
Figure G.6: Policy and Welfare under "High Frisch Elasticity"



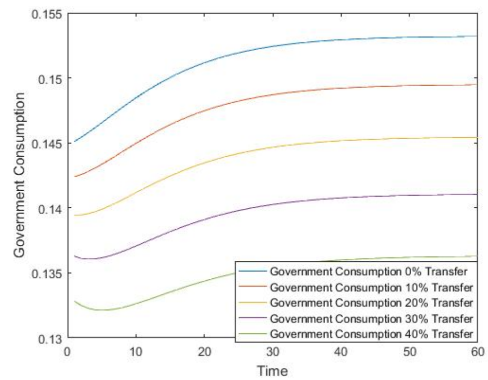
(a) Capital Taxes



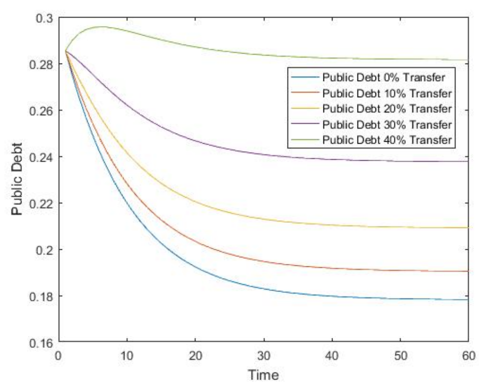
(b) Labour Taxes



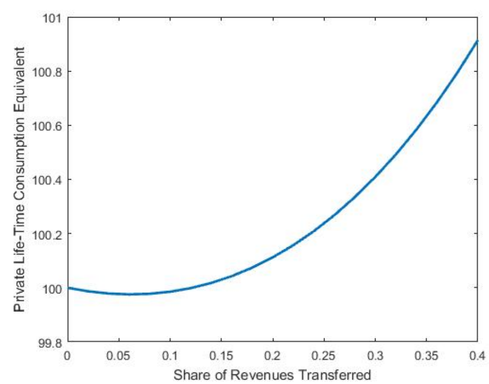
(c) Infrastructure



(d) Government Consumption

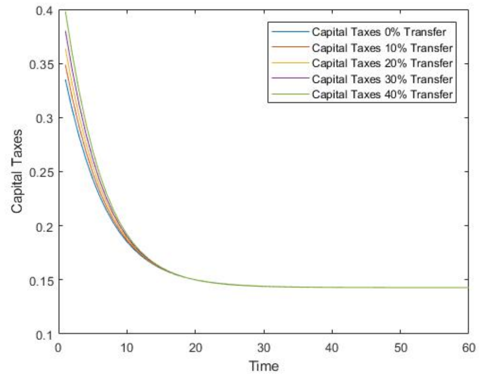


(e) Debt

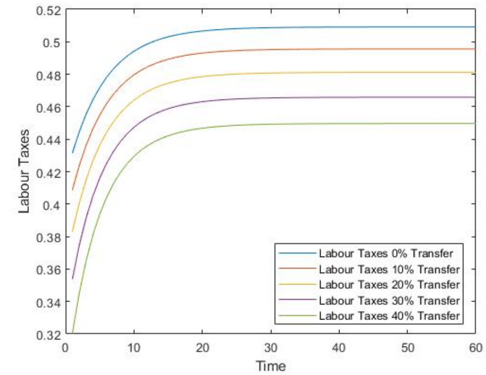


(f) Welfare

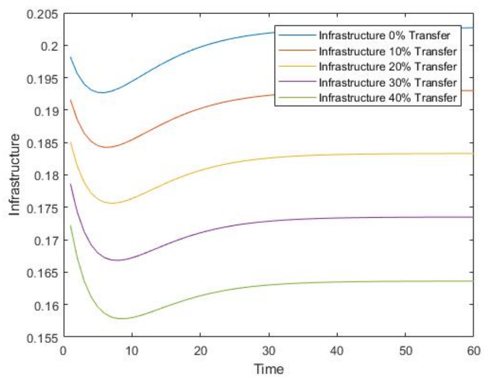
Figure G.7: Policy and Welfare under "Low Frisch Elasticity"



