Ramsey Tax Competition with Real Exchange Rate Determination

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Abstract

How should governments choose tax rates when they face competition from other jurisdictions? This question is answered by solving for the equilibrium of the game played between Ramsey planners in a two good, two country open economy macroeconomic model. There are five effects associated with implementing the Ramsey tax plan: tax distortion reduction; population size; debt revaluation; terms-of-trade; and strategic real exchange rate. This last effect is new to the literature and helps explain why the larger country initially sets a higher capital income tax rate than its smaller rival.

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1 Introduction

Governments around the world compete with respect to taxes – chiefly capital income (corporate) taxation. Within Europe, Luxembourg and Ireland are well-known for their low corporate income tax rates. In the U.S., the Tax Cuts and Job Act of 2017 lowered the corporate tax rate from 35% to 21%, and switched from a global to a territorial tax system – both changes arguably designed to bring U.S. corporate taxation policy into line with that of other countries. The question addressed in this paper is: How *should* benevolent governments choose tax rates in the face of tax competition from other countries?

To answer this tax competition question, I start with an off-the-shelf two country, two good open economy macroeconomic model.[1] In the model, goods produced in different countries are imperfect substitutes and so the real exchange rate is endogenous. In each country, the government must finance an exogenous stream of expenditures through distortionary taxes. Sequences of tax rates are chosen in accord with Ramsey taxation principles: taking as given competitive equilibrium behavior, at an initial date, each government commits to sequences of taxes with the initial capital income tax rate fixed.[2] In addition, each planner treats the path of the real exchange rate as a choice variable, although in equilibrium the planners' choices for the real exchange rate must be mutually compatible. Tax competition is the equilibrium of the game played in the initial period between the two Ramsey planners. In other words, the sequence of taxes chosen by the planner in one country are the best response to the taxes chosen by the planner in the other country, and vice versa.

There are five main effects operating in this tax competition environment. First is the *tax distortion reduction effect:* Ramsey planners seek to minimize the tax distortions associated with financing government expenditures; see Chamley (1986), Judd (1985), and the subsequent literature. As is typical of the Ramsey literature, the government initially

[1] While the term 'country' is used throughout the paper, one could alternatively refer to collections of countries (like the European Union), or units within a country (cities or states).

[2] When the initial capital income tax rate can also be chosen, the government will select an initial capital income levy sufficiently large to finance all its spending needs. In the Ramsey taxation literature, this outcome is considered uninteresting.

taxes capital income at a very high rate; in the long run, capital income is not taxed at all. Owing to the high capital income tax revenue early in the Ramsey plan, the government debt-output ratio falls. Whether or not the government lowers other taxes depends on both its expenditures on public goods, and the level of government debt.

Second is the *population size effect*. As pointed out by Bucovetsky (1991), the government of the larger country will compete less vigorously with respect to the capital tax rate, and so will set a higher capital tax rate than its smaller rival. The logic is as follows. The mobile factor of production, capital, will move in order to equate after-tax returns in the two countries. When the government of the larger country raises its capital tax rate, the immediate effect is to lower its after-tax return to capital. Consequently, capital will flow from the larger to the smaller country. However, due to their different population sizes, a given flow of capital has a larger effect on the capital-labor ratio – and ultimately the after-tax return to capital – in the smaller country. As a result, the government of the larger country sees a lower elasticity of tax revenue with respect to the capital income tax rate than does the smaller country. The larger country competes less zealously, and so sets a higher capital tax rate than its smaller rival.

Third is a *debt revaluation effect*. Recalling that, among other things, the Ramsey planners choose the value of the real exchange rate, there is an incentive for the planner of the net foreign debtor country to move the real exchange rate in favor of its residents.[3]

Fourth is the *terms-of-trade effect*. The planner in each country would like to move the terms-of-trade – here, the real exchange rate – in favor of its residents. More specifically, each planner wants to see the price of its imported goods fall, and the price of its exported goods rise.

Finally, there is a *strategic real exchange rate effect*. Particularly important for this effect are events between year 0 (when the Ramsey tax reforms are initiated) and year 1 (the first date at which the capital income tax rate can be adjusted). In the results below, from

[3]Throughout, the real exchange rate is expressed as the number of units of foreign output per unit of home output, and real exchange rate appreciation/depreciation is from the perspective of the home country.

the perspective of the smaller, home country, the real exchange rate initially appreciates, then depreciates. The real exchange rate depreciation lowers the exchange rate-adjusted after-tax return to home capital, and equality of the return to capital in the two countries is restored, in part, through a higher foreign capital income tax rate, and a lower home tax rate. The higher foreign capital income tax rate directly aids foreign households since the extra tax revenue lowers foreign government debt and so future tax distortions. The lower home capital income tax rate also benefits foreign households, albeit indirectly. To see why, notice that with both countries enacting Ramsey tax reforms at the same time, households in both countries simultaneously experience positive wealth effects associated with lower overall tax distortions. As a result, both home and foreign households wish to increase their consumption (both are competing for scarce output) and reduce their time spent working (making output even scarcer). A smaller increase in the year 1 home capital income tax rate means that the home government debt does not fall as much, and so future tax distortions cannot be reduced as much. The net effect of a smaller increase in the home capital income tax rate is to reduce the size of the home households' wealth effect. In turn, this smaller wealth effect benefits foreign households by reducing competition for output (through a smaller increase in desired home consumption) and increasing available output (a smaller decline in home hours worked). This mechanism by which the planer of the larger, foreign country uses the path of the real exchange rate to influence fiscal policy of its smaller rival appears to be new to the tax competition literature.

The net contribution of these effects is best understood by being more specific about some details of the two country open economy environment studied below. To afford comparability with the early work on dynamic tax competition by Mendoza and Tesar (2005), the home country corresponds to the United Kingdom (UK) while the foreign country is the European Union (EU). Consequently, the home country is much smaller than the foreign one; it initially taxes capital income at a higher rate, and labor income at a lower rate; and the home country is a net foreign debtor.

That the year 1 capital income tax rate is higher in the larger foreign country is consistent with both the population size effect from the microeconomics literature as well as the strategic exchange rate effect discussed above. To see that both effects are in play, I present results showing that the home country's year 1 capital income tax rate falls with openness. Indeed, when the home country is very open, this tax rate actually falls – a phenomenon that is difficult to reconcile through the population size effect alone. Of course, the strategic exchange rate effect "works" only if the planner of the larger, foreign country dominates the setting of the real exchange rate. Results from Auray, Eyquem, and Gomme (2018) suggest that this is the case. In particular, they look at Ramsey-optimal taxation in a small open economy environment in which the strategic taxation elements are necessarily absent. Auray, Eyquem, and Gomme find that the real exchange rate initially depreciates, followed by an appreciation. In other words, they find an exchange rate dynamic that is the opposite of that found for the two country environment studied here. This result strongly suggests that it is, indeed, the foreign planner who tends to prevails in setting the real exchange rate.

Are there other reasons why the foreign planner might wish to engineer a real exchange rate appreciation? Since the home country is initially a net foreign debtor, a real exchange rate appreciation implies a debt revaluation effect that benefits home households. The real exchange rate appreciation also means that the terms of trade change in the favor of home households. This leaves the strategic real exchange rate effect as the most plausible reason for the foreign planner to prefer the predicted real exchange rate dynamics.

Further evidence in support of the presence of the strategic real exchange rate effect is gleaned from considering the tax cooperation case in which a single world Ramsey planner maximizes a weighted sum of the two households' lifetime utility subject to: the competitive equilibrium conditions, present value government budget constraints, and international solvency condition. When the two governments cooperate in this way, the capital income tax rate is higher in both countries, but the increase in the smaller home country is much larger than that seen in the larger foreign country. Crucially, in the first year, the real exchange

rate appreciation in much smaller than in the tax competition environment. Indeed, under tax cooperation, the real exchange rate appreciates for the first two years of the Ramsey plan before starting to depreciate; in the tax competition case, the depreciation starts in the second year.

This paper fits into the macroeconomic tax competition literature. Mendoza and Tesar (2005) made an early contribution to this literature. There are two key differences between their paper and mine. First, in their model, there is but one good produced in the world. Consequently, the real exchange rate is necessarily fixed at one. Second, Mendoza and Tesar look to the equilibrium of a game in which benevolent planners commit to a constant capital income tax rate with the present value government budget constraint satisfied by either a constant labor income tax, or a constant consumption tax. In other words, their planners are restricted relative to Ramsey planners who choose entire time paths for tax rates.

More recently, Ramsey planners have been introduced to the Mendoza and Tesar environment with Gross (2014) developing the game theoretic underpinnings (discussed in more detail in Section 3), and Gross, Klein, and Makris (2017) presenting quantitative implications. Consequently, like Mendoza and Tesar, these authors have a fixed real exchange rate (owing to the single good assumption), thereby precluding the strategic manipulation of the real exchange rate by the planners. They find that the optimal paths for the capital income tax rate gradually and monotonically declines to zero which differs from the small open economy finding of Correia (1996) that this tax rate should immediately fall to zero. As shown in Auray, Eyquem, and Gomme (2018) fixing the real exchange rate, as is implicit in one good open economy models, is far from innocuous. They find that in a small open economy, allowing for an endogenous real exchange rate leads to tax dynamics that are more similar to that seen in the closed economy literature than Correia's immediate fall in the capital income tax.

The two country open economy model is described in Section 2 and the Ramsey problem is developed in Section 3. The model is calibrated in Section 4, and numerical results for

the Ramsey plan presented in Section 5. The welfare implications of Ramsey tax reforms are discussed in Section 6. Some final remarks are in Section 7.

2 Economic Environment

The "world" consists of two large open economies. The home country is of size n while the foreign country is of size $1-n$. Each country is populated by a continuum of infinitely lived households, a continuum of firms, and a benevolent government. Except where noted, the two countries are symmetric and so attention is focused on the home country; foreign variables are distinguished by an asterisk superscript.

2.1 Households

At the start of a period, the household holds physical (home) capital, k_{t-1}, home government debt, d_{t-1}, and net foreign assets, a_{t-1}. While ownership of home capital and home government debt is restricted to home household, this restriction is rendered innocuous by invoking complete international asset markets.

The representative household in the home country receives utility from consumption of its own good good, c_{ht}, consumption of the foreign good, c_{ft}, and disutility from working, h_t. The household's Lagrangian is

$$\mathcal{L} = \max_{\{c_t,h_t,k_t,d_t,a_t\}} \sum_{t=0}^{\infty} \beta^t \Bigg\{ U(c_{ht}, c_{ft}, h_t) + \xi_t \left[(1-\tau_{wt}) w_t h_t + R_{kt} k_{t-1} + d_{t-1} + e_t a_{t-1} - (1+\tau_{ct}) c_{ht} - (1+\tau_{mt}) e_t c_{ft} - k_t - \frac{d_t}{R_{dt}} - e_t \frac{a_t}{R_{at}} \right] \Bigg\} \tag{1}$$

with the gross return to capital given by $R_{kt} \equiv 1+(1-\tau_{kt})(r_t-\delta)$. τ_{wt}, τ_{kt} are factor income tax rates; τ_{ct} and τ_{mt} are tax rates on the locally produced consumption goods and imports, respectively; w_t and r_t are factor prices; e_t is the real exchange rate, expressed as the number

of units of domestic output per unit of foreign output; R_{dt} and R_{at} are, respectively, the gross real return to (domestic) government debt and net foreign assets. In (1), net foreign assets are denominated in units of foreign output, hence the real exchange rate terms; in the foreign household budget constraint, the real exchange rate terms associated with net foreign assets do not appear.

The household's first-order conditions are:

$$c_{ht}: \quad U_1(c_{ht}, c_{ft}, h_t) = \xi_t(1+\tau_{ct}) \tag{2}$$

$$c_{ft}: \quad U_2(c_{ht}, c_{ft}, h_t) = \xi_t(1+\tau_{mt})e_t \tag{3}$$

$$h_t: \quad U_3(c_{ht}, c_{ft}, h_t) + \xi_t(1-\tau_{wt})w_t = 0 \tag{4}$$

$$k_t: \quad \xi_t = \beta\xi_{t+1}R_{k,t+1} \tag{5}$$

$$d_t: \quad \frac{\xi_t}{R_{dt}} = \beta\xi_{t+1} \tag{6}$$

$$a_t: \quad \frac{e_t\xi_t}{R_{at}} = \beta e_{t+1}\xi_{t+1} \tag{7}$$

Later, the set of no-arbitrage conditions on returns implied by (5)–(7) will prove useful:

$$R_{k,t+1} = R_{dt} = \frac{e_{t+1}R_{at}}{e_t}. \tag{8}$$

The problem of the foreign household is presented in full in Appendix A.1.

2.2 Domestic Firms

Goods producing firms are perfectly competitive and face a sequence of static profit maximization problems:

$$\max_{k_{t-1},h_t} \left\{F(k_{t-1}, h_t) - r_t k_{t-1} - w_t h_t\right\}. \tag{9}$$

The associated first-order conditions are

$$r_t = F_1(k_{t-1}, h_t) \text{ and } w_t = F_2(k_{t-1}, h_t). \tag{10}$$

2.3 Government

The Ramsey problem will be considered shortly. For now, it suffices to note that the government faces a sequence of budget constraints,

$$\frac{d_t}{R_{dt}} - d_{t-1} = \underbrace{g - \tau_{ct}c_{ht} - \tau_{mt}e_t c_{ft} - \tau_{wt}w_t h_t - \tau_{kt}r_t k_{t-1}}_{\text{PRDEF}_t} \tag{11}$$

where the right-hand side is the government primary deficit. In order to focus on taxation, government expenditures, g, are assumed to be constant. The government is also subject to the usual transversality condition on its debt.

Alternatively, (11) can be solved forward; applying the transversality condition then delivers the present value form on the government budget constraint,

$$d_{-1} + \sum_{t=0}^{\infty}\left(\prod_{j<t}\frac{1}{R_{dj}}\right)\text{PRDEF}_t = 0. \tag{12}$$

A *feasible fiscal policy* consists of a path for the tax rates that satisfies the present value constraint, (12).

2.4 Balance of Payments

The home country balance of payments equation is

$$\underbrace{\frac{1-n}{n}c^*_{ht} - e_t c_{ft}}_{\text{TB}_t} + e_t a_{t-1} - \frac{e_t a_t}{R_{at}} = 0 \tag{13}$$

where the first two terms constitute the trade balance (notice that c^*_{ht} is per capita consumption of the home good by foreign households). Solving (13) forward and applying the transversality on home net foreign assets yields the international solvency condition,

$$a_{-1} + \sum_{t=0}^{\infty}\left(\prod_{j<t}\frac{1}{R_{aj}}\right)\frac{\text{TB}_t}{e_t} = 0. \tag{14}$$

2.5 Competitive Equilibrium

Given a feasible home fiscal policy, $\{\tau_{ct}, \tau_{mt}, \tau_{wt}, \tau_{kt}\}_{t=0}^{\infty}$, and a feasible foreign fiscal policy, $\{\tau_{ct}^*, \tau_{mt}^*, \tau_{wt}^*, \tau_{kt}^*\}_{t=0}^{\infty}$, a *competitive equilibrium* is given by a set of home quantities, $\{c_{ht}, c_{ft}, h_t, k_t, d_t, a_t\}_{t=0}^{\infty}$, a set of foreign quantities, $\{c_{ht}^*, c_{ft}^*, h_t^*, k_t^*, d_t^*, a_t^*\}_{t=0}^{\infty}$, returns, $\{R_{dt}, R_{dt}^*, R_{at}\}_{t=0}^{\infty}$, and prices, $\{r_t, w_t, r_t^*, w_t^*, e_t\}_{t=0}^{\infty}$, such that

1. The quantities for the home households solve their problem given prices and government policy; the same for foreign households.

2. The quantities for the home firms solve their problems given prices; the same for foreign firms.

3. The international risk-sharing condition holds:[4]

$$e_t \xi_t = \vartheta \xi_t^*. \tag{15}$$

4. Markets clear: goods markets (recall that n is the size of the home country, and so $1-n$ the size of the foreign country)

$$c_{ht} + \frac{1-n}{n} c_{ht}^* + k_t + g = F(k_{t-1}, h_t) + (1-\delta)k_{t-1} \tag{16}$$

$$c_{ft}^* + \frac{n}{1-n} c_{ft} + k_t^* + g^* = F(k_{t-1}^*, h_t^*) + (1-\delta)k_{t-1}^* \tag{17}$$

standard factor market clearing conditions, and the balance of payments condition, (14). Given the present value constraints, (12) and (14) (and corresponding constraints for the foreign economy), there is no need to include bond market clearing conditions.

[4]The international risk-sharing condition is obtained by combining the home first-order condition for net foreign assets, (7), with the corresponding equation for foreign households, then iterating back in time. ϑ is a constant given by initial conditions, and typically involves a ratio of the marginal utility of consumption for home households to that of foreign households.

3 The Ramsey Problem

Relative to the closed economy setting, the international dimension introduces a number of additional considerations. The remainder of this section works through these issues.

As in Mendoza and Tesar (2005), Gross (2014) and Gross, Klein, and Makris (2017), the benevolent government planners in each country fully and credibly commit to tax policies starting from $t = 0$. Tax rates are the equilibrium of the game played between the two planners. Whereas Mendoza and Tesar restrict attention to tax rates that are constant starting at $t = 0$, here each planner chooses time paths for tax rates as in the Ramsey optimal taxation literature generally, and Gross and Gross, Klein, and Makris more specifically. Each planner also treats the real exchange rate as a choice variable, and it is the endogenous exchange rate that distinguishes the economic environment studied here from that of Gross and Gross, Klein, and Makris.

Solving the Ramsey problem is easier if the product of the interest rate terms in the international solvency condition, (14), and the present value government budget constraint, (12), are eliminated. To do so, use the household's first-order condition with respect to net foreign assets, (7) to rewrite (14) as

$$e_0 \xi_0 a_{-1} + \sum_{t=0}^{\infty} \beta^t \xi_t \text{TB}_t = 0. \tag{18}$$

Similarly, use the household's first-order condition with respect to government debt, (6), to substitute out for the interest rate on government debt in (12) to arrive at

$$\xi_0 d_{-1} + \sum_{t=0}^{\infty} \beta^t \xi_t \text{PrDef}_t = 0. \tag{19}$$

The expressions in (18) and (19) are easier to work with since they are *linear* in the Lagrange multiplier associated with the home household's budget constraint, ξ_t.[5]

As is common in the Ramsey literature, the government has an excess of tax instruments

[5] I use a quasi-Newton method to solve for time paths of the model. Such methods require the Jacobian (matrix of partial derivatives) of the relevant equations. (18) and (19) allow the Jacobian to be written as a band diagonal matrix which is computationally less burdensome than a matrix that is simply sparse.

at its disposal. In particular, eliminating the common Lagrange multiplier from the home household's first-order conditions, (2)–(5), leaves three equations that can be used to determine three of the four tax rates. One of the four taxes must be set exogenously; to this end, assume that the consumption tax (τ_{ct}) is constant. In this case, use (2) to solve out for the multiplier ξ_t.

As in Gross (2014), tax competition occurs within a generalized game. Particularly important are the constraints faced by each planner. Gross argues that the strategies of, say, the home planner must be defined for all possible actions of the foreign planner, not just for feasible actions. Specifically, home planner strategies must be specified for foreign planner actions that violate the foreign government budget constraint. Since the home planner must entertain the possibility that the foreign planner may violate its government budget constraint, it follows that the home planner is constrained by the foreign households' budget constraints, not foreign feasibility. This is the approach adopted in Gross, Klein, and Makris (2017), and also here.

