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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 questions is answered by solving for the Nash equilibrium of the game played between Ramsey planners in a two good, two country open economy macroeconomic model. It is shown, analytically, that the planers do not tax capital income in the long run. Short term results, obtained computationally, reveal that the government of the larger country manages the path of the real exchange rate in order to manipulates its smaller rival's choice of tax rates. Tax competition does not lead to a "race to the bottom."

Keywords: Optimal fiscal policy; open economy macroeconomics; Ramsey taxation

JEL Codes: E32, E52, F41

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] Since households value goods produced in both countries, 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. The outcome of tax competition is the Nash 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.

In the closed economy Ramsey taxation literature, it is conventional to combine the equilibrium conditions with the household's present value budget constraint to obtain an implementability condition that subsumes these equilibrium conditions (Lucas and Stokey, 1983). The advantage of this approach is that the Ramsey planner chooses an allocation

[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.

directly. To the open economy model, one must also add an international solvency condition which equates the present value of trade surpluses with initial net foreign indebtedness; see Auray, Eyquem, and Gomme (2018). In the end, each planner chooses an allocation for its households *and* a path for the real exchange rate that maximizes the lifetime utility of those households. From the first-order conditions to this problem, it is shown, analytically, that in the Ramsey steady state, capital income is not taxed – the same as found in the closed economy Ramsey taxation literature; see Chamley (1986), Judd (1985), and the subsequent literature.

The tax competition results are more interesting when the two countries differ. So that the results below are comparable to Mendoza and Tesar's 2005 tax competition work, think of the home country as the United Kingdom, and the foreign country as the EMU countries. The key differences between the two are that the U.K. has a smaller population, it initially taxes capital income more heavily and labor income at a lower rate, it is more open, and it is a net foreign debtor.

Since the larger, foreign economy's tax dynamics following implementation of the Ramsey plan largely resemble those found in closed economy work, it is easiest to explain. The key tax rate is the one on capital income. In the first year of the Ramsey plan, this tax rate cannot be changed. In the second year, the foreign capital income tax rate rises sharply to over 300% before dropping to around zero. As discussed above, in the Ramsey steady state, the capital income tax rate is zero. The high capital income tax revenues in the second year reduce the foreign government's debt, allowing it to lower other tax rates in the long run. Since the Ramsey plan reduces the present value of tax distortions, foreign households experience a wealth effect and so would like to consume more and work less. Accommodating these desires would tend to reduce first year investment, and so second year capital and capital income – exactly when the foreign government plans to tax capital income heavily. To prevent a fall in hours, and so output, in the first year the foreign government *subsidizes* labor income, and to draw consumption from the home economy, the foreign government *subsidizes* imports as

well.

The tax dynamics of the smaller home economy are quite different. In the second year, the home capital income tax rate *falls* by 15 percentage points. As a result, the home government debt-output ratio increases in the long run. Since it does not plan high capital income taxation in the second year, in the first year the home government subsidizes neither labor income nor imports. Why are the home tax dynamics so much different from those of the foreign country? The answer lies in size, real exchange rate dynamics, and the strategic interaction between the two Ramsey planners.

In the microeconomic tax competition literature, Bucovetsky (1991) pointed to the effects of size on the two countrys' capital-labor ratios. When the larger economy raises its capital income tax rate, capital will flow from the larger to the smaller economy in order to equate returns to capital. Shifting a unit of capital from the larger to the smaller economy has a larger effect on the small country's capital-labor ratio. As a result, the larger economy competes less vigorously with respect to its capital income tax rate. While this effect is at work in the model studied below, it is difficult to see how this aspect of size would lead to a second year fall in the home capital income tax rate.

Indeed, it is difficult to develop convincing explanations for why the home government would, on its own, *choose* the tax rate dynamics described above. A more convincing explanation lies in the strategic interaction between the two Ramsey planners, and how size affects this interaction. Specifically, the foreign planner tries to manipulate the choices of the home planner in a way that is advantageous to foreign households. While the home government is trying to do the same thing to the foreign government, the size of the foreign economy works in the favor of the foreign government. Owing to its higher population share, the foreign import share is necessarily lower than the home import share. This fact alone makes the home country more vulnerable to changes in exports and imports since they are a larger fraction of its per capita output. On top of this, the foreign country's lower initial capital income tax rate leads it to have higher initial per capita income. As a result, a given

change in (per capita) foreign imports or exports have a larger effect on (per capita) home exports and imports. These considerations confer on the foreign planner an advantage in manipulating the value of the real exchange rate. As described in Section 5, the returns to capital must be equal once one accounts for exchange rate movements. In the benchmark tax competition case, the real exchange rate exhibits an appreciate-then-depreciate pattern that allows the foreign government to levy a higher second year capital income tax rate while discouraging the home government from raising its capital income tax rate.[3] Why does the foreign government find this exchange rate pattern advantageous? Because it reduces competition faced by foreign households for consumption goods brought on by the wealth effects associated with adopting the Ramsey plan.

To see that tax competition is at the heart of the tax dynamics, consider the cooperative solution. In this case, a single world Ramsey planner maximizes a weighted sum of home and foreign households' lifetime utility (subject to the same constraints faced by the individual Ramsey planners). In the tax cooperation case, the second year capital income tax rates are very high in both countries. In the first year, both countries choose to subsidize labor income in order to maintain their output levels. Since the world Ramsey planner internalizes the fact that one country's imports are another country's exports, in the first year the cooperative solution eschews import subsidize in favor of higher import taxes. Interestingly, the real exchange rate initially depreciates, then appreciates; the opposite pattern was observed under tax competition. Put together, these results lend support for the strategic interaction explanation of the tax rate dynamics in the tax competition case.

There is scant evidence that Ramsey tax competition can be said to lead to a "race to the bottom." First, in the Ramsey steady state, capital income is not taxed under either tax competition or tax cooperation. Since this result mirrors finding in the closed economy literature, it does not support the idea of a "race to the bottom." Second, while it is true that second year capital income tax rates are higher when the governments cooperate than

[3]Exchange rate appreciation or depreciation is expressed from the point of view of the home country.

when the compete, this does not fit with what is generally understood by the term "race to the bottom." Indeed, in the tax competition case, the planner in the larger, foreign economy actually manages the path of the real exchange rate so that the planner in the smaller, home country sets a lower capital income tax rate. It does so to shift some of the costs of implementing the Ramsey plan from foreign to home households. Finally, while it is true that the foreign labor income and import taxes are initially negative, these are not the tax rates considered in "race to the bottom" discussion. To the contrary, among economists there is a consensus that import taxes (tariffs) are too high.

This paper owes an intellectual debt to the closed economy Ramsey taxation literature starting with Chamley (1986) and Judd (1985). The open economy Ramsey literature is considerably smaller. Correia (1996) was the first to study Ramsey taxation in a small open economy setting. She assumed that there was only one good which fixed the real exchange rate at one. More recently, Auray, Eyquem, and Gomme (2018) have developed Ramsey results for the more general two good case; they find that real exchange rate dynamics are quite important in the short run. Chari, Nicolini, and Teles (2017) look at cooperative Ramsey taxation in an environment in which countries trade intermediate goods rather than final consumption goods.

Mendoza and Tesar (2005) is an early and influential work in the macroeconomic tax competition literature. Theirs is a one good model that necessarily fixes the real exchange rate at one. Mendoza and Tesar also assume that after the initial date, tax rates cannot change. As a result, they do not connect with the Ramsey taxation literature. Their tax competition results are also the Nash equilibrium of the game played by the two governments. More recently, Gross, Klein, and Makris (2017) introduced Ramsey planners into essentially the Mendoza and Tesar environment. 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. Fixing the real exchange rate, as is implicit in one good open economy models, is far from

innocuous. Auray, Eyquem, and Gomme (2018) have shown that Correia's capital income tax rate dynamics are sensitive to this assumption. In the current paper, fixing the real exchange rate – as in Gross, Klein, and Makris — would shut down an important channel along which strategic interaction between the two Ramsey planners operates.

The two country open economy model is described in Section 2. The Ramsey problem is developed in Section 3, including the implementability conditions and international solvency. The model is calibrated in Section 4, and numerical results for the Ramsey plan presented in Section 5. 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}. It is well known that stability of open economy models requires a closing assumption. Here, complete international asset markets do the trick. As a result, net foreign assets are, conceptually, state contingent bonds, and the restriction that only home households hold home capital and home government debt is innocuous.

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 $R_{kt} \equiv 1 - \delta + (1-\tau_{kt}) r_t$. 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 term on 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

$$\underbrace{\frac{1-n}{n}c_{ht}^{*}-e_{t}c_{ft}}_{\mathrm{TB}_{t}}+e_{t}a_{t-1}-\frac{e_{t}a_{t}}{R_{at}}=0 \tag{13}$$

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,

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

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

[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.

$1-n$ 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.

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) 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 Nash 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, 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, Klein, and Makris. As in the Ramsey literature, it is convenient to think of each planner as choosing not only a feasible tax policy, but also the relevant quantities and prices subject to private sector optimization. More specifically, given the actions of the foreign planner, the home planner chooses: a feasible fiscal plan and $\{c_{ht}, c_{ft}, h_t, k_t, r_t, w_t, e_t\}_{t=0}^{\infty}$ subject to (2)–(5), (10), (12) and (14)–(16) with $R_{kt} = (1-\tau_{kt})F_1(k_{t-1}, h_t) + 1 - \delta$, and R_{dt} and R_{at} satisfying the return arbitrage conditions in (8). The foreign planner solves an analogous problem. Notice that both planners try to manipulate the real exchange rate, e_t, and that both are subject to the

international risk-sharing condition, (14).

3.1 The Implementability Condition

Substituting the home household's first-order conditions, (2)–(7) into the second term in the household's Lagrangian, namely,

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

yields the familiar implementability condition,

$$\sum_{t=0}^{\infty} \beta^t \left[U_1(c_{ht}, c_{ft}, h_t) c_{ht} + U_2(c_{ht}, c_{ft}, h_t) c_{ft} + U_3(c_{ht}, c_{ft}, h_t) h_t \right] = \xi_0 \left[R_{k0} k_{-1} + d_{-1} + e_0 a_{-1} \right] \tag{18}$$

3.2 International Solvency

Solving the Ramsey problem is easier if the product of the interest rate terms in the earlier international solvency condition, (14), is eliminated. This task is accomplished by using the household's first-order condition with respect to net foreign assets, (7) to rewrite (14) as

$$e_0 \xi_0 a_{-1} + \sum_{t=0}^{\infty} \beta^t \xi_t \mathrm{TB}_t = 0. \tag{19}$$

The convenience of (19) is that it is *linear* in the Lagrange multiplier associated with the home household's budget constraint, ξ_t, which makes it easier to solve the model

3.3 The Home Planner's Problem

Finally, the home Ramsey planner's problem can be cast: taking as given the actions of the foreign Ramsey planner, choose $\{c_{ht}, c_{ft}, h_t, k_t, e_t\}_{t=0}^{\infty}$ to maximize lifetime utility of the representative home household subject to the international risk-sharing condition, (15), home feasibility, (16), the home implementability condition, (18) and the international solvency condition, (19). As is common in the Ramsey literature, the government has an excess of

tax instruments 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; the home planner's Lagrangian is

$$\begin{aligned}\max_{\{c_{ht},c_{ft},h_t,k_t,e_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty}\beta^t\Bigg\{ & W(c_{ht},c_{ft},h_t) \\ & + \lambda_{1t}\left[F(k_{t-1},h_t)+(1-\delta)k_{t-1}-c_{ht}-\frac{1-n}{n}c^*_{ht}-k_t-g\right] \\ & + \lambda_{2t}\left[e_t\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}-\vartheta\frac{U_2^*(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\right] \\ & + \Omega\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}\left[\frac{1-n}{n}c^*_{ht}-e_tc_{ft}\right]\Bigg\} \\ & + \Omega e_0\frac{U_1(c_{h0},c_{f0},h_0)}{1+\tau_c}a_{-1} \\ & - \Lambda\frac{U_1(c_{h0},c_{f0},h_0)}{1+\tau_c}\Big[\big(1-\delta+(1-\tau_{k0})F_1(k_{-1},h_0)\big)k_{-1}+d_{-1}+e_0a_{-1}\Big]\end{aligned} \tag{20}$$

with

$$\begin{aligned}W(c_{ht},c_{ft},h_t) \equiv & \, U(c_{ht},c_{ft},h_t) \\ & + \Lambda\left[U_1(c_{ht},c_{ft},h_t)c_{ht}+U_2(c_{ht},c_{ft},h_t)c_{ft}+U_3(c_{ht},c_{ft},h_t)h_t\right]\end{aligned} \tag{21}$$

where λ_{1t} is the multiplier associated with the home goods market condition, λ_{2t} the multiplier on the international risk-sharing condition, Ω is the multiplier for the international solvency condition, and Λ is the multiplier associated with the implementability condition. The foreign Ramsey planner solves a similar problem; see Appendix A.3 for its problem in full.

The first-order conditions for $t > 0$

$$c_{ht}: \quad W_1(c_{ht},c_{ft},h_t)-\lambda_{1t}+\lambda_{2t}e_t\frac{U_{11}(c_{ht},c_{ft},h_t)}{1+\tau_c}+\Omega\frac{U_{11}(c_{ht},c_{ft},h_t)}{1+\tau_c}\mathrm{TB}_t=0 \tag{22}$$

$$
\begin{aligned}
c_{ft}: \quad & W_2(c_{ht}, c_{ft}, h_t) + \lambda_{2t} e_t \frac{U_{12}(c_{ht}, c_{ft}, h_t)}{1+\tau_c} + \Omega \frac{U_{12}(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \mathrm{TB}_t \\
& - \Omega e_t \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} = 0
\end{aligned} \tag{23}
$$

$$
\begin{aligned}
h_t: \quad & W_3(c_{ht}, c_{ft}, h_t) + \lambda_{1t} F_2(k_{t-1}, h_t) + \lambda_{2t} e_t \frac{U_{13}(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \\
& + \Omega \frac{U_{13}(c_{ht}, c_{ft}, h_t)}{1+\tau_c} \mathrm{TB}_t = 0
\end{aligned} \tag{24}
$$

$$
k_t: \quad -\lambda_{1t} + \beta \lambda_{1,t+1} \left[F_1(k_t, h_{t+1}) + 1 - \delta \right] = 0 \tag{25}
$$

$$
e_t: \quad \lambda_{2t} \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} - \Omega \frac{U_1(c_{ht}, c_{ft}, h_t)}{1+\tau_c} c_{ft} + \lambda_{3t} U_1(c_{ht}, c_{ft}, h_t) = 0 \tag{26}
$$

and the first-order conditions for the initial period ($t = 0$)

$$
\begin{aligned}
c_{h0}: \quad & W_1(c_{h0}, c_{f0}, h_0) - \lambda_{10} + \lambda_{20} e_0 \frac{U_{11}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} + \Omega \frac{U_{11}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} \mathrm{TB}_t \\
& + \Omega e_0 \frac{U_{11}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} - \Lambda \frac{U_{11}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} A_0 = 0
\end{aligned} \tag{27}
$$

$$
\begin{aligned}
c_{f0}: \quad & W_2(c_{h0}, c_{f0}, h_0) + \lambda_{20} e_0 \frac{U_{12}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} + \Omega \frac{U_{12}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} \mathrm{TB}_t \\
& - \Omega e_0 \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} + \Omega e_0 \frac{U_{12}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} - \Lambda \frac{U_{12}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} A_0 = 0
\end{aligned} \tag{28}
$$

$$
\begin{aligned}
h_0: \quad & W_3(c_{h0}, c_{f0}, h_0) + \lambda_{10} F_2(k_{-1}, h_0) + \lambda_{20} e_0 \frac{U_{13}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} \\
& + \Omega \frac{U_{13}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} \mathrm{TB}_t + \Omega e_0 \frac{U_{13}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} - \Lambda \frac{U_{13}(c_{h0}, c_{f0}, h_0)}{1+\tau_c} A_0 \\
& - \Lambda \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} (1-\tau_{k0}) F_{12}(k_{-1}, h_0) k_{-1} = 0
\end{aligned} \tag{29}
$$

$$
k_0: \quad -\lambda_{10} + \beta \lambda_{11} \left[F_1(k_0, h_1) + 1 - \delta \right] = 0 \tag{30}
$$

$$
\begin{aligned}
e_0: \quad & \lambda_{20} \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} - \Omega \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} c_{f0} + \Omega \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} \\
& - \Lambda \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} a_{-1} = 0
\end{aligned} \tag{31}
$$

where

$$
A_0 \equiv \left[1 - \delta + (1-\tau_{k0}) F_1(k_{-1}, h_0) \right] k_{-1} + d_{-1} + e_0 a_{-1} \tag{32}
$$

is the initial value of household wealth and

$$\text{TB}_t = \frac{1-n}{n} c^*_{ht} - e_t c_{ft}$$

is, again, the trade balance.

