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A Tale of Tax Policies in Open Economies*

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Abstract: To evaluate fiscal policy reforms for Euro-area countries, this paper develops and calibrates a small open economy model. Debt reduction reforms require higher tax rates in the short term in exchange for lower rates in the long term as the debt servicing burden falls. Using the capital income tax to implement such a policy leads to welfare gains; the consumption tax, a very small welfare gain; and the labor income tax, a welfare loss. Holding fixed the long run debt-output ratio, offsetting a lower capital income tax with either a higher labor income or consumption tax generally yields welfare gains.

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1 Introduction

The fiscal situation in Greece, Italy, Ireland, Portugal and Spain (GIIPS) is grim. France's situation is not much better although it has, to date, avoided a crisis. These observations all point to the need for developed countries to get (and keep) their fiscal houses in order.

One need not be a 'debt nutter' to think that there are benefits from reducing the size of government debt, at least in the long run. In particular, given the real interest rate, every percentage point drop in the debt-output ratio leads to a proportional decline in the primary deficit in the long run. While reducing the debt-output ratio requires raising taxes in the short term, doing so allows for lower tax rates in the long run as the government debt servicing burden drops.

We build several dynamic general equilibrium, macroeconomic models to assess the welfare implications of various tax reforms. The benchmark model is an incomplete international asset markets, small open economy model with two goods, home and foreign. To evaluate the importance of some of the key features of the benchmark model, several related alternatives are considered. The first is a complete markets version of the benchmark model. Relative to the benchmark model, the key difference is that the Euler equation governing the accumulation of net foreign assets is replaced by a risk sharing condition; see Section 2.2 for details. The second variant is a one good version of the benchmark model, similar in spirit to Mendoza (1991). The final version is of a closed economy.

Two calibrations of the model are presented. The first calibrates to a high government debt subgroup of Euro Area countries consisting of Greece, Italy, Ireland, Portugal and Spain (GIIPS hereafter); the second calibration collects together Euro Area countries with lower government debt levels (EA7 hereafter, composed of Austria, Belgium, Finland, France, Germany, Luxembourg, and the Netherlands).

The first set of reforms lowers the long run government debt-output ratio by 10 percentage points, a figure chosen as being sizable but not implausible. This reduction in the government debt-to-output ratio is financed via one of: the consumption tax, the labor income tax, or the capital income tax. To ensure stability of the debt dynamics, the government follows a fiscal policy rule that links deviations of the primary surplus from its long run target to deviations of the debt-to-output ratio from its long run target. Simply put, when the debt-to-output ratio is above target, one of the tax rates is adjusted to push the primary surplus above its long run value.

When the labor income tax rate is used to implement such a government debt reduction, the change in policy distorts households' decisions through the labor-leisure choice. In this case, all four model variants deliver similar dynamics. The short term increase in the labor income tax rate reduces the after-tax real wage, leading households to cut back on their hours worked. In turn, output and consumption also fall. This policy-induced recession lasts roughly a decade.

Naturally enough, the capital income tax rate affects the after-tax return to capital, and so affects capital accumulation. In this case, there are large differences across the four model variants which can be traced to the behavior of the real interest rate. To understand these differences, start with the simplest model, the one of a closed economy. A 'no arbitrage' condition dictates that the after-tax return to capital equal the return on government debt. The initial increase in the capital income tax rate lowers the after-tax return to capital. The rate of return equality condition then requires a drop in the real interest rate on government debt. In the one good open economy model, there is a third asset return to consider, that on international bonds. Since the model is of a small open economy, the return on international bonds is close to constant. Further, since it is a one good model, the real exchange rate is, necessarily, fixed (at one). Then the return on international bonds must equal that on domestic government debt which, in turn, must equal the after-tax return on capital. Because all rates of return are equal and close to constant, the increase in the capital income tax rate necessitates a large drop in the capital stock in order to increase the marginal product of capital so that the after-tax return to capital is unchanged. Next, consider the benchmark model with incomplete international markets and two goods. While the world real interest rate is not very responsive to domestic events, in this model there is a real exchange rate channel that affects the effective world real interest rate. This real exchange rate effect leads to a greater response of domestic returns, and so, on impact, the capital stock does not need to fall so much. The dynamics of the two good, complete markets model are very close to those observed under incomplete markets in the short run. In the long run, the cumulative effects of shutting down the international wealth effects (under complete markets) lead to substantial differences in final steady states.[2]

The effects of the consumption tax operate through both the after-tax real wage, and asset returns. While it is generally known that the effects of an increase in the consumption tax affect the labor-leisure choice in much the same way as an increase in the labor income tax rate, the asset return channel is, perhaps, more subtle. In particular, what matters for asset returns is the *timing* of the consumption tax. The debt reduction scenarios involve initially raising the consumption tax, then gradually reducing it. Apart from the first period, future consumption tax rates are lower than current tax rates. As a result, the temporal pattern of the consumption tax acts as a subsidy to all asset returns. However, the size of this subsidy effect is small relative to those seen under the capital income tax. Consequently, the short term dynamics of macroeconomic variables look broadly similar to those associated with the labor income tax, although the subsidy effect cuts the length of the policy-induced recession roughly in half.

To easily summarize the welfare results, we need to take a stand on which of the four models is our preferred model. While the closed economy model provides useful insight to the model's mechanisms, Euro Area countries can hardly be described as closed economies. Treating the GIIPS and EA7 regions as one good open economies means fixing the real exchange rate, an assumption that does not fit the facts. The one good model also predicts that a region will either import goods, or export goods, but not both simultaneously; yet, these regions have considerable imports *and* exports. While complete international asset

[2]See Auray and Eyquem (2014) for a discussion of differences between complete and incomplete markets.

markets may have desirable theoretical properties, it is evident to most observers that the GIIPS countries have experienced considerable pain over the past few years; such pain seems inconsistent with the risk sharing inherent to complete asset models. For the benchmark model, using the capital income tax rate as the policy instrument yields the largest welfare gains, 0.16 percent of consumption for the GIIPS group, and 0.36 percent for the EA7 countries. The consumption tax is associated with a small but positive welfare benefit while the labor income tax delivers a small welfare *loss*. These welfare effects are computed over the full transition path. In contrast, 'naïve' welfare gains computed across steady states are considerably larger – as much as 2.7 percent.

The second set of policy reforms is inspired by the optimal taxation literature which typically finds that in the long run, capital income taxes should be close to zero. With this in mind, leaving the long run debt-output ratio unchanged, consider a 10 percentage point reduction in the capital income tax rate. To satisfy the fiscal policy feedback rule, the capital income tax cut is financed through either the labor income tax or the consumption tax. The short run dynamics of such a reform are dominated by the effects of the capital income tax rate cut. For the benchmark model, there are sizable welfare gains associated with such a reform: the GIIPS group, the gains are either 0.24 percent (labor income tax) or 0.40 percent (consumption tax); for the EA7, 0.58 percent (labor income tax) or 0.77 percent (consumption tax). Such results should dissuade policymakers from a scenario like the following: having raised the capital income tax rate to bring down the government debt-output ratio, it may be tempting to maintain this increase in the capital income tax rate, lowering instead one of the other taxes. This scenario delivers the 'worst of both worlds' since the benefits of using the capital income tax rate to lower the debt-output ratio accrue from the long term benefits of eventually lowering this tax rate.

In many of the reforms considered, we find that the welfare gains are larger for the EA7 countries than for the GIIPS. The chief reason is that taxation is initially higher in these countries (and debt-to-output lower), generating larger potential efficiency gains from lower long run taxation in these countries.

Our paper is broadly related to a variety of papers. As in the early contribution of Mendoza and Tesar (1998), the model is unabashedly neoclassical, focusing exclusively on fiscal policy. The first key difference relative to Mendoza and Tesar is that their model has only one good (producible in both countries) while we distinguish between domestic and foreign goods. Second, they have complete international asset markets while we consider both complete and incomplete international asset markets. Third, while our tax replacement experiments are in the same spirit as those conducted in Mendoza and Tesar, they do not consider the debt reduction experiments that we motivate with reference to contemporary fiscal crises. Our paper is also related to Mendoza, Tesar and Zhang (2014). The two regions they study are the European 'crisis' countries (GIIPS) and the rest of the EMU. Their analysis is conducted within a one good model and consequently, real exchange rate movements are not considered. Their focus is on changes in factor income tax rates that can reduce government debt-to-output levels in the crisis region. They find that adjustments in capital income taxes cannot raise sufficient revenue, a result that arises chiefly from variable capital utilization. An important technical distinction between our work and that of Mendoza et al. is that they solve their model through log-linear approximations whereas we solve the nonlinear equations of our model, a procedure that delivers more accurate transitional dynamics, and is better suited to welfare comparisons of alternative policies.

Like Mendoza and Tesar (1998) and Mendoza et al. (2014), our paper is not about the optimal structure of taxation, although it is broadly related to that body of work. The bulk of the optimal taxation literature has focused on closed economy models; see Lucas and Stokey (1983) or Chari and Kehoe (1999) among many others. The open economy dimension has received less attention. Recently, Benigno and De Paoli (2010) characterized optimal fiscal policy in a small open economy model with a single income tax and public debt; they consider both steady state and business cycle fluctuations. In a richer environment with capital, sticky prices and a larger set of taxes, Auray, de Blas and Eyquem (2011) have shown that trade openness does not matter for the optimal steady state tax system when financial markets are complete, so long as one focuses on a symmetric steady state. The current paper deviates from both papers by considering both complete and incomplete international financial markets, and a small open economy. Allowing for explicit trade relations with the rest of the world, and for potential wealth transfers (made possible by assuming incomplete international financial markets) opens up additional transmission mechanisms following tax reforms. Overall, our paper complements the optimal taxation literature by quantifying the effects of various permanent tax reforms. One of the contributions of the paper is to consider a full set of policy instruments (here, tax rates); most open economy papers do not do so.

Finally, the current paper is related to recent work by Trabandt and Uhlig (2011) who present Laffer curves for capital income, labor income and consumption taxes, for the U.S. and a subset of the EU. Much of their analysis makes comparisons across balanced growth paths. The distinctions between the current work and Trabandt and Uhlig are: we work with an open economy model whereas they used a closed economy model; and we do considerably more analysis of the transition paths following a policy change. The open economy provides insight into the effects of tax reforms on external trade and the real exchange rate, as well as pushing some of the burden of increased tax revenue onto the foreign sector. As Trabandt and Uhlig show, considering the transition path can lead to dramatically different welfare results relative to comparisons across steady states or balanced growth paths.

The paper is organized as follows. Section 2 presents the model in detail. Section 3 discusses the calibration, as well as the steady state implications of the model. Section 4 proceeds to tax policy experiments and analyzes both qualitatively and quantitatively the different policy scenarios, as well as a sensitivity analysis. Section 5 concludes.