Finally, the home Ramsey planner's problem can be cast. In specifying the home Ramsey planner's problem, notice that domestic fiscal policy is now given by $\{\tau_{mt}, \tau_{wt}, \tau_{k,t+1}\}_{t=0}^{\infty}$; foreign fiscal policy is $\{\tau_{mt}^*, \tau_{wt}^*, \tau_{k,t+1}^*\}_{t=0}^{\infty}$; and the private sector allocation is given by $\{c_{ht}, c_{ft}, h_t, k_t, c_{ht}^*, c_{ft}^*, h_t^*, k_t^*, e_t\}_{t=0}^{\infty}$. Use (10) to eliminate factor prices in the household's first-order conditions. Given the foreign planner's fiscal policy, the home Ramsey planner's

problem is to choose home fiscal policy and the private sector allocation to maximize

$$
\begin{aligned}
\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \Bigg\{ & U(c_{ht}, c_{ft}, h_t) \\
& + \lambda_{1t} \left[F(k_{t-1}, h_t) + (1-\delta)k_{t-1} - c_{ht} - \frac{1-n}{n} c^*_{ht} - k_t - g \right] \\
& + \lambda_{2t} \left[\frac{e_t U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_{mt}} \right] \\
& + \lambda_{3t} \left[U_3(c_{ht}, c_{ft}, h_t) + \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} (1-\tau_{wt}) F_2(k_{t-1}, h_t) \right] \\
& + \lambda_{4t} \left[\beta \frac{U_1(c_{ht+1}, c_{ft+1}, h_{t+1})}{1+\tau_c} \left[1 + (1-\tau_{k,t+1}) \left(F_1(k_t, h_{t+1}) - \delta \right) \right] - \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \right] \\
& + \lambda_{5t} \left[e_t \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \vartheta \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} \right] \\
& + \lambda_{6t} \Bigg[(1-\tau^*_{wt}) F_2(k^*_{t-1}, h^*_t) h^*_t + \left[1 + (1-\tau^*_{kt}) \left(F_1(k^*_{t-1}, h^*_t) - \delta \right) \right] k^*_{t-1} + d^*_{t-1} + a^*_{t-1} \\
& \qquad - (1+\tau^*_{mt}) \frac{c^*_{ht}}{e_t} - (1+\tau^*_{ct}) c^*_{ft} - k^*_t - \frac{d^*_t}{R^*_{dt}} - \frac{a^*_t}{R_{at}} \Bigg] \\
& + \lambda_{7t} \left[\frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} - \frac{e_t U^*_1(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_{mt}} \right] \\
& + \lambda_{8t} \left[U^*_3(c^*_{ht}, c^*_{ft}, h^*_t) + \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} (1-\tau^*_{wt}) F_2(k^*_{t-1}, h^*_t) \right] \\
& + \lambda_{9t} \left[\beta \frac{U^*_2(c^*_{ht+1}, c^*_{ft+1}, h^*_{t+1})}{1+\tau^*_c} \left[1 + \left(1 - \tau^*_{k,t+1} \right) \left(F_1(k^*_t, h^*_{t+1}) - \delta \right) \right] - \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} \right] \\
& + \Omega \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \left[\frac{1-n}{n} c^*_{ht} - e_t c_{ft} \right] \\
& - \Lambda \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \left[g - \tau_c c_{ht} - \tau_{mt} c_{ft} e_t - \tau_{wt} F_2(k_{t-1}, h_t) h_t - \tau_{kt} (F_1(k_{t-1}, h_t) - \delta) k_{t-1} \right] \Bigg\} \\
& + \Omega e_0 \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} \\
& - \Lambda \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} d_{-1}.
\end{aligned}
\tag{20}
$$

In (20), the first nine constraints (in order) are: home feasibility, the three home household first-order conditions, the international risk-sharing condition, the foreign households' budget constraint, and the three foreign household first-order conditions. The constraint associated

with Ω is the home country international solvency condition while Λ is associated with the present value government budget constraint.

The foreign planner solves an analogous problem, stated in detail in appendix A.2. The first-order conditions to the Ramsey planner problems are very long and provide little useful insight and so are omitted for brevity.

At this stage, a couple of notes are in order. First, if the foreign international solvency condition is satisfied, then so is the home international solvency condition. Consequently, only one of the multipliers Ω and Ω^* can be determined. Since the international solvency condition cannot be slack, set $\Omega = 1$ and let one of the international solvency conditions determine Ω^*. Second, there are 42 time-dated equations (12 first-order equations and nine constraints for each planner) to determine the paths of 33 variables: six tax rates, nine private sector variables, and 18 Lagrange multipliers. However, seven of the constraints are common to the two planners (the six household first-order conditions and international risk-sharing condition). In addition, in the equilibrium of the game between the two planners, both government budget constraints must be satisfied. Consequently, only two of the following equations are necessary: the two household budget constraints, and the two feasibility conditions. Computationally, it is more convenient to work with the two feasibility conditions since the system of equations no longer includes either foreign bonds or government debt. This leaves 33 sets of time-dated equations to determine 33 time-dated variables and multipliers.

The model is solved as follows:

1. Guess values for the undated multipliers Λ, Λ^* and Ω^*.

2. Solve the model as a two point boundary problem using an extended path algorithm (Fair and Taylor, 1983). The initial condition is the original steady state while the terminal condition is a set of 'no change' conditions on the model's variables.

3. If the two present value government budget constraints and international solvency

condition are all sufficiently close to zero, stop; otherwise, revise the values of Λ, Λ^* and Ω^* and return to step 2.

3.1 A Partial Primal Approach

The usual approach in the Ramsey optimal taxation literature is to substitute the household and firm first-order conditions into the household's present value budget constraint yielding an implementability condition (Lucas and Stokey, 1983). The planner then chooses an allocation directly, and prices and tax rates can be recovered using the privater sector first-order conditions. This primal approach has been successfully applied in closed economies (starting with Chamley (1986) and Judd (1985)), and small open economies (Correia (1996) and Auray, Eyquem, and Gomme (2018)).

As in Gross, Klein, and Makris (2017), the problem with applying the primal approach in a tax competition environment is that each Ramsey planner must take into account the fiscal policy of its opposite number. For example, in solving the home Ramsey planner problem, the home planner needs to know the tax rates chosen by the foreign planner. As a result, it simply is not possible to eliminate *all* taxes from the Ramsey planner problems.

Nonetheless, an implementability condition can be derived. Substituting the home household's first-order conditions, (2)–(7) into the second term in the household's Lagrangian, namely,

$$\sum_{t=0}^{\infty} \beta^t \xi_t \left[(1-\tau_{wt})\, w_t h_t + R_{kt} k_{t-1} + d_{t-1} + e_t a_{t-1} - (1+\tau_{ct})\, c_{ht} - (1+\tau_{mt})\, e_t c_{ft} - k_t - \frac{d_t}{R_{dt}} - e_t \frac{a_t}{R_{at}} \right]$$

and using the firm's first-order conditions yields the familiar implementability condition,

$$\sum_{t=0}^{\infty} \beta^t \left[U_1(c_{ht}, c_{ft}, h_t) c_{ht} + U_2(c_{ht}, c_{ft}, h_t) c_{ft} + U_3(c_{ht}, c_{ft}, h_t) h_t \right] = \xi_0 \left[R_{k0} k_{-1} + d_{-1} + e_0 a_{-1} \right] \tag{21}$$

Using (21), the home planner's problem is now to choose $\{c_{ht}, c_{ft}, h_t, k_t, e_t, c^*_{ht}, c^*_{ft}, h^*_t, k^*_t\}_{t=0}^{\infty}$

to maximize

$$
\begin{aligned}
\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \Bigg\{ & W(c_{ht}, c_{ft}, h_t) \\
& + \lambda_{1t} \left[F(k_{t-1}, h_t) + (1-\delta)k_{t-1} - c_{ht} - \frac{1-n}{n} c^*_{ht} - k_t - g \right] \\
& + \lambda_{2t} \left[e_t \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \vartheta \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} \right] \\
& + \lambda_{3t} \left[\frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} - \frac{e_t U^*_1(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_{mt}} \right] \\
& + \lambda_{4t} \left[U^*_3(c^*_{ht}, c^*_{ft}, h^*_t) + \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} (1-\tau^*_{wt}) F_2(k^*_{t-1}, h^*_t) \right] \\
& + \lambda_{5t} \left[\beta \frac{U^*_2(c^*_{ht+1}, c^*_{ft+1}, h^*_{t+1})}{1+\tau^*_c} \left[1 + \left(1-\tau^*_{k,t+1}\right) \left(F_1(k^*_t, h^*_{t+1}) - \delta \right) \right] - \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} \right] \\
& + \lambda_{6t} \Bigg[\left(1-\tau^*_{wt}\right) F_2(k^*_{t-1}, h^*_t) h^*_t + \left[1 + \left(1-\tau^*_{kt}\right) \left(F_1(k^*_{t-1}, h^*_t) - \delta \right) \right] k^*_{t-1} + d^*_{t-1} + a^*_{t-1} \\
& \qquad - \left(1+\tau^*_{mt}\right) \frac{c^*_{ht}}{e_t} - \left(1+\tau^*_{ct}\right) c^*_{ft} - k^*_t - \frac{d^*_t}{R^*_{dt}} - \frac{a^*_t}{R_{at}} \Bigg] \\
& + \Omega \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \left[\frac{1-n}{n} c^*_{ht} - e_t c_{ft} \right] \Bigg\} \\
& + \Omega e_0 \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} \\
& - \Lambda \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} \Big[\left[1 + (1-\tau_{k0})(F_1(k_{-1}, h_0) - \delta) \right] k_{-1} + d_{-1} + e_0 a_{-1} \Big]
\end{aligned}
\tag{22}
$$

with

$$
\begin{aligned}
W(c_{ht}, c_{ft}, h_t) \equiv & \, U(c_{ht}, c_{ft}, h_t) \\
& + \Lambda \left[U_1(c_{ht}, c_{ft}, h_t) c_{ht} + U_2(c_{ht}, c_{ft}, h_t) c_{ft} + U_3(c_{ht}, c_{ft}, h_t) h_t \right]
\end{aligned}
\tag{23}
$$

where Λ is now the Lagrange multiplier associated with the home implementability condition. The foreign Ramsey planner's problem is quite similar and is given in (A.4).

Computationally, there is little advantage to using the first-order conditions to (22) and (A.4) instead of those arising from following the dual approach. Analytically, however, there are major advantages of this partial primal approach. Of particular interest is

the first-order condition with respect to k_t:

$$\lambda_{1t} = \beta\lambda_{1,t+1}\left[F_1(k_t, h_{t+1}) + 1 - \delta\right]. \tag{24}$$

Assuming that the economy converges to a steady state, this equation reads

$$1 = \beta\left[F_1(k, h) + 1 - \delta\right]. \tag{25}$$

The corresponding equation for the household is

$$1 = \beta\left[(1 - \tau_k)F_1(k, h) + 1 - \delta\right]. \tag{26}$$

Comparing (25) and (26) delivers the familiar Chamley (1986)–Judd (1985) prescription: in the long run, capital income should not be taxed: $\tau_k = 0$.

3.2 International Tax Cooperation

Below, the tax competition model is compared to an environment with international tax cooperation. In this latter case, the 'usual' primal approach can be followed. The world Ramsey planner maximizes a weighted sum of the utilities of the representative households in the two countries subject to: feasibility, international risk sharing, the two international solvency conditions, and two implementability conditions (one for each country). Let ϕ be the weight that the world planner places on the representative home household. The full

problem is:

$$
\begin{aligned}
\max_{\{c_{ht},c_{ft},h_t,k_t,c^*_{ht},c^*_{ft},h^*_t,k^*_t,e_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty}\beta^t\Bigg\{ & \phi W(c_{ht},c_{ft},h_t)+(1-\phi)W^*(c^*_{ht},c^*_{ft},h^*_t) \\
& +\lambda_{1t}\left[F(k_{t-1},h_t)+(1-\delta)k_{t-1}-c_{ht}-\frac{1-n}{n}c^*_{ht}-k_t-g\right] \\
& +\lambda^*_{1t}\left[F(k^*_{t-1},h^*_t)+(1-\delta)k^*_{t-1}-c^*_{ft}-\frac{n}{1-n}c_{ft}-k^*_t-g^*\right] \\
& +\lambda_{2t}\left[e_t\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}-\vartheta\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\right] \\
& +\Omega^*\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\left[\frac{n}{1-n}c_{ft}-\frac{c^*_{ht}}{e_t}\right]\Bigg\} \\
& +\Omega^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}a^*_{-1} \\
& -\Lambda\frac{U_1(c_{h0},c_{f0},h_0)}{1+\tau_c}\Big[\big[1+(1-\tau_{k0})(F_1(k_{-1},h_0)-\delta)\big]k_{-1}+d_{-1}+e_0a_{-1}\Big] \\
& -\Lambda^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}\Big[\big[1+(1-\tau^*_{k0})(F_1(k^*_{-1},h^*_0)-\delta)\big]k^*_{-1}+d^*_{-1}+a^*_{-1}\Big]
\end{aligned}
\tag{27}
$$

where, recall, n is the size of the home economy.

There is an additional consideration in solving the world planner problem: each country should have the option of choosing tax competition over tax cooperation if doing so makes its residents better off. The voluntary nature of tax competition is captured as follows. It seems natural to start with $\phi = n$: the planner weight on each country coincides with its population share. If lifetime utility under tax cooperation exceeds that associated with tax competition for both countries, no further work is necessary. Similarly, if lifetime utility under tax competition is greater than that under tax cooperation for both countries, no further work is needed. This leaves the case in which one country is better off under tax competition while the other is better off under tax cooperation. In this case, adjust the world planner weight, ϕ, until the country that preferred tax competition is now indifferent between tax competition and tax cooperation. With ϕ chosen in this way, both countries (weakly) prefer tax cooperation over tax competition. One should expect to see that the country that preferred tax competition when $\phi = n$ will end up being assigned a weight that

exceeds its population share.

4 Parameterization and Calibration

There is little that can be said about the short run dynamics of the model without computing solutions of the model. In turn, computational solutions require specifying functional forms, and assigning values to all of the parameters of the model. To start, the utility function exhibits a constant Frisch labor supply elasticity, κ:

$$U(c_h, c_f, h) = \begin{cases} \ln C(c_h, c_f) - \omega h^{1+1/\kappa} & \eta = 1 \\ \frac{C(c_h,c_f)^{1-\sigma}\left[1-\omega(1-\sigma)h^{1+1/\kappa}\right]^{\sigma}-1}{1-\sigma} & \eta \in (0,1) \cup (1,\infty) \end{cases}$$

with consumption aggregator

$$C(c_h, c_f) = \left[\varphi c_h^{\frac{\mu-1}{\mu}} + (1-\varphi) c_f^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}.$$

The production function is Cobb-Douglas:

$$F(k, h) = k^{\alpha} h^{1-\alpha}.$$

The interesting case is when the two countries differ in some ways. Below, attention is focused on tax rates, population size, and initial net foreign assets.[6]

The first order of business is setting the length of a model period. Since tax rates are typically in force for a year at a time, a model period is set to one year.

Turn next to the parameters and calibration targets that are common to the two countries. In the benchmark model, preferences are logarithmic ($\sigma = 1$). The Frisch labor supply elasticity, κ, is set to one, a common value in the macroeconomics literature. As in Backus, Kehoe, and Kydland (1993), the trade elasticity (corresponding to μ in the consumption aggregator) is set to 1.5 which allows fairly easy substitution between home and foreign

[6] As a check on the model solutions, Fig. C.1 presents results for the symmetric case. As expected, the responses of both countries to a Ramsey reform are identical.

goods. There are direct relationships between observations on capital's share of income and depreciation, and the corresponding model parameters. Evidence for the U.S., presented in Gomme and Rupert (2007), motivates setting capital's share of income, α, to 0.3, and the depreciation rate, δ, to 0.075.

To facilitate comparison with Mendoza and Tesar (2005), the home economy is identified with the U.K. while the foreign one corresponds to the EMU countries (what Mendoza and Tesar referred to as "Continental Europe"). I use their tax rates, the values for which are summarized in Table 1. Mendoza and Tesar do not separately report tax rates for domestic and imported consumption goods. Since the model treats the tax on imports like a consumption tax, the initial tax on imports is set to their tax rate on consumption goods generally. The home population share, n, is set to 1/4.

Five parameters remain: the weights on labor in preferences (ω and ω^*), the weights on home goods in the consumption aggregator (φ and φ^*), and the common discount factor, β. These parameters are chosen so that in steady state: hours worked is 0.2 in both countries (Mendoza and Tesar, 2005); the real interest rate is 4%; the home consumption import share is 22.5% (roughly the U.K.'s import share since 1990); and home foreign debt of 10% of its output (again, roughly in line with the U.K. experience). In addition, in steady state, government consumption is 18% of output (Mendoza and Tesar, 2005), and the real exchange rate is one. It is well known that the units for exchange rates are generally indeterminate; changes in the initial exchange rate would merely change the value of ϑ, the parameter in the international risk-sharing condition.

The calibrated parameter values are summarized in Table 1, and the resulting steady state reported in Table 2. In the latter table, "aggregate consumption" corresponds to the *value* of consumption (for the home economy, $c_h + ec_f$). The level of government debt reported in Table 2 is computed after solving for steady state as the present value of steady state primary deficits. The government debt-output ratio for the model is not directly comparable to that in the data since the model does not include transfer payments (associated with various

social programs).