Given the allocation that solves the above Ramsey problem, the paths of taxes, $\{\tau_{mt}, \tau_{wt}, \tau_{k,t+1}\}$, are obtained from

$$\frac{U_1(c_{ht}, c_{ft}, h_t)}{U_2(c_{ht}, c_{ft}, h_t)} = \frac{1+\tau_{mt}}{1+\tau_c} e_t \tag{33}$$

$$U_3(c_{ht}, c_{ft}, h_t) + \frac{1-\tau_{wt}}{1+\tau_c} U_1(c_{ht}, c_{ft}, h_t) F_2(k_{t-1}, h_t) \tag{34}$$

$$U_1(c_{ht}, c_{ft}, h_t) = \beta U_1(c_{ht+1}, c_{ft+1}, h_{t+1}) \left[1 - \delta + (1-\tau_{k,t+1}) F_1(k_t, h_{t+1})\right] \tag{35}$$

which, in turn, are obtained by combining the households' first-order conditions with those of the firms.

Assuming that the economy eventually settles into a steady state, (35) reads

$$1 = \beta \left[(1-\tau_k) F_1(k, h) + 1 - \delta\right]. \tag{36}$$

For the planner, the relevant steady state condition comes from the planner's first-order condition with respect to capital, (25):

$$1 = \beta \left[F_1(k, h) + 1 - \delta\right]. \tag{37}$$

Comparing (36) and (37) delivers the familiar Chamley (1986)–Judd (1985) prescription: in the long run, capital income should not be taxed: $\tau_k = 0$.

3.4 International Tax Cooperation

Below, the tax competition model is compared to an environment with international tax cooperation. In this latter case, a world Ramsey planner maximizes a weighted sum of the utilities of the representative households in the two countries subject to: feasibility, interna-

tional risk sharing, the two international solvency conditions, and the two implementability conditions. Let ϕ be the weight that the world planner places on the representative home household. The full problem is:

$$\begin{aligned}
\max_{\{c_{ht},c_{ft},h_t,k_t,c^*_{ht},c^*_{ft},h^*_t,k^*_t,e_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty}\beta^t\Bigg\{ & \phi W(c_{ht},c_{ft},h_t)+(1-\phi)W^*(c^*_{ht},c^*_{ft},h^*_t) \\
& +\lambda_{1t}\left[F(k_{t-1},h_t)+(1-\delta)k_{t-1}-c_{ht}-\frac{1-n}{n}c^*_{ht}-k_t-g\right] \\
& +\lambda^*_{1t}\left[F(k^*_{t-1},h^*_t)+(1-\delta)k^*_{t-1}-c^*_{ft}-\frac{n}{1-n}c_{ft}-k^*_t-g^*\right] \\
& +\lambda_{2t}\left[e_t\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}-\vartheta\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\right] \\
& +\Omega\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}\left[\frac{1-n}{n}c^*_{ht}-e_tc_{ft}\right]\Bigg\} \\
& +\Omega^*\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\left[\frac{n}{1-n}c_{ft}-\frac{c^*_{ht}}{e_t}\right]\Bigg\} \\
& +\Omega e_0\frac{U_1(c_{h0},c_{f0},h_0)}{1+\tau_c}a_{-1} \\
& +\Omega^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}a^*_{-1} \\
& -\Lambda\frac{U_1(c_{h0},c_{f0},h_0)}{1+\tau_c}\Big[\big(1-\delta+(1-\tau_{k0})F_1(k_{-1},h_0)\big)k_{-1}+d_{-1}+e_0a_{-1}\Big] \\
& -\Lambda^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}\Big[\big(1-\delta+(1-\tau^*_{k0})F_1(k^*_{-1},h^*_0)\big)k^*_{-1}+d^*_{-1}+a^*_{-1}\Big]
\end{aligned} \tag{38}$$

where, recall, n is the size of the home economy. (The remainder of the notation follows from the earlier Ramsey tax competition problem.)

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.[5]

The first order of business is setting the length of a model period. Since tax rates are

[5] 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.

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 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 value 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 import share is 25% (roughly the U.K.'s import share since 1990); and home foreign debt of 10% of its output. 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, $c_h + ec_f$), not the value implied by the consumption aggregator. 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	7.949	6.931
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	0.557	0.213
ϑ	1.159	1.159
Population share (n or $1-n$)	0.250	0.750
Planner weight (ϕ or $1-\phi$)	0.250	0.750

Solving the model involves finding not only time paths for the variables of interest, but also values for the multipliers on the present value government budget constraints, (Λ, Λ^*) and the international solvency conditions (Ω, Ω^*). Given the relationships between trade balances and initial net foreign assets for the two economies, a violation of the home international solvency condition implies violation of the foreign country's condition (with an opposite sign). In other words, the multipliers Ω and Ω^* cannot be solved for separately. The value of Ω is normalized to equal one. The model is then solved as follows:

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

Table 2: Initial Steady State

Variable	Home	Foreign
Output	0.218	0.264
Consumption: Home	0.093	0.022
Consumption: Foreign	0.065	0.157
Consumption: Aggregate	0.158	0.179
Hours worked	0.200	0.200
Capital stock	0.268	0.507
Capital-output ratio	1.226	1.917
Gov. share	0.180	0.180
Tax Revenues	0.095	0.120
Primary deficit	−0.056	−0.072
Public debt	1.449	1.884
Debt-output ratio	6.640	7.128
Exchange rate	1.000	1.000
Trade balance	0.001	−0.000
Net foreign assets	−0.022	0.007

2. Solve the model conditional on the values of these multipliers using an extended path algorithm (Fair and Taylor, 1983).

3. If the present value government budget constraints and foreign international solvency conditions are sufficiently close to zero, stop; otherwise, use deviations from these conditions to update the guesses for Λ, Λ^*, and Ω^* and return to the previous step.

5 Implementing The Ramsey Plan

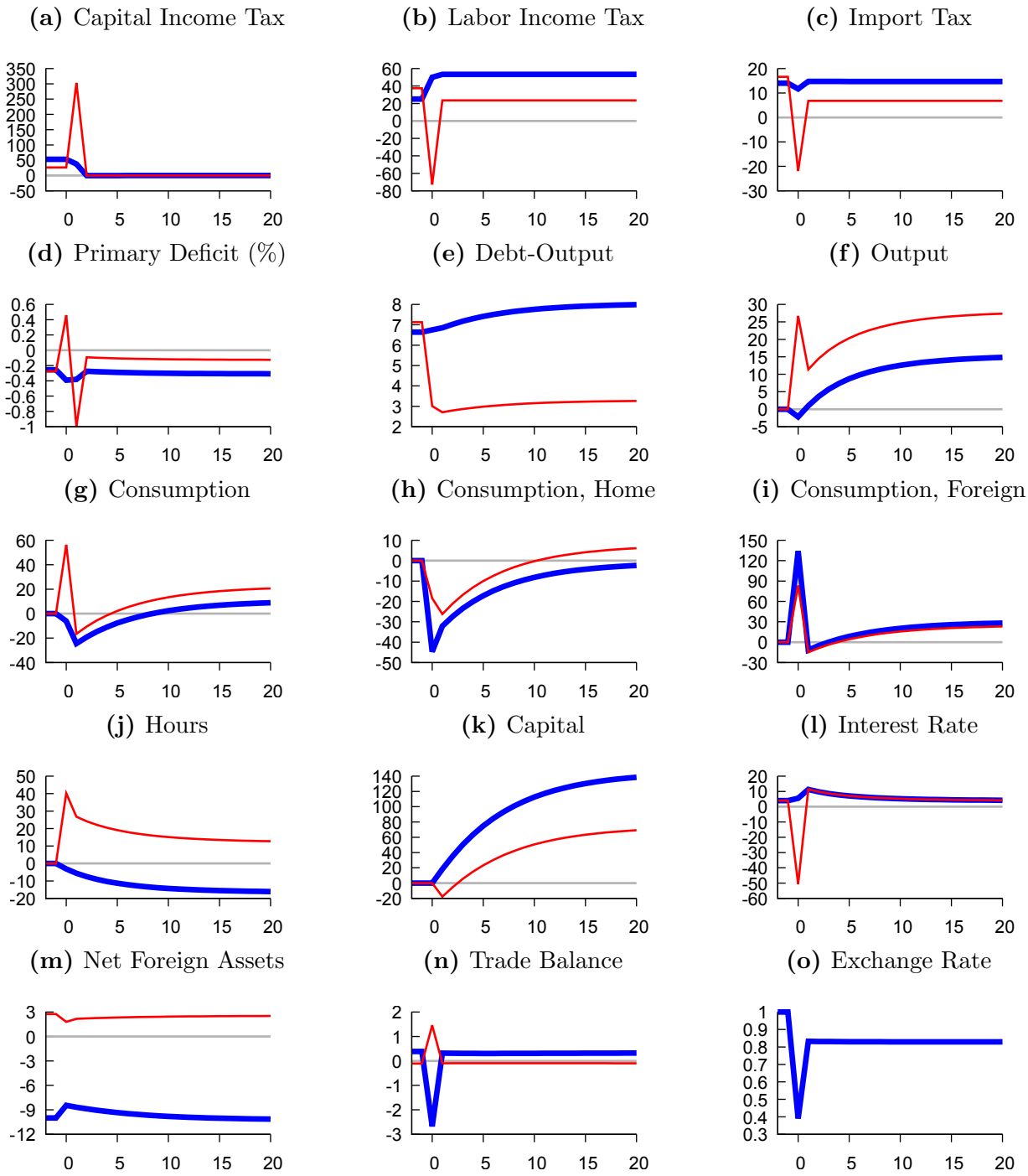
The Ramsey plan is announced and implemented in year 0. A useful way to think about the Ramsey plan is that each government seeks to minimize the tax distortions associated with financing its government expenditure stream in the competitive equilibrium allocation. The key insight of Ramsey (1927) is 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 generally 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 helps drive down the level of government debt, thereby lowering long run tax distortions. Since the Lagrange multiplier associated with the implementability condition 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 follow from the behavior of 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 In year 1, when the foreign government is first able to adjust the capital income tax rate, it chooses a very high value: 303%. In the following years, this tax rate falls to around zero. Of course, 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). The fall in the foreign government debt-output ratio allows the foreign government to lower other taxes. Figs. 1(b) and 1(c) shows that in the Ramsey steady state, the foreign government sets its labor income and import taxes below their original steady state values.

Why does the foreign government choose 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

Figure 1: Ramsey Tax Competition: Benchmark



Legend: Thick blue lines: home; thin red lines: foreign.

government subsidizes labor income. *Some* of the extra consumption *could* come from the other (home) economy, and so the planner subsidizes imports as well.

The tax settings for the home planner are harder to fathom if one thinks exclusively through the point of view of the home planner. In particular, Fig. 1(a) shows that the home capital income tax actually falls in year 1 (to 38%). As a result, the home government debt-output ratio actually rises. Since the home planner does not apply a high tax rate on capital income in year 1, there is no need to subsidize labor income, as seen in Fig. 1(b). While the home import tax rate falls slightly in year 1, this decline is quite modest, particularly when views alongside the foreign import tax rate; see Fig. 1(c). The loss of capital income tax revenue in the long term (the home government still chooses a zero tax rate on capital income in the new Ramsey steady state) along with the higher debt-output ratio means that the government must raise other taxes. The import tax ends up a smidge higher (14.7% rather than 14%) while the labor income tax rate more than doubles (from 25% to 53.3%).

Understanding the time paths of the home tax rates rests on two factors: the relative sizes of the home and foreign economies, and the strategic interaction between the two planners. The microeconomic tax competition literature has emphasized one particular aspect of relative country size. The intuition offered by Bucovetsky (1991) centers on effects on the two capital-labor ratios. Specifically, when the government of the larger 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. However, a one unit shift of capital has a larger effect on the capital-labor ratio of the smaller economy owing to its smaller population. As a result, the foreign capital stock does not change very much. Put differently, the foreign government sees a smaller elasticity of tax revenue with respect to its capital tax rate than does the home government. Thus, the larger economy compete less vigorously with respect to its capital income tax rate than does the smaller economy: the government of the larger economy will, in general, choose a higher capital income tax rate.

Strategic interaction between the two planners arises not only through their settings of their respective tax rates, but also through the real exchange rate which, recall, is a choice variable of both planners. Clearly, the planners cannot choose different values for the real exchange rate; in the Nash equilibrium, the planners' choices for the real exchange rate must coincide. Each planner tries to manipulate the path of the real exchange rate in favor of its own households. To see how this works, notice that the rate of return arbitrage conditions for the home and foreign countries, (8) and (A.2), imply

$$\frac{e_{t-1}}{e_t}\underbrace{[(1-\tau_{kt})r_t+1-\delta]}_{R_{kt}}=\underbrace{(1-\tau^*_{kt})r_t+1-\delta}_{R^*_{kt}},\quad t\geq 1. \tag{39}$$

As shown in Fig. 1(o), the real exchange rate exhibits an appreciation-then-depreciation pattern that pushes down the left-hand side of (39). This real exchange rate pattern allows the foreign government raises its capital income tax rate, τ^*_{kt}, in year 1 with less impact on the foreign capital stock (that is, the loss of capital that lies at the heart of the microeconomic tax competition literature).

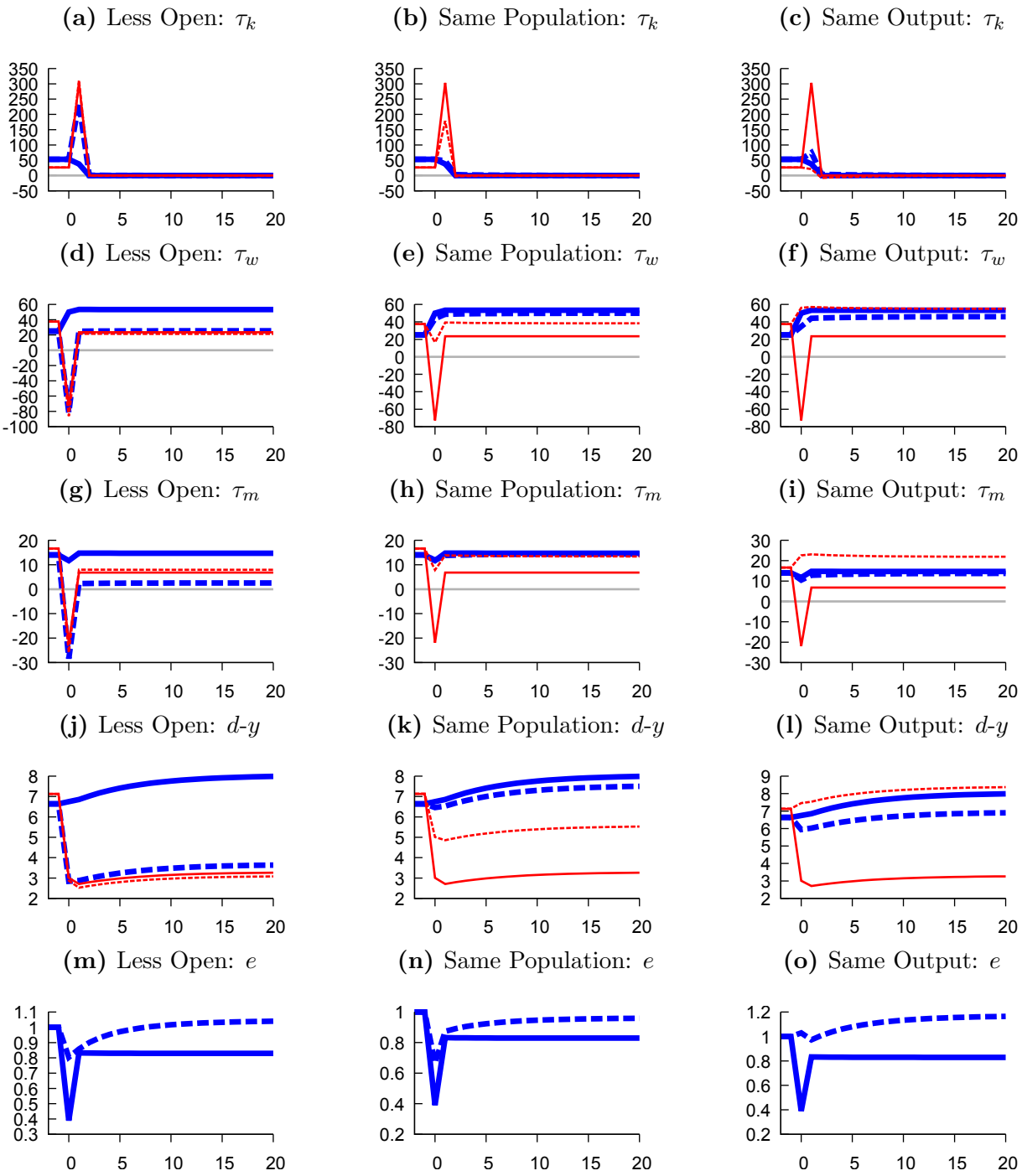
Clearly, the foreign government wants to push the benefits of adopting the Ramsey plan in favor of its own households, and is willing to do so at the detriment of the home households. The earlier discussion of the foreign government actions points to the role of a very high year 1 capital income tax rate in lowering the long term level of government debt. It is this year 1 capital income tax revenue that allows the foreign government to lower its other taxes, and preserving this tax revenue that motivates it to subsidize both imports and labor income. If the home government acts in the same way, then not only will the foreign economy find it more difficult to obtain more consumption via imports (since these would have to come from the home country which also is trying to expand its consumption), it will tend to lose more of its output via exports to the home country (for the same consumption-expansion reasons). The foreign government can avoid this competition for consumption if it can manipulate the home government into choosing a path for its tax rates that shuts down the mechanisms under discussion. Given the centrality of the capital income tax rate discussed above, the

foreign government can best achieve its aims if it can manipulate the home government to choose a path for its capital income tax rate that does not involve a high year 1 home capital income tax rate. It is the exchange rate movements in Fig. 1(o) that the foreign government uses to achieve its goal. With the home government now choosing a lower capital income tax rate in year 1, home government debt never falls, and the home government does not subsidize year 0 imports (or labor income).