2 Model

Four models are analyzed. The first – described in detail – is a two good, small open economy with incomplete international asset markets. In this case, the interest rate paid on foreign debt depends on the country's foreign debt-output ratio. This assumption ensures that the model is stationary as discussed in Schmitt-Grohé and Uribe (2003).

The other models are described in terms of their deviations from the first model. In the the second model, international asset markets are complete, an assumption that also ensures stationarity. The difference between the first and third models is that the third has only one good. Consequently, the model cannot distinguish between imports and exports – there are simply net exports. The last model is of a closed economy.

2.1 A Two Good, Small Open Economy with Incomplete International Asset Markets

Following the approach of Benigno and De Paoli (2010) and De Paoli (2009), a small open economy is developed as the limit of a two country model when the size of the domestic economy tends to zero. The model features trade in consumption goods, balanced growth, and incomplete international asset markets. Below, attention is focused on the home region; the rest of the world is symmetric apart from its size and tax system. Rest of the world variables are distinguished from home variables using an asterisk superscript. Since the model is solved under perfect foresight, the expectation operator is suppressed.

Households

The representative household values a private good, c_t, and receive disutility from supplying labor, h_t. As discussed below, the private good is a composite of domestic and foreign-produced goods. Households maximize the discounted sum of utility,

$$\sum_{t=0}^{\infty} \beta^t u\left(c_t, h_t\right), \quad 0<\beta<1, \tag{1}$$

subject to the budget constraint

$$\left(1+\tau_{ct}\right) p_t c_t + k_t + \Phi_{kt} + d_t + s_t b_t = r_{t-1} d_{t-1} + s_t r_{t-1}^* b_{t-1} + \left(1-\tau_{ht}\right) w_t h_t + R_t k_{t-1} + \tau, \tag{2}$$

and the appropriate transversality condition. Starting on the right-hand side of (2), the first term is after-tax wage income: the tax rate on earnings is τ_{ht} and the real wage is w_t. In the next term, $R_t = 1 + \left(1-\tau_{kt}\right)\left(r_{kt}-\delta\right)$ is the gross real, after-tax return to capital: the tax rate is τ_{kt}, and r_{kt} denotes the real rental rate. The subtraction of the depreciation rate, δ, from the real rental rate captures a capital consumption allowance that reflects the tax deductibility of depreciation from capital income. The next term is the proceeds from holding domestic bonds, d_{t-1}, where r_{t-1} is the real interest rate. Next is income from holding foreign bonds, b_t, which are denominated in units of foreign output; here, s_t is the real exchange rate (defined as the number of units of domestic output per unit of foreign output) and r_{t-1}^* is the foreign interest rate. Finally, τ is a lump-sum transfer.

Now, consider the left-hand side of (2). The first term is purchases of aggregated consumption goods, including payment of taxes, τ_{ct}. p_t denotes the price of aggregated consumption expressed in units of domestic output; as with the details concerning the aggregated consumption good, discussion of this relative price is deferred until later. The second term is investment in (domestic) capital, k_t, net of adjustment costs, Φ_{kt}, specified as in Mendoza (1991):

$$\Phi_{kt} = \frac{\phi^k}{2} \frac{\left(k_t - \gamma_a k_{t-1}\right)^2}{a_t}. \tag{3}$$

Adjustment costs are expressed relative to the level of labor-augmenting productivity a_t, that grows at rate γ_a, to ensure a well-defined balanced-growth equilibrium. As is typical in open economy macroeconomic models, capital adjustment costs are included to avoid implausibly large swings in investment. The remaining terms on the left-hand side of (2) are purchases of domestic and foreign bonds.

The household's first-order conditions (Euler equations) are:

$$u_h(c_t, h_t) + \frac{(1-\tau_{ht})w_t}{(1+\tau_{ct})p_t} u_c(c_t, h_t) = 0, \tag{4}$$

$$\frac{u_c(c_t, h_t)}{(1+\tau_{ct})p_t} = \beta r_t \frac{u_c(c_{t+1}, h_{t+1})}{(1+\tau_{c,t+1})p_{t+1}}, \tag{5}$$

$$\left[1 + \phi^k \frac{k_t - \gamma_a k_{t-1}}{a_t}\right] \frac{u_c(c_t, h_t)}{(1+\tau_{ct})p_t} = \beta \frac{u_c(c_{t+1}, h_{t+1})}{(1+\tau_{c,t+1})p_{t+1}} \left[1 + (1-\tau_{k,t+1})(r_{k,t+1} - \delta) + \gamma_a \phi^k \frac{k_{t+1} - \gamma_a k_t}{a_{t+1}}\right], \tag{6}$$

$$s_t \frac{u_c(c_t, h_t)}{(1+\tau_{ct})p_t} = \beta s_{t+1} r_t^* \frac{u_c(c_{t+1}, h_{t+1})}{(1+\tau_{c,t+1})p_{t+1}}, \tag{7}$$

Equation (4) is the standard labor-leisure choice describing the intratemporal trade-off between consumption and time spent working. Equation (5) is the intertemporal Euler equation governing purchases of domestic bonds. As such, it relates the marginal rate of substitution between consumption at dates t and $t+1$ to the real interest rate. Equation (6) governs the accumulation of domestic capital. Finally, (7) determines the accumulation of foreign bonds. It relates the marginal rate of substitution for consumption between two dates (accounting for changes in the consumption tax) to changes in the real exchange rate and the real interest rate on foreign bonds.

Whereas investment goods are composed exclusively of domestic output, consumption goods consist of domestic and foreign goods. As in Benigno and De Paoli (2010), aggregate consumption is a composite of a good produced at home (h), and a good produced in the rest of the world (f) according to:

$$c_t = \left[\varphi^{\frac{1}{\mu}} c_{ht}^{\frac{\mu-1}{\mu}} + (1-\varphi)^{\frac{1}{\mu}} c_{ft}^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}, \tag{8}$$

where $\varphi = 1 - (1-n)\gamma$ governs the importance of home goods in the composite; it depends on n, the relative size of the domestic economy, and γ, which measures trade openness. Symmetrically, the consumption of a representative household in the rest of the world is:

$$(9) \qquad c_t^* = \left[\varphi^{*\frac{1}{\mu}} c_{ht}^{*\frac{\mu-1}{\mu}} + (1-\varphi^*)^{\frac{1}{\mu}} c_{ft}^{*\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}},$$

where $\varphi^* = n\gamma^*$. Assuming that the law of one price holds at the producer level, consumer prices are given by

$$(10) \qquad p_t = \left[\varphi + (1-\varphi) s_t^{1-\mu} \right]^{\frac{1}{1-\mu}},$$

$$(11) \qquad p_t^* = \left[1 - \varphi^* + \varphi^* s_t^{\mu-1} \right]^{\frac{1}{1-\mu}}.$$

In these expressions, $\mu \geq 1$ is the elasticity of substitution between domestic and foreign goods.[3]

Optimal demands for domestically- and foreign-produced goods can be obtained from a cost minimization problem,

$$(12) \qquad \min_{\{c_{ht}, c_{ft}\}} c_{ht} + s_t c_{ft},$$

subject to (8), with a similar problem for the foreign consumer. Optimal demands for

[3]To derive the prices p_t and p_t^*, it is convenient to express all prices, including that of output, in terms of an abstract unit of account. p_t and p_t^* can, then, be derived by solving the consumption bundler's cost minimization problem for producing one unit of aggregated consumption. Then, choose output in a country to be that country's numeraire good so that its price is one.

domestic and foreign production goods are:

$$c_{ht} = \varphi \left[\varphi + (1-\varphi)\, s_t^{1-\mu} \right]^{\frac{\mu}{1-\mu}} c_t, \tag{13}$$

$$c_{ht}^* = \varphi^* \left[(1-\varphi^*)\, s_t^{1-\mu} + \varphi^* \right]^{\frac{\mu}{1-\mu}} c_t^*, \tag{14}$$

$$c_{ft}^* = (1-\varphi^*) \left[(1-\varphi^*) + \varphi^* s_t^{\mu-1} \right]^{\frac{\mu}{1-\mu}} c_t^*, \tag{15}$$

$$c_{ft} = (1-\varphi) \left[\varphi s_t^{\mu-1} + (1-\varphi) \right]^{\frac{\mu}{1-\mu}} c_t. \tag{16}$$

As discussed in Schmitt-Grohé and Uribe (2003), open economy models need some feature to render their dynamics stationary. Here, stationarity is ensured by assuming that the interest rate on foreign bonds depends on the home region's holdings of foreign bonds:

$$r_t^* = \overline{r}^* \exp\left(\frac{-\phi^f s_t b_t}{y_t} \right). \tag{17}$$

It should be noted that (17) holds for the economy as a whole; individual households continue to treat r_t^* as fixed. There is strong empirical support for (17). For nine European countries, Bernhardsen (2000) reports that interest rate differentials with respect to Germany are positively related to current account deterioration. Lane and Milesi-Ferretti (2002) also find a negative relation between the interest rate differentials of 20 industrialized countries (with respect to the U.S.) and their net foreign asset position. In a business cycle framework closely related to the current model, Bouakez and Eyquem (2015) also confirm the empirical relevance of this assumption.

Firms

The domestic economy has a measure n of competitive firms. The representative firm produces output, $\tilde{y}_t$, using domestic labor, $\tilde{h}_t$, and physical capital, $\tilde{k}_{t-1}$ according to the neoclassical production function, $\tilde{y}_t = F(\tilde{k}_{t-1}, a_t \tilde{h}_t)$. Profit maximization implies that factors will be optimally allocated according to

$$z_t = F_k(\tilde{k}_{t-1}, a_t\tilde{h}_t), \tag{18}$$

$$w_t = a_t F_h(\tilde{k}_{t-1}, a_t\tilde{h}_t). \tag{19}$$

Growth in the model occurs through labor-augmenting technological change: $a_t = \gamma_a^t$ where the initial level of technology is normalized to equal one.

Government

The home government finances a stream of public expenditures by levying distortionary taxes on factor incomes (labor and capital), and on consumption. The government may also issue non-state-contingent local bonds to finance potential deficits. The primary deficit of the domestic government is:

$$\text{PrDef}_t = g_t + \overline{\tau} - p_t\tau_{ct}\overline{c}_t - \tau_{ht}w_t\overline{h}_t - \tau_{kt}\left(r_{kt} - \delta\right)\overline{k}_{t-1}, \tag{20}$$

where $\overline{c}_t$, $\overline{h}_t$, $\overline{k}_{t-1}$, and $\overline{\tau}$ are per capita quantities. Its bonds evolve according to

$$\overline{d}_t - r_{t-1}\overline{d}_{t-1} = \text{PrDef}_t. \tag{21}$$

It is well known that the debt dynamics implied by (21) are unstable. To induce stability, one instrument of government fiscal policy will be chosen to satisfy the following feedback rule:

$$\text{PrDef}_t/y_t - \left(\text{PrDef}/y\right)_t = -\omega\left[\overline{d}_t/y_t - (d/y)_t\right], \tag{22}$$

where $(\text{PrDef}/y)_t$ is the date t target deficit-output ratio, $(d/y)_t$ is the target debt-output ratio, and $\omega > 0$ is a parameter that governs how aggressively the government responds to deviations of the debt-to-output ratio from its target. These two ratios are connected via

$$(\text{PrDef}/y)_t = (1 - r)\,(d/y)_t\,,$$

where r is the steady state real interest rate.