Table 1: Parameter Values

Parameter	Home	Foreign
Consumption tax, τ_c	0.140	0.166
Import tax, τ_m	0.140	0.166
Labor income tax, τ_w	0.250	0.374
Capital income tax, τ_k	0.530	0.265
Discount factor, β	0.962	0.962
Risk aversion, σ	1.000	1.000
Labor weight, ω	8.520	7.251
Frisch elasticity, κ	1.000	1.000
Trade elasticity, μ	1.500	1.500
Capital share, α	0.300	0.300
Capital depreciation, δ	0.075	0.075
φ	0.695	0.156
ϑ	1.074	1.074
Population share (n or $1-n$)	0.250	0.750
Planner weight (ϕ or $1-\phi$)	0.250	0.750

5 Implementing the Ramsey Plan

The Ramsey plan is announced and implemented in year 0. A useful way to think about the Ramsey plan is that each government seeks to minimize the tax distortions associated with financing its government expenditure stream in the competitive equilibrium allocation. The key insight of Ramsey (1927) is that the government should tax more heavily those goods that are either inelastically supplied, or inelastically demanded. In the closed economy, neoclassical growth model, Ramsey's prescription typically implies initially very high capital income taxation when capital is supplied inelastically, and no capital income taxation in the new Ramsey steady state since in the long run capital supply is very elastic; see the literature starting with Chamley (1986) and Judd (1985). The high capital income tax revenues early in the Ramsey plan drives down the level of government debt, thereby lowering long run tax distortions. Since the Lagrange multiplier associated with the present value government

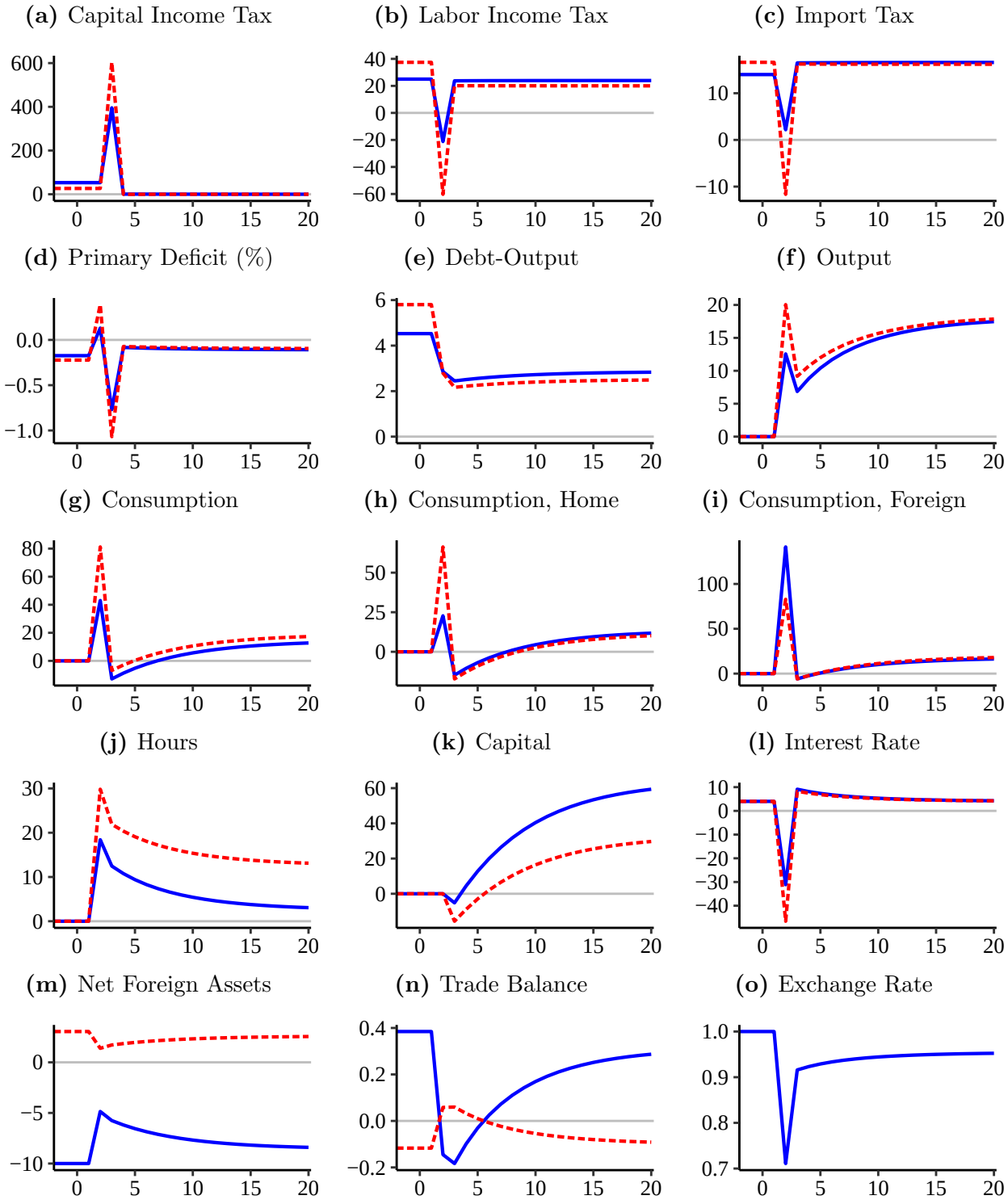
Table 2: Initial Steady State

Variable	Home	Foreign
Output	0.262	0.287
Consumption: Home	0.137	0.014
Consumption: Foreign	0.040	0.172
Consumption: Aggregate	0.177	0.186
Hours worked	0.200	0.200
Capital stock	0.490	0.665
Capital-output ratio	1.874	2.318
Government share	0.180	0.180
Tax Revenues	0.093	0.116
Primary deficit	−0.046	−0.064
Public debt	1.185	1.663
Debt-output ratio	4.527	5.800
Exchange rate	1.000	1.000
Trade balance	0.001	0.000
Net foreign assets	−0.026	0.009

budget constraint is positive owing to the need for the government to raise tax revenue, tax rates on labor income and consumption tax are generally positive.

It is easiest to explain the behavior of the foreign government since it conforms most closely with the familiar closed economy dynamics. At the risk of stating the obvious, all of the dynamics analyzed below can be attributed to changes in the tax rates following adoption of the Ramsey plan. For the most part, the dynamics are driven by the time path of the capital income tax rate. As shown Fig. 1(a), in year 1, when the foreign government is first able to adjust the capital income tax rate, it chooses a very high value: 604%. In the following years, this tax rate falls to around zero. As shown analytically in Section 3.1, in the long run, the capital income tax rate is zero. As a result of the spike in the capital income tax rate in year 1, the foreign government debt-output ratio falls to less than half of its original steady state value; see Fig. 1(e). As shown in Fig. 1(c), in the long term there is little change in the tax rate on imports. Even with the loss of capital income tax revenue, the fall in the foreign government's debt-output ratio is large enough to allow it to lower the labor income tax rate in the Ramsey steady state; see Fig. 1(b).

Figure 1: Ramsey Tax Competition: Benchmark



Legend: Solid blue lines: home; dashed red lines: foreign. Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Why does the foreign government choose, in the short term, to subsidize imports and labor income as shown in Figs. 1(b) and 1(c)? Since adoption of the Ramsey plan reduces the present value of tax distortions, foreign households feel richer and so, owing to wealth effects, would like to consume more and work less. In the closed economy setting, accommodating these desires would lead to a fall in investment both because the additional consumption squeezes out investment, and because of the lower level of output owing to the lower labor input. Recall, though, that the planner wishes to tax year 1 capital income at a very high rate, and so prefers to keep investment, and so capital, high. To encourage households' labor supply, the government subsidizes labor income. *Some* of the extra consumption *could* come from the other (home) economy, and so the planner subsidizes imports as well.

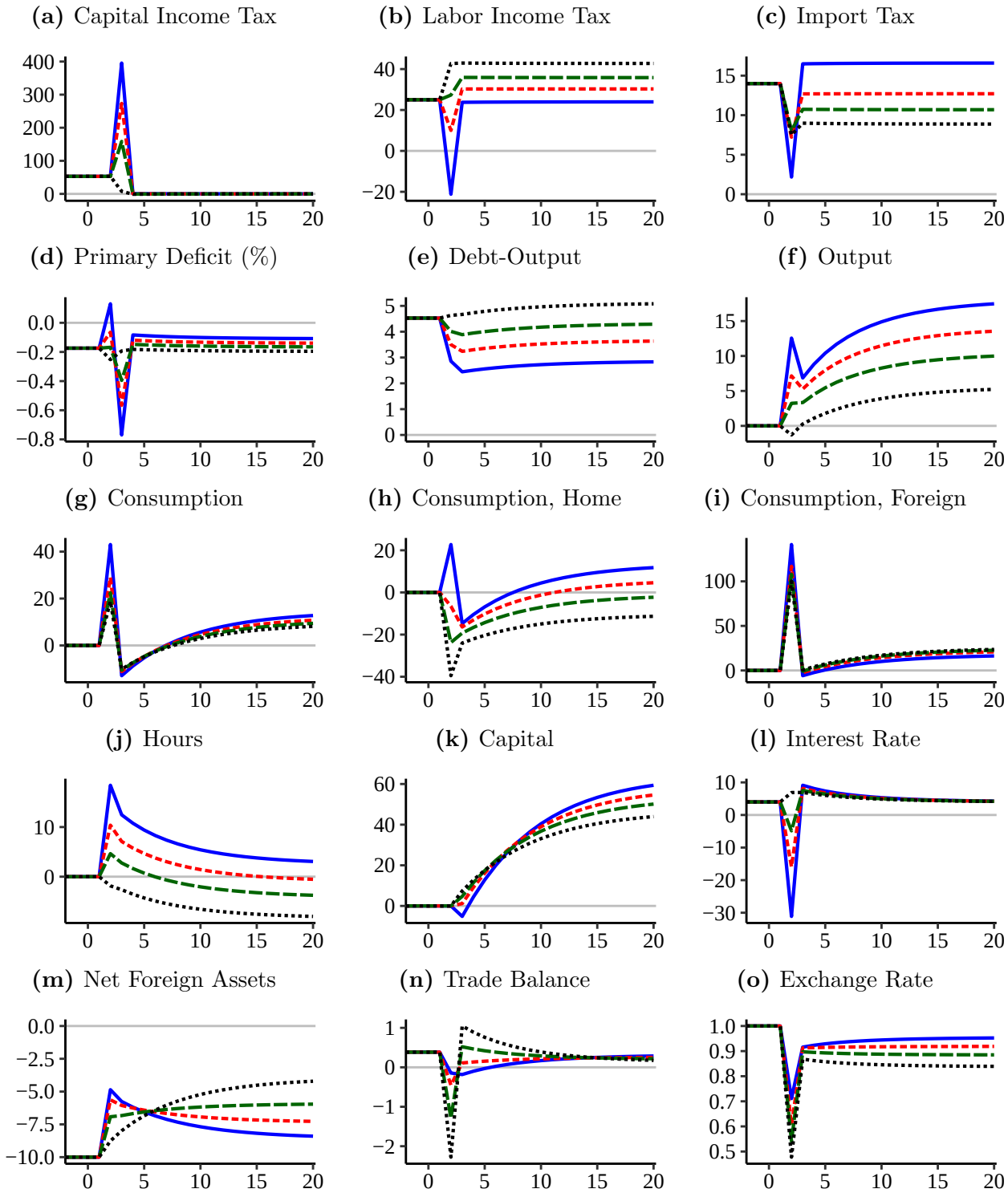
Turn now to the home economy. The time path for its capital income tax rate is qualitatively similar to that chosen by the foreign government: high in year 1, then dropping to around zero. However, in year 1 the home capital income tax rate is noticeably lower than its foreign counterpart: 395% compared to 604%. Accounting for this large gap in the year 1 capital income tax rates is best understood by noticing that the rate of return arbitrage conditions for the home and foreign countries, (8) and (A.2), imply

$$\frac{e_{t-1}}{e_t}\underbrace{[(1-\tau_{kt})F_1(k_{t-1},h_t)+1-\delta]}_{R_{kt}}=\underbrace{(1-\tau^*_{kt})F_1(k^*_{t-1},h^*_{t-1})+1-\delta}_{R^*_{kt}},\quad t\geq 1. \tag{28}$$

Apart from the capital income tax rates, the most important terms in (28) are the capital-labor ratios and the real exchange rate. The microeconomic tax competition literature has emphasized the role of population size operating through the capital-labor ratio (Bucovetsky, 1991). Specifically, when the government of the larger, more populous economy considers raising its capital income tax rate, it recognizes that doing so will initially lower the return to capital in its country. Rate of return arbitrage is restored as capital then flows from the larger to the smaller economy.[7] However, a one unit shift of capital has a larger effect on the

[7]While the microeconomic literature tends to think of capital as literally "flowing" between countries, this does not occur in the two country model studied here. As in Mendoza and Tesar (2005), rates of return are equalized through changes in net foreign assets, and the fact that physical capital and international bonds

Figure 2: Ramsey Tax Competition: Home Country, Higher Imports



Legend: Solid blue lines: benchmark (22.5% import share); short dashed red lines: 40% import share; long dashed green lines: 50% import share; and dotted black lines: 60% import share. Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

capital-labor ratio of the less populous economy. As a result, the foreign capital stock does not change very much. Put differently, the larger foreign government sees a lower elasticity of tax revenue with respect to its capital tax rate than does the smaller home government. Thus, the foreign planner competes less vigorously with respect to its capital income tax rate than does the planner of the smaller economy, and the government of the larger economy will, in general, choose a higher capital income tax rate.

However, the capital-labor ratio channel is only part of the story. To see this, consider the results of calibrating to a higher home consumption import share, presented in Fig. 2. As the home country becomes more open, its year 1 capital income tax rate falls. (Fig. C.6 shows that the foreign capital income tax rate is relatively insensitive to openness.) Indeed, when the home consumption import share is calibrated to be 60%, the home country actually lowers this tax rate – a phenomenon difficult to understand if one focuses only on the effects operating through the capital-labor ratios. As already noted, real exchange rate dynamics also play a role in the return to capital arbitrage condition, (28). Holding fixed the capital-labor ratios, a decrease in the exchange rate ratio, e_{t-1}/e_t, allows for a combination of higher foreign and lower home capital income tax rates. Consequently, the fall in the home capital income tax rate depicted in Fig. 2(a) in the high openness case can be reconciled if the exchange rate ratio, e_0/e_1, is sufficiently small. Sure enough, Fig. 2(o) shows that this is the case.

The discussion above leads to the conclusion that a low e_0/e_1 ratio (reflecting a real exchange rate depreciation) tends to raise the foreign capital income tax rate in year 1, and lower the home capital income tax rate. The higher foreign capital income tax rate directly benefits foreign households for reasons discussed earlier in this section: high capital income tax revenue in year 1 lowers government debt and so future tax distortions.[8] The lower home capital income tax rate also benefits foreign households, but more indirectly. To

are perfect substitutes given the assumption of perfect foresight.

[8]Of course, a higher year 1 capital income tax rate raises a distortion in the short run, and so there is a limit as to how high the planner would want to set this tax rate.

understand why, recall that households experience an immediate wealth effect upon adoption of the Ramsey tax plan, and as a result wish to consume more and work less. Since both countries are simultaneously enacting Ramsey tax reforms, households in both countries experience wealth effects at the same time. Since imported goods are a component of the overall consumption bundle, home and foreign households are competing for output that has been made scarcer owing to the desire to work less.[9] A lower setting of the year 1 home capital income tax rate therefore reduces the size of the wealth effect experienced by home households, and so reduces competition faced by foreign households for output while simultaneously raising output through home hours worked. This indirect effect associated with lower home capital income taxation suggests that the planner of the larger country is using the path of the real exchange rate strategically in order to manipulate fiscal policy of its smaller rival.

The preceding discussion clearly shows that an exchange rate ratio, e_0/e_1, less than one is in the best interests of the foreign planner, not the home planner. Indeed, in a small open economy – in which all of the elements of tax competition are absent – Auray, Eyquem, and Gomme (2018) find that the Ramsey planner chooses an exchange rate path characterized by an e_0/e_1 ratio bigger than one. Their intuition is that such a ratio allows the planner to set a higher capital income tax rate in year 1, thereby reducing future tax distortions. Since the planner of a small open economy chooses $e_0/e_1 > 1$, one can conclude that $e_0/e_1 < 1$ is in the interests of the foreign planner.

Are there other reasonable explanations for the real exchange rate appreciation? Two candidates come to mind. First, such an appreciation leads to a revaluation of net foreign assets which benefits home households since they are initially net foreign debtors. Second, the exchange rate appreciation moves the terms of trade in the favor of home households since the appreciation makes foreign goods relatively cheaper. In other words, neither of these factors explain why the foreign planner would want the real exchange rate to appreciate.

[9] A government can offset this work effect by lowering the labor income tax rate, but doing so increases the governments debt, leading to higher future tax distortions.

Thus, it seems safe to conclude that the capital return arbitrage condition, (28), is the main channel governing the interaction between the two planners with respect to the path of the real exchange rate.

Clearly, the countries need to be sufficiently open for the strategic exchange rate mechanism to operate. Trivially, when the two economies are closed, they do not interact and there is no role for the strategic exchange rate mechanism. Fig. C.12 presents results for the home country when it is less open than the benchmark case. Less openness reduces the exchange rate movements, and raises the year 1 capital income tax rate. The initial subsidy to labor income increases as the home country becomes less open, as does the import subsidy. When home is less open, its higher year 1 capital income tax revenue leads to a greater decline in the government debt-output ratio, and in the long term a (slightly) lower labor income tax rate. Earlier, Fig. 2 showed that greater openness was associated with a stronger real exchange rate depreciation (smaller e_0/e_1 ratio) and a lower year 1 home capital income tax rate. Collectively, these results show that there is an interaction between population size and openness pointing to the role of the real exchange rate in the strategic interaction between the two Ramsey planners.

Table 3: Year 1 Capital Income Tax Rate

Case	Home	Foreign
Tax competition	395.4	603.6
Asymmetric initial net foreign assets	401.8	396.3
Asymmetric population size	397.8	459.4
Asymmetric initial tax rates	401.9	560.6
Tax cooperation	540.6	630.8

Further insight into the mechanisms at work in the model can be obtained by isolating those elements that (initially) differ between the two countries. As discussed in calibrating the model in Section 4, the two countries differ with respect to initial international indebtedness, population size, and initial taxes. The implications of each asymmetry can be assessed by re-calibrating the model with only one asymmetry in place; any resulting difference rel-

ative to the benchmark case can be attributed to the other two asymmetries. Given the importance of the year 1 capital income tax rate to the model's dynamics, Table 3 only reports this tax rate; more complete results are presented in Figs. C.2–C.4.

When the only difference is initial net foreign assets, the choices for the capital income tax rate are quite similar across the two countries. There is roughly a 60 percentage point gap in the capital income tax rates when the countries only differ with regards to their population, and nearly a 160 percentage point gap when they differ with respect to initial tax rates. Since the initial capital income tax rate is lower in the foreign economy, it has a higher per capita capital stock, as reported in Table 2. As a result, the foreign country has more capital income to tax in year 1, and chooses a higher capital income tax rate. Jointly, these results show that differences in international indebtedness are not particularly important for the determination of the gap in the capital income tax rates across the two jurisdictions; differences in initial tax rates and population are far more important.

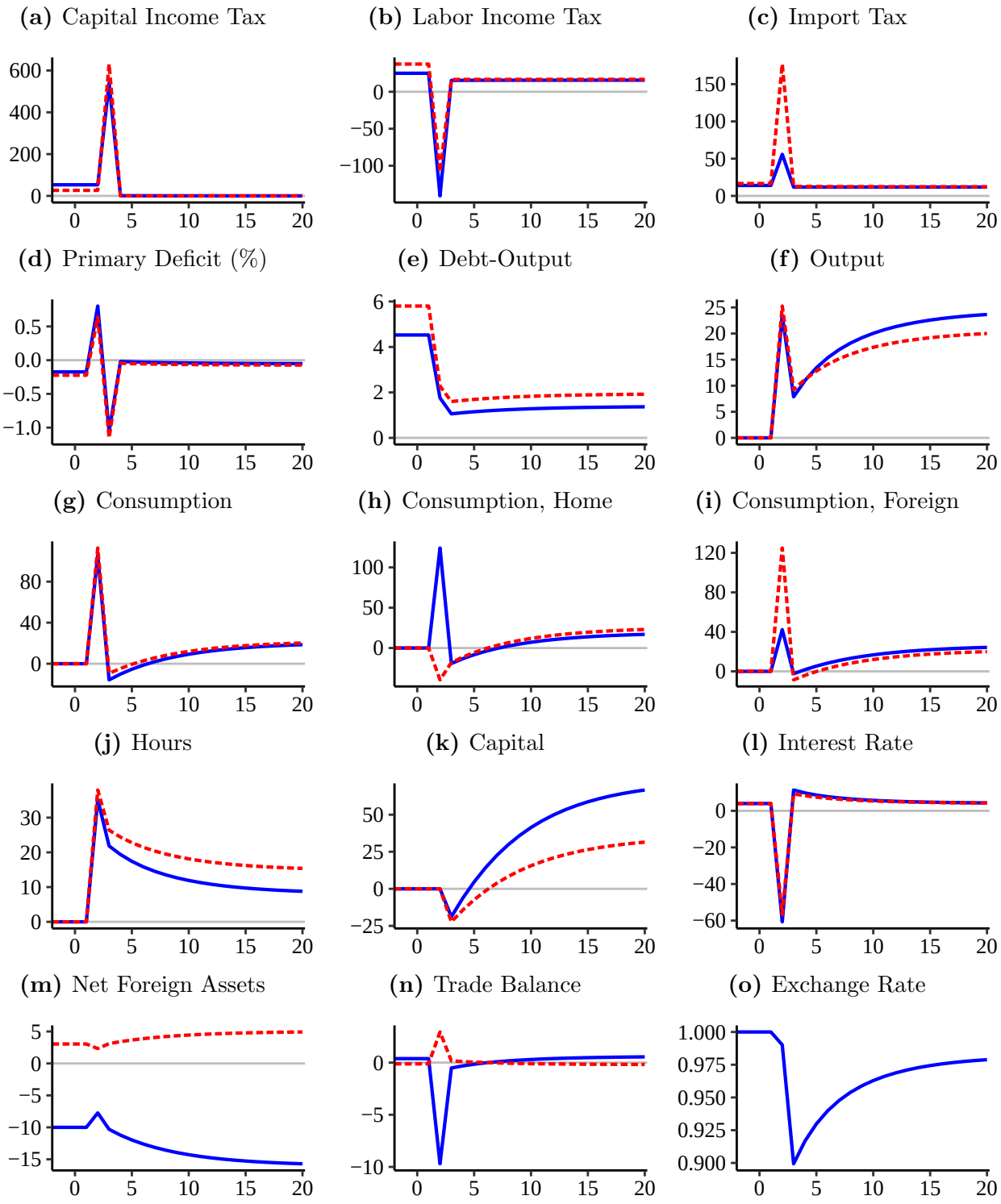
Tax Cooperation

Here, the results of the benchmark tax competition model are compared to those of tax cooperation in which a benevolent world planner chooses tax rates to maximize a weighted sum of lifetime utilities as described in Section 3.2.