At this stage, there are three important observations to make regarding openness and size. First, the countries under study need to be sufficiently open for the strategic behavior to come to the forefront. Trivially, when the two economies are closed, they do not interact, and the strategic interaction disappears. By continuity, when the economies are not very open, the strategic elements are weaker. The left hand columns of figures in Fig. 2 summarizes the case when the model is calibrated to a 5% home import share; Fig. C.5 presents a more comprehensive set of figures. In this case, the dynamics of the home tax rates are quite similar to their foreign counterparts, and the initial response of the real exchange rate is muted relative to the benchmark.

Second, there are two relevant dimensions to size. The first is simply population size which plays prominently in Bucovetsky (1991). The middle set of figures in Fig. 2 summarize the case of equal populations: $n = 1/2$; see Fig. C.6 for a fuller set of figures. While the foreign government sets a lower year 1 capital income tax rate than in the benchmark case, the dynamics in this case are still qualitatively similar to those of the benchmark case. It turns out that equalizing population size is not sufficient. In the benchmark calibration, the capital income tax rate in the foreign country is much smaller than in the home country. As a result, the foreign capital-labor ratio is 90% higher than that in the home country, and foreign output per capita is 21% larger. These differences are relevant because they imply that the share of imports and exports are larger in the home economy than the foreign economy, even when their population shares are the same. This difference is enough to give the foreign planner the edge in choosing the path for the real exchange rate. The gauge

Figure 2: Ramsey Tax Competition: The Roles of Openness and Size



Legend: Thick blue lines: home; thin red lines: foreign.

the importance of this second aspect of size, the right-hand figures in Fig. 2 summarize the case when initial aggregate output is the same in the two countries: $ny = (1-n)y^*$; more time series are presented in Fig. C.7. Now, it is the home government that raises its year 1 capital income tax rate (albeit modestly), and the real exchange rate exhibits a depreciation-then-appreciation pattern which is qualitatively different from the benchmark case.

Table 3: Year 1 Capital Income Tax Rate

Case	Home	Foreign
Tax competition	37.7	303.4
Asymmetric initial net foreign assets	71.1	75.7
Asymmetric population size	67.7	233.9
Asymmetric initial tax rates	56.5	186.7
Tax cooperation	279.9	324.1

Further insight into the mechanisms at work in the model can be obtained by isolating those elements that 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 relative 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, with the foreign country choosing a slightly higher tax rate. There is a larger gaps between the capital income tax rates reported in Table 3 when the countries differ only with respect to either population, or initial taxes. 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. Evidently, what matters is the size of the economy, either due to differences in population, or in output per

capita arising due to disparity in initial taxes.

Finally, a few words on the long run import tax rate. Recall that in the initial steady state, this tax rate equals the tax rate on locally-produced consumption goods. On the face of it, the differences in the long run import tax rate and the fixed consumption tax rate seems to violate the Ramsey principle of applying the same tax rate to goods that enter utility symmetrically. However, it is not the quantity of imports that is relevant but rather their value. In other words, exchange rate dynamics are also apropos. Looking across various model solutions, including Figs. C.1–C.17, shows that when the real exchange rate appreciates in the long run, the home country ends up with a higher import tax rate than consumption tax rate while the foreign country exhibits the opposite pattern.

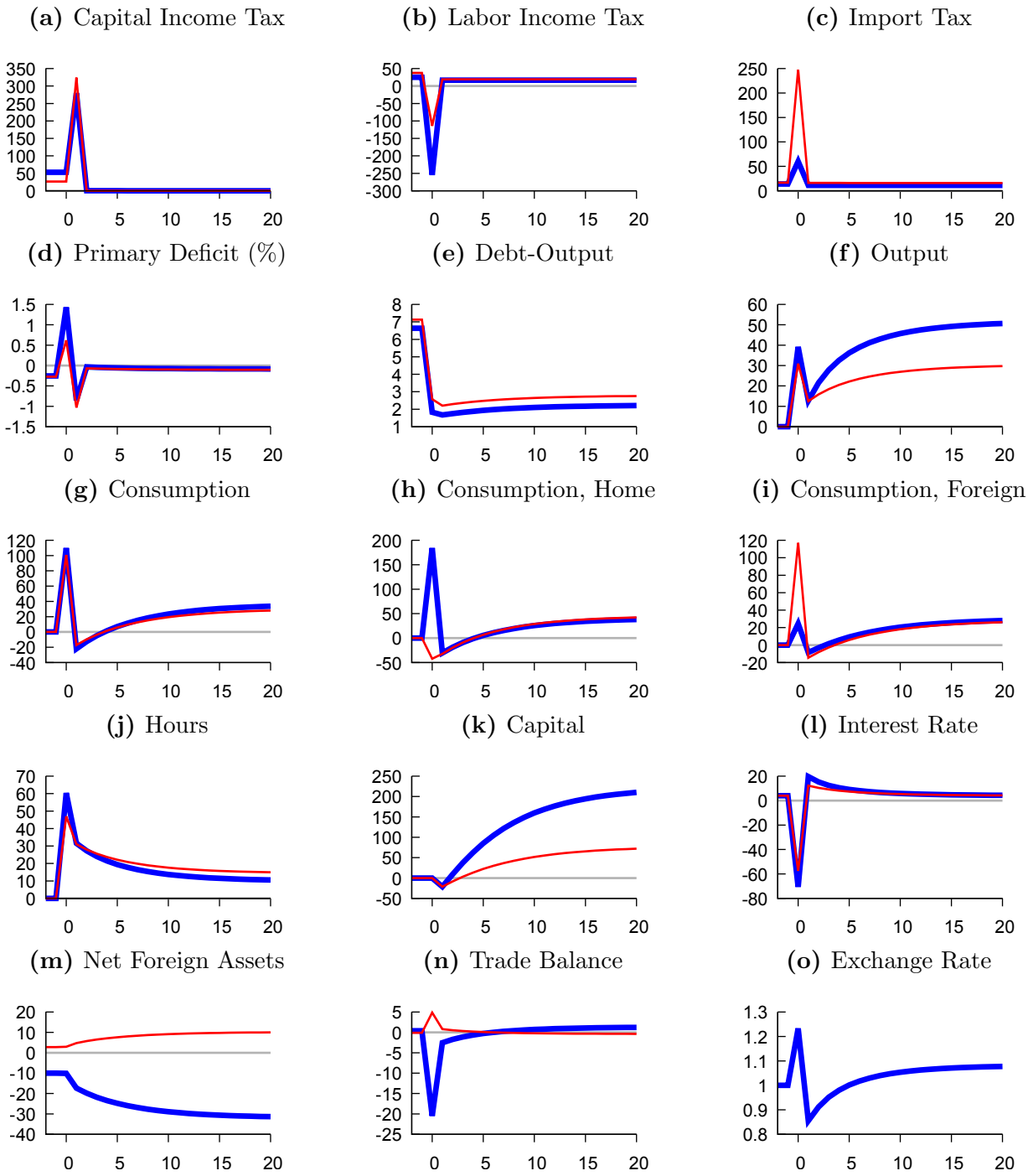
5.1 Tax Cooperation

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 3.4.

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, the foreign capital income tax rate is over 20 percentage points higher when the governments cooperate than when they compete. While the home capital income tax rate is lower than that in the foreign country, it is still a very substantial 280%. Also remember that under tax competition, the home government actually lowered its capital income tax rate in year 1, from 53% to 38%.

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

Figure 3: Ramsey Tax Cooperation: Benchmark



Legend: Thick blue lines: home; thin red lines: foreign

collect capital income tax revenue in year 1. To get households to work more, the after-tax wage needs to increase. 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 raise this tax rate, with the foreign import tax rising in year 0 to nearly 250%. 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 income 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 so that the home government chooses not to raise its capital income tax rate). When strategic considerations are less important, as they are when the home country is less open, the path of the home tax rates look much more like their foreign counterparts; see the earlier discussion of Fig. 2. 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. The contrast with the tax competition environment is particularly stark for the home government: in that case, its debt rose in the long run rather than declining.

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 the foreign government's efforts to manipulate the home government's tax policy. Specifically, the foreign government wanted to moderate the increase in the home year 1 capital income tax rate in order to reduce competition for resources in year 0. When the governments cooperate, the exchange rate dynamics flip: there is a depreciate-then-appreciate pattern which tends to help the home government. Recall the earlier capital

return arbitrage condition, (39). The microeconomics literature has emphasized the role of the capital-labor ratio in equating the returns to capital, ignoring the role of the real exchange rate (Bucovetsky, 1991). Here, the home government sets a capital income tax rate in year 1 that is higher than it could absent these exchange rate dynamics.

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.

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

Case	Home	Foreign
Tax Competition		
· Benchmark	11.004	4.725
· Differences in initial net foreign assets, $\overline{a}$	5.032	5.105
· Differences in population weight, n	11.296	9.262
· Differences in initial tax rates	7.508	1.846
· Differences in initial capital income tax rates	4.287	1.326
· Differences in initial labor income tax rates	8.715	6.013
· Differences in initial import tax rates	5.260	5.468
Tax Cooperation		
· Benchmark	11.140	7.864

The welfare benefit of adopting the Ramsey plan is substantial. As seen in Table 4, under

tax competition, for home households the welfare gain is 11% of consumption; for foreign households, 4.7%. It may seem odd that the home country enjoys the larger welfare benefit of the Ramsey tax reform, particularly in light of the success of the foreign government in manipulating the path of the real exchange rate in its favor. Recall, though, that the initial capital income tax in the home country is roughly double that of the foreign country. Since the Ramsey policy implies a zero capital income tax rate in new steady state, it is capital accumulation in the home country that is initially most distorted, and so the home country has the most to gain.

Table 4 shows that the differences in welfare between the home and foreign countries is due chiefly to initial differences in the tax rates on capital income. For example, when the only difference is initial net foreign assets, both countries enjoy almost the same welfare benefit of Ramsey tax reform. When the countries only differ in size, the gap in measured welfare falls from 6.3 to 2 percentage points. Further investigating which of the taxes is most responsible for the differences in welfare reveals that initial differences in import taxes (τ_m) lead to small differences in welfare. Initial differences in the capital income taxes delivers a 3 percentage point gap in the welfare benefits; the labor income tax, 2.7 percentage points.

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 find 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. For the benchmark calibration, the home country experiences a slightly larger welfare gain, 11.1% whereas the foreign country enjoys a larger gain (7.9% as opposed to 4.7% under tax competition).

7 Conclusion

Optimal tax rates were obtained as the Nash equilibrium of a game played between two Ramsey planners. These planners interacted through a two good, two country open economy macroeconomic model. The endogenous real exchange rate afforded by considering distinct goods produced in each country was a key element in the tax competition game. Due to its size, the planner of the larger, foreign economy dominates in setting the path of the real exchange rate. The foreign planner chooses an exchange rate path that manipulates its smaller rivals choice of tax rates. This form of strategic interaction appears to be new to the literature.

Relative to the cooperative outcome, tax competition leads to lower capital income tax rates. Nonetheless, it seems fair to say that Ramsey-optimal tax choices do not lead to a "race to the bottom." Indeed, optimal taxation under either competition or cooperation prescribes zero capital income taxation in the long term – a result reminiscent of those typical of the Ramsey taxation literature.

Substantial welfare benefits are associated with Ramsey tax reforms. Under tax competition, the welfare gains are 11% of consumption for the home country, and 4.7% for the foreign country. Tax cooperation is of greater value to the foreign country, raising its welfare gain to 7.9% whereas the home country's benefit rises to 11.1%.

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 treated as equivalent.

A.2 Other Constraints

The foreign implementability condition:

$$\sum_{t=0}^{\infty} \beta^t \left[U_1^*(c_{ht}^*, c_{ft}^*, h_t^*) c_{ht} + U_2^*(c_{ht}^*, c_{ft}^*, h_t^*) c_{ft} + U_3^*(c_{ht}^*, c_{ft}^*, h_t^*) h_t \right] = \xi_{10}^* \left[R_{k0}^* k_{-1}^* + d_{-1}^* + a_{-1}^* \right] \tag{A.3}$$

where $R_{kt}^* = (1 - \tau_{kt}^*) F_1(k_{t-1}^*, h_t^*) + 1 - \delta$.

The present value government budget constraint:

$$d_{-1}^* + \sum_{t=0}^{\infty} \left(\prod_{j<t} \frac{1}{R_{dj}^*} \right) \underbrace{\tau_{ft}^* c_{ft}^* + \tau_{mt}^* \frac{c_{ht}^*}{e_t} + \tau_{wt}^* w_t^* h_t^* + \tau_{kt}^* r_t^* k_{t-1}^* - g^*}_{\text{PRDEF}_t^*} . \tag{A.4}$$

The foreign economy international solvency condition:

$$a_{-1}^* + \sum_{t=0}^{\infty} \left(\prod_{j<t} \frac{1}{R_{aj}} \right) \underbrace{\left(\frac{n}{1-n} c_{ft} - \frac{c_{ht}^*}{e_t} \right)}_{\text{TB}_t^*} . \tag{A.5}$$

A.3 The Foreign Planner's Ramsey 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.