To allow for some persistence in the debt-to-output target, also suppose that

$$(d/y)_t = (1 - \rho_d)\,(d/y) + \rho_d\,(d/y)_{t-1}\,, \tag{23}$$

where (d/y) is the long run target for the debt-output ratio, and ρ_d determines how quickly the debt-output ratio reaches its ultimate target value.

Competitive Equilibrium

For the incomplete international markets model, a competitive equilibrium consists of quantities for the domestic household, $\{c_t, h_t, k_t, d_t, b_t\}_{t=0}^{\infty}$, quantities for domestic firms, $\{\tilde{y}_t, \tilde{k}_{t-1}, \tilde{h}_t\}_{t=0}^{\infty}$, prices, $\{p_t, w_t, r_{kt}\}_{t=0}^{\infty}$, interest rates, $\{r_t, r_t^*\}_{t=0}^{\infty}$, and government-related variables, $\{\overline{d}_t, \text{PrDef}_t, \tau_{ct}, \tau_{ht}, \tau_{kt}\}_{t=0}^{\infty}$ such that:

1. The quantities for the household solve its problem given prices, interest rates, and the behavior of other economic actors.
2. The quantities for the firm solve its problem given prices.
3. The government obeys its budget constraint and chooses *one* of its tax instruments to satisfy its fiscal policy rule (with the other tax rates equal to their steady state values).

4. Markets clear:

$$h_t = \tilde{h}_t = \overline{h}_t, \tag{24 — labor}$$

$$k_{t-1} = \tilde{k}_{t-1} = \overline{k}_{t-1}, \tag{25 — capital}$$

$$d_t = \overline{d}_t, \tag{26 — domestic bonds}$$

$$ny_t = nc_{ht} + (1-n)c^*_{ht} + nk_t - (1-\delta)nk_{t-1} + n\Phi_{kt} + ng_t, \tag{27 — goods}$$

where, recall, n is the size of the domestic region.

To obtain a small open economy, divide both sides of (27) by n and use the expressions relating demand for individual goods to the aggregated good, (13) and (14), to obtain

$$y_t = \varphi p_t^{\mu} c_t + \frac{1-n}{n}\varphi^* \left(s_t p_t^*\right)^{\mu} c_t^* + k_t - (1-\delta)k_{t-1} + \Phi_{kt} + g_t. \tag{28}$$

Recalling that $\varphi = 1-(1-n)\gamma$ and $\varphi^* = n\gamma$, substituting into the above, and taking the limit as $n \to 0$ (the small open economy assumption),

$$y_t = (1-\gamma)p_t^{\mu} c_t + \gamma s_t^{\mu} c_t^* + k_t - (1-\delta)k_{t-1} + \Phi_{kt} + g_t, \tag{29}$$

which also used the fact that the rest of the world price, p_t^*, equals one when $n \to 0$ (in the limit, the rest of the world looks like a closed economy). Since there are no shocks to the rest of the world, its consumption, c_t^*, will be constant.

For future reference, note that net foreign assets, defined as $f_t = s_t b_t$, evolve as:[4]

$$f_t - \left(s_t/s_{t-1}\right) r_t^* f_{t-1} = \left(p_t^{\mu} - p_t\right) c_t + \gamma\left(s_t^{\mu} c_t^* - p_t^{\mu} c_t\right). \tag{30}$$

[4] To derive (30), combining the household's and government budget constraints along with goods market clearing and given the expressions for factor prices.

2.2 A Two Good, Small Open Economy with Complete International Asset Markets

An alternative means of ensuring stationarity of an open economy model is to assume that international asset markets are complete. In this case, domestic and foreign households trade in a complete set of contingent claims markets. The non-contingent foreign bond, b_t, is no longer relevant (it is replaced by contingent claims) and so the Euler equation (7) is no longer in play; it is replaced by the following risk-sharing condition:

$$\frac{s_t u_c\left(c_t, h_t\right)}{p_t\left(1+\tau_{ct}\right)} = \vartheta \frac{u_c\left(c_t^*, h_t^*\right)}{p_t^*\left(1+\tau_{ct}^*\right)}, \tag{31}$$

where, as mentioned earlier, rest of the world variables are distinguished using asterisk superscripts. Equation (31) states that, up to a factor of proportionality, denoted ϑ, the after-tax marginal utility of consumption in the home region equals that in the rest of the world. Also note that the international interest rate, r_t^*, no longer appears in the set of equations to be solved.

2.3 A One Good Small Open Economy with Incomplete International Asset Markets

The differences relative to the two good model are as follow. Since there is now only one good, the real exchange rate is one: $s_t = 1$. Furthermore, the price of consumption is also one: $p_t = 1$. Since domestic and foreign bonds are now interchangeable, only the Euler equations (4) to (6) are relevant and (7) is replaced by $r_t = r_t^*$. The firm and government sectors are as in the two good model. Goods market clearing is now

$$y_t = c_t + x_t + k_t - (1-\delta)k_{t-1} + \Phi_{kt} + g_t. \tag{32}$$

where x_t denotes net exports. Net foreign assets evolve according to

$$f_t - r_t^* f_{t-1} = x_t. \tag{33}$$

2.4 A Closed Economy

Finally, to compare the model results with a closed economy, it is necessary to describe such an economy. Relative to the two good, incomplete markets model, drop foreign bonds (b_t) and so the Euler equation (7). Set the price of consumption goods to $p_t = 1$. The firm and government sectors are as before. Goods market clearing is given by

$$y_t = c_t + k_t - (1-\delta)k_{t-1} + \Phi_{kt} + g_t. \tag{34}$$

3 Balanced growth equilibrium and calibration

Balanced growth. The models feature labor-augmenting technological change. Consequently, to solve the model, it is necessary to render the model stationary by deflating by the state of technology.

Functional forms. The utility function features a constant Frisch labor supply elasticity:

$$U(c,n) = \begin{cases} \ln c - \kappa n^{1+1/\psi} & \rho = 1, \\ \frac{c^{1-\rho}(1-\kappa(1-\rho)n^{1+1/\psi})^{\rho} - 1}{1-\rho} & \rho \in (0,1) \cup (1,\infty). \end{cases} \tag{35}$$

where ρ is the coefficient of relative risk aversion and ψ is the Frisch elasticity of labor supply. The production function is Cobb-Douglas:

$$y = F(k, an) = k^{\alpha} (an)^{1-\alpha}. \tag{36}$$

Calibration. The model is quarterly and calibrated using European data between 2005

Table 1: Common Calibration Targets

Description	Symbol	Value
Risk aversion	ρ	2
Labor elasticity	ψ	1/3
Home vs foreign good elasticity	μ	1.5
Real interest rate	r	1.01
Capital depreciation	δ	0.018
Capital adjustment cost	ϕ^k	0.025
World real interest rate	ϕ^f	0.001
Capital's share	α	0.3
Growth rate	γ_a	1.0016
Policy feedback	ω	0.05

Table 2: Region-specific Calibration Targets

Description	Symbol	GIIPS	EA7
Hours	h	0.3047	0.2507
Government share of output	g/y	0.1944	0.2119
Government debt-output ratio	d/y	0.8147	0.6814
Consumption tax rate	τ_c	0.1871	0.1902
Labor income tax rate	τ_h	0.3776	0.4325
Capital income tax rate	τ_k	0.4103	0.5036
Import-output ratio	γ	0.3104	0.3863
Net foreign assets-output ratio	f/y	−0.5304	0.1005
Real exchange rate	s	1.0801	0.9868

Notes: The government debt-output ratio and net foreign assets-output ratio are expressed on an annual basis.

and 2010. Two subsets of the Euro Area countries are considered, and each is separately calibrated: (1) Greece, Italy, Ireland, Portugal and Spain (GIIPS), and (2) Austria, Belgium, Finland, France, Germany, Luxembourg and the Netherlands (EA7). Between 2005 and 2010, the GIIPS and EA7 countries experienced a rise in their public debt-to-GDP ratios of 19.5 and 12.7 percentage points respectively, based on GDP-weighted measures of debt-to-GDP, suggesting different tax and debt issues in these respective areas.

Common targets. Table 1 summarizes the calibration targets that are common to the GIIPS and EA7 calibrations. The steady state real interest rate is set to 1 percent per quarter, or 4 percent per annum, a value commonly used in the macroeconomics literature. Over the relevant sample period, the weighted average real growth rate of GDP per capita in the EMU-12 was 0.65 percent annually which requires setting $\gamma_a = 1.0016$. Capital's share of income is set to 0.3, a value within the range typically found for developed countries. The depreciation rate is set to 1.8 percent per quarter, or 7 percent annually, a value reported in Gomme and Rupert (2007) for the U.S. As in Mendoza (1991), the capital adjustment parameter is set to $\phi^k = 0.025$. When international asset markets are incomplete, the intermediation parameter is set to $\phi^f = 0.001$, as in Benigno (2009) and Schmitt-Grohé and Uribe (2003). On the preference side of the model, the risk aversion parameter, ρ, is set to 2; relative to logarithmic preferences, this value implies that households are less willing to substitute goods over time. The labor supply elasticity, ψ, is set to 1/3 which is toward the upper end of the range typically estimated in the micro-labor literature, and within the range considered by Trabandt and Uhlig (2011).[5] Following Backus, Kehoe and Kydland (1993), the elasticity of substitution between domestic and foreign goods is set to $\mu = 1.5$. Finally, the policy parameter, ω – which determines how responsive the government is to deviations of the debt-to-output ratio from target – is set to 0.05. This value implies half

[5] A more elastic labor supply – larger values of ψ – amplifies the responses of macroeconomic variables. Indeed, when $\psi = 1$ – Trabandt and Uhlig (2011)'s benchmark value – our debt reduction experiments lead to severe and very long lived recessions.

of this gap will be closed in 13.5 quarters – a little over 4 years. The persistence of the debt-to-output target, ρ_d, is 0 in the baseline case. Positive values will be investigated as a sensitivity analysis.