As in the tax competition case, these results are best understood by looking, first, at the capital income tax rate. Fig. 3(a) shows that both governments raise this tax rate when they cooperate. In fact, as reported in the final line of Table 3, in year 1 the foreign capital income tax rate is just over 25 percentage points higher when the governments cooperate than when they compete. While the year 1 home capital income tax rate is lower than that in the foreign country, it is still a very substantial 540%, or 145 percentage points higher than in the tax competition environment.

The forces at work behind the year 0 labor income tax subsidy (negative tax rate) are the same as for the tax competition case. The reduction in tax distortions leads to wealth effects:

Figure 3: Ramsey Tax Cooperation: Benchmark



Legend: home (solid blue); foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

households want to work less and consume more. However, accommodating these desires will lower investment as less output is produced, and more output goes to consumption. The planner wants to maintain investment in order to collect capital income tax revenue in year 1. To get households to work more, the after-tax wage needs to increase, and in the end, the planner chooses to subsidize labor.

The path of the import tax is quite different when the governments cooperate. In this case, both governments raise this tax rate, with the foreign import tax rising in year 0 to 177%, the home import tax to 56%. Recall that under tax competition, the foreign government subsidizes imports in year 0 in order to encourage its households to obtain some of the extra consumption they crave from the home economy. While the home government does not subsidize imports in the benchmark tax competition case, this is largely because its tax rates were heavily influenced by the foreign government (its manipulation of the exchange rate). The world planner realizes that reallocating goods to foreign households comes at a cost to home households. The planner internalizes this consideration, realizing that a policy of 'robbing Peter to pay Paul' is not very desirable when one cares about both Peter and Paul.

Given the broadly similar time paths of the tax rates in the two countries, both end up with lower government debt in the long run. For the most part, these lower debt levels can be attributed to the very high rates of capital income taxation in year 1.

Under tax cooperation, real exchange rate dynamics are quite different from those in the tax competition case. In the earlier discussion, the appreciate-then-depreciate pattern was attributed to a combination of the foreign government further raising its capital income tax rate, and the foreign government's efforts to manipulate the home government's tax policy. Specifically, the foreign government wanted to moderate the increase in the year 1 home capital income tax rate in order to reduce competition for resources in year 0. When the governments cooperate, the exchange rate initially appreciates slightly, then somewhat more substantially in year 1. In this case, the exchange rate ratio, e_0/e_1, is greater than one, a

pattern which tends to help the home government as can be seen in the earlier capital return arbitrage condition, (28). In summary, the real exchange rate dynamics allow for a higher year 1 home capital income tax rate.

Earlier, for the tax competition case, I presented results for higher import share calibrations as support for the notion that the large gap in the year 1 capital income tax rates was due, in part, to strategic manipulation by the foreign planner of the home planner. In particular, Fig. 2(a) showed that the year 1 home capital income tax rate *falls* with openness. When the two countries cooperate, increased openness leads to a *higher* capital income tax rate as shown in Fig. C.10. Furthermore, under tax cooperation, the gap between the foreign and home year 1 capital income tax rates declines with openness; under tax competition, the gap widens. In other words, the alternative openness calibrations are consistent with the strategic manipulation effect discussed earlier.

6 Welfare Analysis

The welfare benefit of adopting the Ramsey plan is measured in the usual way: for the home country, find the value of ζ such that

$$\sum_{t=0}^{\infty} \beta^t U\left((1-\zeta)c_{ht}, (1-\zeta)c_{ft}, h_t\right) = \frac{U\left(\overline{c}_h, \overline{c}_f, \overline{h}\right)}{1-\beta}.$$

The right-hand side is the lifetime utility of the representative home household in the initial steady state. When $\zeta = 0$, the left-hand side is the lifetime utility associated with the Ramsey allocation. ζ is the constant fraction of consumption (of both home and foreign goods) that can be taken from the home household under the Ramsey plan that leaves it just as well off as the original status quo steady state. The welfare benefit for foreign households is computed in an analogous fashion.

The welfare benefit of adopting the Ramsey plan is substantial. As seen in Table 4, under tax competition, home households experience a welfare gain equivalent to 5.5% of

Table 4: Welfare Benefit of Ramsey Allocation (percent of consumption)

Case	Home	Foreign
Tax Competition		
· Benchmark	5.541	4.765
· Differences in initial net foreign assets, $\overline{a}$	4.008	3.877
· Differences in population weight, n	4.285	4.177
· Differences in initial tax rates	4.957	3.975
· Differences in initial capital income tax rates	3.500	2.268
· Differences in initial labor income tax rates	5.272	5.533
· Differences in initial import tax rates	4.174	4.147
Tax Cooperation		
· Benchmark	5.541	4.927

consumption; for foreign households, 4.8%. These gains reflect the elimination of capital income taxation in the Ramsey steady state, as well as the reductions in the government debt-output ratios in both countries which means that other taxes do not change much in moving to the Ramsey steady state.

The results in Table 4 point to the factors that account for the nearly 0.8 percentage point gap in the welfare benefits experienced by the two countries. When the only difference between the two countries is their population size, the difference in welfare is 0.1 percentage points; when they only differ with respect to initial net foreign assets, there is similarly a 0.1 percentage point gap. Thus, the differences in the welfare benefits for the benchmark calibration can be traced to disparities in initial tax rates, as confirmed in the fourth line of Table 4. Of these tax rates, the capital income tax rate accounts for the bulk of the differences in welfare.

That the largest single contributor to differences in welfare benefits across the two countries can be trace to differences in capital income tax rates fits well with results in the literature. Macroeconomic models typically find that the largest (long run) tax distortions are those associated with capital income taxation. Almost invariably, the Ramsey taxation literature finds that capital income should not be taxed in the long run, suggesting that this is the most important distortion in these models.

Also recorded in Table 4 are the welfare benefits of tax cooperation. Section 3.2 discussed the fact that tax cooperation needs to be voluntary in that neither country can be made worse off by cooperating compared to engaging in tax competition. For the benchmark calibration, when the planner weights countries by their population size, the home country is worse off under cooperation. Raising the planner weight on the home country to 0.326 makes the home country indifferent between tax cooperation and tax competition. As a result, the foreign country is only slightly better off under tax cooperation, suggesting that there is little incentive for countries to coordinate their tax reforms.

7 Conclusion

Optimal tax rates were obtained as the equilibrium of a game played between two Ramsey planners in an open economy setting with distinct good produced in each country, and so an endogenous real exchange rate. The Ramsey analysis distinguished my work from that of Mendoza and Tesar (2005) while the endogenous real exchange rate differentiates my model from Gross, Klein, and Makris (2017). As is typical of closed economy Ramsey taxation analyses, the short term supply of capital is very inelastic, and so capital income is taxed very heavily; conversely, in the long term, capital supply is very elastic and capital income is not taxed at all.

A particularly interesting result is that in the short run, the capital income tax rate in the larger country is considerably higher than that in the smaller country. The microeconomic tax competition literature offers an explanation for this result which operates through the role of the capital-labor ratio in equating after-tax returns to capital; see Bucovetsky (1991) and the subsequent literature. Briefly, owing to its larger labor force, the capital-labor ratio in the larger country is less sensitive to changes in its capital stock. As a result, the elasticity of tax revenue with respect to the capital income tax rate is smaller in the larger country, and so the planner chooses a higher capital tax rate. While this aspect of size is at work in

the international macroeconomic model analyzed above, it is also only part of the story.

The real exchange rate is a choice variable for each of the Ramsey planners, and each planner tries to set a path for the real exchange rate that advantages households in its own country. Of particular interest for the setting of the capital income tax rates is how the temporal pattern of the real exchange rate affects the cross-country after-tax return to capital arbitrage condition. As discussed in Section 5, it seems that the planner of the larger, foreign country dominates in setting the real exchange rate. Early in the implementation of the Ramsey tax plans, the real exchange rate first appreciates, then depreciates. In the short term, this exchange rate dynamic lowers the exchange rate-adjusted after-tax return to capital in the smaller country. This lower return has two effects: first, it allows the planner of the larger country to set a higher capital income tax rate; and second, it discourages the smaller country's planner from raising its capital income tax rate.

Limiting the short term rise in the capital income tax rate in the smaller country benefits households in the larger country. To see this, recall that the Ramsey plan reduces tax distortions, thereby leading to an immediate wealth effect: households want to consume more and work less. In a small open economy setting, like Auray, Eyquem, and Gomme (2018), some of this extra consumption can come from the other country (the rest of the world). However, in the two country setting analyzed above, when both countries are executing Ramsey tax reforms, it simply is not possible to import extra consumption from the other country since both countries wish to increase their consumption and imports. Limiting the short term increase in the capital income tax rate in the smaller country reduces the wealth effect experienced by households in that country, and so limits competition for consumption goods at the start of the Ramsey taxation plan. In other words, the planner of the larger country influences the path of the real exchange rate in order to manipulate tax policy of its smaller rival. This strategic use of the real exchange rate appears to be novel to the open economy literature, and is necessarily absent from one good open economy models, like Mendoza and Tesar (2005) and Gross, Klein, and Makris (2017), in which the real exchange

rate is necessarily fixed at one.

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A The Foreign Economy

A.1 Foreign households

$$\mathcal{L}^* = \max_{\{c_{ht},c_{ft},h_t,k_t,d_t,a_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \Bigg\{ U^*(c_{ht}^*, c_{ft}^*, h_t^*) + \xi_t^* \left[(1-\tau_{wt}^*)\, w_t^* h_t^* + R_{kt}^* k_{t-1}^* + d_{t-1}^* + a_{t-1}^* - (1+\tau_{mt}^*)\, \frac{c_{ht}^*}{e_t} - (1+\tau_{ct}^*)\, c_{ft}^* - k_t^* - \frac{d_t^*}{R_{dt}^*} - \frac{a_t^*}{R_{at}} \right] \Bigg\} \tag{A.1}$$

First-order conditions:

$$\begin{aligned}
c_{ht}^*: &\quad U_1^*(c_{ht}^*, c_{ft}^*, h_t^*) = \frac{\xi_t^*(1+\tau_{mt}^*)}{e_t} \\
c_{ft}^*: &\quad U_2^*(c_{ht}^*, c_{ft}^*, h_t^*) = \xi_t^*(1+\tau_{ct}^*) \\
h_t^*: &\quad U_3^*(c_{ht}^*, c_{ft}^*, h_t^*) + \xi_t^*(1-\tau_{wt}^*) w_t^* = 0 \\
k_t^*: &\quad \xi_t^* = \beta \xi_{t+1}^* R_{k,t+1}^* \\
d_t^*: &\quad \frac{\xi_t^*}{R_{dt}^*} = \beta \xi_{t+1}^* \\
a_t^*: &\quad \frac{\xi_t^*}{R_{at}} = \beta \xi_{t+1}^*
\end{aligned}$$

The foreign rate of return arbitrage conditions read:

$$R_{k,t+1}^* = R_{dt}^* = R_{at}^* \tag{A.2}$$

Notes:

1. The real exchange rate, e_t, is expressed as the number of units of the home good per foreign good.

2. International bonds are priced in units of the foreign good. Hence, for foreign households, government debt (d_t^*) and net foreign assets (a_t^*) are perfect substitutes.

A.2 The Foreign Ramsey Planner's Problem

As for the home government, assume that the consumption tax, τ_{ct}^*, is fixed; recall that otherwise there is a surplus of tax rates to determine.

$$
\begin{aligned}
\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \Bigg\{ & U^*(c_{ht}^*, c_{ft}^*, h_t^*) \\
& + \lambda_{1t}^* \left[F(k_{t-1}^*, h_t^*) + (1-\delta)k_{t-1}^* - c_{ft}^* - \frac{n}{1-n} c_{ft} - k_t^* - g^* \right] \\
& + \lambda_{2t}^* \left[\frac{U_2^*(c_{ht}^*, c_{ft}^*, h_t^*)}{1+\tau_c^*} - \frac{e_t U_1^*(c_{ht}^*, c_{ft}^*, h_t^*)}{1+\tau_{mt}^*} \right] \\
& + \lambda_{3t}^* \left[U_3^*(c_{ht}^*, c_{ft}^*, h_t^*) + \frac{U_2^*(c_{ht}^*, c_{ft}^*, h_t^*)}{1+\tau_c^*} (1-\tau_{wt}^*) F_2(k_{t-1}^*, h_t^*) \right] \\
& + \lambda_{4t}^* \left[\beta \frac{U_2^*(c_{ht+1}^*, c_{ft+1}^*, h_{t+1}^*)}{1+\tau_c^*} \left[1 + \left(1-\tau_{k,t+1}^*\right) \left(F_1(k_t^*, h_{t+1}^*) - \delta \right) \right] - \frac{U_2^*(c_{ht}^*, c_{ft}^*, h_t^*)}{1+\tau_c^*} \right] \\
& + \lambda_{5t}^* \left[e_t \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \vartheta \frac{U_2^*(c_{ht}^*, c_{ft}^*, h_t^*)}{1+\tau_c^*} \right] \\
& + \lambda_{6t}^* \Bigg[(1-\tau_{wt}) w_t h_t + \left[1 + (1-\tau_{kt}) \left(F_1(k_{t-1}, h_t) - \delta \right) \right] k_{t-1} + d_{t-1} + e_t a_{t-1} \\
& \qquad - (1+\tau_{ct}) c_{ht} - (1+\tau_{mt}) e_t c_{ft} - k_t - \frac{d_t}{R_{dt}} - e_t \frac{a_t}{R_{at}} \Bigg] \\
& + \lambda_{7t}^* \left[\frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_{mt}} - \frac{e_t U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \right] \\
& + \lambda_{8t}^* \left[U_3(c_{ht}, c_{ft}, h_t) + \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c} (1-\tau_{wt}) F_2(k_{t-1}, h_t) \right] \\
& + \lambda_{9t}^* \left[\beta \frac{U_2(c_{ht+1}, c_{ft+1}, h_{t+1})}{1+\tau_c} \left[1 + (1-\tau_{k,t+1}) \left(F_1(k_t, h_{t+1}) - \delta \right) \right] - \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \right] \\
& + \Omega^* \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c^*} \left[\frac{n}{1-n} c_{ft} - \frac{c_{ht}^*}{e_t} \right] \\
& - \Lambda \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c^*} \left[g^* - \tau_c^* c_{ft}^* - \tau_{mt}^* \frac{c_{ht}^*}{e_t} - \tau_{wt}^* F_2(k_{t-1}^*, h_t^*) h_t^* - \tau_{kt}^* (F_1(k_{t-1}^*, h_t^*) - \delta) k_{t-1}^* \right] \Bigg\} \\
& + \Omega^* \frac{U_2^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} a_{-1}^* \\
& - \Lambda \frac{U_2^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} d_{-1}^*.
\end{aligned}
\tag{A.3}
$$

A.3 The Foreign Planner's Partial Primal Problem

The foreign government chooses $\{c_{ht}, c_{ft}, h_t, k_t, e_t, c^*_{ht}, c^*_{ft}, h^*_t, k^*_t\}_{t=0}^{\infty}$ to maximize

$$
\begin{aligned}
\mathcal{L}^* = \max \sum_{t=0}^{\infty} \beta^t \Bigg\{ & W^*(c^*_{ht}, c^*_{ft}, h^*_t) \\
& + \lambda^*_{1t} \left[F(k^*_{t-1}, h^*_t) + (1-\delta)k^*_{t-1} - c^*_{ft} - \frac{n}{1-n} c_{ft} - k^*_t - g^* \right] \\
& + \lambda^*_{2t} \left[\vartheta \frac{U^*_2(c^*_{ht}, c^*_{ft}, h^*_t)}{1+\tau^*_c} - e_t \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \right] \\
& + \lambda^*_{3t} \left[\frac{e_t U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_{mt}} \right] \\
& + \lambda^*_{4t} \left[U_3(c_{ht}, c_{ft}, h_t) + \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c} (1-\tau_{wt}) F_2(k_{t-1}, h_t) \right] \\
& + \lambda^*_{5t} \left[\beta \frac{U_2(c_{ht+1}, c_{ft+1}, h_{t+1})}{1+\tau_c} \left[1 + (1-\tau_{k,t+1}) \left(F_1(k_t, h_{t+1}) - \delta \right) \right] - \frac{U_2(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \right] \\
& + \lambda^*_{6t} \Bigg[(1-\tau_{wt}) w_t h_t + \left[1 + (1-\tau_{kt}) \left(F_1(k_{t-1}, h_t) - \delta \right) \right] k_{t-1} + d_{t-1} + e_t a_{t-1} \\
& \qquad - (1+\tau_{ct}) c_{ht} - (1+\tau_{mt}) e_t c_{ft} - k_t - \frac{d_t}{R_{dt}} - e_t \frac{a_t}{R_{at}} \Bigg] \\
& + \Omega^* \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \left[\frac{1-n}{n} c^*_{ht} - e_t c_{ft} \right] \Bigg\} \\
& + \Omega^* e_0 \frac{U^*_2(c^*_{h0}, c^*_{f0}, h^*_0)}{1+\tau^*_c} a_{-1} \\
& - \Lambda^* \frac{U^*_2(c^*_{h0}, c^*_{f0}, h^*_0)}{1+\tau^*_c} \left[\left[1 + (1-\tau^*_{k0})(F_1(k^*_{-1}, h^*_0) - \delta) \right] k^*_{-1} + d^*_{-1} + a^*_{-1} \right]
\end{aligned}
\tag{A.4}
$$

B Lower Trade Elasticity

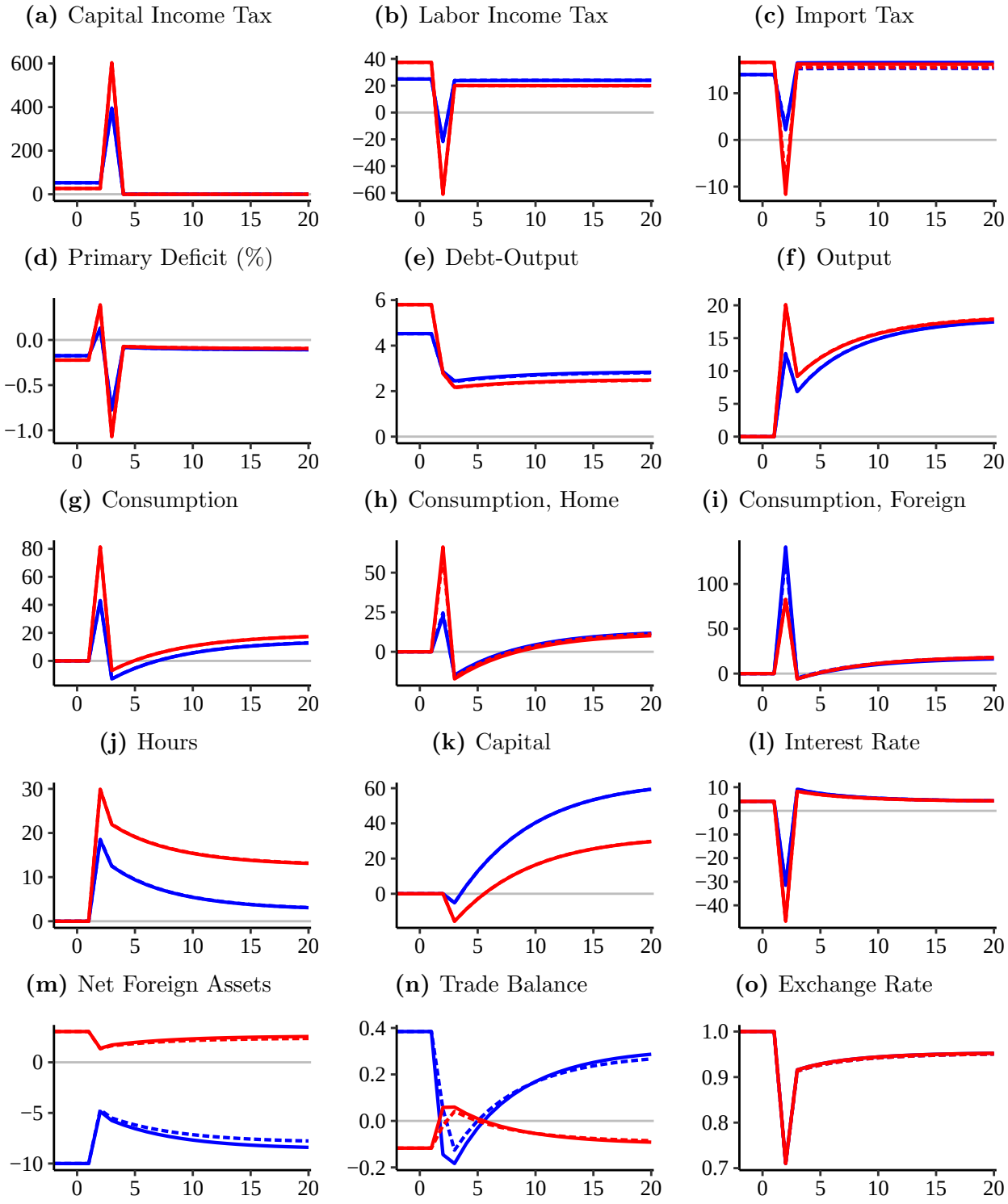
It is well known that the dynamics of open economy models can be sensitive to whether the trade elasticity is larger or smaller than one. This section explores the implications of setting this elasticity below one: $\mu = 0.8$. Results for this case are presented in Fig. B.1 for the tax competition environment.