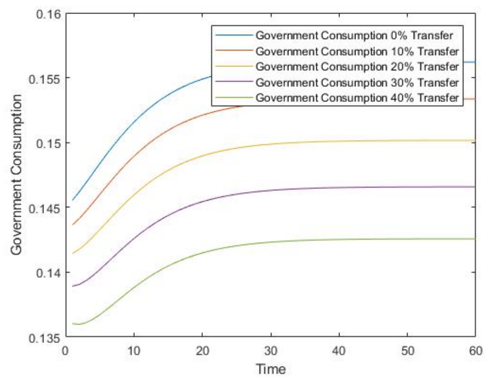
(a) Capital Taxes



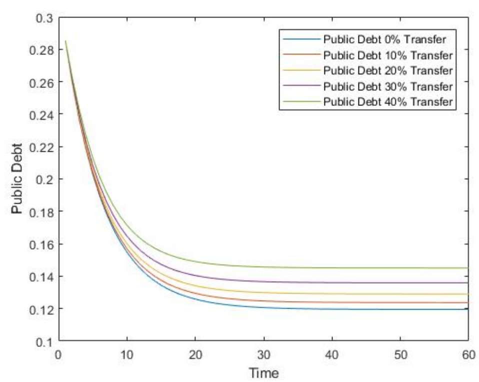
(b) Labour Taxes



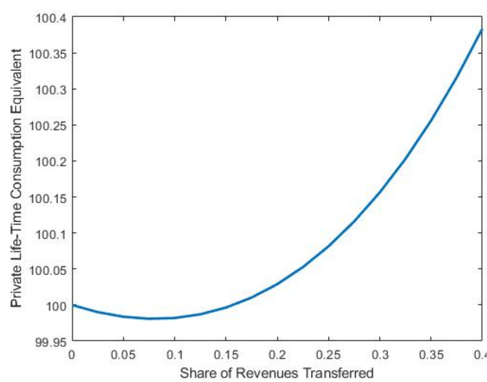
(c) Infrastructure



(d) Government Consumption

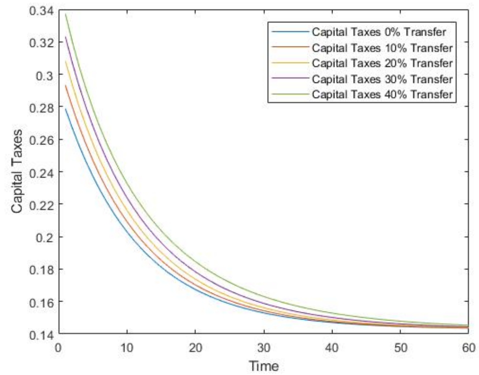


(e) Debt

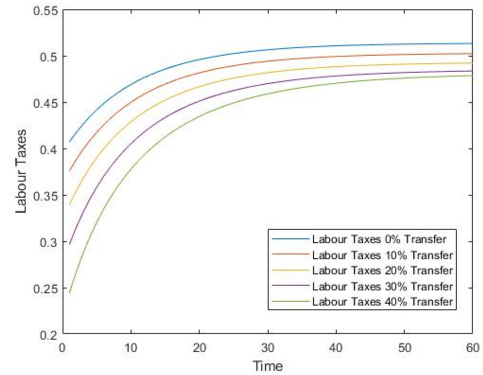


(f) Welfare

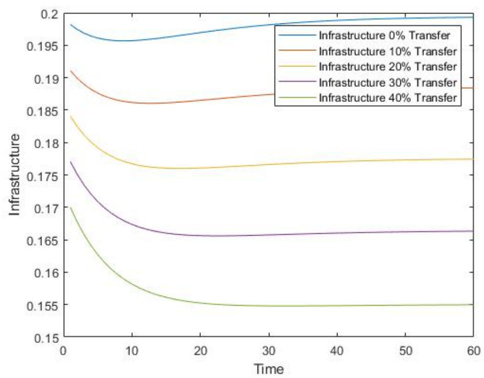
Figure G.8: Policy and Welfare under "High Intertemporal Elasticity"