Region-specific targets. The remaining targets, summarized in Table 2, are specific to the region being calibrated and Section A.2 gives a detailed description of the data used in these calculations. In all cases, calibration targets are computed as GDP weighted averages of the country values in the relevant region. Hours are expressed as a fraction of discretionary time; for GIIPS, this target is 0.3047; for EA7, 0.2507. The trade openness parameter, γ, is set based on the imports-to-GDP ratio. The specific values are 0.3104 for GIIPS and 0.3863 for EA7.[6] A number of steady state values are imposed during calibration: government's share of output, the government debt-to-GDP ratio, the tax rates (consumption, labor income and capital income), the ratio of net foreign assets-to-GDP, and the real exchange rate; see Table 2 for these values. For the most part, these steady state values are straightforward computations from the data. An exception is the real exchange rate which is computed from numbers reported in Berka, Devereux and Engel (2012).

Steady state. For the two good, open economy models, solve for steady state as follows. Set hours (h), the real exchange rate (s) and the real interest rates (r and r^*) to their target values. Solve for c, κ, k, c^* and f using the balanced growth versions of (4), (6), (29) and (30) and the target for net foreign assets; values for the remaining variables (y, r_k, w, g, p) can be computed from the production function, the firms' first-order conditions, (18) and (19), the target for government spending, and the expression for the price of consumption goods, (10). The calibrated values for κ, the weight on labor in utility, are 9.2912 for GIIPS and 17.7706 for EA7. Having solved for steady state, the lump-sum tax is obtained from the government budget constraint, (20). For the complete international assets version of this

[6] Assuming that the composition of imports is isomorphic to the composition of domestic absorption, imports-to-GDP is a good proxy for the ratio of imports of consumption goods to consumption, which is γ in the steady state of our model.

model, the left-hand side of the international risk sharing condition, (31), is used to infer the value of the right-hand side of that equation (this latter condition is needed in solving for the dynamic paths of the economy). For the incomplete international asset markets model, the value of the parameter $\overline{r}^*$ is computed from the balanced growth version of (17) so that the interest rate on foreign bonds equals that on domestic bonds.

Steady state of the one good, open economy model is computed in much the same way except that the real exchange rate is set to one; consequently, the price of the consumption good is also one. Rather than solving for foreign consumption, c^*, instead solve for net exports, x. In the place of (29) and (30), use (32) and (33). In this case, $\kappa = 9.2912$ (GIIPS) or 17.7706 (EA7).

Solving for the steady state of the closed economy model is even simpler. It is no longer necessary to solve for any of the international variables and the relative price of consumption goods is necessarily equal to one. In this case, use the feasibility constraint, (34). Now, $\kappa = 9.0160$ (GIIPS) or 17.8702 (EA7).

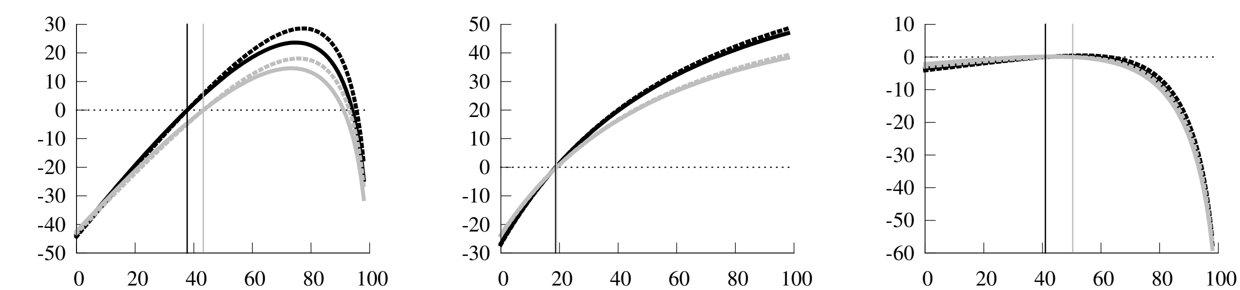
4 Results

The model is solved as a two point boundary problem. Such problems are classified as follows: Dirichlet or First Kind which impose starting and terminal values on the *levels* of the variables of interest; Newmann or Second Kind which impose starting and terminal values on the *rate of change* of the variables of interest; and Robin or Third or Mixed Kind which combine the first two restrictions. While the restrictions on net foreign assets and the real exchange rate imply that it is possible to solve for an initial condition on the levels of variables, for the incomplete markets versions of the model, it simply is not possible to solve for terminal values of the levels of the endogenous variables in order to solve the problem as a Dirichlet Kind. Briefly, there are a continuum of real exchange rates for which a steady state can be computed, and in general the values of the other steady state variables differ depending on the value of the real exchange rate imposed. Instead, the model is solved as a Robin Kind of boundary problem: for a starting value, the initial steady state is imposed on the levels of variables; for the terminal constraint, the rates of change of the variables is restricted to equal one. In essence, the terminal constraint requires that the model economy eventually settles in to an endogenously-determined steady state. While the model *could* be solved using a general Newton routine, exploiting the time structure of the model, as described in Section A.1, delivers considerable speed gains.

4.1 Laffer Curves

Figure 1: Laffer curves. Percentage variation of total fiscal revenue as a function of tax rates

(a) Tax on labor income, τ_h **(b)** Consumption tax, τ_c **(c)** Tax on capital income, τ_k



Legend: Black: GIIPS. Gray: EA7. Solid: complete markets. Dotted: incomplete markets. Vertical lines indicate current tax rates. Tax rates are measured on the horizontal axis.

To understand some of the results to come, it is helpful to know the revenue potential of the model's taxes. Figure 1 presents Laffer curves for the two regions (GIIPS and EA7) for the three tax rates in the model for the two good models; results for the one good open economy model and closed economy model are omitted in the interests of readable figures. These Laffer curves are computed from the dynamic simulations of the model, varying one tax at a time and tracing out the total revenue in the final steady state. To render the dynamics of government debt stationary, for the Laffer curve calculations, government spending adjusts to bring the primary deficit into balance with the stock of debt.

There are several interesting regularities with regards to the Laffer curves. First, the

GIIPS block (solid lines) has greater potential revenue increases than the EA7 group (dotted lines). This prediction from the model can be traced to the overall lower current level of taxation within GIIPS as well as a greater labor supply. These facts are clearly linked: the lower labor income tax rate in the GIIPS group helps explain why individuals work more than in EA7.

Second, the consumption tax offers the greatest long run potential revenue enhancement. Whereas labor income tax revenue can be expected to fall to zero at a tax rate of 100 percent, the same cannot be said of the consumption tax. At a consumption tax of 100 percent, the GIIPS countries would see nearly a 50 percent increase in government tax revenue; for the EA7, the increase is closer to 40 percent. By way of comparison, for GIIPS, the labor income tax can increase revenue by up to 29 percent (incomplete international asset markets) or 23.6 percent (complete markets) by pushing this tax rate into the mid-70s. For the EA7, the maximum increase in tax revenue through the labor income tax rate is either 18 percent (incomplete markets) or 14.6 percent, again at a tax rate in the mid-70s.

Third, the long run potential tax revenue enhancement associated with the capital income tax is extremely modest. The largest potential gain, 0.5 percent, is for the incomplete markets version of the GIIPS model. The GIIPS group capital income tax rate is roughly 10 percentage points below the value that would maximize capital income tax revenue while the EA7 is several points beyond the peak of the Laffer curve. Overall, the long run capital income tax Laffer curves are quite flat around their maximums.

Finally, the potential for augmenting long run tax revenue is higher under incomplete international asset markets than when these markets are complete (compare the dotted and solid lines). To understand why, consider, for concreteness, the effects of an increase in the labor income tax rate. Such a change lowers the after-tax wage rate. When international asset markets are incomplete, both the income and substitution effects are in play: the substitution effect is associated with a reduction in hours worked while the income effects boost hours. However, under complete international asset markets, the risk sharing condition implies that the income effect is out of the picture, and only the substitution effect operates. Consequently, the decline in hours under complete markets will be larger than under incomplete markets and so tax revenue falls off more rapidly when international asset markets are complete.

Overall, holding market structure and the region fixed, the Laffer curve effects are fairly similar to those in Trabandt and Uhlig (2011) for a closed economy model calibrated to the U.S.

4.2 Debt Reduction

The specific scenario considered is a 10 percentage point reduction in the long run government debt-to-output ratio. The size of this reduction was chosen to represent a substantial but realistic reduction in government debt. From (21), such a reduction also implies a fall in the long run primary deficit. Throughout, the policy rule (22) is in place, and one tax at a time is selected to satisfy this rule. As is well-known from the fiscal policy literature, such a reduction in the debt-to-output ratio lowers the debt servicing costs of the government, and so the need for government tax revenue. Consequently, while these experiments have tax rate increases in the short term, in the longer term the tax rates fall below their initial steady state levels. Since the GIIPS and EA7 cases are *qualitatively* similar, attention is focused on GIIPS; the EA7 cases is presented in Section A.3.