Overall, the core results of the benchmark tax competition model remain intact. For the most part, visually there are few differences between the benchmark (that is, high trade elasticity) and the low trade elasticity cases. A notable exception is the import tax rate. In the benchmark economy, the foreign government initially lowered this tax rate; with the lower trade elasticity, it initially raises the import tax rate. The home government's setting for this tax rate is similar.

Naturally, the lower trade elasticity implies that households in each country are less willing to substitute between home- and foreign-produced goods. As a result, in year 0 foreign consumption of the home good changes very little under the lower trade elasticity; home consumption of the foreign good likewise displays a muted response. As a result, the trade balance dynamics are quite different, and so are those of net foreign assets.

Given the fairly minor differences in the results between the benchmark and low trade elasticity cases, it should not be surprising that the welfare results are quite similar. Indeed, the welfare benefit to foreign households is virtually unchanged (4.9% of consumption) while that of home households rises from 5.5% to 6.1%.

Figure B.1: Ramsey Tax Competition: Lower Trade Elasticity

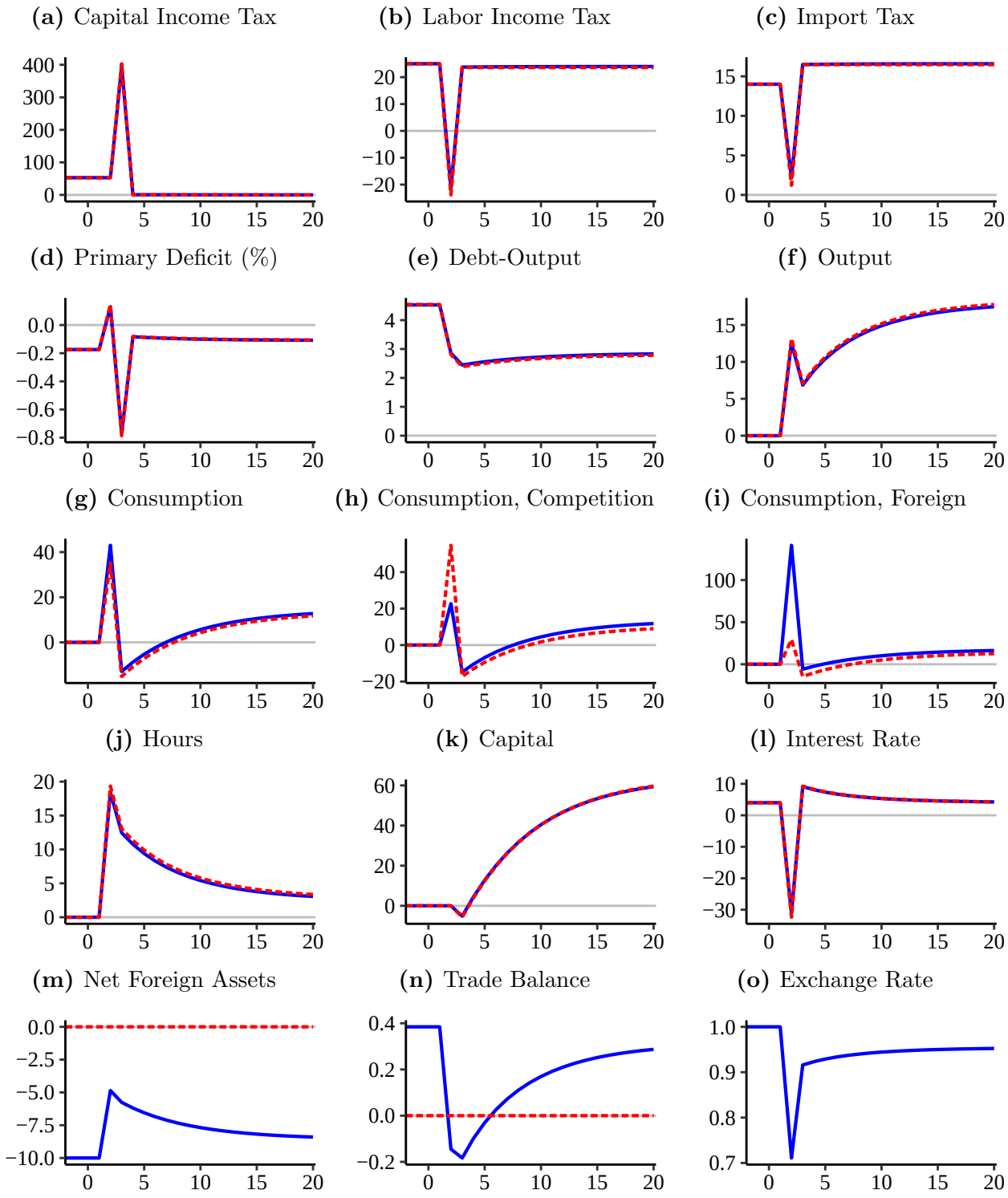


Legend: Benchmark: home (solid blue), foreign (solid red). Lower trade elasticity: home (long dashed green), foreign (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

C Guide to Supplementary Figures

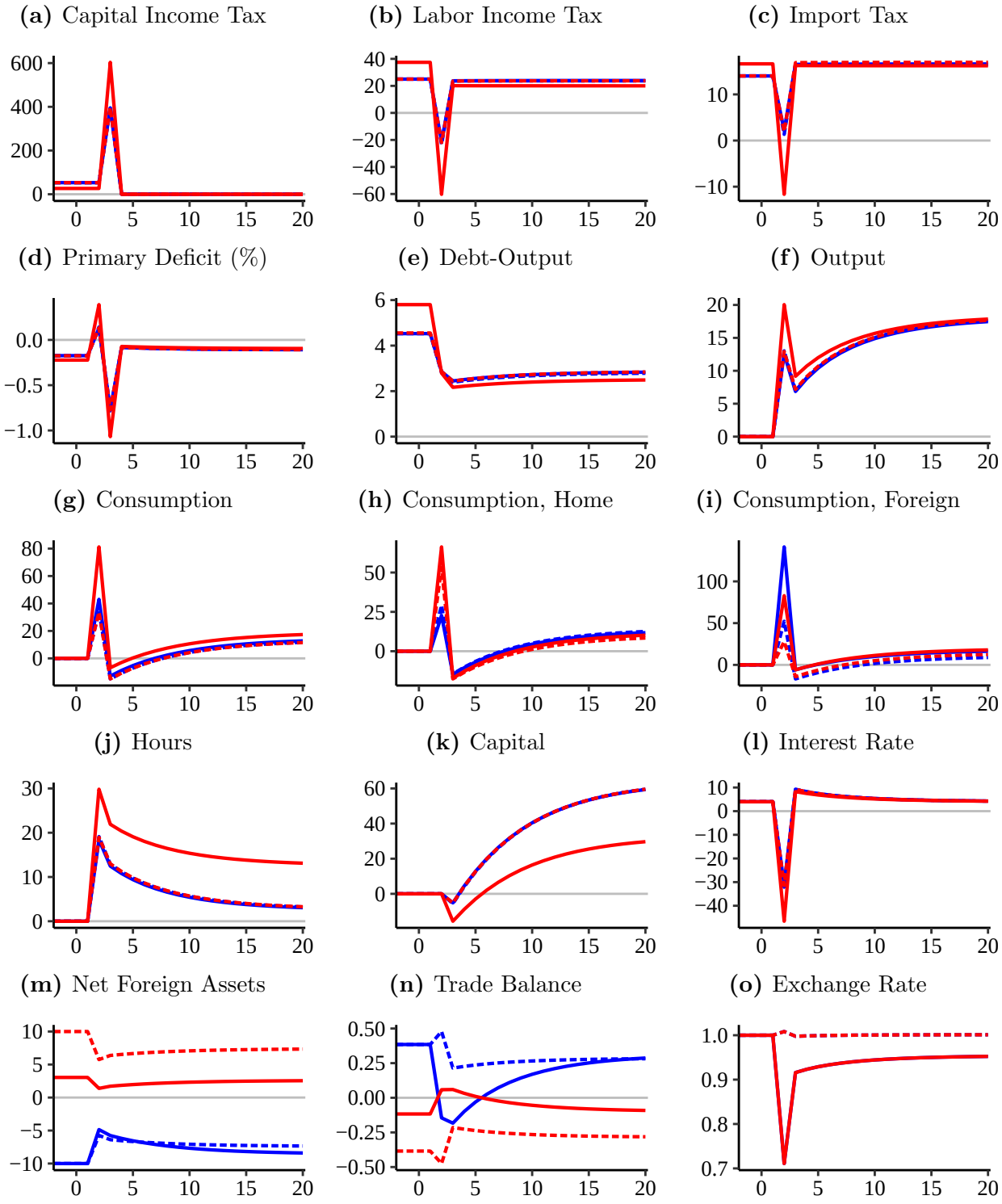
- Fig. C.1: Full symmetry
- Fig. C.2: Differences in initial net foreign assets only
- Fig. C.3: Differences in population only
- Fig. C.4: Differences in initial tax rates only
- Fig. C.5: Lower import share target (5%)
- Fig. C.6: Effect of higher imports, foreign country
- Fig. C.7: Same population
- Fig. C.8: Comparison of tax competition and tax cooperation for the home country
- Fig. C.9: Comparison of tax competition and tax cooperation for the foreign country
- Fig. C.10: Home: Tax cooperation, higher imports
- Fig. C.11: Effect of higher risk aversion (σ) for the home country
- Fig. C.12: Effects of less openness on the home country
- Fig. C.13: Effects of different labor supply elasticities on the home country
- Fig. C.14: Same consumption tax rates ($\tau_c = \tau_c^*$)
- Fig. C.15: Same initial import tax rates ($\tau_m = \tau_m^*$)
- Fig. C.16: Same initial labor income tax rates ($\tau_w = \tau_w^*$)
- Fig. C.17: Same initial capital income tax rates ($\tau_k = \tau_k^*$)

Figure C.1: Ramsey Tax Competition: Symmetric Case



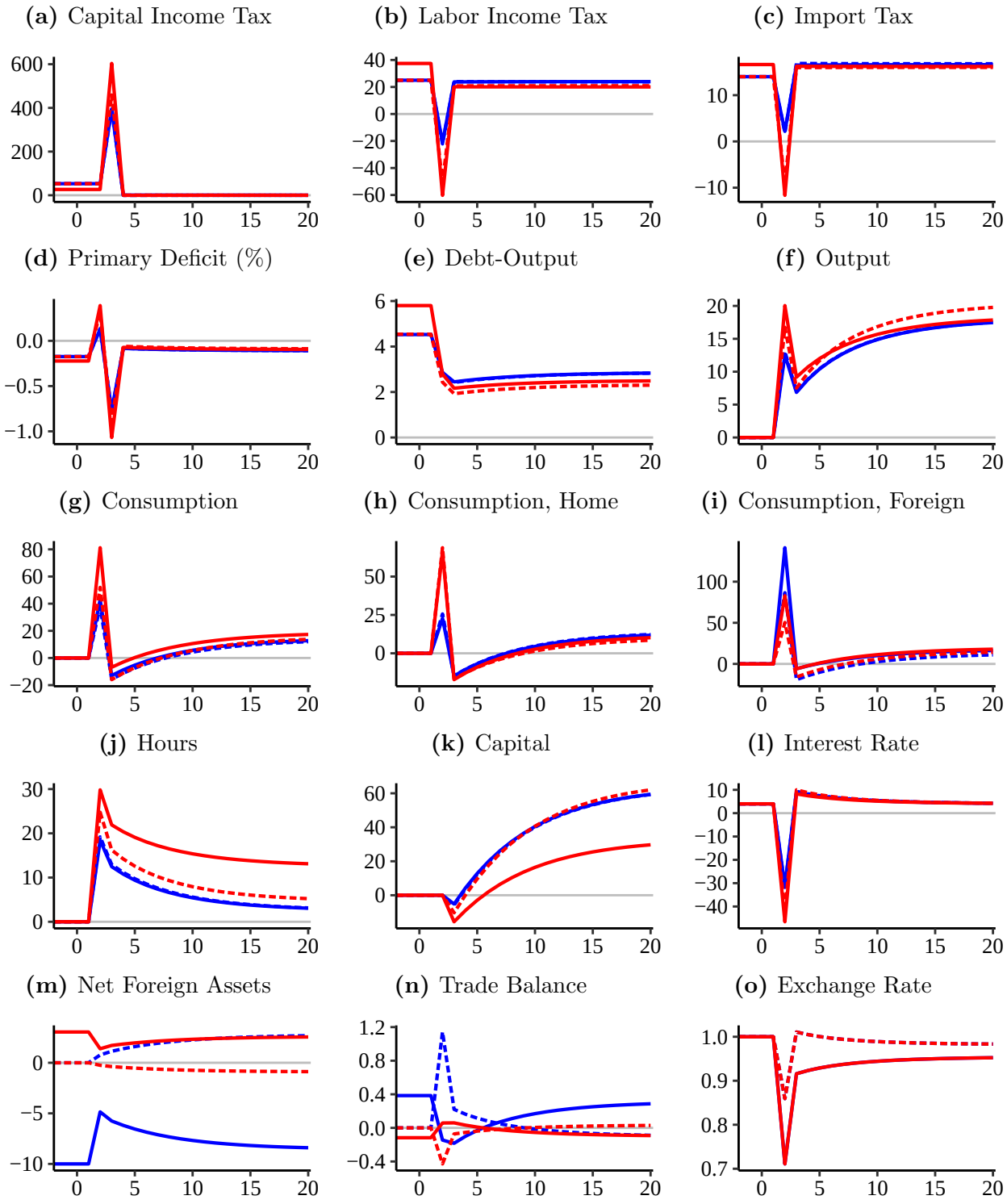
Legend: home (solid blue); foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.2: Ramsey Tax Competition: Differences in Initial Net Foreign Assets Only



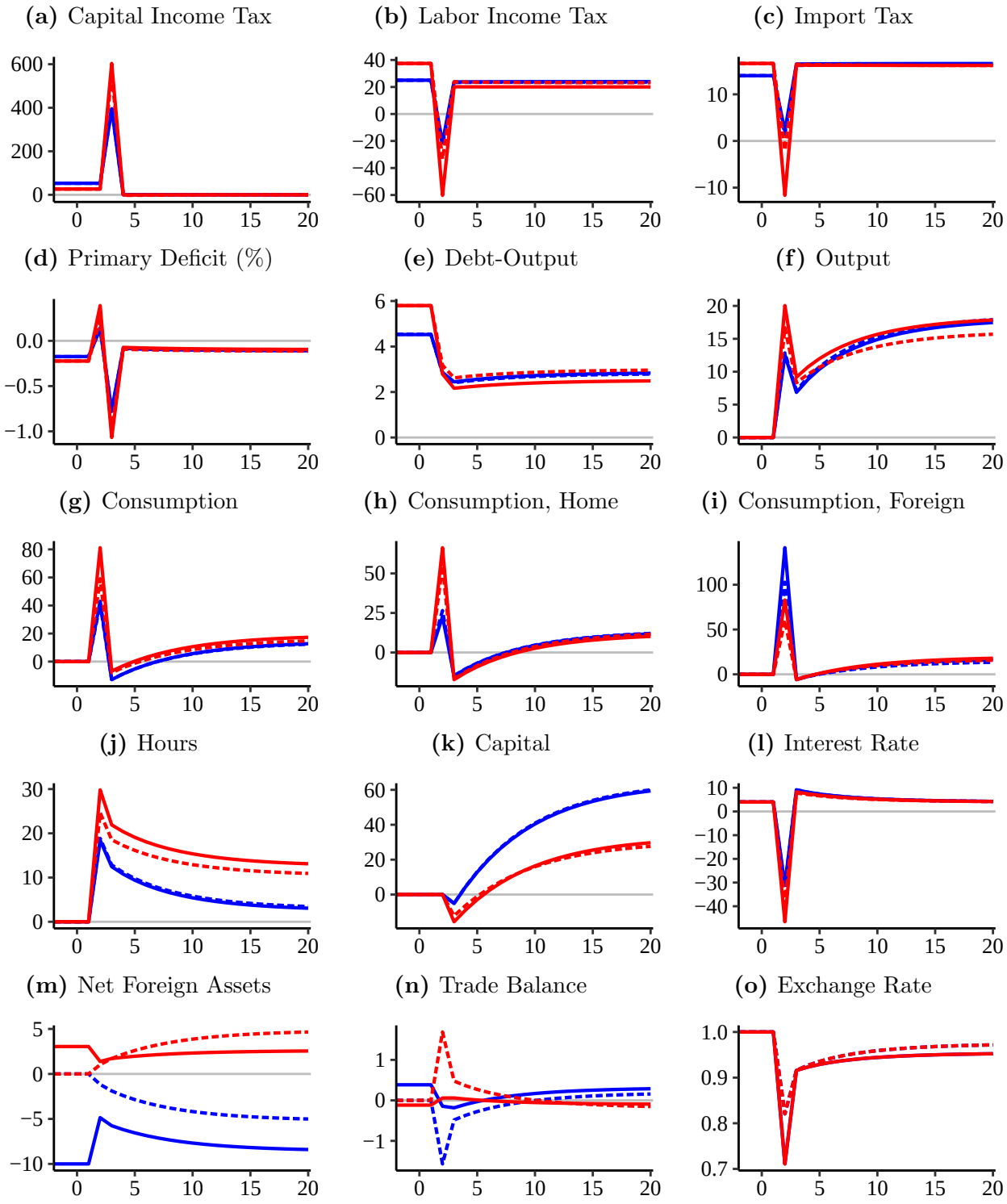
Legend: Benchmark: home (solid blue), foreign (solid red). Differences in net foreign assets only: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.3: Ramsey Tax Competition: Different Country Size Only