As in the main text, using the household's first-order conditions for bond holdings simplifies the expressions for the two present value constraints. The foreign government's Ramsey

problem is:

$$\begin{aligned}\max_{\{c^*_{ht},c^*_{ft},h^*_t,k^*_t,e_t\}} \sum_{t=0}^{\infty}\beta^t\Bigg\{ & W^*(c^*_{ht},c^*_{ft},h^*_t) \\ & + \lambda^*_{1t}\left[F(k^*_{t-1},h^*_t)+(1-\delta)k^*_{t-1}-c^*_{ft}-\frac{n}{1-n}c_{ft}-k^*_t-g^*\right] \\ & + \lambda^*_{2t}\left[\vartheta\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}-e_t\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}\right] \\ & + \Omega^*\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\left[\frac{n}{1-n}c_{ft}-\frac{c^*_{ht}}{e_t}\right]\Bigg\} \\ & + \Omega^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}a^*_{-1} \\ & - \Lambda^*\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}\Big[\big(1-\delta+(1-\tau^*_{k0})F_1(k^*_{-1},h^*_0)\big)k^*_{-1}+d^*_{-1}+a^*_{-1}\Big]\end{aligned} \tag{A.6}$$

The first-order conditions ($t>0$):

$$\begin{aligned}c^*_{ht}: \quad & W^*_1(c^*_{ht},c^*_{ft},h^*_t)+\lambda^*_{2t}\vartheta\frac{U^*_{12}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c} \\ & + \Omega^*\frac{U^*_{12}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\mathrm{TB}^*_t-\frac{\Omega^*}{e_t}\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}=0\end{aligned} \tag{A.7}$$

$$c^*_{ft}: \quad W^*_2(c^*_{ht},c^*_{ft},h^*_t)-\lambda^*_{1t}+\lambda^*_{2t}\vartheta\frac{U^*_{22}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}+\Omega^*\frac{U^*_{22}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\mathrm{TB}^*_t=0 \tag{A.8}$$

$$\begin{aligned}h^*_t: \quad & W^*_3(c^*_{ht},c^*_{ft},h^*_t)+\lambda^*_{1t}F_2(k^*_{t-1},h^*_t)+\lambda^*_{2t}\vartheta\frac{U^*_{23}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c} \\ & + \Omega^*\frac{U^*_{23}(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\mathrm{TB}^*_t=0\end{aligned} \tag{A.9}$$

$$k^*_t: \quad -\lambda^*_{1t}+\beta\lambda^*_{1,t+1}\left[F_1(k^*_t,h^*_{t+1})+1-\delta\right]=0 \tag{A.10}$$

$$e_t: \quad -\lambda^*_{2t}\frac{U_1(c_{ht},c_{ft},h_t)}{1+\tau_c}+\Omega^*\frac{U^*_2(c^*_{ht},c^*_{ft},h^*_t)}{1+\tau^*_c}\frac{c^*_{ht}}{e^2_t}=0 \tag{A.11}$$

The first-order conditions ($t=0$):

$$\begin{aligned}c^*_{h0}: \quad & W^*_1(c^*_{h0},c^*_{f0},h^*_0)+\lambda^*_{20}\vartheta\frac{U^*_{12}(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}+\Omega^*\frac{U^*_{12}(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}\mathrm{TB}^*_t \\ & - \frac{\Omega^*}{e_0}\frac{U^*_2(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}+\Omega^*\frac{U^*_{12}(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}a^*_{-1}-\Lambda^*\frac{U^*_{12}(c^*_{h0},c^*_{f0},h^*_0)}{1+\tau^*_c}A^*_0=0\end{aligned} \tag{A.12}$$

$$
\begin{aligned}
c_{f0}^*: \quad & W_2^*(c_{h0}^*, c_{f0}^*, h_0^*) - \lambda_{10}^* + \lambda_{20}^* \vartheta \frac{U_{22}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} + \Omega^* \frac{U_{22}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} \mathrm{TB}_t \\
& + \Omega^* \frac{U_{22}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} a_{-1}^* - \Lambda^* \frac{U_{22}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} A_0^* = 0
\end{aligned} \tag{A.13}
$$

$$
\begin{aligned}
h_0^*: \quad & W_3^*(c_{h0}^*, c_{f0}^*, h_0^*) + \lambda_{10}^* F_2(k_{-1}^*, h_0^*) + \lambda_{20}^* \vartheta \frac{U_{23}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} \\
& + \Omega^* \frac{U_{23}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} \mathrm{TB}_t^* + \Omega^* \frac{U_{23}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} a_{-1}^* - \Lambda^* \frac{U_{23}^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} A_0^* \\
& - \Lambda^* \frac{U_2^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} (1-\tau_{k0}^*) F_{12}(k_{-1}^*, h_0^*) k_{-1}^* = 0
\end{aligned} \tag{A.14}
$$

$$
k_0^*: \quad -\lambda_{10}^* + \beta \lambda_{11}^* \left[F_1(k_0^*, h_1^*) + 1 - \delta \right] = 0 \tag{A.15}
$$

$$
e_0: \quad -\lambda_{20}^* \frac{U_1(c_{h0}, c_{f0}, h_0)}{1+\tau_c} + \Omega^* \frac{U_2^*(c_{h0}^*, c_{f0}^*, h_0^*)}{1+\tau_c^*} \frac{c_{h0}^*}{e_0^2} = 0 \tag{A.16}
$$

where

$$
A_0^* \equiv \left[1 - \delta + (1-\tau_{k0}^*) F_1(k_{-1}^*, h_0^*) \right] k_{-1}^* + d_{-1}^* + a_{-1}^* \tag{A.17}
$$

and

$$
\mathrm{TB}_t^* = \left[\frac{n}{1-n} c_{ft} - \frac{c_{ht}^*}{e_t} \right]
$$

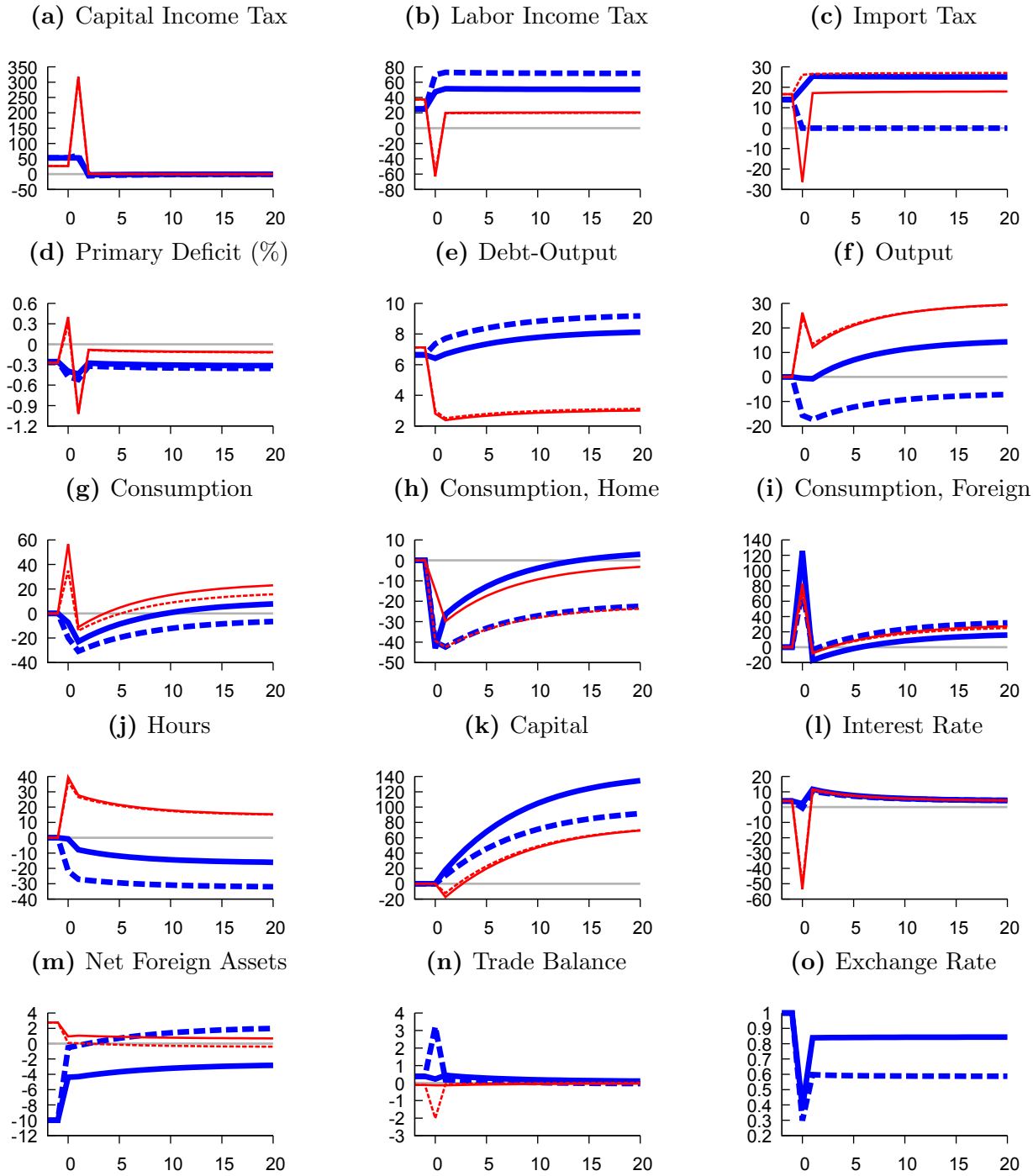
B Lower Trade Elasticity

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: $\mu = 0.8$. Solving the model with parameters and calibration targets as in the benchmark model, except with $\mu = 0.8$, proved problematic: Λ, the Lagrange multiplier on the home implementability constraint, was pushed to zero. For this reason, this section compares two cases: one as for the benchmark model except the coefficient of relative risk aversion is set to $\sigma = 1\frac{1}{4}$; the other with, in addition, a lower trade elasticity: $\sigma = 1\frac{1}{4}$ and $\mu = 0.8$. As shown in Fig. C.10 the model's dynamics are not much changed when risk aversion is higher. The results for these two cases are summarized in Fig. B.1 for the tax competition environment.

Overall, the core results of the benchmark tax competition model remain intact. The larger foreign economy chooses a very high capital income tax rate in year 1 which pushes down its government debt-output ratio. In the longer term, the foreign economy enjoys a lower labor income tax rate. Further, the foreign government continues to manage the real exchange rate in favor of its households (the appreciate-then-depreciate pattern discussed earlier), thereby manipulating the home government's setting of tax rates.

Visually, there are very small differences in the paths of foreign variables. There are more pronounced differences for the home economy. To start, across the two cases, there is only a small difference in the year 1 home capital income tax rate Consequently, there continues to be no drop in the home government debt-output ratio. As shown in Fig. B.1(c), the home government immediately drops the import tax rate to zero, and keeps it there. The associated loss of import tax revenue pushes the home government debt up, and the home labor income tax rate rises to cover this shortfall. In turn, the higher labor income tax rate leads to a substantial decline in work time. While the home capital stock rises, its increase is smaller than that high trade elasticity case: the effects of the dropping the capital income tax rate to zero is partially offset by the lower labor input.

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



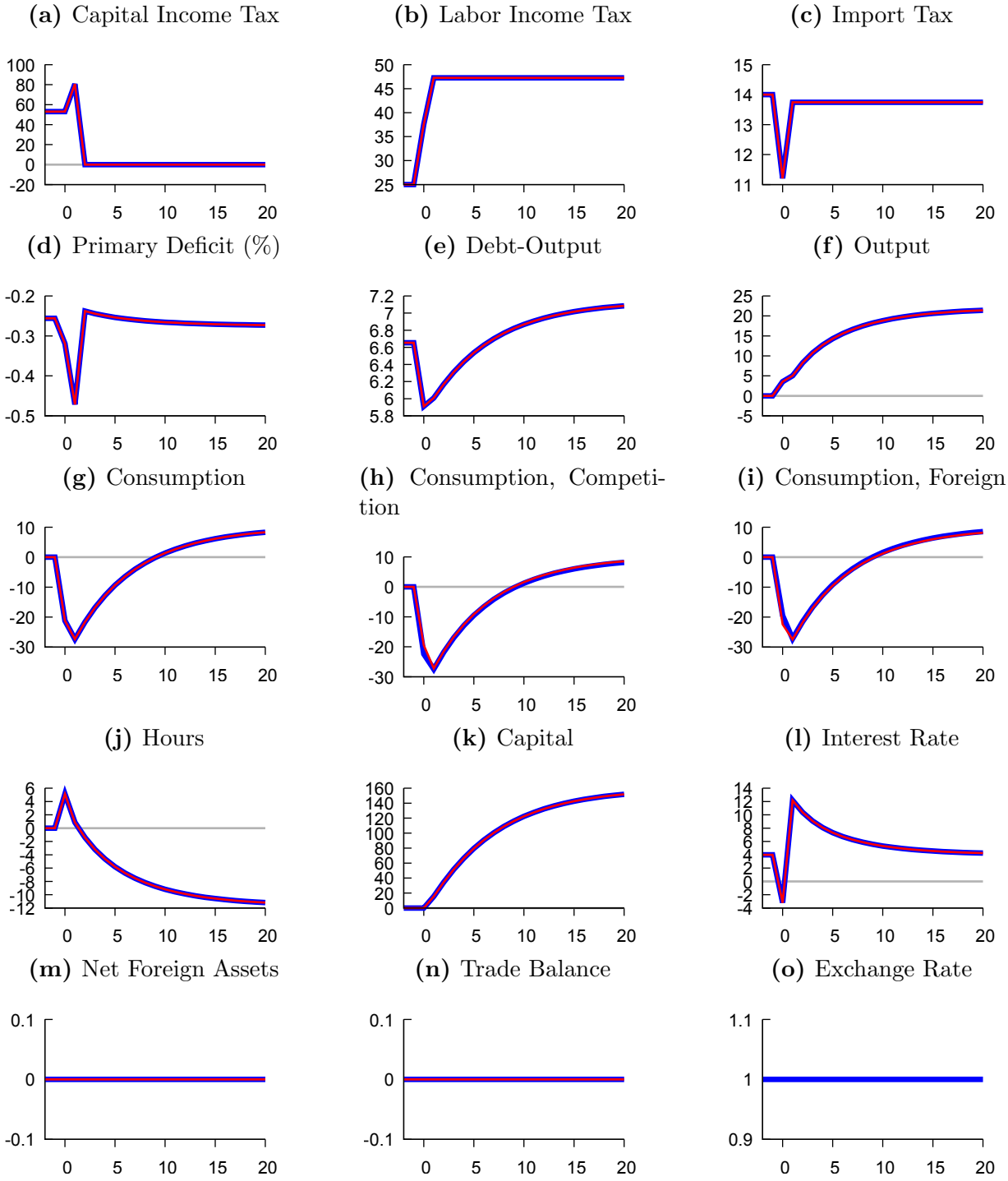
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: lower trade elasticity.

An interesting difference across the two settings of the trade elasticity is that under the lower elasticity, the home country becomes a net foreign creditor; in the initial steady state, it is a net debtor. The behavior of net foreign assets can likely be attributed to complete international asset markets which provide a degree of insurance to households. It would seem that with the lower trade elasticity, the bulk of the gains associated with adoption of the Ramsey plan accrue to foreign households. With complete international asset markets, the two countries share these gains. As an operational matter, these gains are shared by increasing the wealth – net foreign assets – of home households. In turn, to run up its net foreign assets, the home country initially runs trade surpluses; the the longer term, its positive net foreign asset position allows it to run trade deficits in the new steady state.