The Labor Income Tax

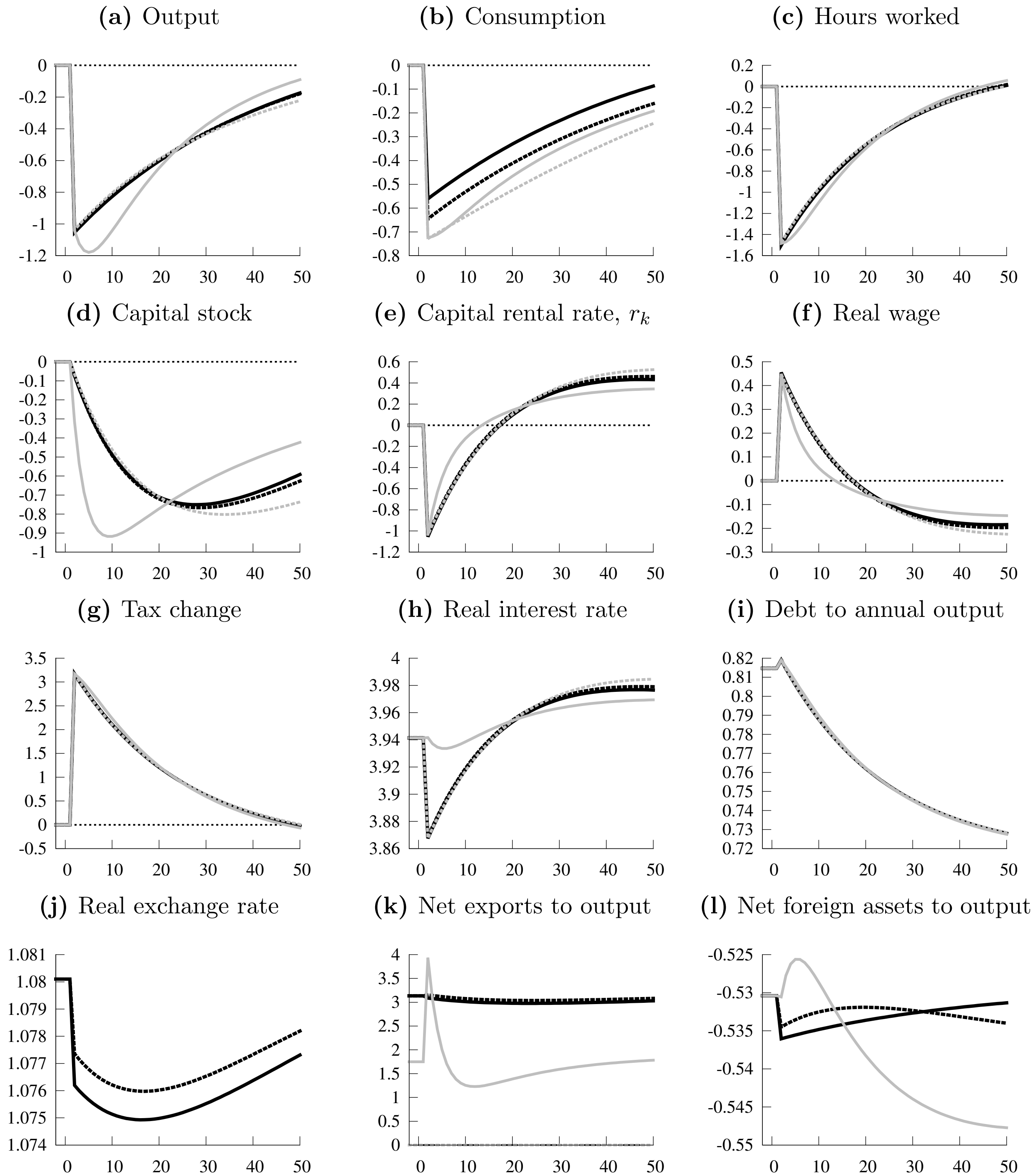
All of the debt reduction cases involve initially raising a tax rate – in this case, the labor income tax – in order to increase government tax revenue which (eventually) brings down the debt-output ratio. The initial increase in the labor income tax rate is around 3.2 percentage points across the four model variants. In the long term, the tax rate in question is then reduced owing to the lower debt servicing costs. In this case, in the long run, the labor income tax rate is 0.6 percentage points below its initial value. This decline in the labor income tax raises macroeconomic activity by roughly 0.2 percent.

Broadly speaking, the four model variants exhibit similar dynamics. The initial increase in the labor income tax rate reduces the after-tax real wage, and households reduce their hours worked in response. It takes over a decade for hours to return to their original steady state level. The knock on effect of the fall in hours is to reduce the marginal product of capital which induces a drop in the capital stock. The combined effects of hours and the capital stock is a fall in output, and it takes nearly 20 years for output to recover to its initial steady state value.

Apart perhaps from the initial 'surprise' nature of the decision to reduce the debt-output ratio, perfect foresight implies equality of all returns in the model. In the closed economy model, this means that the 'effective' return to capital (that is, including the effects of the capital adjustment costs) must equal the real return on domestic government debt. Consequently the fall in the return to capital described above must be associated with an equal decline in the real interest rate.

Contrast the closed economy dynamics with those of the one good open economy model. Now, the returns on capital, domestic bonds *and* foreign bonds must be equalized. In the one good model, the real exchange rate is constant at one. While the return on foreign bonds depends on the level of net foreign assets relative to output, the coefficient on this ratio is quite small (0.001). Given the rate of return equality, the effects on the foreign real interest rate can be read off Figure 2(h) which plots the path for the domestic real interest rate. As can be seen, these real interest rates do not change very much. Consequently, neither can the effective real return to capital. Since the capital adjustment parameter is fairly small (0.025), the marginal product of capital has to do most of the work in ensuring that the effective return to capital does not change much. As a result, the fall in hours reported in Figure 2(c) must be associated with a fairly similar decline in the capital stock in order to keep the capital-hours ratio – and so the marginal product of capital – roughly constant. As a result, the fall in the capital stock in Figure 2(d) is, in the short term, more severe in the

Figure 2: Labor income tax-financed debt reduction in GIIPS



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

one good open economy model than in the closed economy model.

The dynamics of the two good open economy models is much more similar to those of the closed economy model than the one good open economy model. The reason why is that the return to holding a foreign bond is $r_t^* s_{t+1}/s_t$. As a result, while the foreign real interest rate, r_t^*, still does not move very much, the return to foreign debt *can* owing to the real exchange rate movements. Again, the real return to foreign debt can be inferred from the behavior of the domestic real interest rate in Figure 2(h). For the two good open economy models, the decline in the real interest rate most closely approximates that seen in the closed economy model. As a consequence, the dynamics of macroeconomic variables end up being quite similar across the closed economy and two good open economy models. Most of the differences appear in the paths of consumption. In the closed economy model, the relative price of consumption goods is fixed at one. In the two good open economy models, (10) implies that the price of the aggregated consumption good moves in the same direction as the real exchange rate. In turn, the broad-based decline in macroeconomic activity decreases imports and so increases net exports. In part to forestall this decline in imports – and to encourage exports – the real exchange rate appreciates (s_t declines) as shown in Figure 2(j). As a result, the price of the consumption good falls, thus moderating the fall in the aggregated consumption good.

The Capital Income Tax

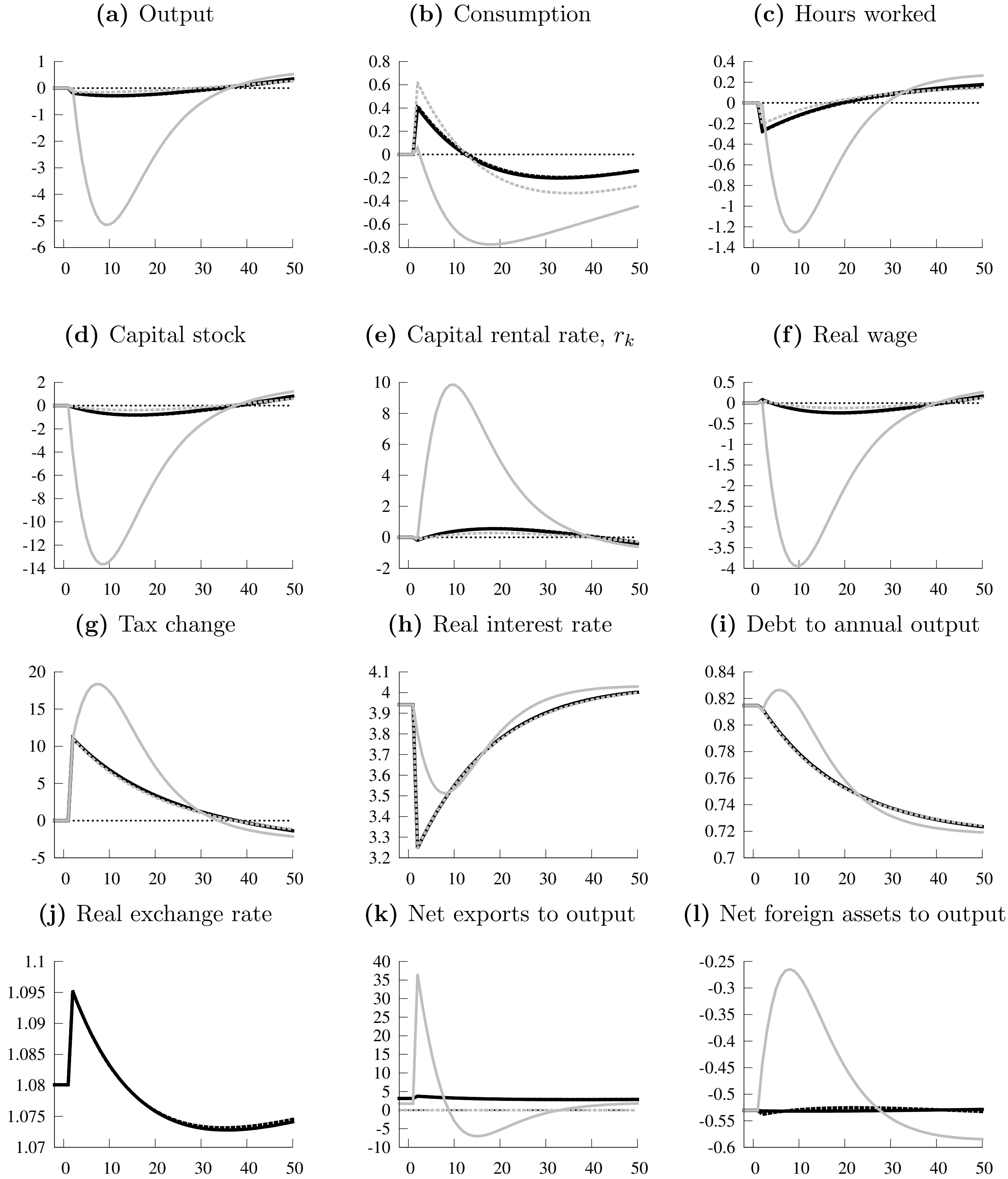
Now, turn to the effects associated with using the capital income tax to engineer a fall in the long run government debt-output ratio. On impact, this tax rate rises by 11 percentage points; in the long run, the lower government tax revenue requirement allows a 6 percentage points decline in the capital income tax rate. Given the small change in the long run labor income tax rate above, it may seem curious that the effect on the capital income tax rate is so much larger. The long run Laffer curves help to understand these differences. In particular, Figure 1 shows that the long run capital income tax Laffer curve is very flat around current tax rates while that associated with labor income taxes is much steeper. Consequently, a given drop in long run government tax revenue requirements (measured on the vertical axes in Figure 1) will elicit a larger fall in the capital income tax rate.

To trace through the effects of adjusting the capital income tax rate, start with the closed economy model. The initial increase in the tax is a surprise, and as such acts like a lump-sum tax. Thereafter, the increase in this tax rate operates through the capital accumulation equation, (6). In particular, under this scenario, the after-tax return to capital falls, discouraging capital accumulation. However, as shown in Figure 3(g), after its initial increase, the capital income tax rate declines fairly rapidly and so the effects are not very long lived. While there is a persistent decline in output, for the first few years of the simulation, consumption is actually higher than its previous steady state level owing to the decline in investment. Later, when households switch back to accumulating capital, their investment requirements cause them to sacrifice consumption.

Now, consider the one good open economy model. To analyze these effects, suppose – counterfactually – that the real interest rates on domestic and foreign debt do not change. In light of the large increase in the capital income tax rate, keeping the after-tax return to capital unchanged would require a similarly large increase in the marginal product of capital which, in turn, would require a substantial decline in the stock of capital. Of course, real interest rates are not constant as seen in Figure 3(h). In other words, some of the adjustment occurs through the capital stock and some of it occurs through interest rates. However, the small parameter on the net foreign assets-to-output ratio in the world real interest rate equation implies that the bulk of the adjustment will operate through the capital stock. As a consequence, the macroeconomic effects of using the capital income tax rate in the one good small open economy model are substantially larger than in the closed economy model which features a larger real interest rate response in the near term.