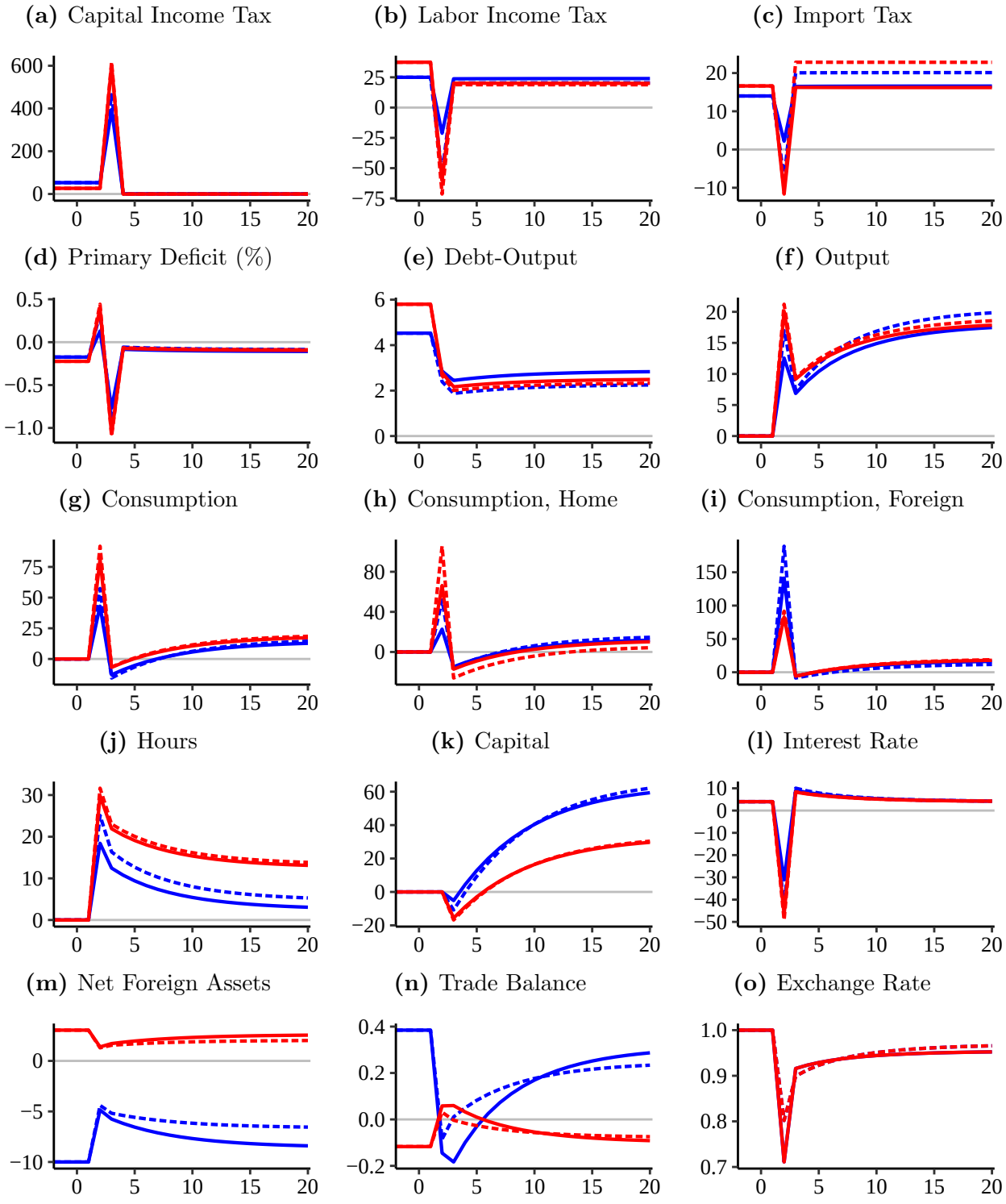
Legend: Benchmark: home (solid blue), foreign (short dashed red). Differences in population size only: home (long dashed green), foreign (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.4: Ramsey Tax Competition: Different Initial Tax Rates Only



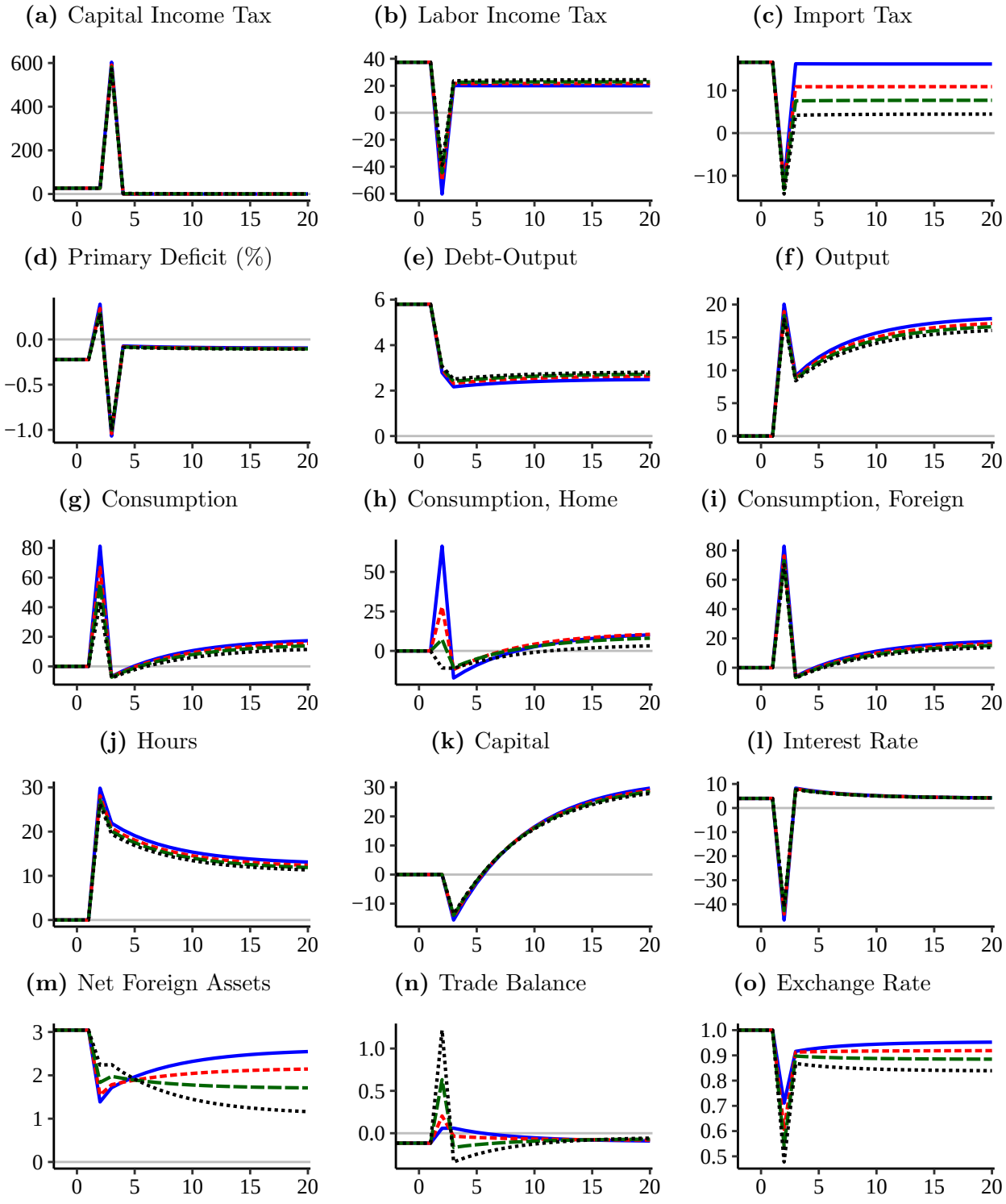
Legend: Benchmark: home (solid blue), foreign (short dashed red). differences in initial taxes only: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.5: Ramsey Tax Competition: Less Open



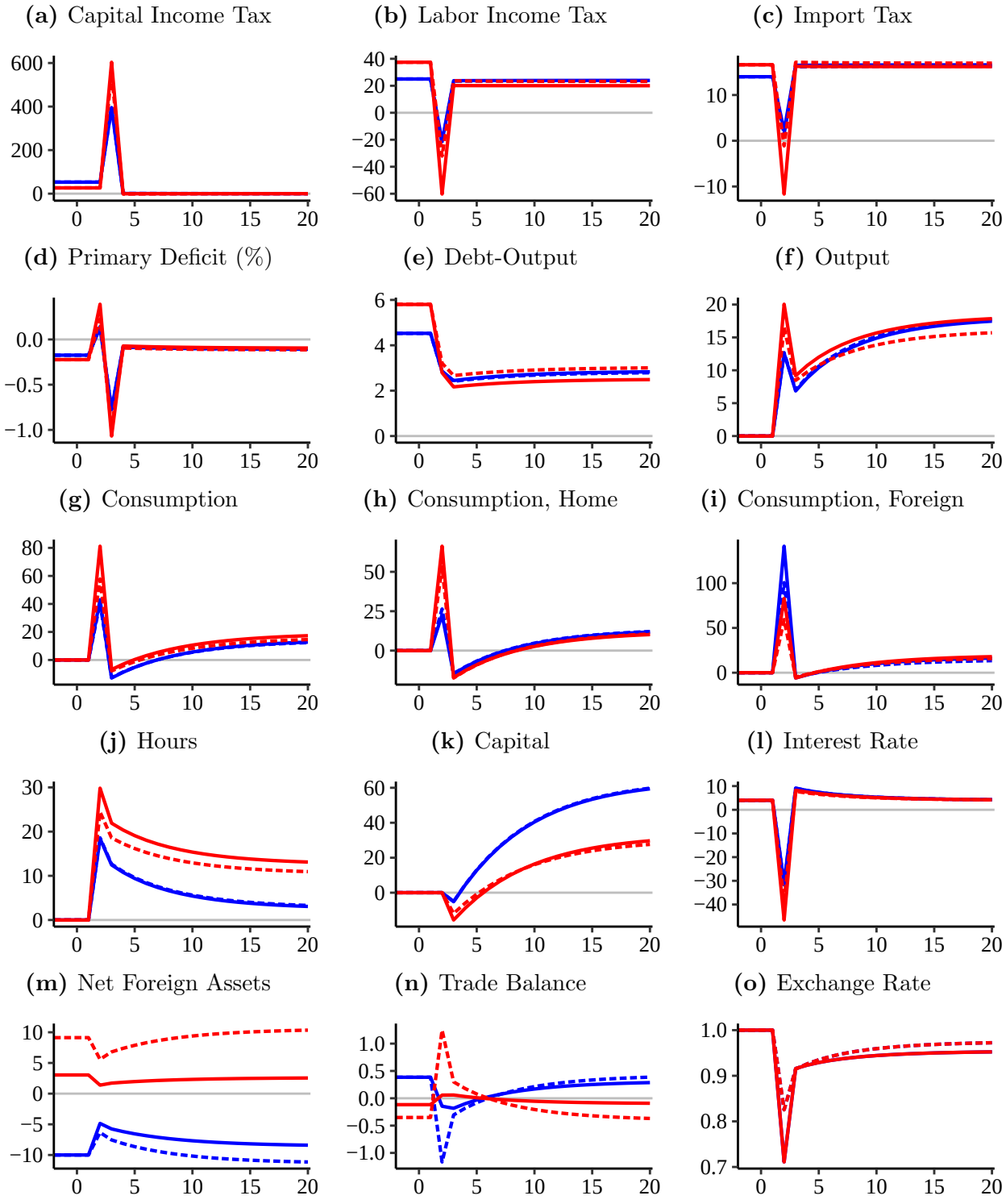
Legend: Benchmark: home (solid blue), foreign (solid red). Less open (lower imports): home (dotted blue), foreign (dotted red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.6: Ramsey Tax Competition: Foreign Country, Higher Imports



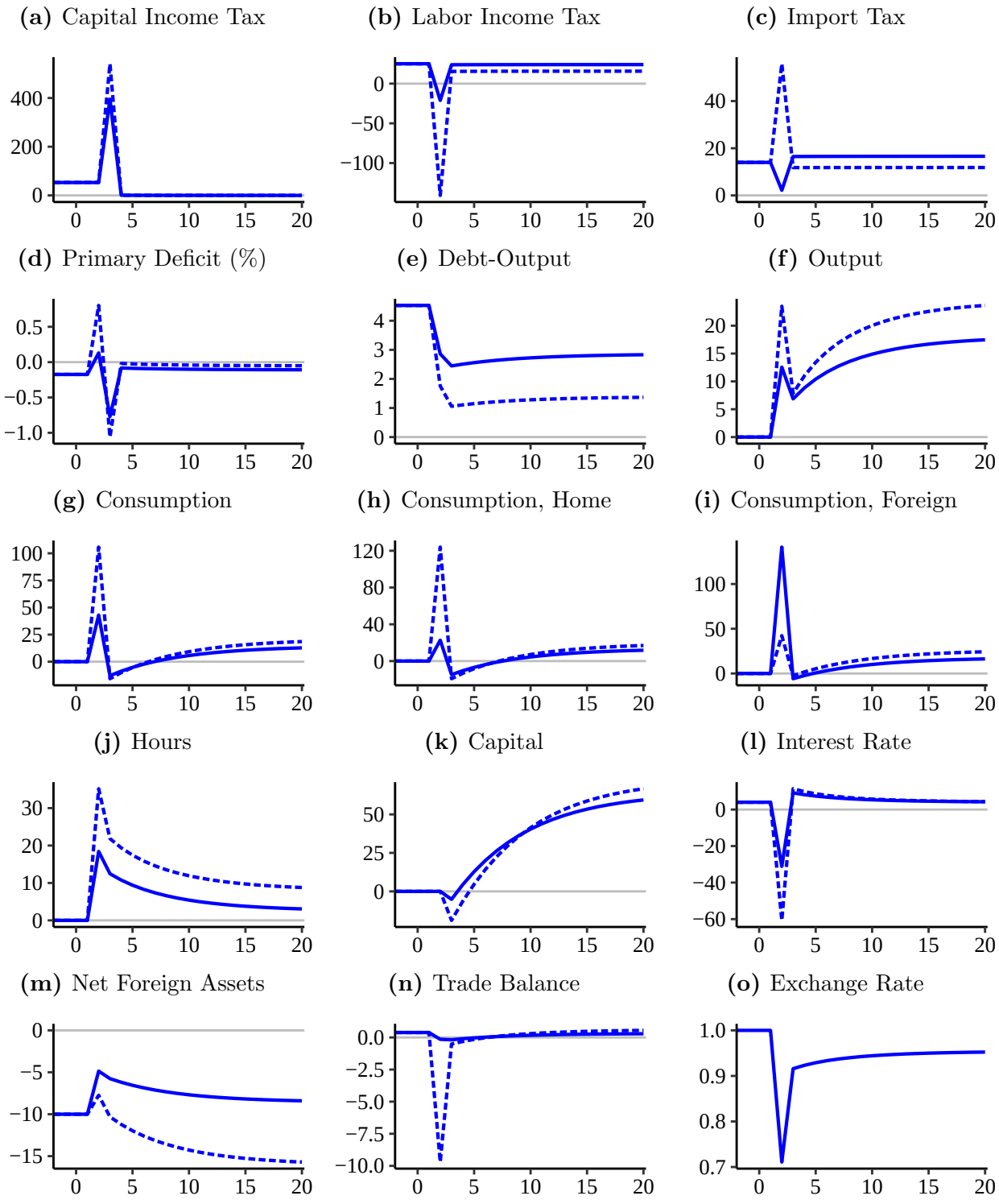
Legend: Import shares: Benchmark (22.5%, solid blue); 40% (short dashed red); 50% (long dashed green); 60% (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.7: Ramsey Tax Competition: Same Population Size



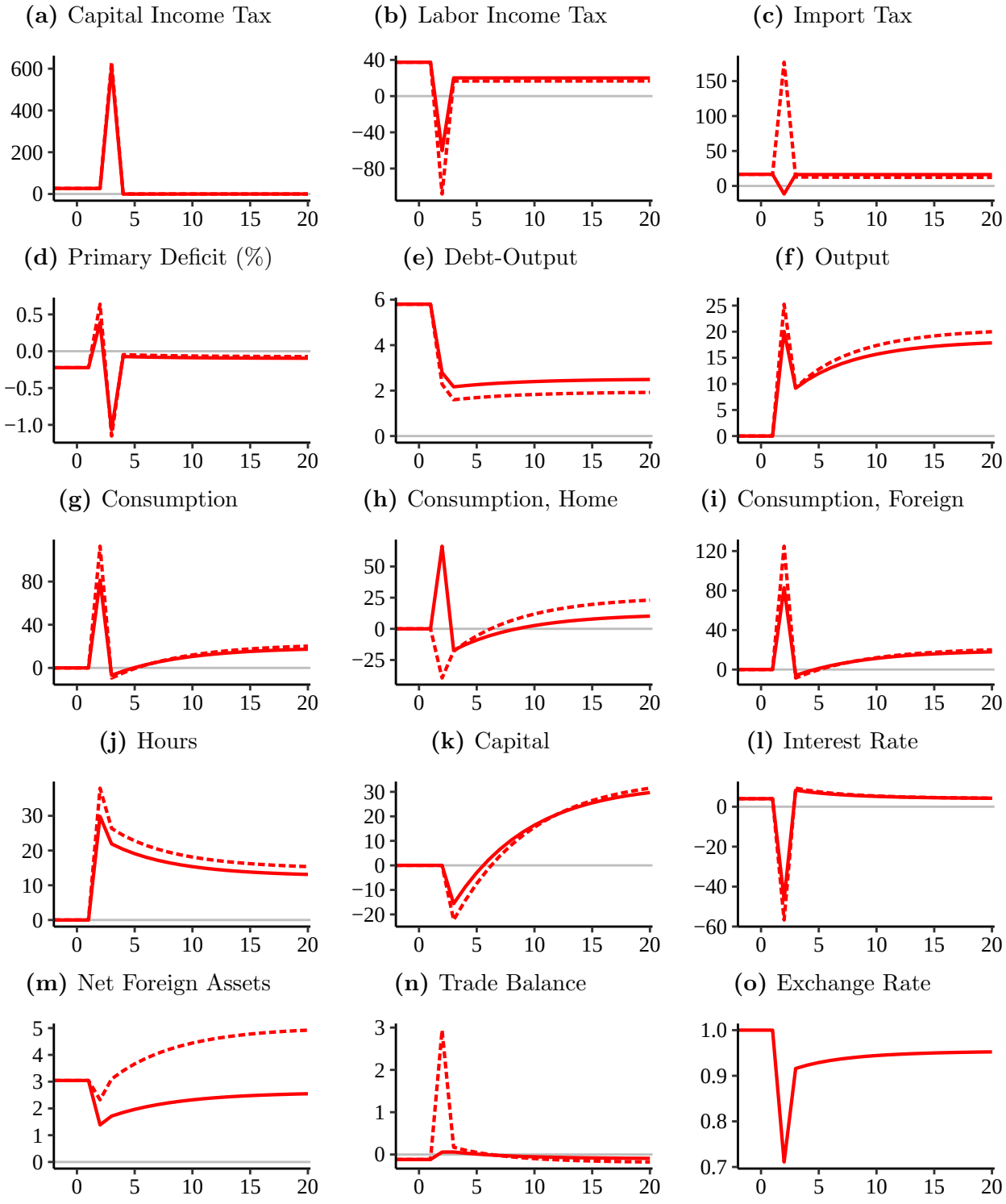
Legend: Benchmark: home (solid blue), foreign (solid red). Equal population ($n = 1/2$): home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.8: Tax Competition versus Tax Cooperation: Home