C Guide to Supplementary Figures

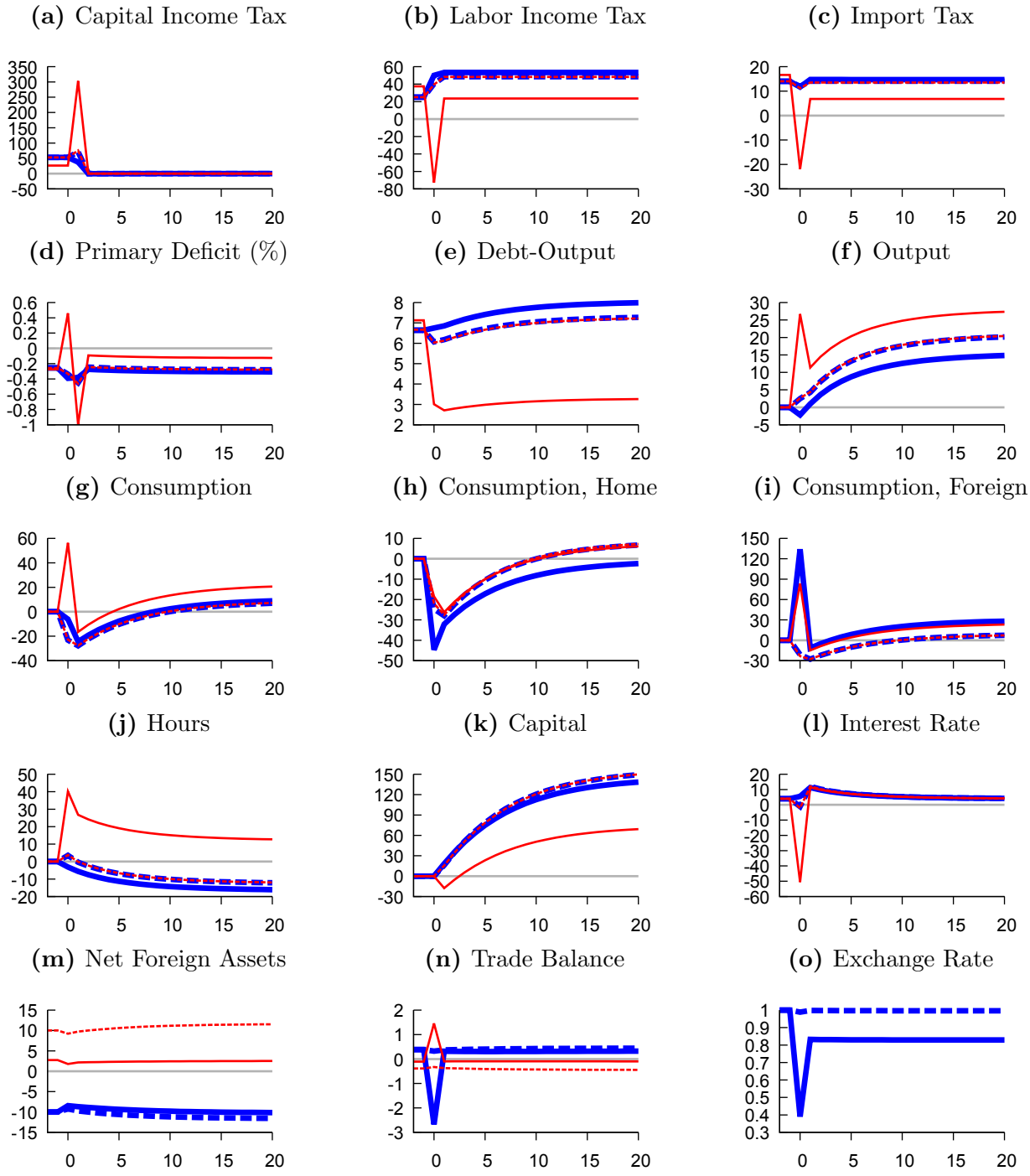
- Fig. C.1: Full symmetry
- Fig. C.2: Differences in initial net foreign assets only
- Fig. C.3: Differences in population only
- Fig. C.4: Differences in initial tax rates only
- Fig. C.5: Lower import share target (5%)
- Fig. C.6: Same population
- Fig. C.7: Same initial aggregate output ($ny = (1-n)y^*$)
- 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: Effect of higher risk aversion (σ) for the home country
- Fig. C.11: Effects of more openness on 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



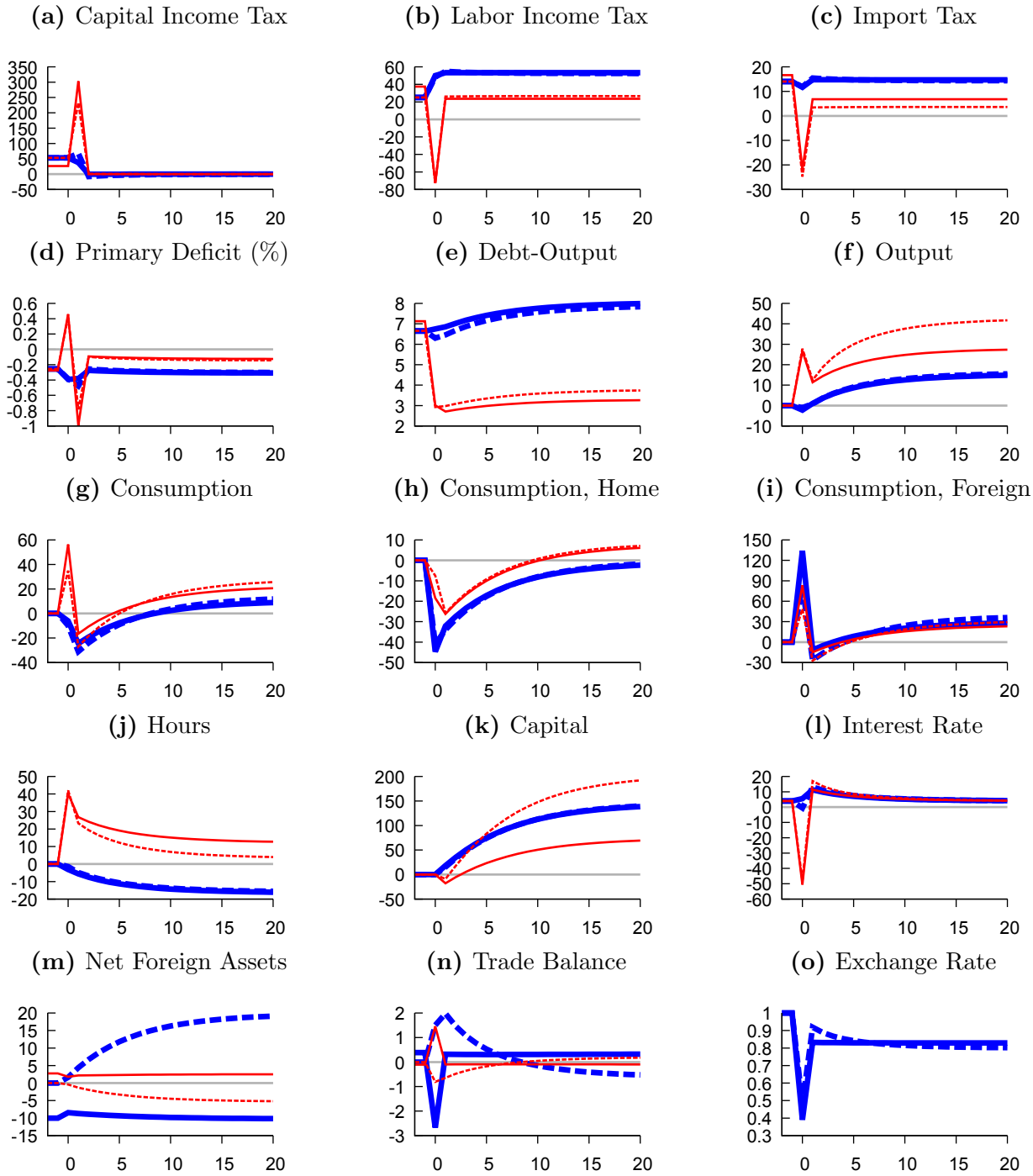
Legend: Thick blue lines: home; thin red lines: foreign.

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



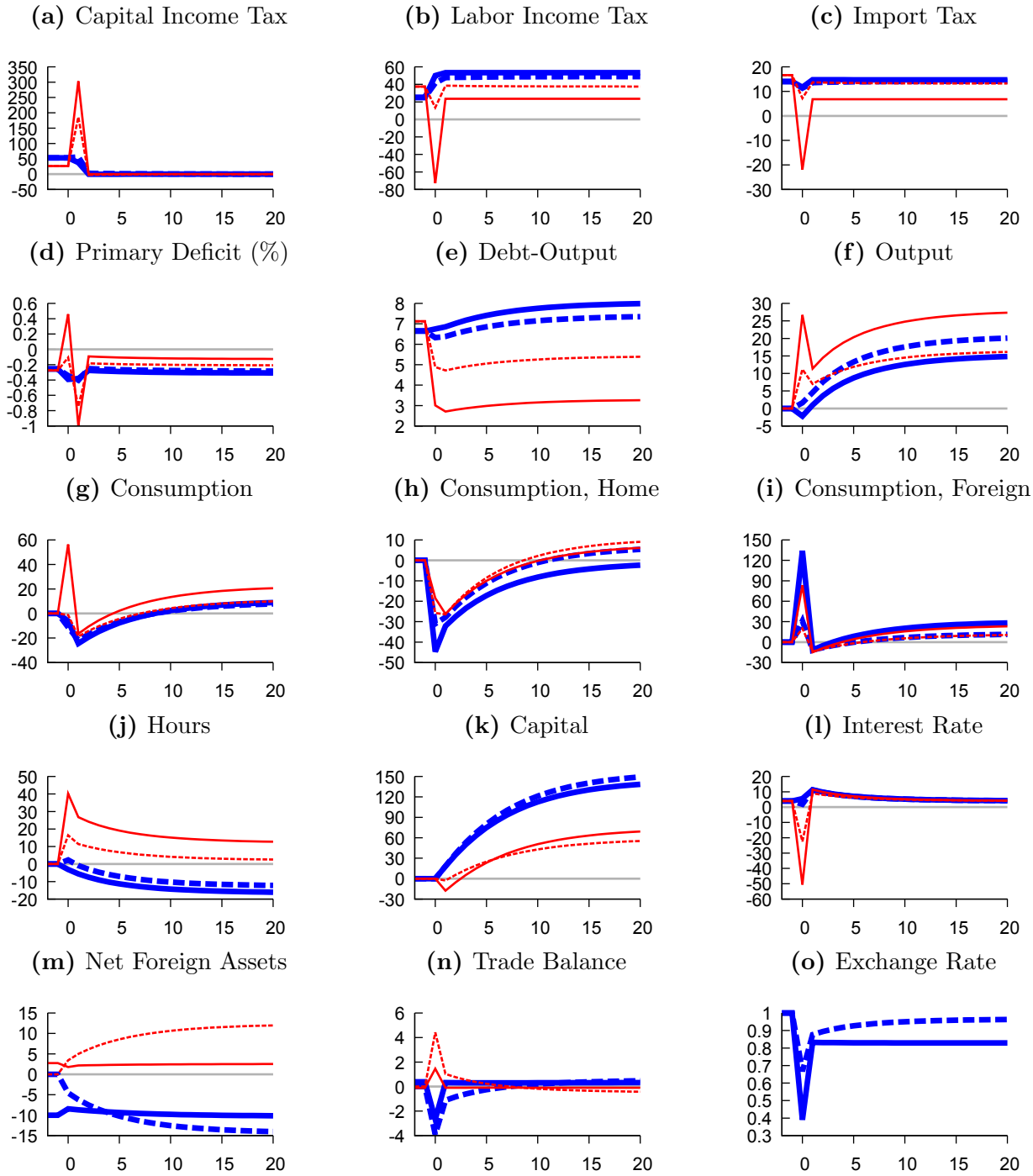
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: differences in initial net foreign assets only.

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



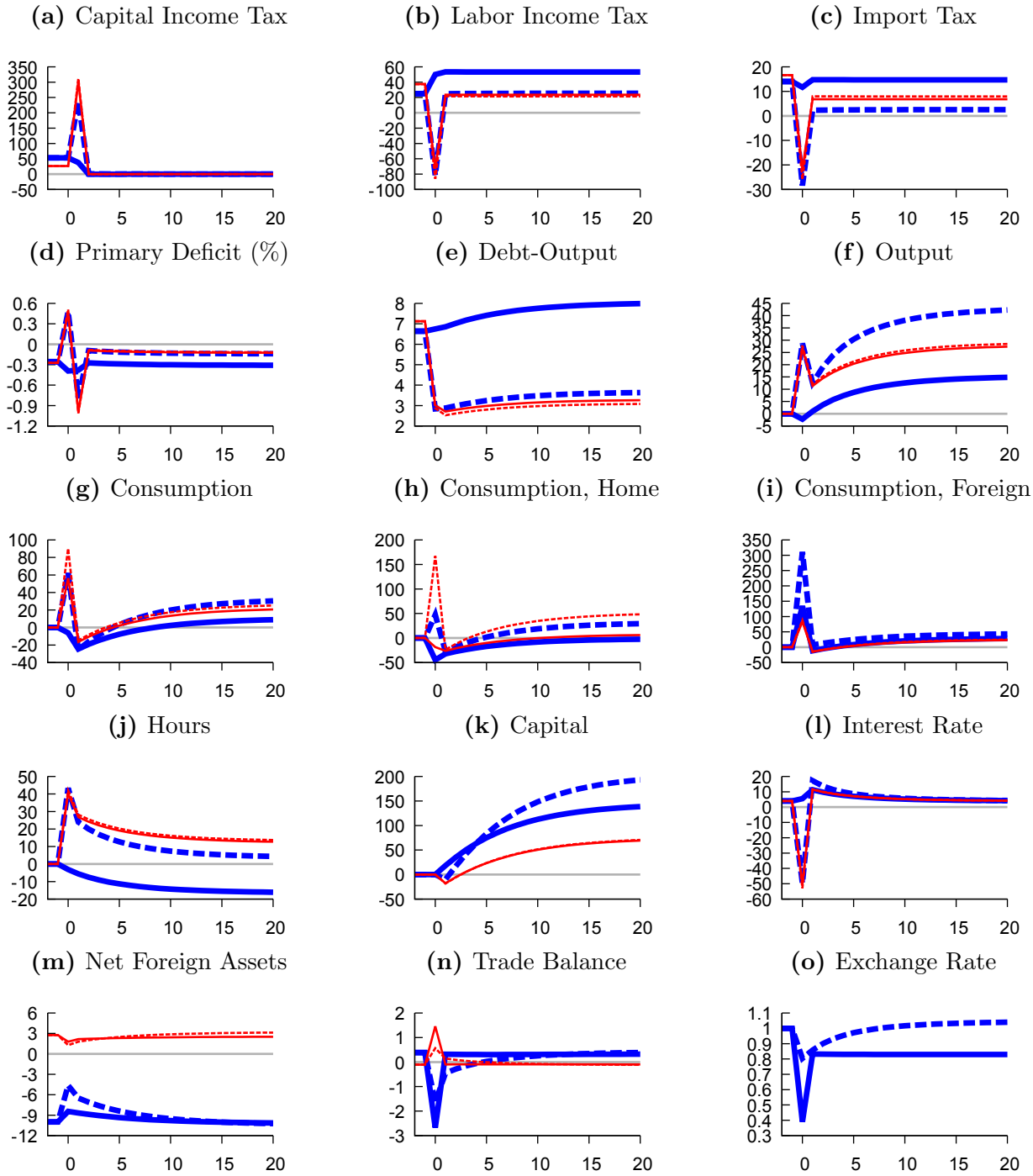
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: differences in population size only.

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



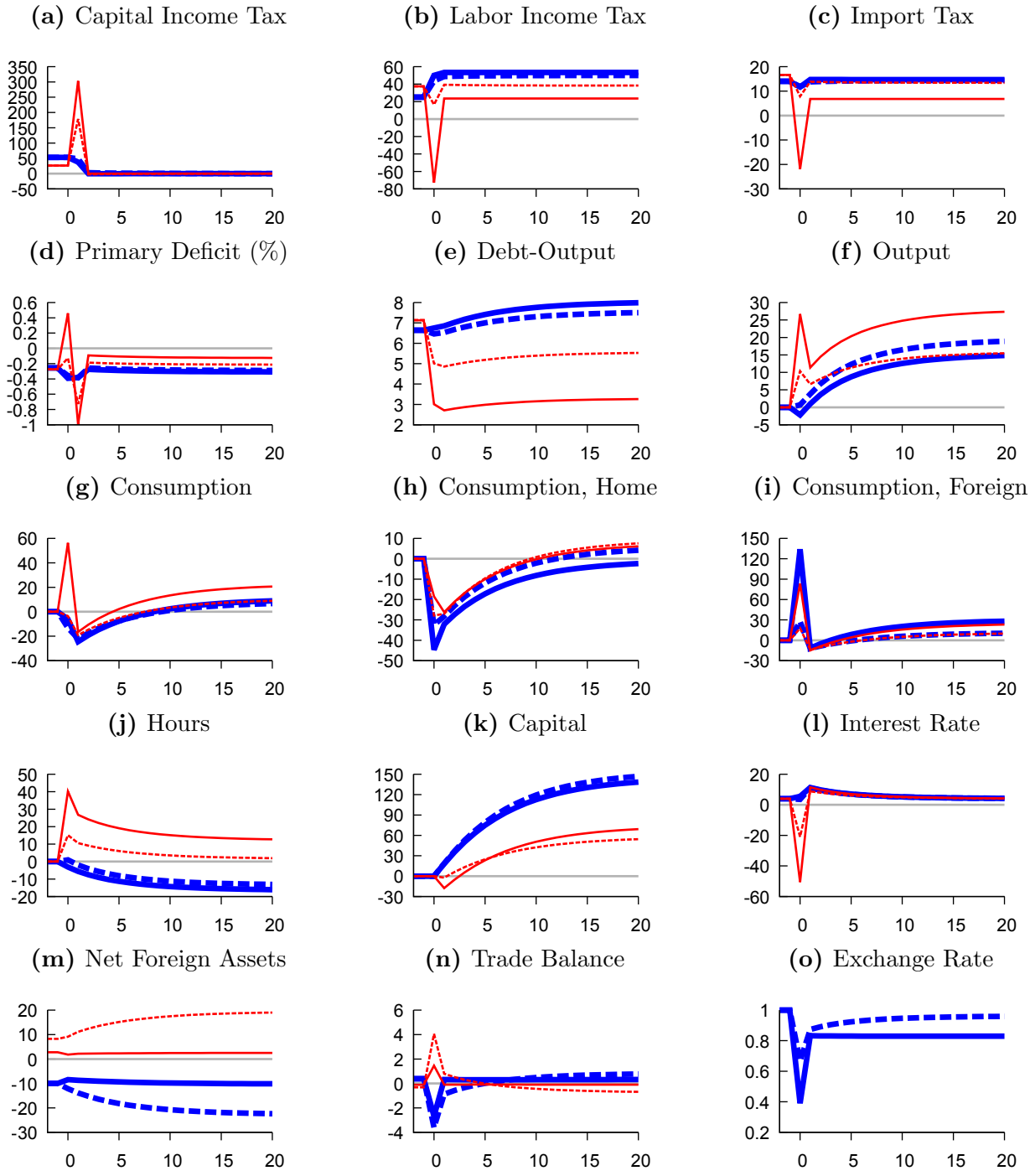
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: differences in initial taxes only.