As with the labor income tax, when the capital income tax rate is the instrument of policy, the paths of macroeconomic variables for the two good open economy models more

Figure 3: Capital income tax-financed debt reduction in GIIPS



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

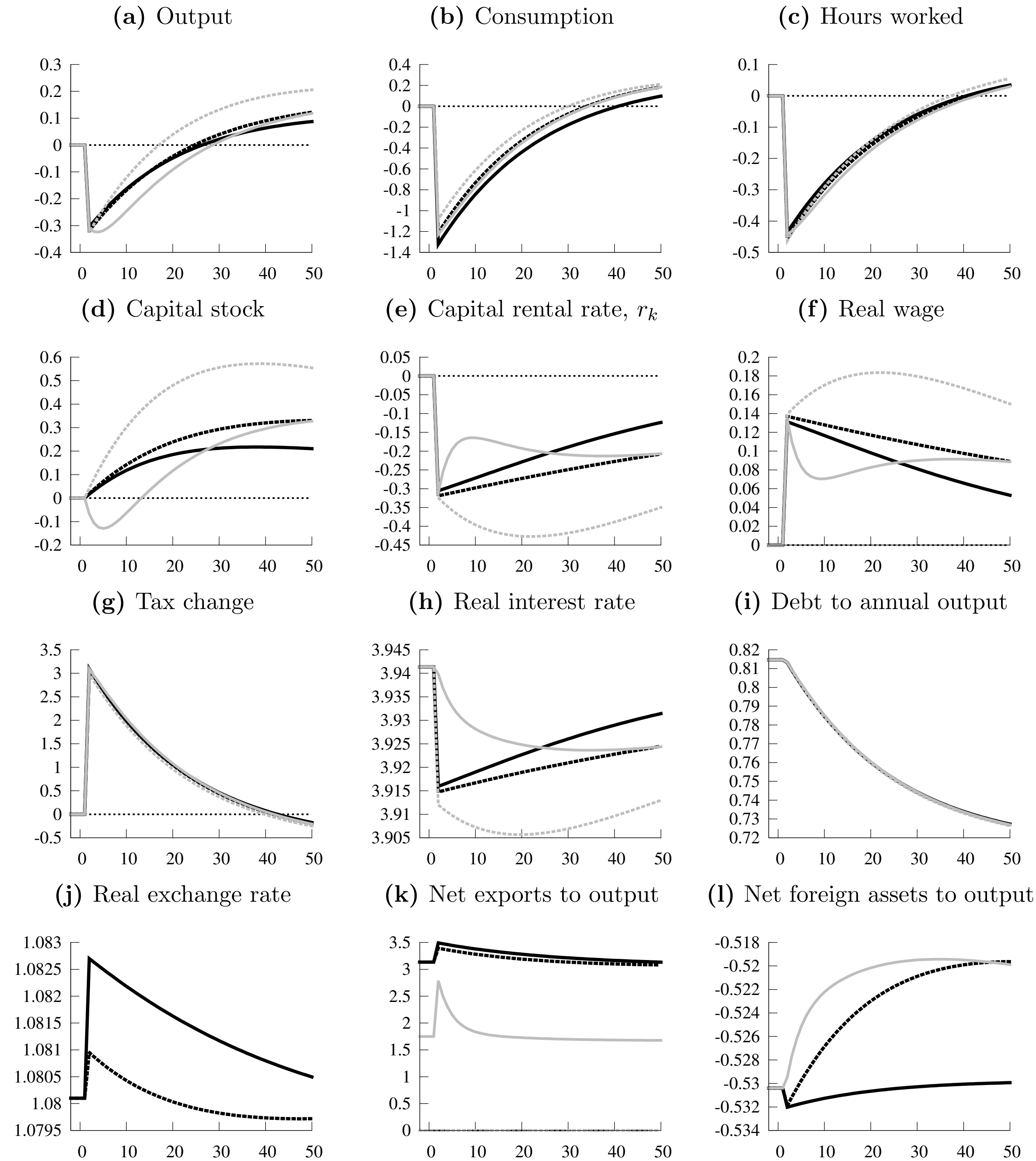
closely follow those of the closed economy model than the one good open economy model. Again, the near constancy of the foreign real interest rate is more than offset by the real exchange rate movements. Indeed, as seen in Figures 3(h) and 3(j), the short term dynamics of the real interest rate are largely determined by those of the real exchange rate. Given the sizable decline in the real interest rate, the marginal product of capital does not need to move too much to maintain rate of return equality, and so the capital stock changes are far more modest than those associated with the one good open economy model.

The Consumption Tax

Variation in the consumption tax affects the models through two channels. First, an increase in the consumption tax affects the labor-leisure choice in much the same way as an increase in the labor income tax; see (4). Second, the temporal pattern of the consumption tax affects all asset returns. In particular, (5) to (7) all feature a term with $(1+\tau_{ct})/(1+\tau_{c,t+1})$. When the consumption tax rate is declining over time (as it does after the initial increase), this time pattern to the tax operates like a subsidy to asset returns.

Once again, start with the closed economy model. On impact, the consumption tax rises by 3.1 percentage points. The magnitude of this change is virtually the same as the increase in the labor income tax rate described above. However, the impact of the consumption tax on hours and output is roughly a third of that seen under the labor income tax. There are two reasons for this difference. First, from (4), what matters for the labor-leisure choice is the 'effective' tax rate on earnings: $1-(1-\tau_{ht})/(1+\tau_{ct})$. The calibrated GIIPS tax rates imply that the 3.2 percentage point increase in the labor income tax rate translates into roughly a 2 percentage point increase in this effective tax rate; for the consumption tax, the 2.7 percentage point increase raises the effective tax rate by only 1.3 percentage points. As a result, the impact effect of the increase in the consumption tax operating through the labor-leisure channel can be expected to be roughly half that seen under the labor income tax. Second, the timing of the consumption tax, operating through the return

Figure 4: Consumption tax-financed debt reduction in GIIPS



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

subsidy channel, encourages capital accumulation as seen in Figure 4(d). Accommodating this desire to acquire capital requires some combination of a smaller fall in hours and a drop in consumption, both of which are observed – see Figures 4(b) and 4(c). The net result is that under the consumption tax, hours and output fall by less than when the labor income tax is the policy instrument. Further, as measured by output, the policy-induced recession is considerably shorter when the consumption tax is used – six years as opposed to 19 under the labor income tax.

Now, consider the effects of this policy change in the one good open economy model. As with the previous tax experiments, in this model there is no real exchange rate adjustment. Consequently, the real interest rate on domestic and foreign debt coincide. Since the response of the foreign rate to the net foreign assets-to-output ratio is small, these interest rates respond sluggishly. *Ceteribus paribus*, the fall in hours reduces both the return and the marginal product of capital; the subsidy effect of the timing of the consumption tax operates in the opposite direction. On net, Figure 4(d) shows that the capital stock declines. This figure shows that it takes three-and-a-half years for capital to return to its previous steady state level. Since in the short term the responses of hours, output and consumption in the one good model look similar to those in the closed economy model, it must be the case that net exports increase as shown in Figure 4(k), leading to a lessening of net foreign indebtedness as reflected in Figure 4(l). The resulting recession is about as long – seven years – in the one good open economy model as in the closed economy model.

Finally, look at the effects in the two good open economy models. Relative to the one good model, there is a sharper short term interest rate response. This difference can be attributed to the fact that in the two good model, real exchange rate movements (an initial depreciation followed by a slow appreciation) drive a wedge between the domestic and foreign real interest rates. Unlike the one good model, there is no need for the capital stock to fall (to raise the marginal product of capital, and so the return to capital). Indeed, qualitatively the dynamics of the capital stock in the two good models are similar to that observed in the closed economy model.

Understanding the real exchange rate movements, particularly compared to the labor income tax case, requires thinking about how net exports feed into the GDP identity. Under the labor income tax, all macroeconomic activity falls. Part of the adjustment in maintaining the GDP identity involves an appreciation in the real exchange rate (a fall in s_t) which serves to soften the decline in imports and boost exports. The chief difference in the economy under the consumption tax is that investment actually rises. In this case, the real exchange rate depreciates, promoting imports and discouraging exports. The resulting decline in net exports makes it easier to satisfy the adding up constraint for GDP.

Welfare

Debt reduction involves short term pain (higher tax rates and generally a decline in economic activity, but not necessarily utility) to achieve long run gain (eventually lower tax rates and a higher level of economic activity). A natural question at this stage is: Given the decision to reduce the debt-to-output ratio, how should this decision be implemented? This question is answered by computing the welfare benefit of these policy changes. The specific welfare criterion is the constant percentage of consumption that the representative household would be ready to pay that leaves it indifferent between a particular reform and the original path where the economy remains at its initial steady state, namely the value of ζ that solves

$$\sum_{t=0}^{J} \beta^t U\left(\hat{c}_t\left(1-\zeta\right), h_t)\right) = U(c,h)\sum_{t=0}^{J} \beta^t. \tag{37}$$

If ζ is negative, it means that households have to be compensated to experience the reform, and the reform generates welfare losses. To capture the idea that politicians – who would need to implement the debt reduction policies – operate at relatively short horizons, these welfare benefits are computed at horizons of one year (4 quarters), four years, ten years, and the infinite horizon.

Table 3: Welfare benefit of debt reduction experiments, in percent

	τ_h				τ_c				τ_k			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
GIIPS												
4	0.14	0.21	0.10	0.06	−0.67	−0.76	−0.69	−0.58	0.38	0.37	0.11	0.48
16	0.06	0.15	0.04	−0.05	−0.59	−0.70	−0.61	−0.48	0.22	0.20	0.05	0.24
40	−0.04	0.04	−0.08	−0.16	−0.31	−0.42	−0.33	−0.23	−0.01	−0.03	−0.32	−0.07
∞	−0.05	−0.01	−0.07	−0.08	0.02	−0.02	0.02	0.03	0.16	0.05	−0.05	0.18
Steady state	0.13	0.02	0.18	0.18	0.07	0.21	0.09	0.09	1.14	0.46	1.40	1.43
EA7												
4	0.12	0.21	0.07	−0.02	−0.68	−0.77	−0.69	−0.59	0.38	0.35	25.74	0.52
16	0.04	0.15	−0.01	−0.14	−0.60	−0.72	−0.61	−0.49	0.22	0.18	−7.27	0.26
40	−0.07	0.04	−0.13	−0.26	−0.33	−0.44	−0.33	−0.22	−0.02	−0.06	−5.35	−0.10
∞	−0.07	−0.01	−0.10	−0.13	0.01	−0.02	0.02	0.05	0.36	0.13	0.03	0.40
Steady state	0.15	0.02	0.24	0.24	0.07	0.22	0.10	0.10	2.70	0.93	2.87	3.43

Notes: I: Two goods with incomplete markets, II: Two goods with complete markets, III: One good with incomplete markets, IV: Closed economy.