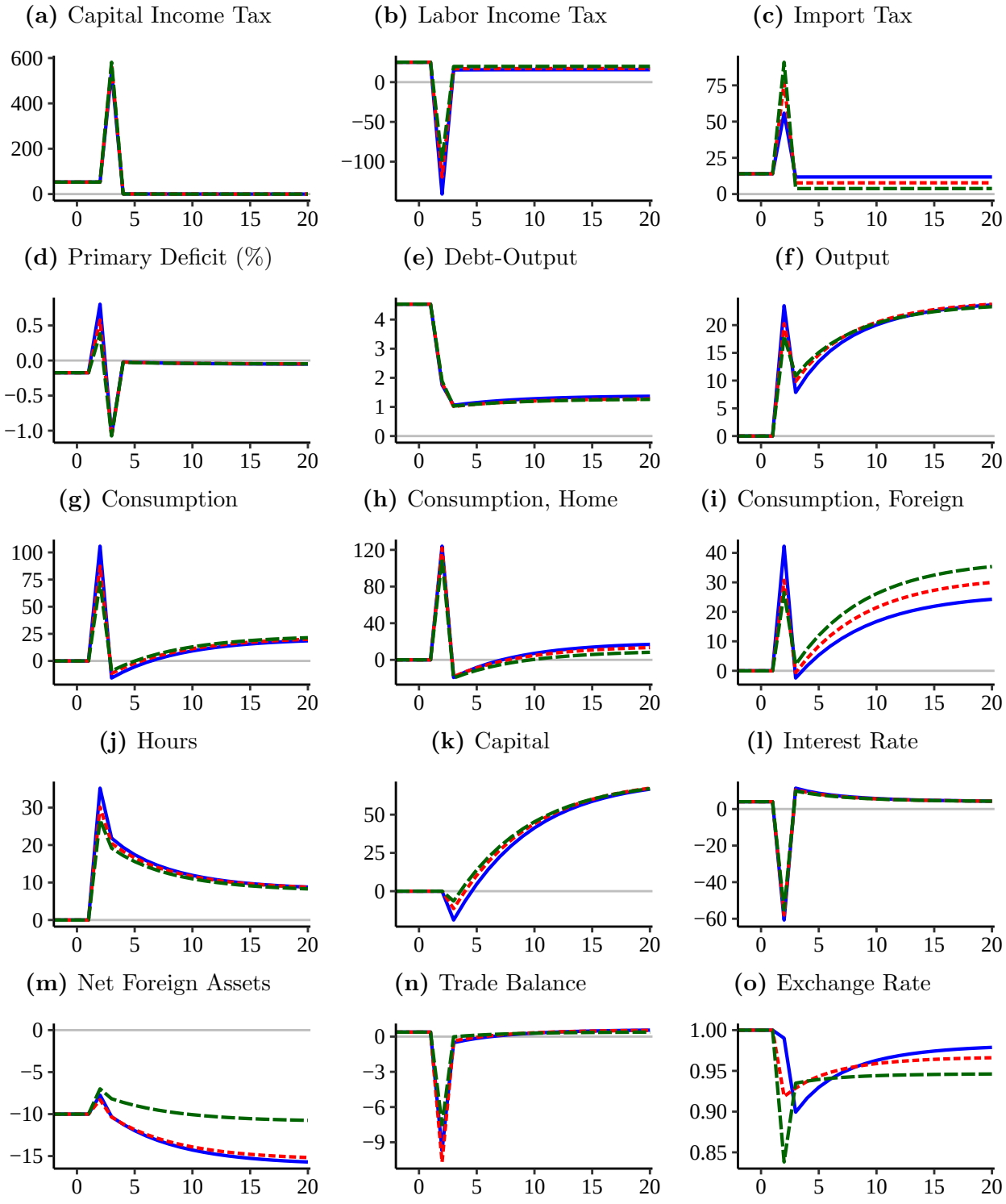
Legend: Competition: solid. Cooperation: dashed. Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.9: Tax Competition versus Tax Cooperation: Foreign



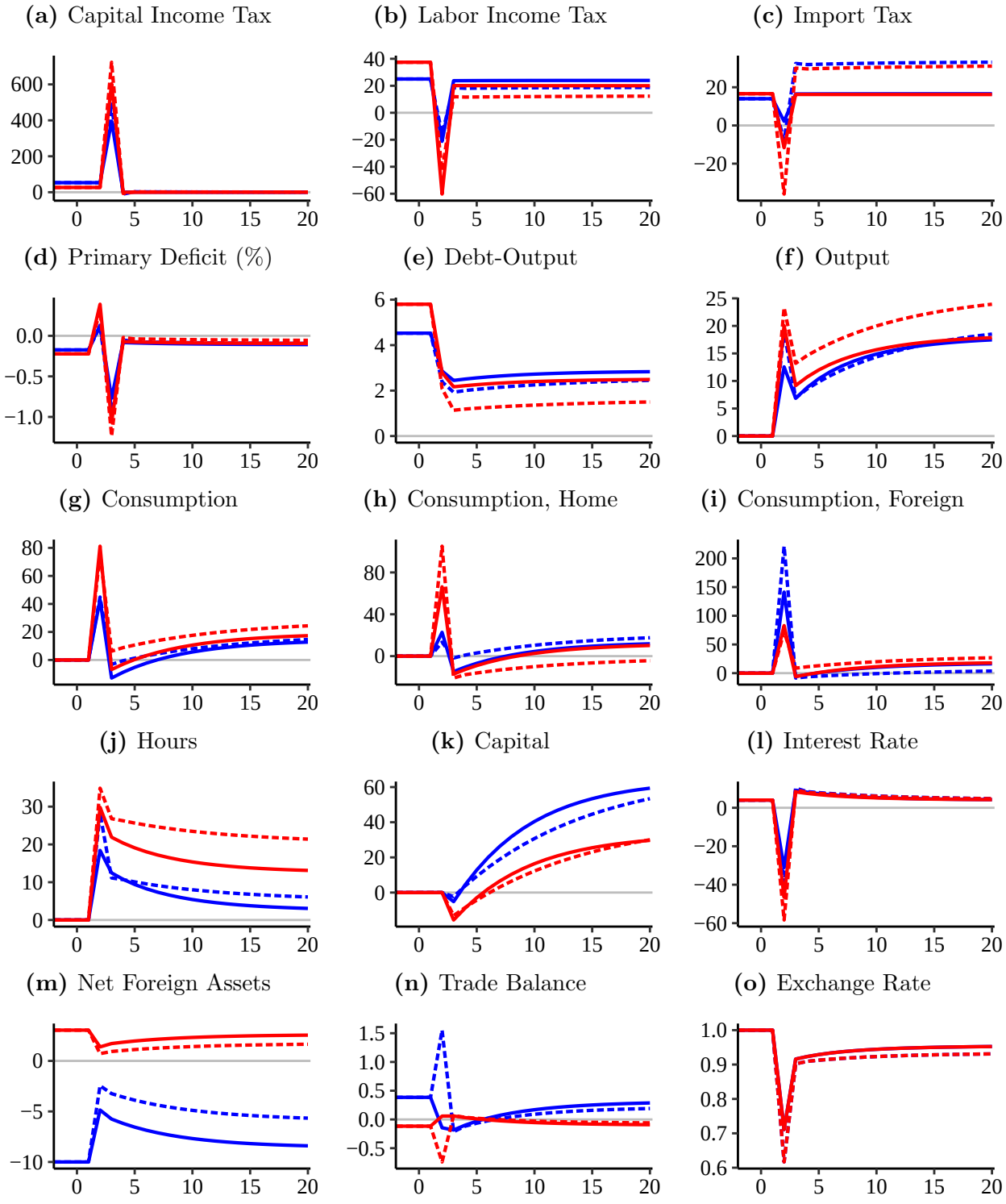
Legend: Competition: solid. Cooperation: dashed. Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.10: Ramsey Tax Cooperation: Home Country, Higher Imports



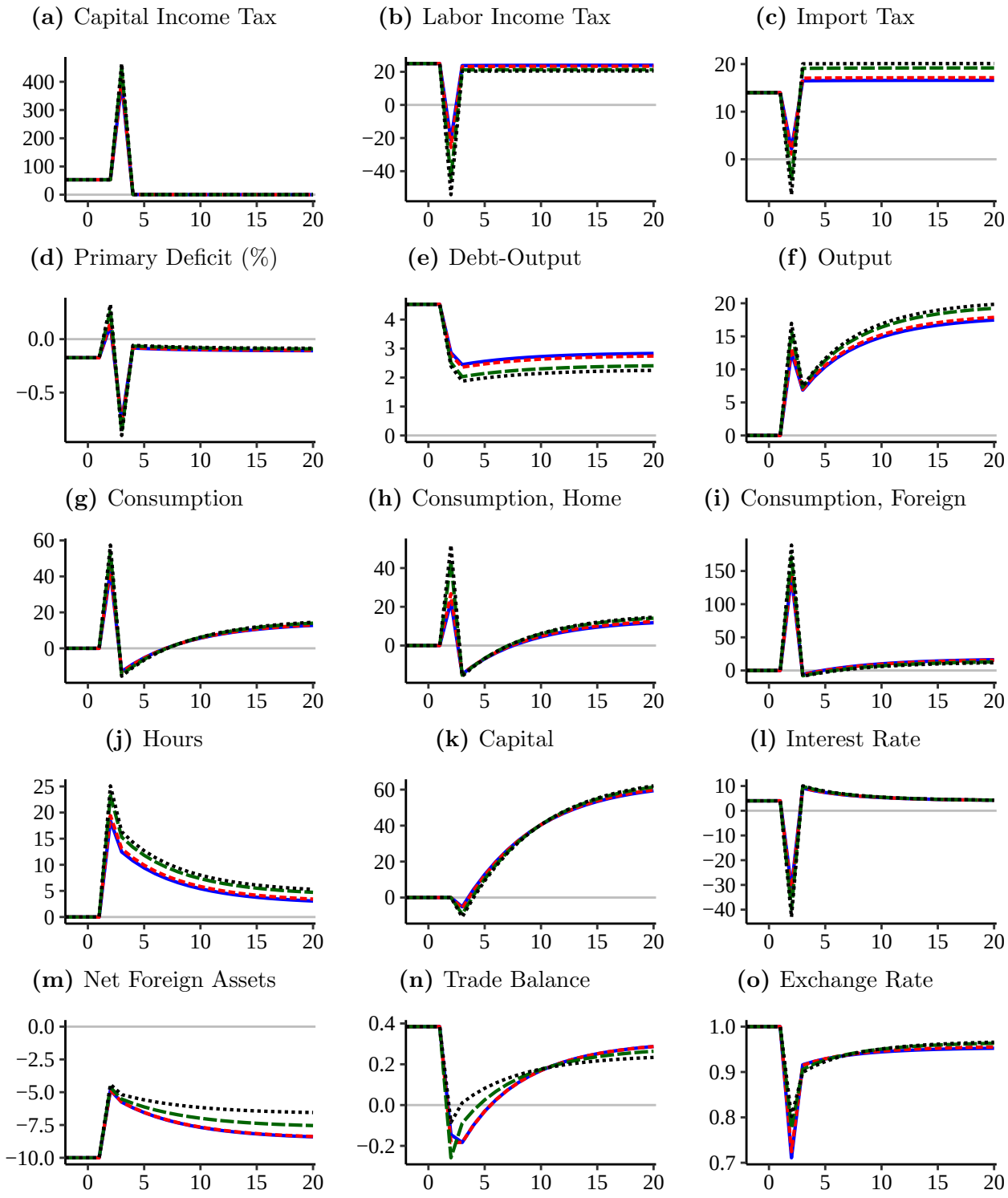
Legend: Import share: benchmark (22.5%, solid blue); 40% (short dashed red); 50% (long dashed green). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.11: Ramsey Tax Competition: Higher Risk Aversion



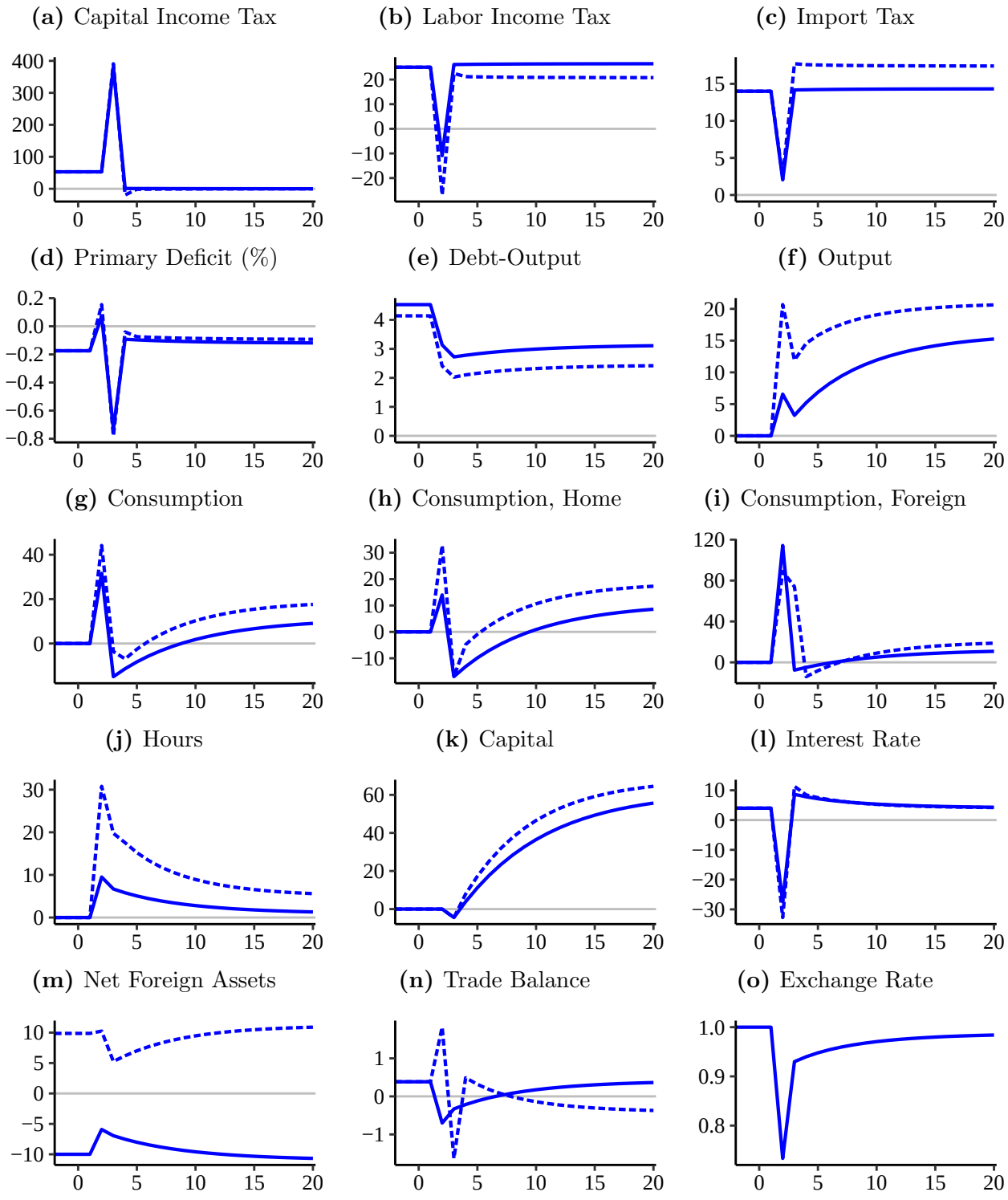
Legend: Benchmark: home (solid blue), foreign (solid red). Higher risk aversion ($\sigma = 2$): home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.12: Ramsey Tax Competition: Home, Less Open



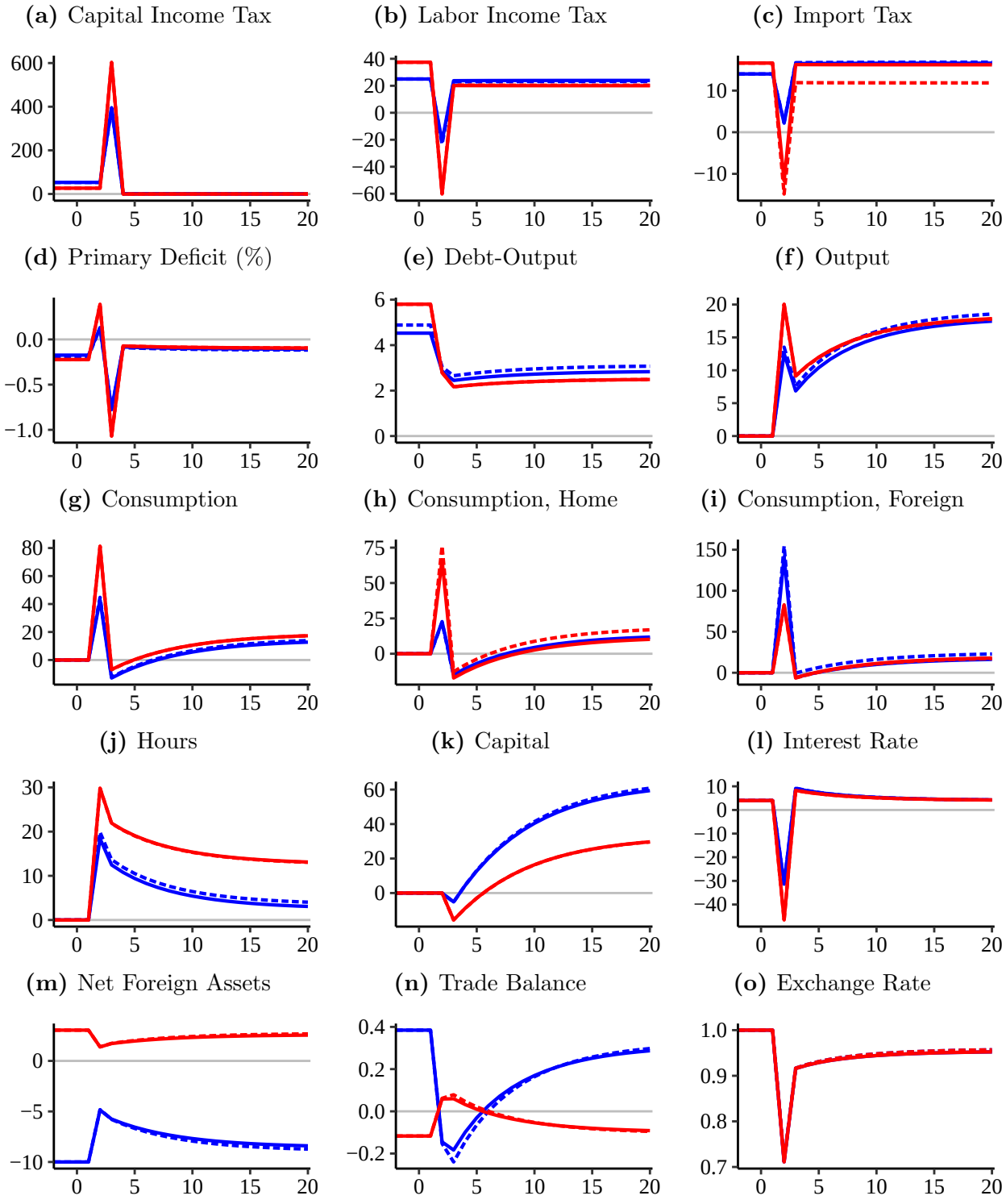
Legend: Import share: benchmark (22.5%, solid blue), 20% (short dashed red), 10% (long dashed green) and 5% (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.13: Ramsey Tax Competition: Home, Labor Supply Elasticity