Figure C.5: Ramsey Tax Competition: Less Open



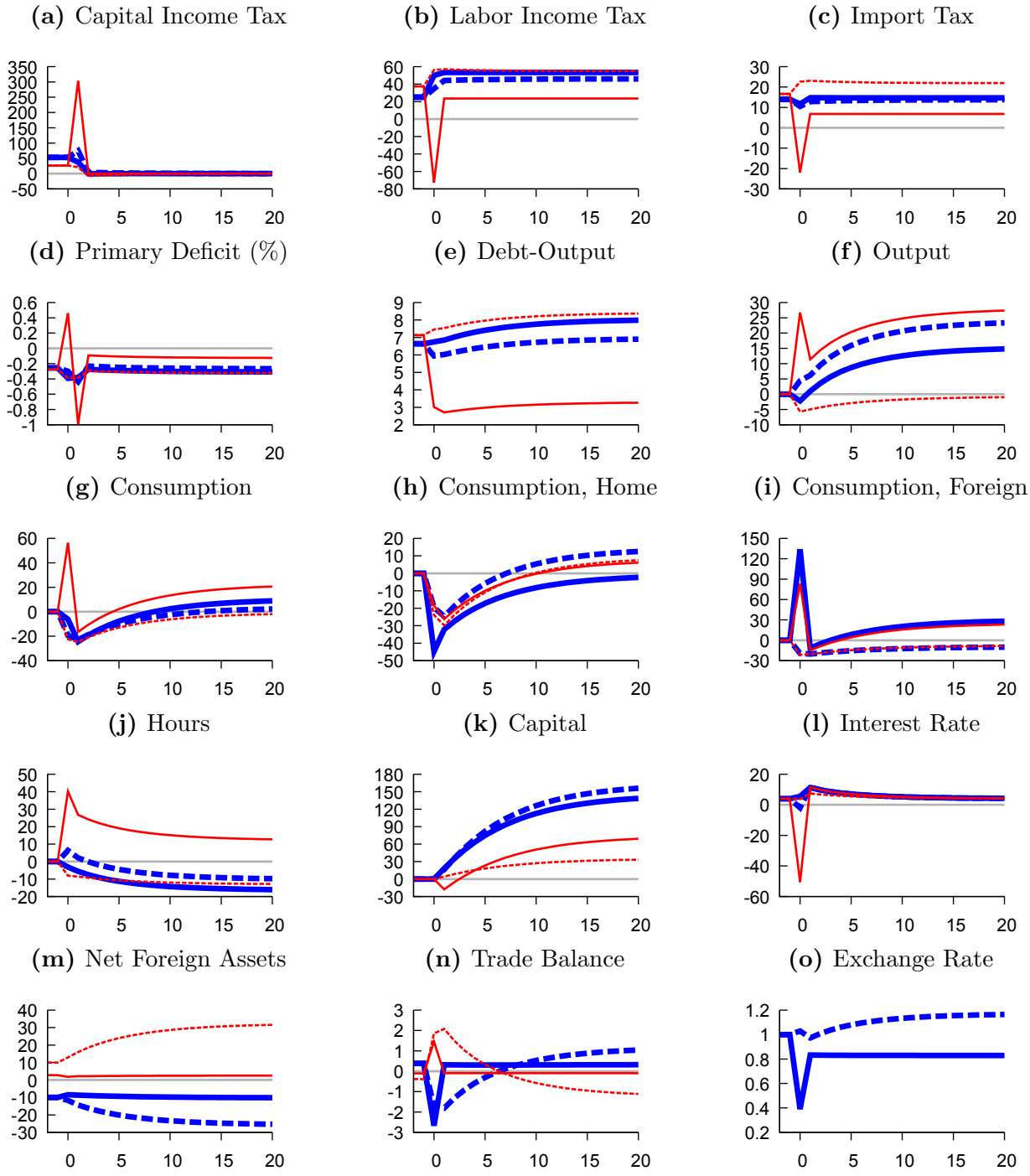
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: less open (lower imports).

Figure C.6: Ramsey Tax Competition: Same Population Size



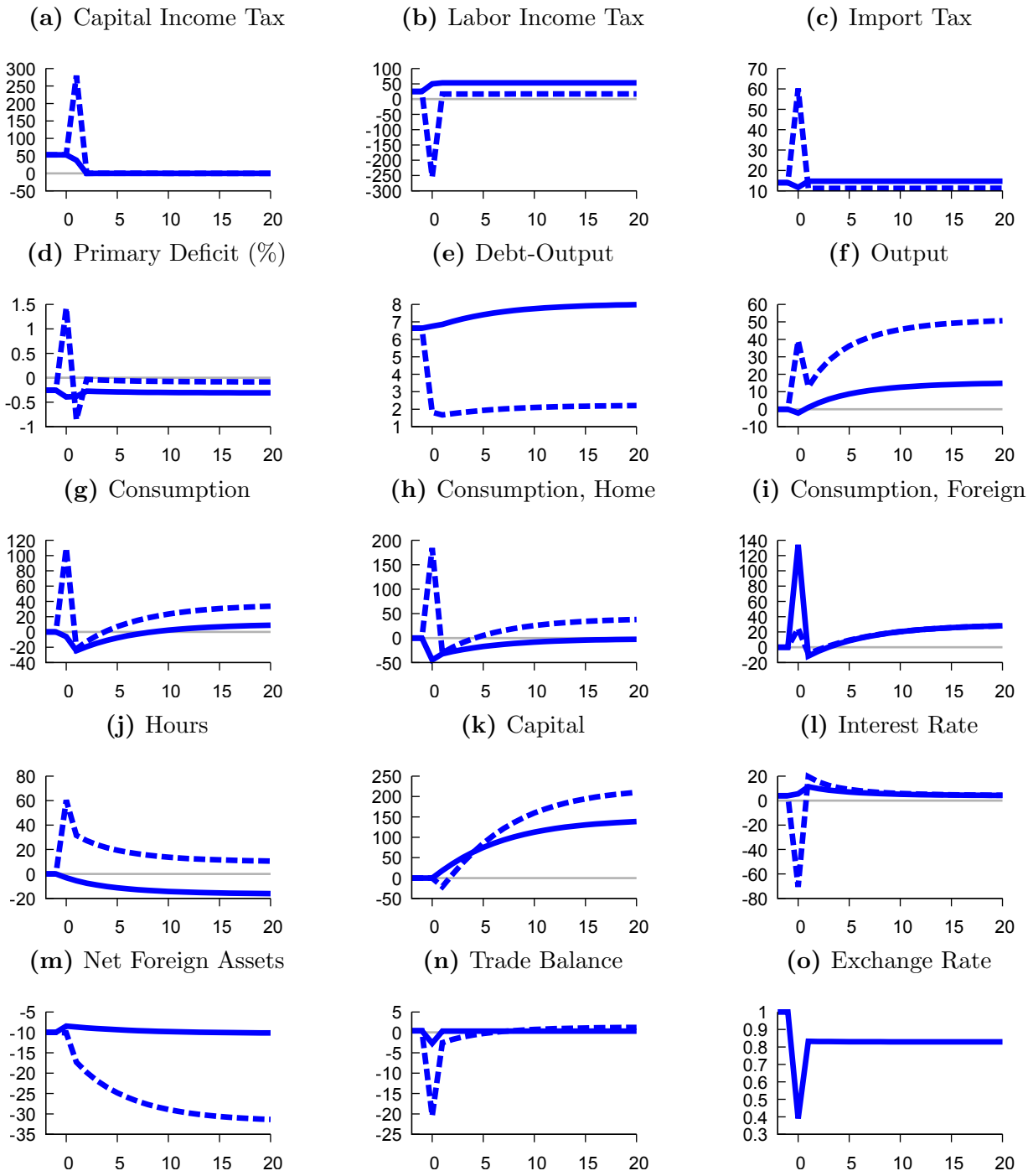
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $n = 1/2$.

Figure C.7: Ramsey Tax Competition: Same Initial Aggregate Output



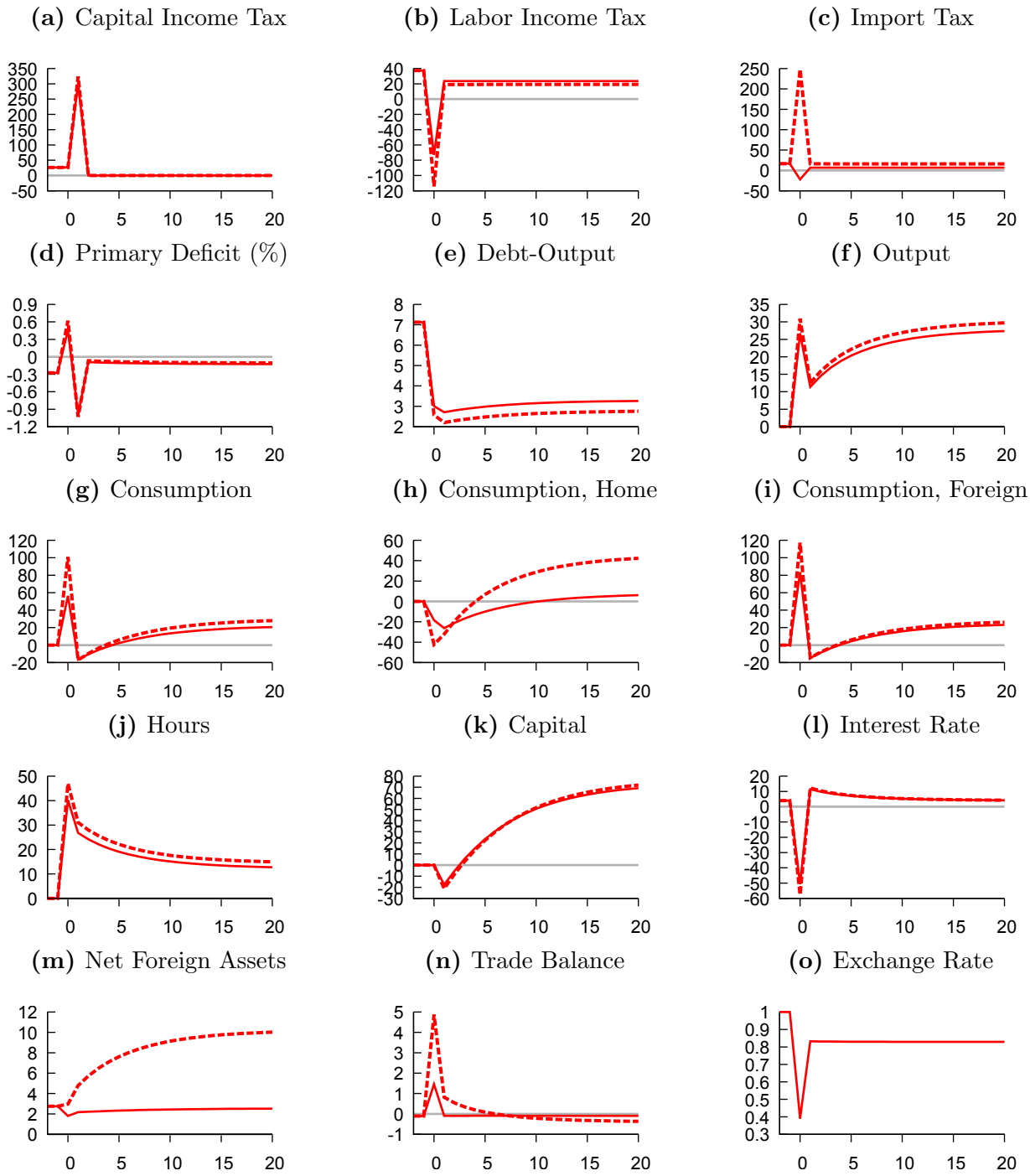
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $ny = (1-n)y^*$.

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



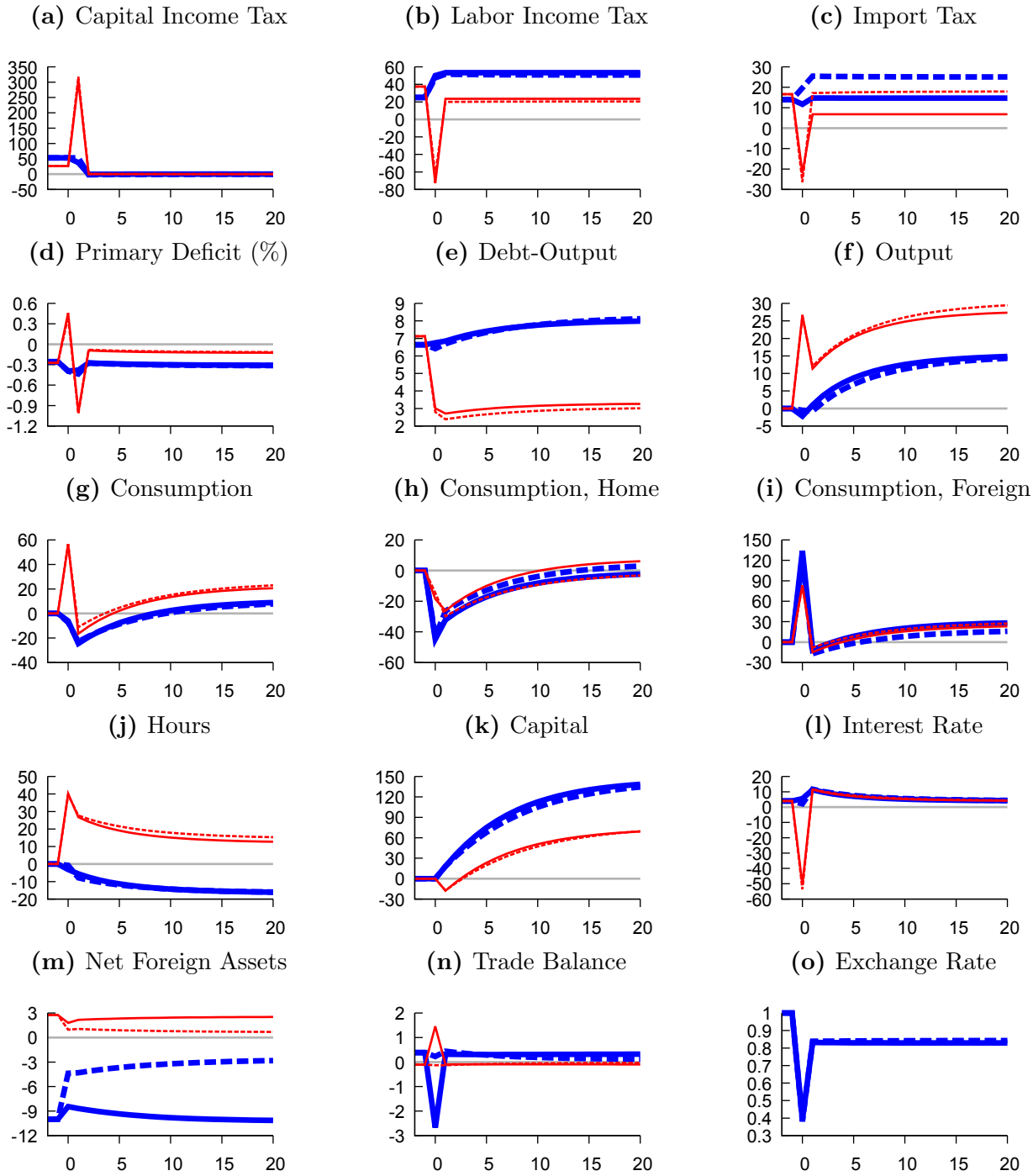
Legend: Solid lines: competition; dashed lines: cooperation.