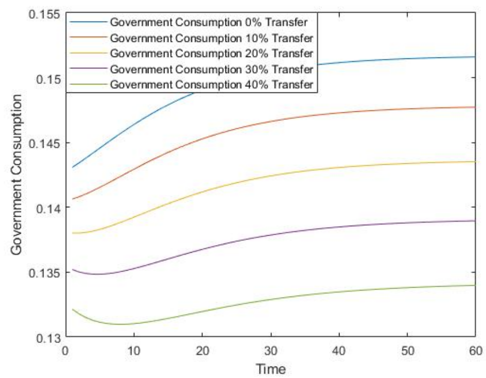
(a) Capital Taxes



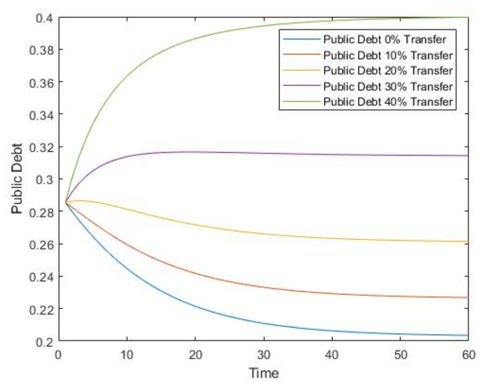
(b) Labour Taxes



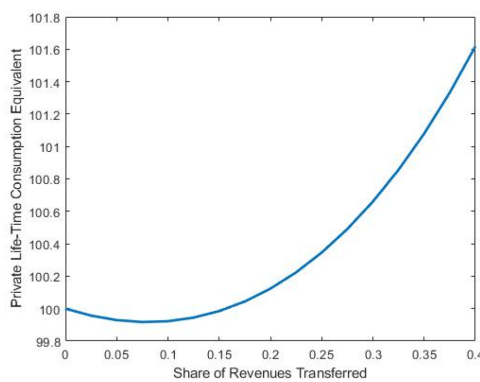
(c) Infrastructure



(d) Government Consumption

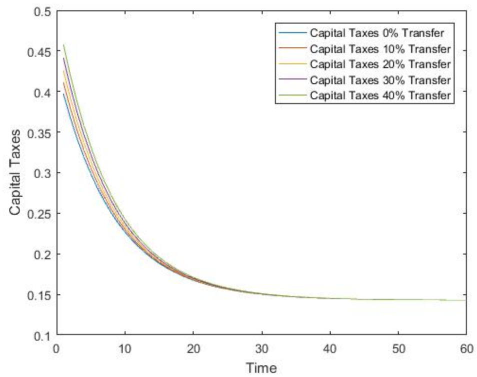


(e) Debt

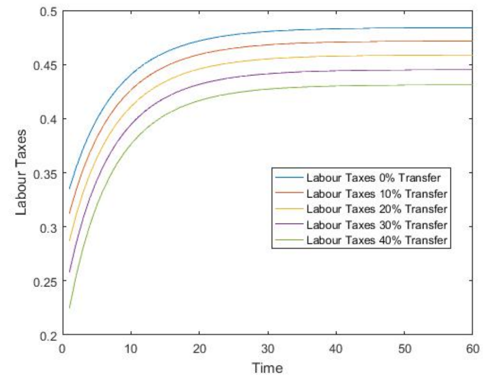


(f) Welfare

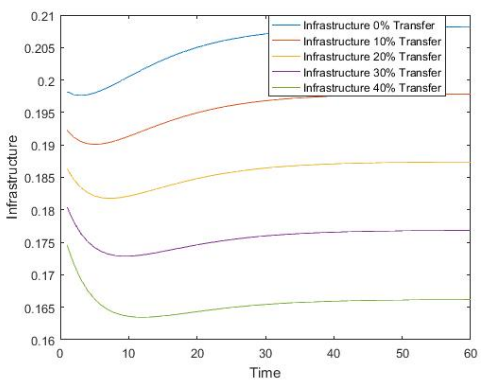
Figure G.9: Policy and Welfare under “Low Intertemporal Elasticity”