Table 3 also reports welfare benefits computed by comparing steady state allocations. Since all of the policies result in lower tax rates in the new steady state, all generate welfare benefits when measured across steady states.[7] When computed across steady states, welfare gains range from modest in the case of labor income and consumption taxes, to fairly substantial for capital income taxes. However, the 'correct' calculation includes the entire transition path so as to capture not only the long run gains, but also the short term pain. Uniformly, welfare benefits – if any – are substantially smaller when computed over the entire transition rather than only across steady states. Since the welfare implications for the EA7 calibration are fairly similar to those of the GIIPS calibration, attention is focused on the GIIPS case.

To start, consider the welfare implications of using the labor income tax rate as the instrument of policy. In the two good model, when international asset markets are complete, the debt reduction in GIIPS results in a very small welfare gain when computed across steady states, or an extremely small welfare loss when the transition path is included. At shorter horizons, decent-sized welfare gains are recorded since the utility gains due to higher leisure offset the losses associated with lower consumption. However, as the horizon lengthens, the welfare gains fall. Switching to the incomplete international assets model, welfare benefits computed using at least some part of the transition path are smaller than in the complete markets case reflecting the greater disruption to economic activity under incomplete markets. The steady state welfare gains are larger when markets are incomplete since the long run increase in consumption is larger (0.13 percent) than in the complete markets case (0.02 percent) while the changes in hours worked differ only slightly. While the steady state welfare benefits are even higher in the one good, incomplete international asset markets case, the benefits are smaller along the transition path. These differences in the welfare

[7] The initial steady state is computed as in Section 3. The final steady state is obtained from the dynamic solution of the model which, as a terminal condition, requires that the model be in steady state (that is, the changes in variables are zero).

benefits reflect the larger upheaval in the economy in the short term as well as the larger increase in consumption in the long run. Finally, the closed economy model delivers welfare numbers that are quite similar to those of the one good open economy model, reflecting the general similarity in the paths for consumption and hours for these two models.

Next up is the consumption tax. Across the four model variants, sizable welfare losses are recorded at short horizons which tend to decline at longer horizons. This temporal pattern reflects the fact that in the short term, consumption falls sharply to accommodate the increase in investment needed to build up the capital stock. At, say, the four quarter horizon, Figure 4(b) shows that the consumption hit is largest for the complete assets, two good model, followed by the one good open economy model, then the incomplete assets, two good model, and finally the closed economy model. Since the changes in hours are similar across the model variants, the welfare losses at the four quarter horizon shadow the declines in consumption.

Finally, consider the capital income tax. When measured across steady states, the welfare gains are substantial: between 0.46 percent and 1.43 percent depending on the specific model.[8] At very short horizons, there are also reasonably large welfare gains reflecting the fact that the increase in the capital income tax rate in the short run discourages capital accumulation; the fall in investment allows consumption to rise. However, at longer horizons the capital income tax rate falls below its initial steady state value: consumption falls to accommodate the required increase in investment. The one good open economy model warrants further discussion. For this model, Figure 3(b) shows that, in the short term, consumption falls (in the other models, consumption rises) while Figure 3(c) reveals that hours fall sharply and persistently. Thus, for the one good model, the fall in hours worked more than compensates for the fall in consumption leading to the small welfare gains at short horizons.

Which tax instrument is the best one to use to engineer a fall in the government debt-

[8]The EA7 calibration delivers even more substantial gains.

output ratio? While the welfare measures at short horizons may reflect political (electoral) motivations, and steady state comparisons are simply naïve, the appropriate measure is the one that includes the entire transition path. While the closed economy and two good models imply that the capital income tax rate is the instrument that delivers the highest welfare gain, the one good open economy model gives the nod to the consumption tax (although the welfare gain is extremely small, as is the welfare loss associated with using the capital income tax). Clearly, the GIIPS and EA7 regions are not closed economies. Treating them as one good models – with the associated requirement of a fixed real exchange rate – also falls short: (i) real and nominal Euro exchange rates are not constant; (ii) real exchange rates within the Euro zone can – and do – move, albeit not as quickly as they did prior to the adoption of the Euro; and (iii) there is considerable movement of goods in and out of the GIIPS and EA7 regions which does not occur in the one good open economy model. While complete markets are a nice theoretical construct, if international asset markets were truly complete, why have so many of the GIIPS countries experience such pain? With all of this in mind, the two good, incomplete international asset markets model probably best captures reality. For this model, it is clear that the capital income tax delivers the highest welfare gains. This result should not be too surprising since the optimal taxation literature typically finds that capital income taxes should be around zero in the long run. Consequently, any lowering of capital income taxes in the long run is likely to be welfare-improving. While the gains – 0.16 percent for GIIPS and 0.36 percent for EA7 – may seem on the small side, recall that the experiment is a 10 percentage point reduction in the debt-output ratio; larger cuts to this ratio can be expected to deliver larger welfare benefits.[9]

[9]Certainly, it is true that the long run benefits will be larger. It is, of course, possible that a sufficiently larger reduction in the target debt-output ratio would imply such a large increase in the capital income tax rate that the short term disruptions would overshadow the long run benefits.

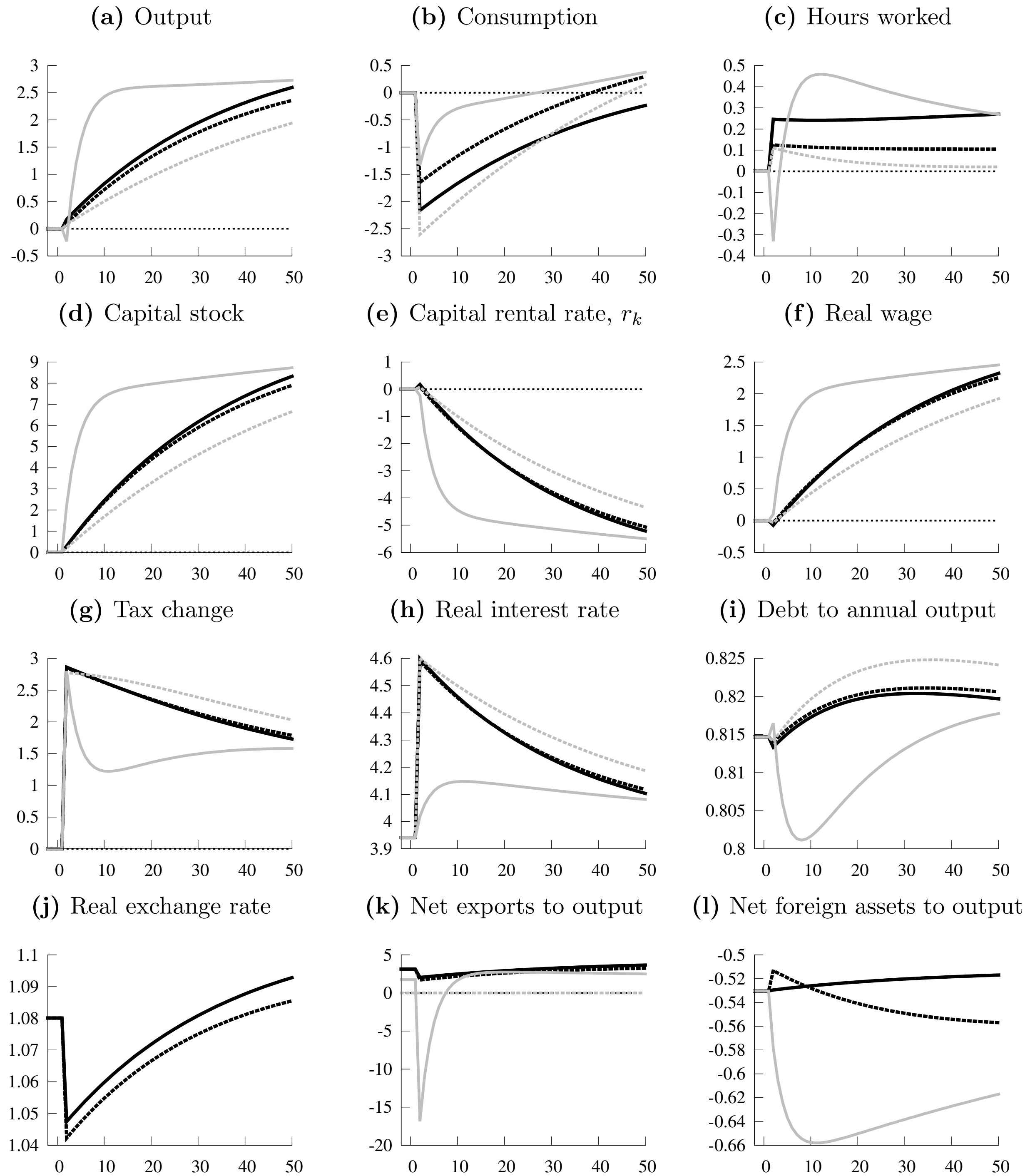
4.3 Debt-neutral Capital Tax Reductions

The message from the previous section is that if a government wishes to reduce its debt-output ratio, and if the government wishes to do so using only one tax, the capital income tax is the way to go. That said, there may be combinations of taxes, or different paths for the capital income tax rate, that yield even higher welfare gains. The optimal taxation aspects of the model are left to the future, although this paper offers some suggestions for fruitful avenues of research into thinking about the appropriate mix of taxes to achieve a reduction in the government debt-to-output ratio. Since the optimal fiscal policy literature typically finds that capital income tax rates should be quite low (see Chamley 1986, Judd 1985, Chari and Kehoe 1999 and the subsequent literature), here the model is solved with a permanent cut in the capital income tax rate. Specifically, the capital income tax rate is permanently reduced by 10 percentage points, financed by changes in either the labor income tax or the consumption tax rates. As with the debt reduction exercises, the government adjusts its tax rate to satisfy the policy rule.

Figure 5 summarizes the dynamic effects of financing the capital income tax reduction through the consumption tax while Figure 6 does the same for the labor income tax. Comparing across these two figures suggests that the dynamics are dominated by the effects of the capital income tax rate cut. The long run effects of these policy changes are presented in Table 4.