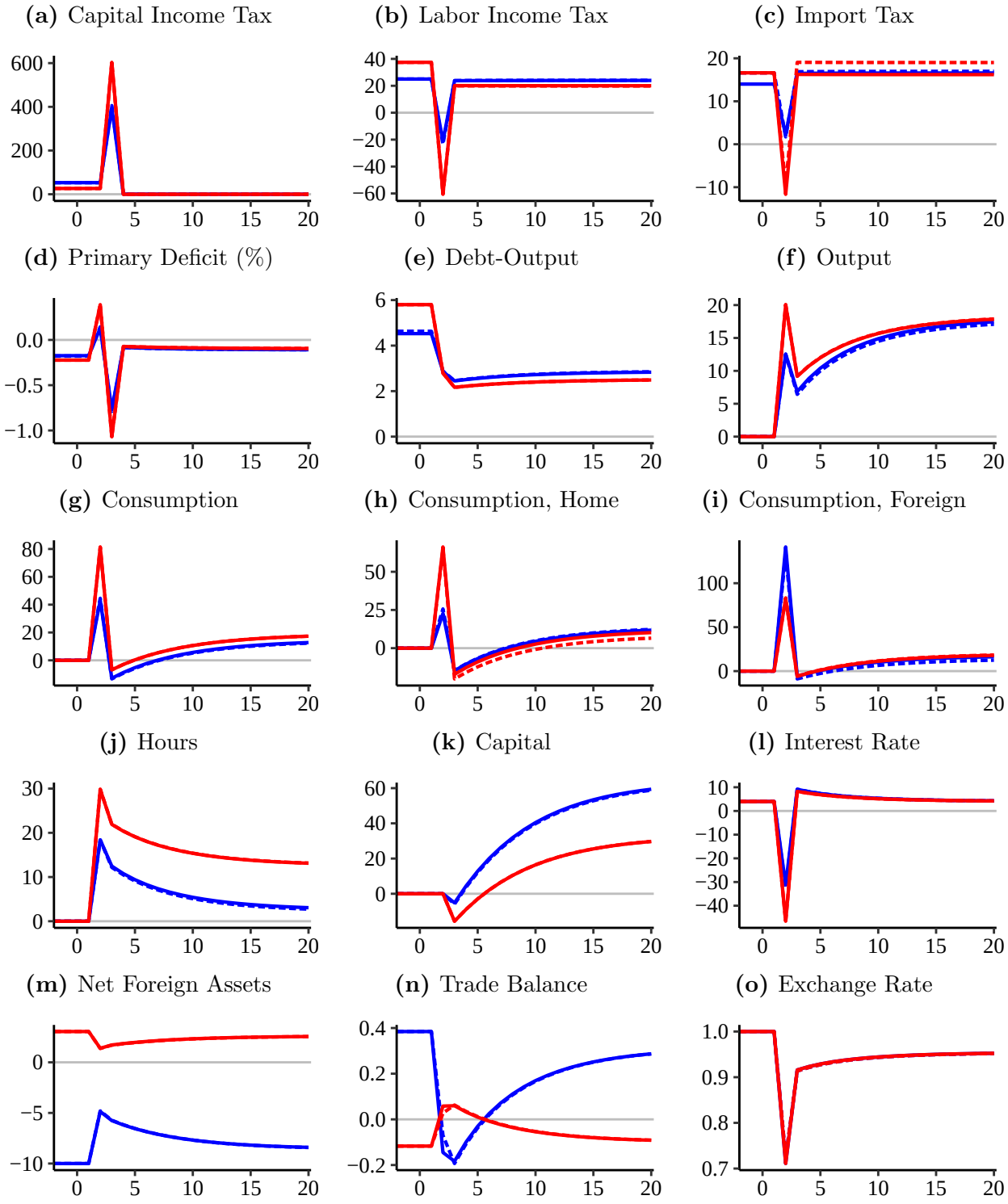
Legend: Labor supply elasticity: $\frac{1}{2}$ (solid), 3 (dashed). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.14: Ramsey Tax Competition: $\tau_c = \tau_c^*$



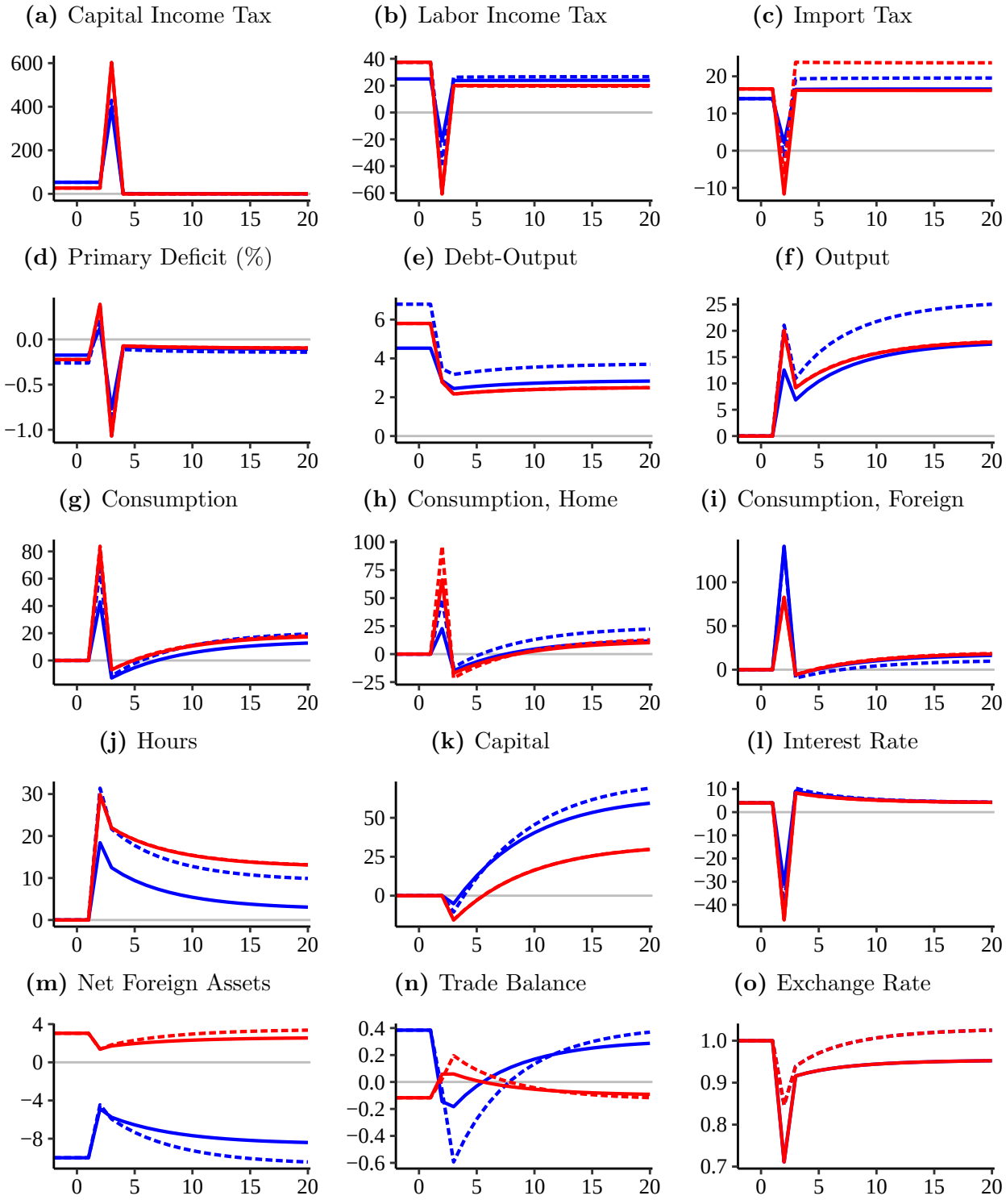
Legend: Benchmark: home (solid blue), foreign (solid red). $\tau_c = \tau_c^*$: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.15: Ramsey Tax Competition: $\tau_m = \tau_m^*$



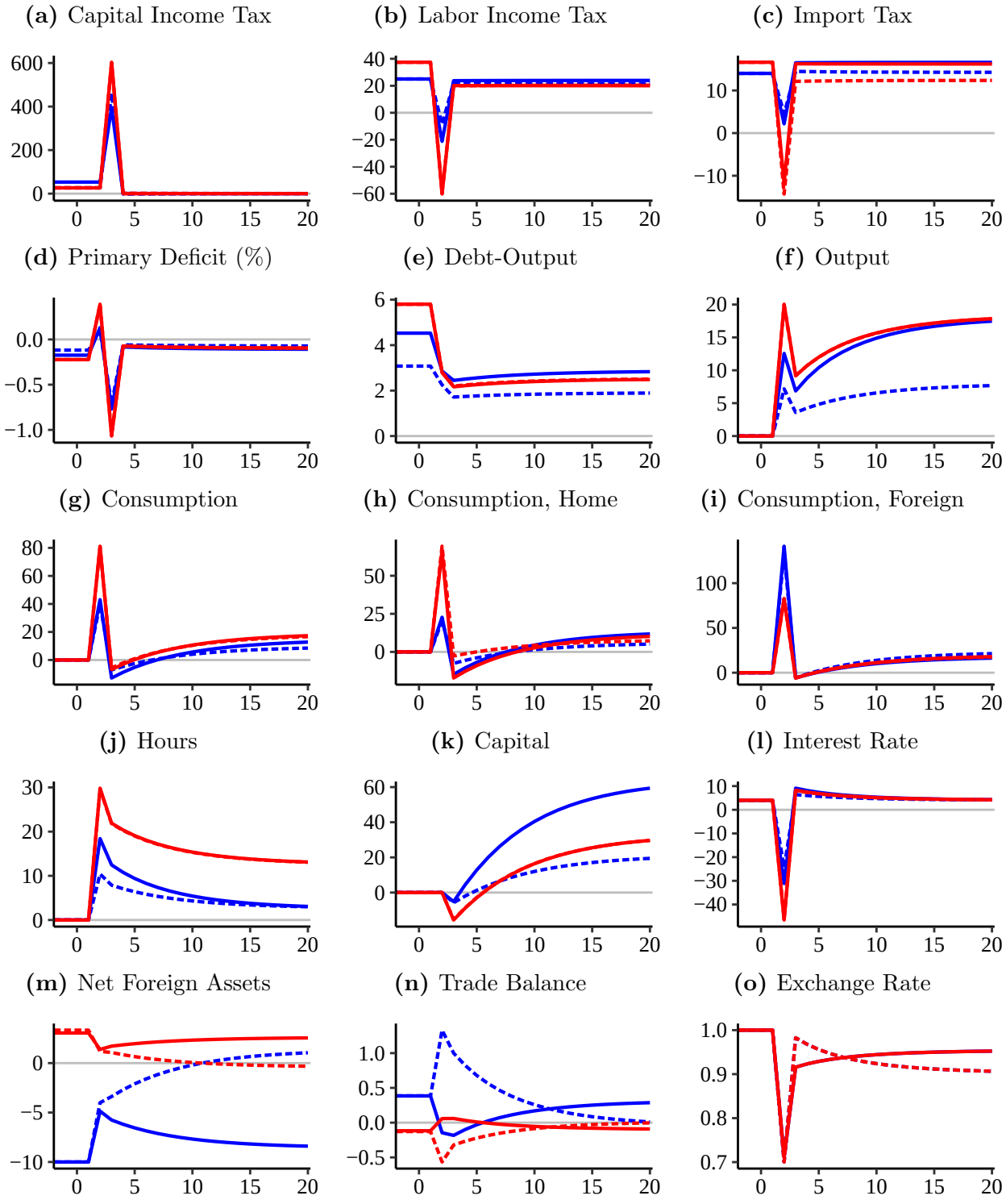
Legend: Benchmark: home (solid blue), foreign (solid red). $\tau_m = \tau_m^*$: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.16: Ramsey Tax Competition: $\tau_w = \tau_w^*$



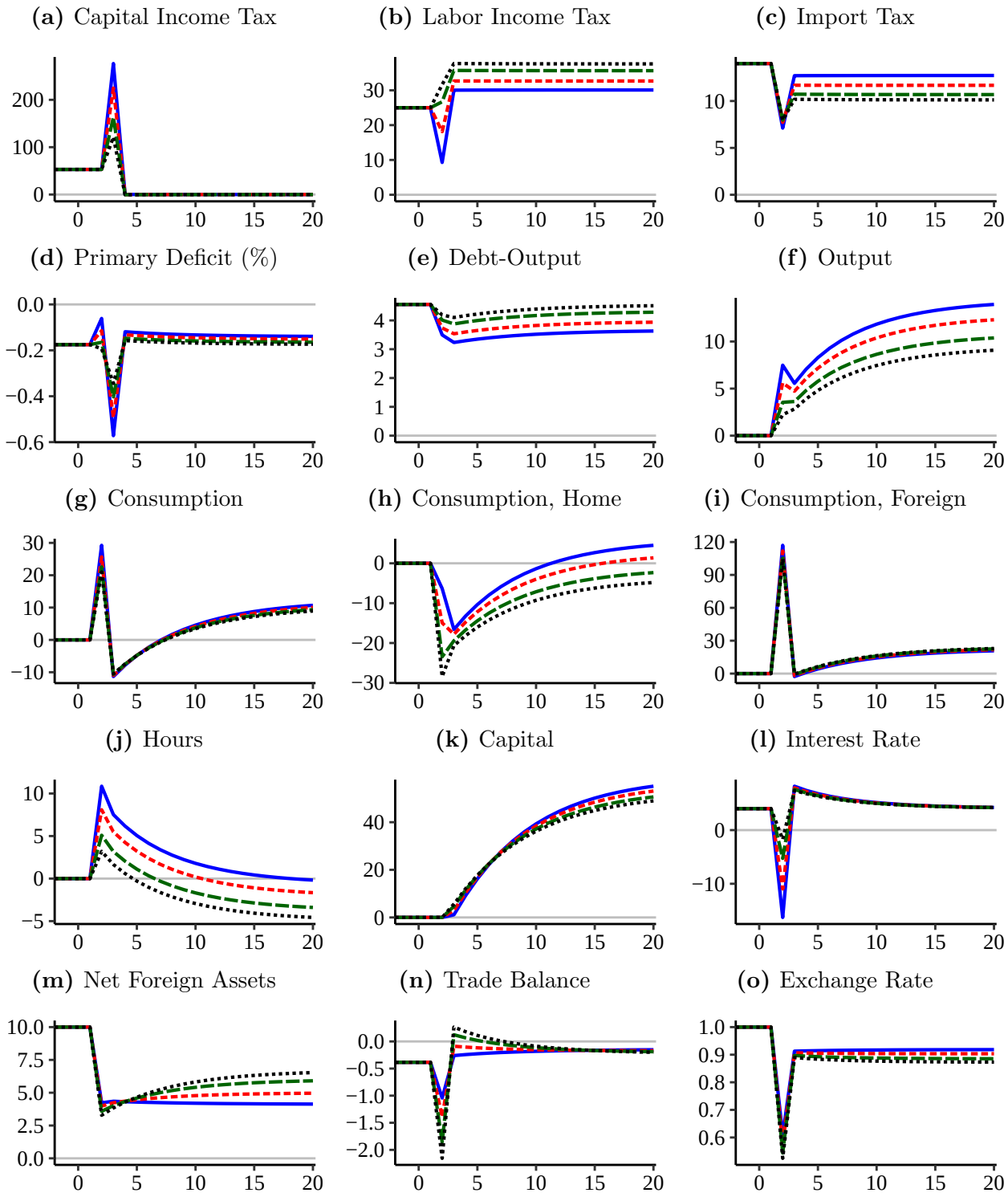
Legend: Benchmark: home (solid blue), foreign (solid red). $\tau_w = \tau_w^*$: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.17: Ramsey Tax Competition: $\tau_k = \tau_k^*$



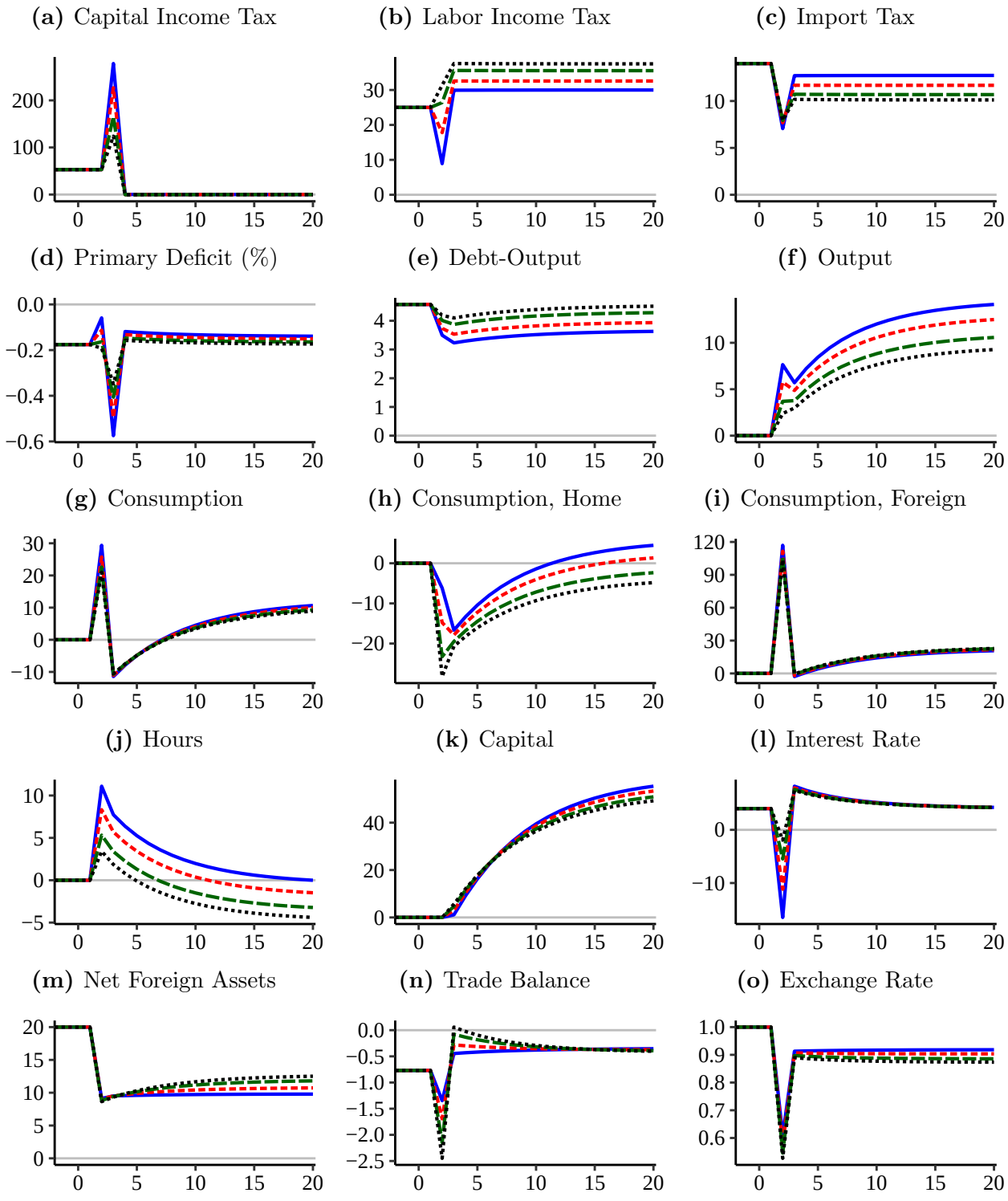
Legend: Benchmark: home (solid blue), foreign (solid red). $\tau_k = \tau_k^*$: home (dashed blue), foreign (dashed red). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.18: Ramsey Tax Competition: Home Country a Net Foreign Creditor, Higher Imports



Legend: Import share: benchmark (22.5%, solid blue); 40% (short dashed red) import share; 50% (long dashed green); 53% (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.

Figure C.19: Ramsey Tax Competition: Home Country a Larger Net Foreign Creditor, Higher Imports



Legend: Import share: benchmark (22.5%, solid blue); 40% (short dashed red) import share; 50% (long dashed green); 53% (dotted black). Output, consumption, hours and capital are expressed as percentage deviations from steady state; all other series are in levels.