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



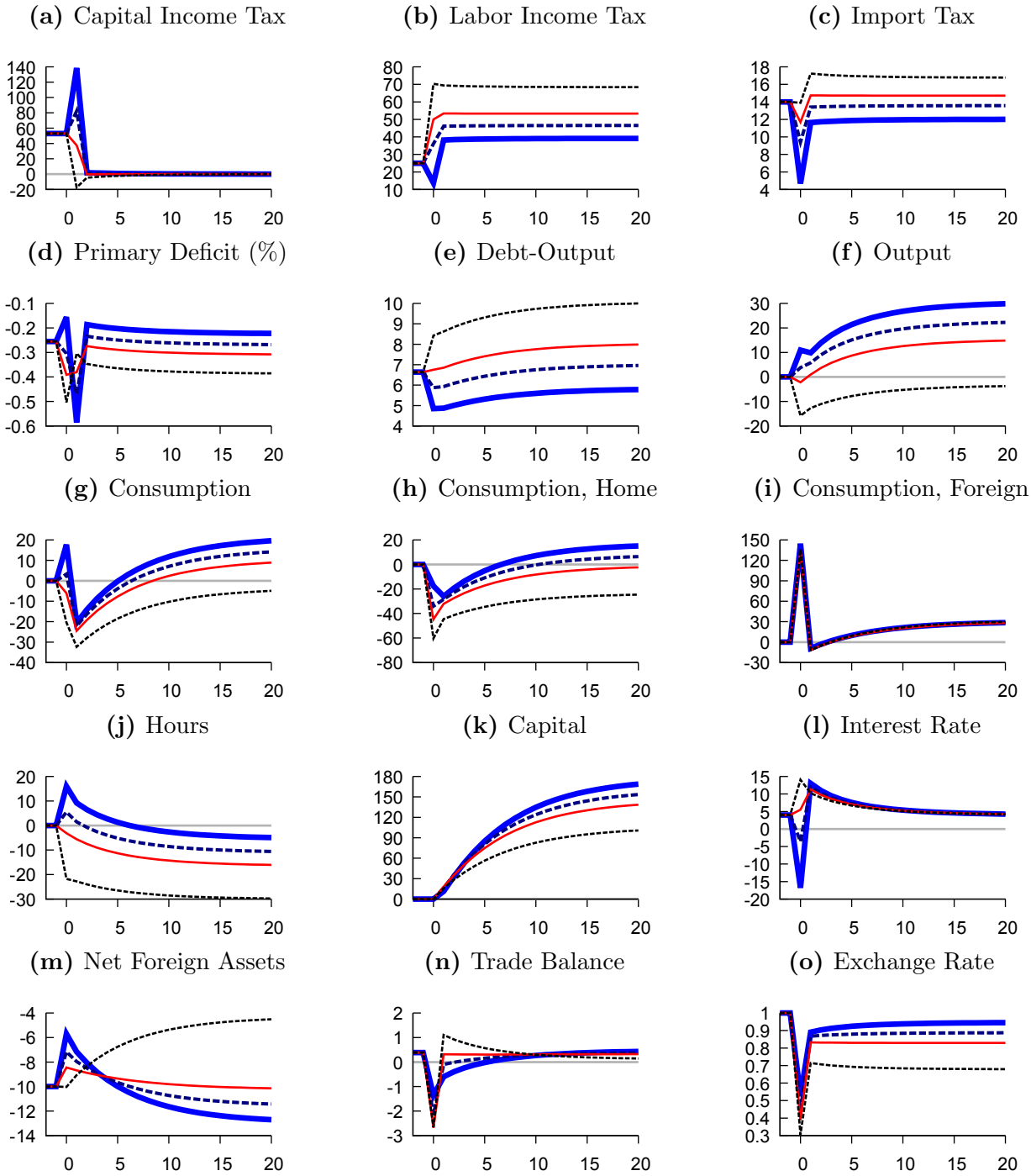
Legend: Solid lines: competition; dashed lines: cooperation.

Figure C.10: Ramsey Tax Competition: Higher Risk Aversion



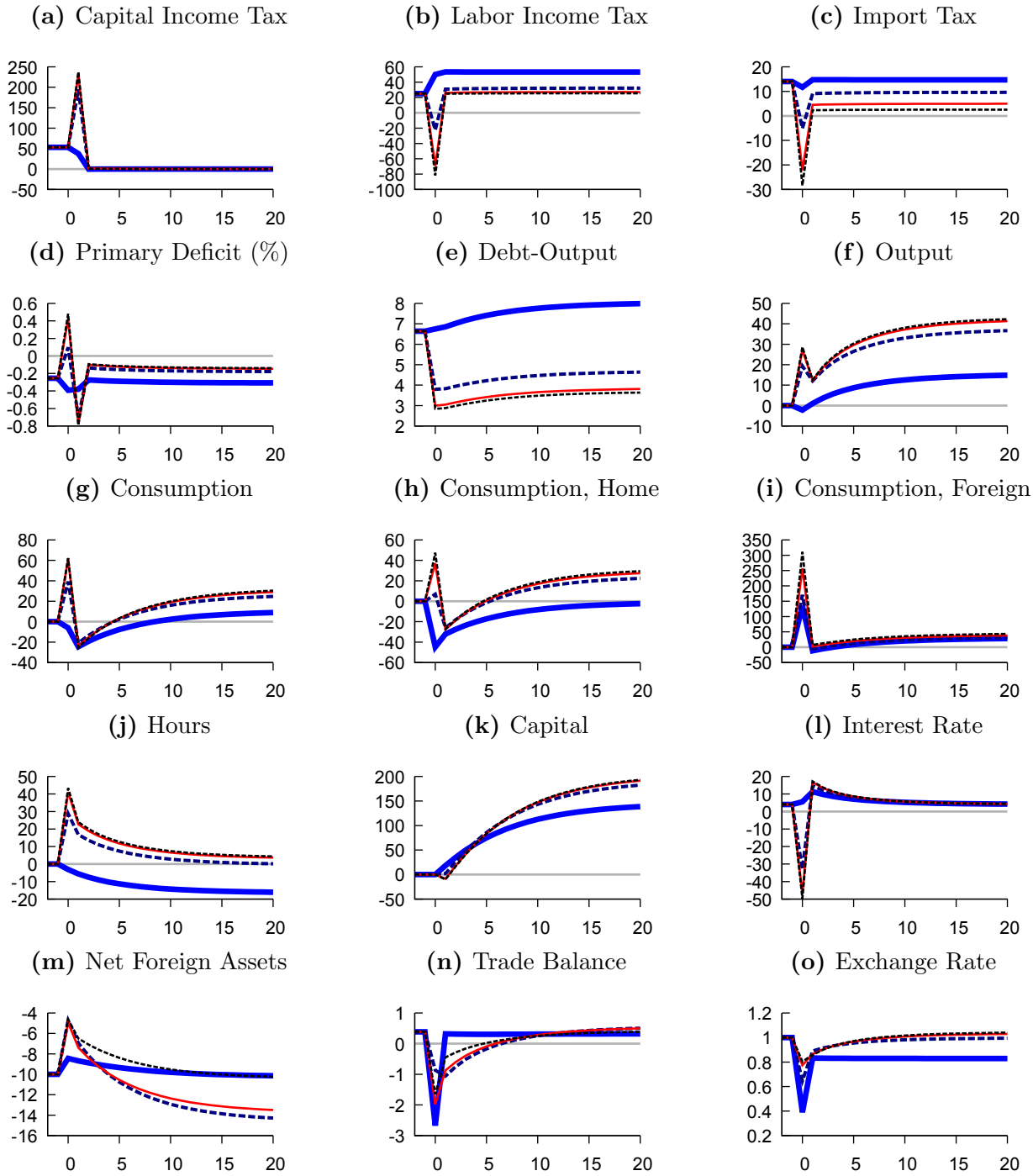
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: higher risk aversion ($\sigma = 1\frac{1}{4}$).

Figure C.11: Ramsey Tax Competition: Home, More Open



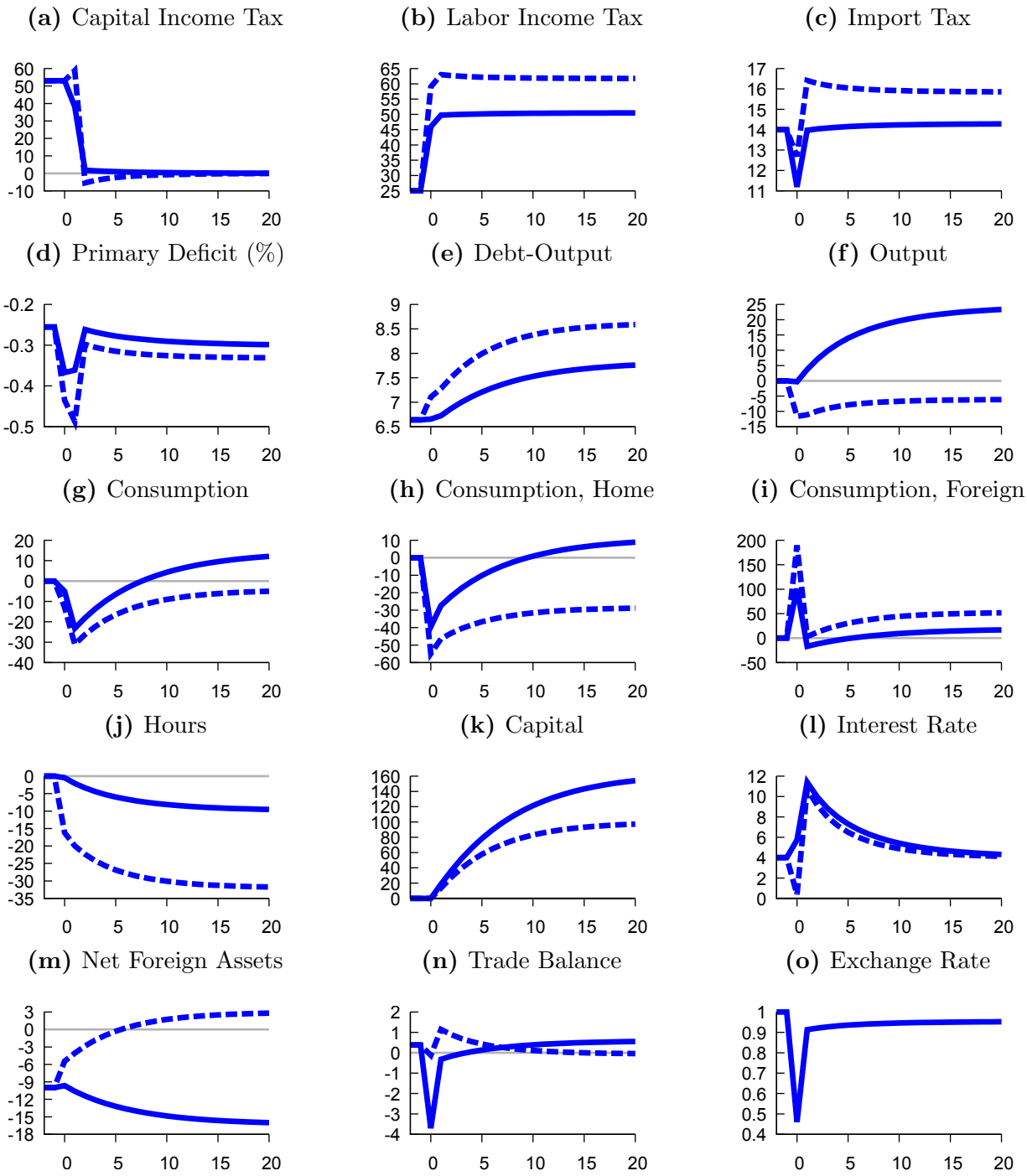
Legend: Import share: 25% (thick blue), 28% (dashed navy), 30% (thin red) and 33% (dotted black)

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



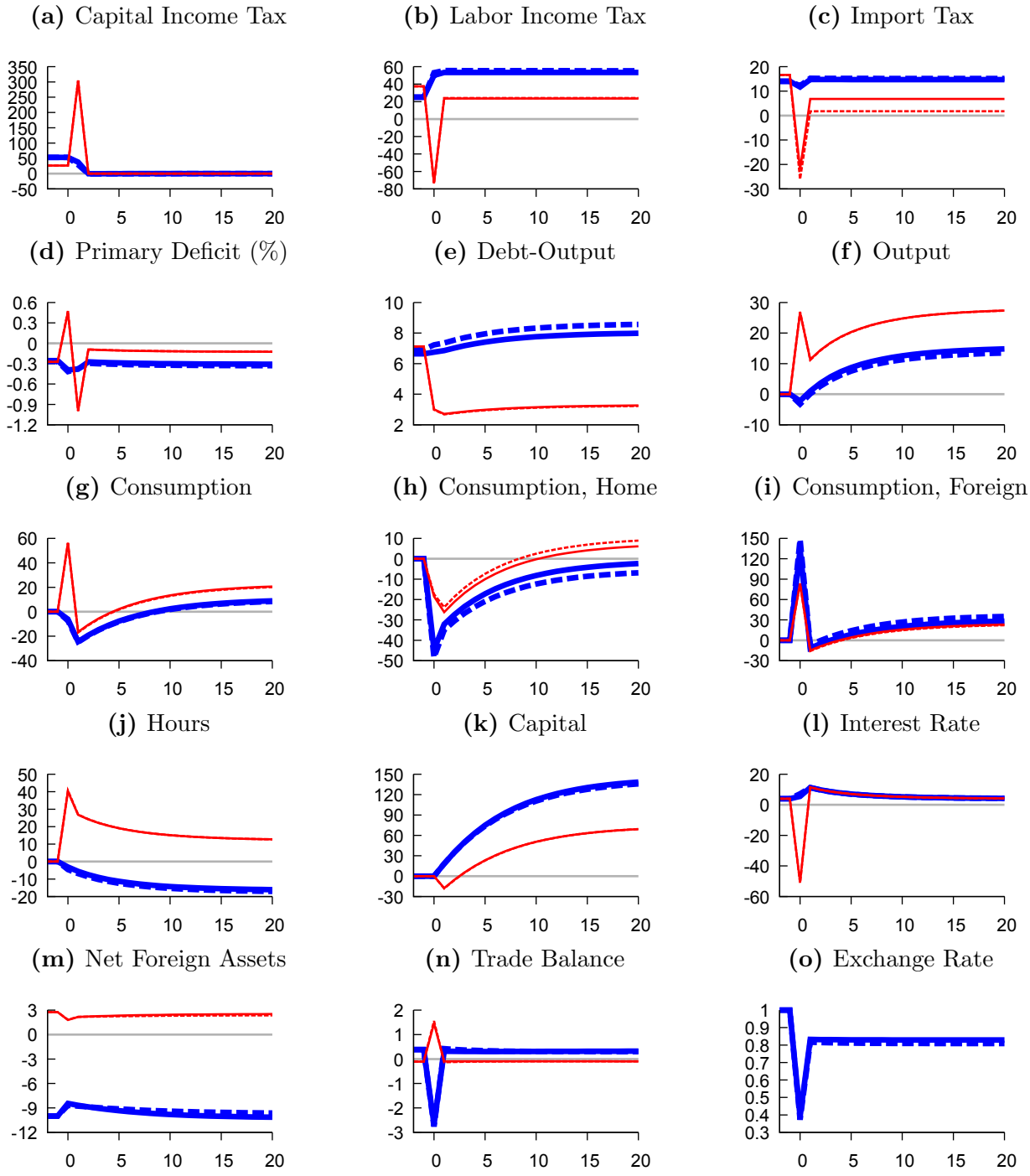
Legend: Import share: 30% (thick blue), 2% (dashed navy), 10% (thin red) and 5% (dotted black)