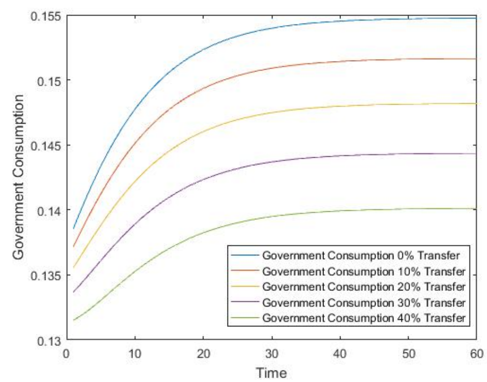
(a) Capital Taxes



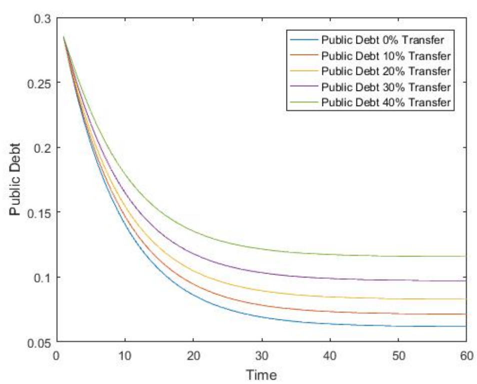
(b) Labour Taxes



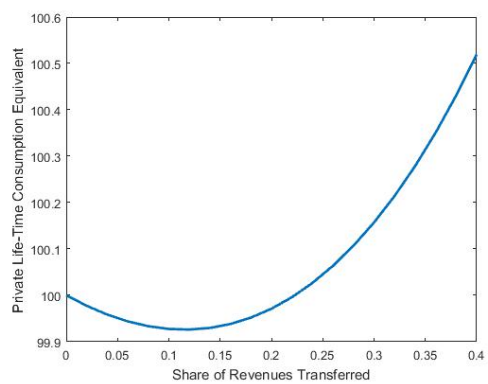
(c) Infrastructure



(d) Government Consumption

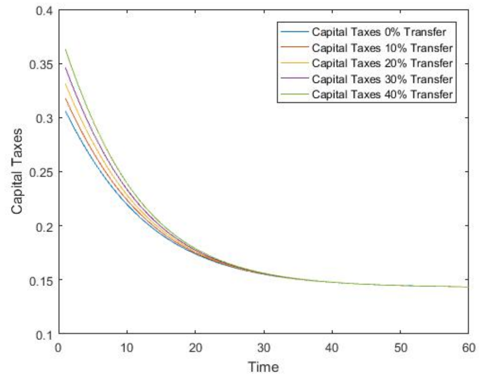


(e) Debt

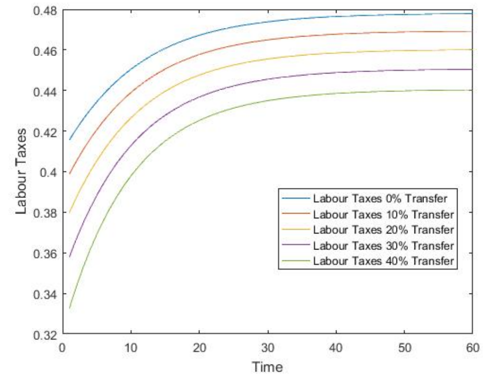


(f) Welfare

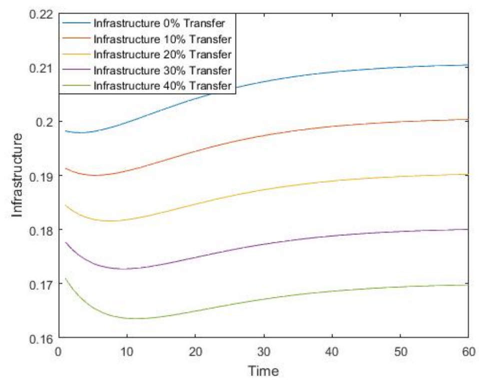
Figure G.10: Policy and Welfare under “Cobb-Douglas Utility”



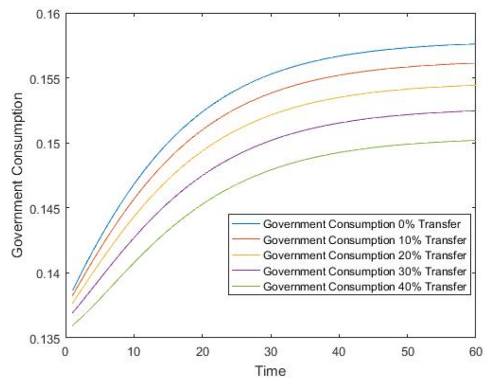
(a) Capital Taxes



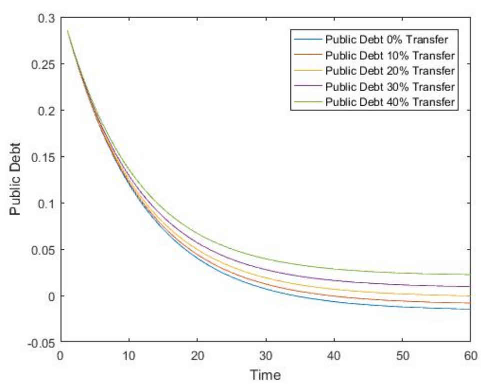
(b) Labour Taxes



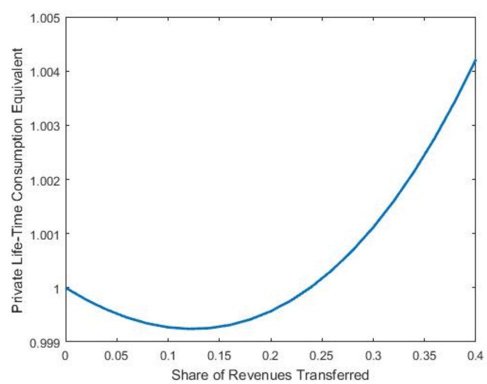
(c) Infrastructure



(d) Government Consumption



(e) Debt



(f) Welfare

Figure G.11: Policy and Welfare under "GHH Utility"