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



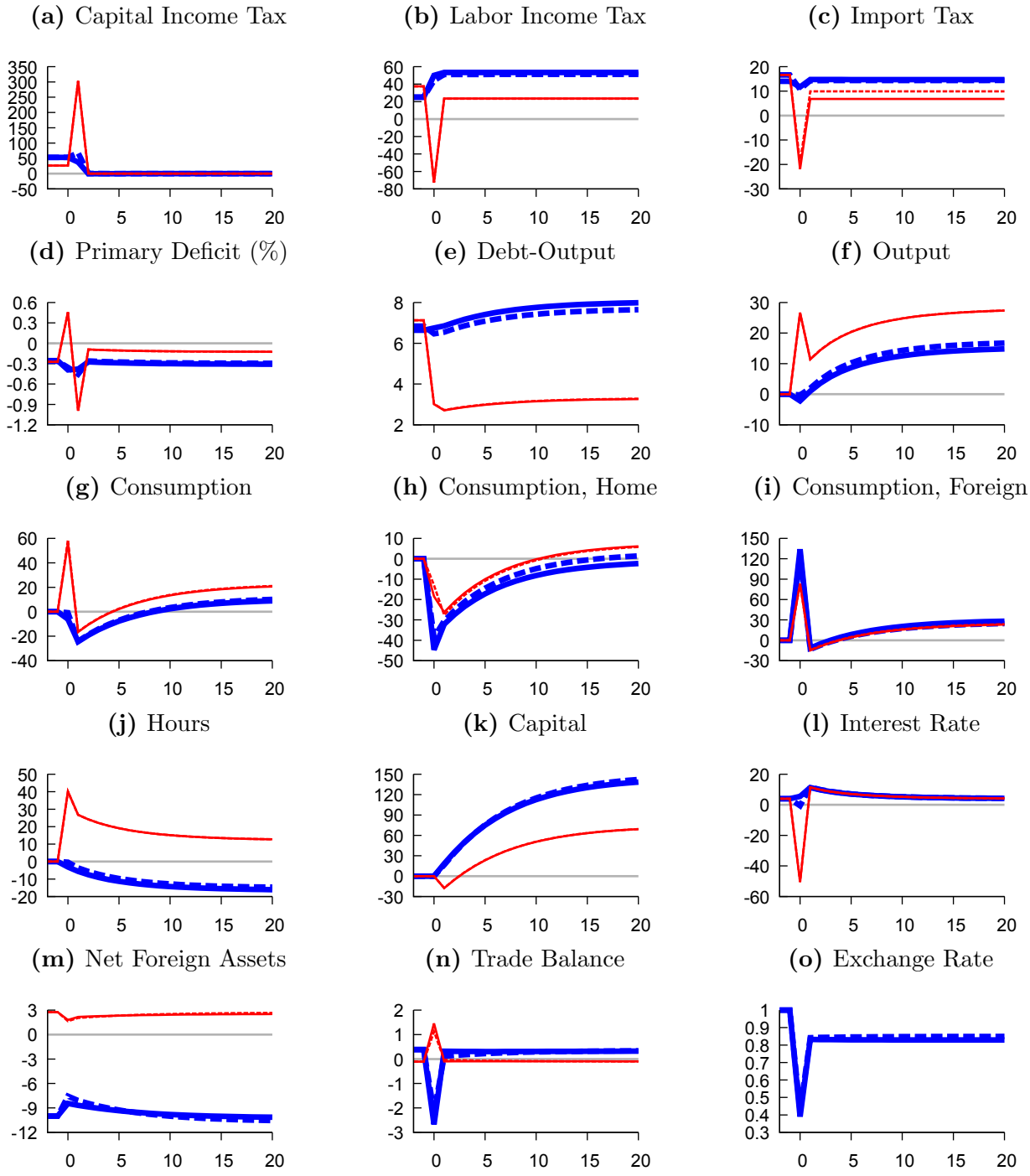
Legend: Labor supply elasticity: $\frac{1}{2}$ (thick blue), 3 (thin red)

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



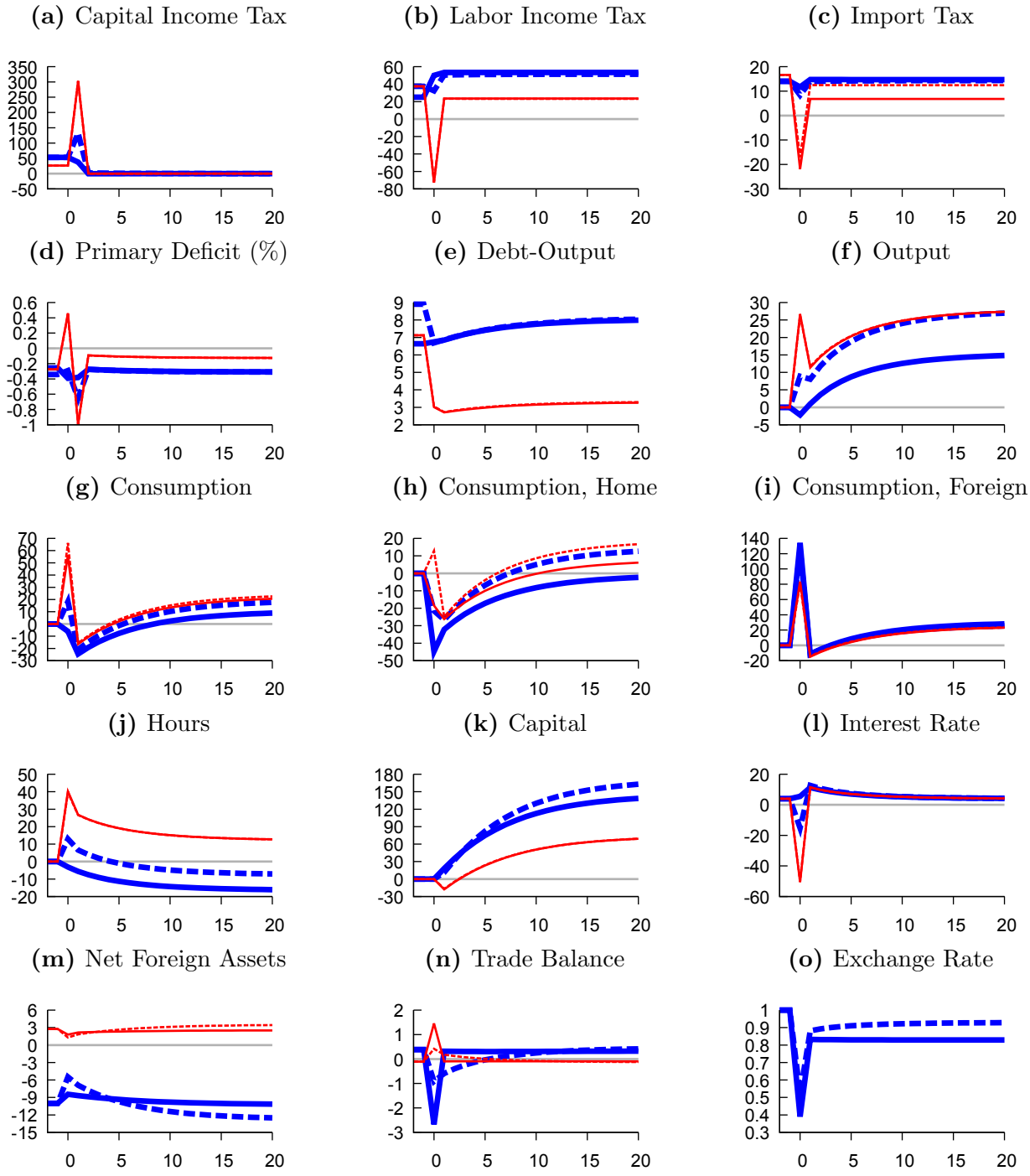
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $\tau_c = \tau_c^*$.

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



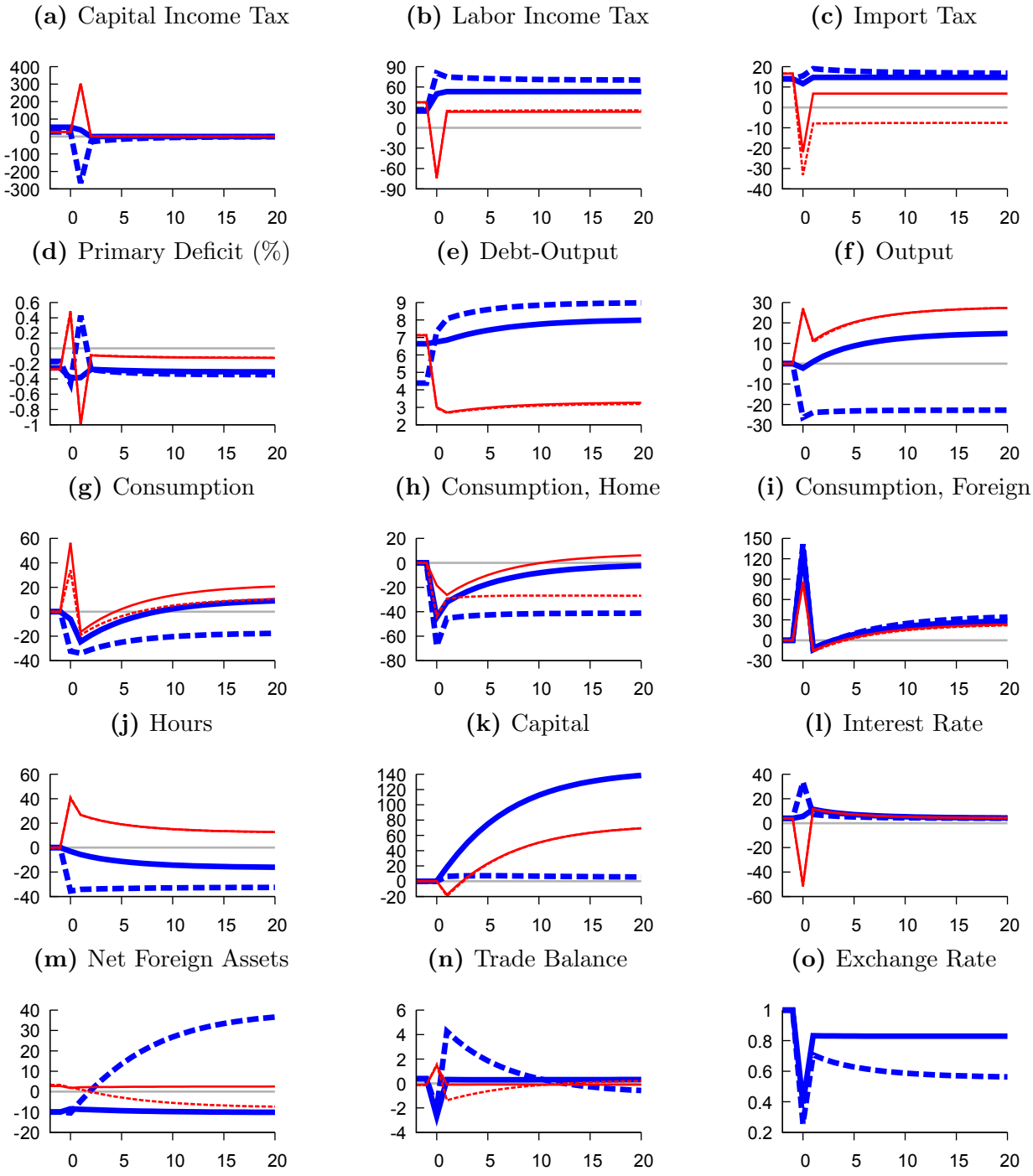
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $\tau_m = \tau_m^*$.

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



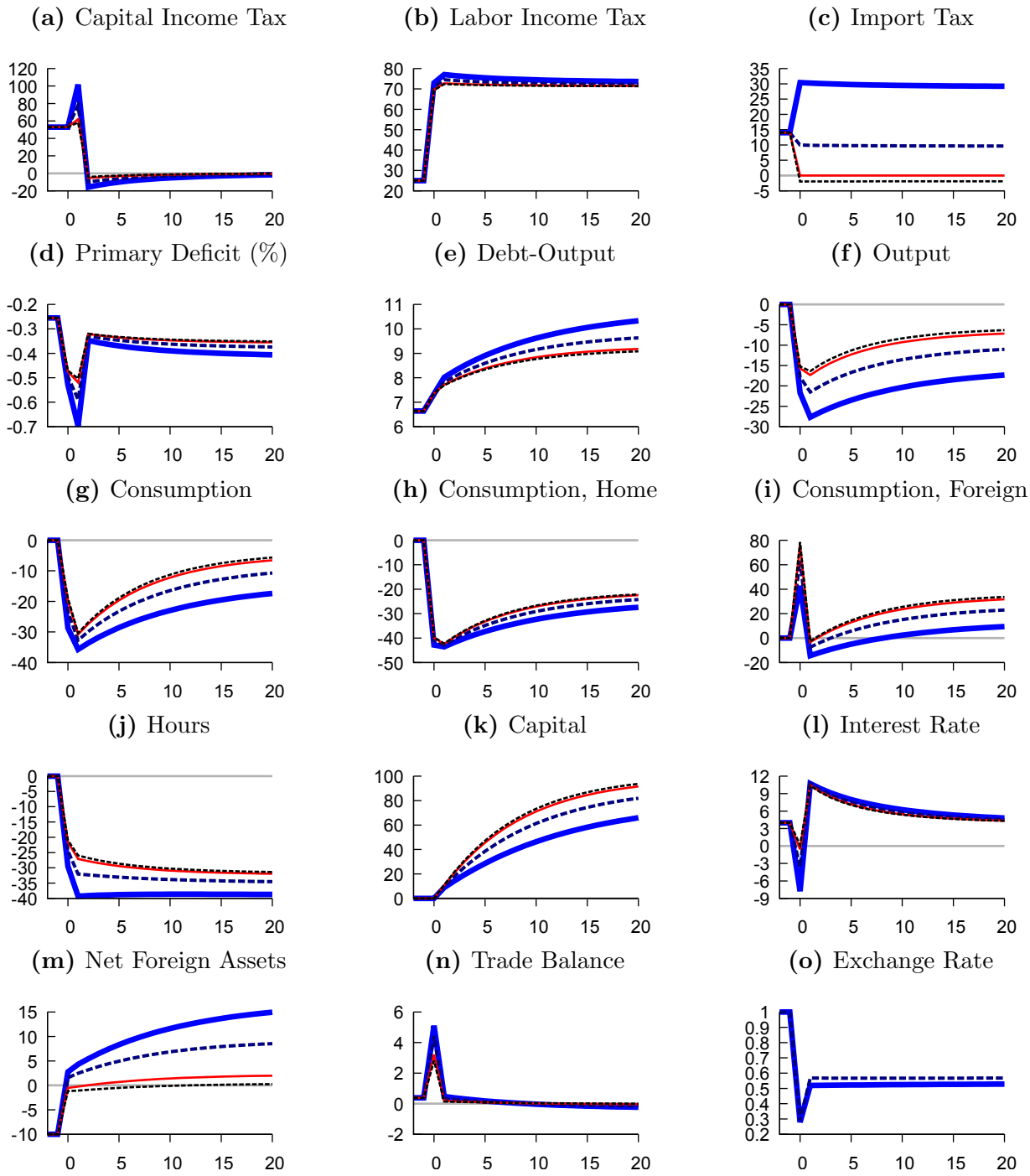
Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $\tau_w = \tau_w^*$.

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



Legend: Thick blue lines: home; thin red lines: foreign. Solid lines: benchmark; dashed lines: $\tau_k = \tau_k^*$.

Figure C.18: Ramsey Tax Competition: Home, Lower Trade Elasticity, Higher Risk Aversion



Legend: Trade elasticity: $\mu = \mu^* = 0.8$. Risk aversion: 2 (thick blue), $1\frac{1}{2}$ (dashed navy), $1\frac{1}{4}$ (thin red) and 1.2 (dotted black)

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