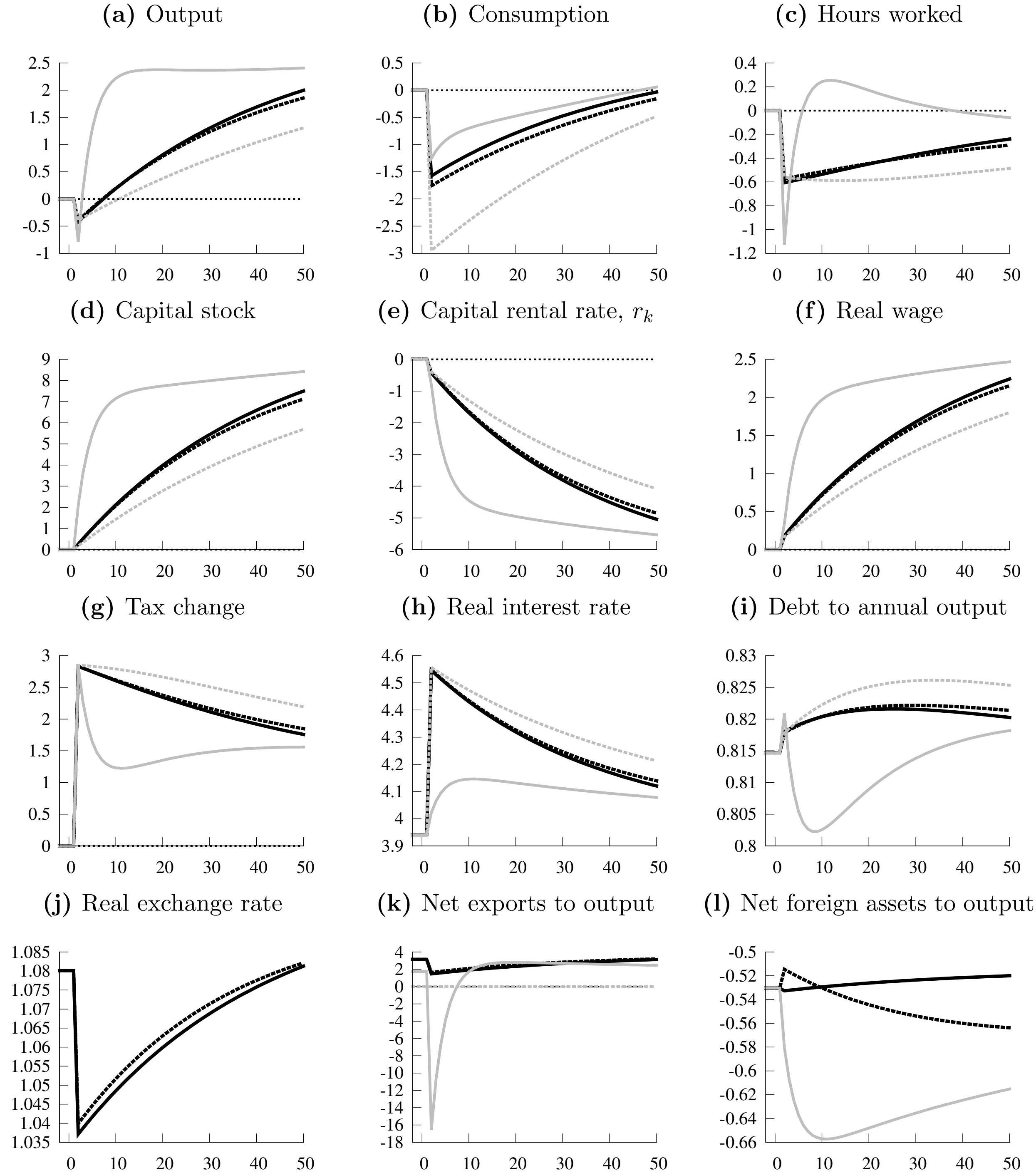
Once more, the analysis of the macroeconomic effects will start with the closed economy model. On impact, the consumption tax jumps by 2.8 percentage points, followed by a gradual decline. In the short term, the fall in the capital income tax rate encourages capital accumulation and consumption falls in part to accommodate the required increase in investment. The rise in the capital stock raises the marginal product of labor (and so the real wage) leading to an increase in hours. Output rises owing to the rise in both factors of production. Since the drop in the capital income tax rate boosts the after-tax return to capital, the real interest rate rises so that the return to government debt maintains equality with

Figure 5: Tax substitution in the GIIPS. 10 percentage point fall in τ_k financed by an increase in τ_c



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

Figure 6: Tax substitution in the GIIPS. 10 percentage point fall in τ_k financed by an increase in τ_n



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

Table 4: Long run changes following tax substitution experiments

	τ_h				τ_c			
	I	II	III	IV	I	II	III	IV
GIIPS								
$\%\Delta y$	2.99	3.17	2.99	2.99	3.20	3.47	3.20	3.21
$\%\Delta c$	1.50	0.71	1.82	1.84	1.72	0.55	2.09	2.12
$\%\Delta h$	−0.15	0.02	−0.15	−0.16	0.05	0.32	0.05	0.05
$\%\Delta k$	10.72	10.92	10.72	10.72	10.95	11.24	10.95	10.95
$\%\Delta s$	1.05	2.02	0.00	0.00	1.20	2.65	0.00	0.00
$\Delta\tau$	1.06	1.07	1.06	1.05	1.06	1.09	1.06	1.02
EA7								
$\%\Delta y$	4.05	4.36	4.05	4.05	4.19	4.55	4.19	4.19
$\%\Delta c$	2.31	0.98	2.95	2.94	2.46	0.91	3.13	3.13
$\%\Delta h$	0.02	0.33	0.02	0.02	0.16	0.51	0.16	0.16
$\%\Delta k$	14.08	14.43	14.08	14.08	14.23	14.63	14.23	14.23
$\%\Delta s$	1.61	2.93	0.00	0.00	1.71	3.24	0.00	0.00
$\Delta\tau$	0.55	0.54	0.55	0.56	0.51	0.50	0.51	0.51

Notes: I: Two goods with incomplete markets, II: Two goods with complete markets, III: One good with incomplete markets, IV: Closed economy.

that on capital. In the long run, the 10 percentage point decrease in the capital income tax rate requires a 1 percentage point increase in the consumption tax rate. Since the after-tax return to capital is pinned down, in the long run, by the discount factor, the pre-tax rental rate for capital must decline which, in turn, requires an increase in the capital stock. In the long run, the capital stock is roughly 11 percent higher than its initial steady state level. Indeed, overall macroeconomic activity rises in the long run: hours by a scant 0.05 percent, consumption by 2.12 percent, and output by 3.21 percent.

The story is much the same in the closed economy model when the labor income tax finances the capital income tax cut. On impact, the labor income tax rate jumps by 2.8 percentage points; in the long run, it stands 1 percentage point higher than its initial value. Thus, the change in the labor income tax rate is almost exactly the same as that for the consumption tax. The dynamics of macroeconomic variables are quite similar across the two tax rates. In the long run, the increase in the labor income tax results in a modest 0.16

percent decline in hours, a 1.84 percent increase in consumption, and 2.99 percent rise in output.

Turn next to the one good small open economy. While the impact effects on either the consumption or labor income tax rates are similar to those observed in the closed economy model, the tax rates then drop off more quickly; the long run changes are quite similar. As with the debt reduction experiments, the dynamics of the one good model are driven by the small response of the foreign interest rate, r_t^*, to changes in the foreign debt-output ratio along with the fact that the real exchange rate is fixed at one in this model. Since the domestic real interest rate must equal that on foreign debt, the domestic real interest rate does not move much either – see Figures 5(h) and 6(h). Rate of return equivalence with the after-tax return to capital then implies a large short term increase in the capital stock as shown in Figures 5(d) and 6(d). To give some idea how rapidly capital is accumulated, under the consumption tax, 50 percent of the long run adjustment is made in just 5 quarters; for the closed economy model, it takes 38 quarters. The fact that the real interest rate rises following these policy changes is due to the fact that net foreign assets fall (Figures 5(l) and 6(l)) due to the sharp drop in net exports (Figures 5(k) and 6(k)); in essence, the domestic economy simply buys up investment goods from the rest of the world in order to moderate the decline in consumption relative to that seen in the closed economy case.

As under the debt reduction experiments, the dynamics for the two good open economy models more closely resemble those of the closed economy model than the one good open economy model. Once more, the difference lies in the real exchange rate dynamics. Specifically, the exchange rate appreciates on impact, followed by a gradual depreciation. As a consequence, despite the fact that the foreign real interest rate responds very weakly to macroeconomic developments, the domestic real interest rate spikes up (recall that in this case, rate of return equivalence implies $r_t = r_t^* s_{t+1}/s_t$). As a result, the capital stock does not need to change as much as in the one good model to maintain equality between the after-tax return to capital and the real interest rate. While net exports fall, this decline is much

Table 5: Welfare benefit of tax substitution experiments, in percent

	τ_h				τ_c			
	I	II	III	IV	I	II	III	IV
GIIPS								
4	−1.05	−0.89	−0.54	−1.96	−1.26	−1.71	−0.75	−1.98
16	−1.07	−0.88	−0.74	−2.06	−1.24	−1.80	−0.62	−2.04
40	−0.75	−0.57	−0.54	−1.53	−0.79	−1.37	−0.39	−1.41
∞	0.24	0.14	0.43	0.14	0.40	−0.38	0.60	0.41
Steady state	1.56	0.69	1.87	1.90	1.66	0.36	2.02	2.05
EA7								
4	−0.96	−0.82	−0.29	−2.24	−1.30	−1.77	−0.63	−2.24
16	−0.96	−0.80	−0.45	−2.34	−1.23	−1.81	−0.35	−2.26
40	−0.61	−0.49	−0.18	−1.70	−0.69	−1.31	−0.03	−1.47
∞	0.58	0.23	1.04	0.44	0.77	−0.19	1.23	0.83
Steady state	2.25	0.80	2.85	2.84	2.32	0.63	2.96	2.95

Notes: I: Two goods with incomplete markets, II: Two goods with complete markets, III: One good with incomplete markets, IV: Closed economy.

smaller than in the one good model. As a result, the change in the net foreign asset-output ratio is much smaller. While the two good open economy models exhibit similar long run changes in tax rates (a little over 1 percentage points on either the consumption or labor income tax rate), the responses of macroeconomic variables differ across the two market structures. Substituting the labor income tax for the capital income tax, hours rise slightly (0.02 percent) under complete markets, but fall 0.15 percent under incomplete markets. For the consumption tax substitution, hours rise under both market structures, but is smaller (0.05 percent versus 0.32 percent) when markets are incomplete. These differences between complete and incomplete markets are due to the presence of wealth effects under incomplete markets.[10]

The welfare implications of reducing the capital income tax are explored in Table 5. Overall, for GIIPS there are substantial welfare losses in the short term while in the long run

[10] When the trade elasticity is above unity, Auray and Eyquem (2014) show that wealth effects lead to larger movements in relative consumptions and smaller movements in the real exchange rate under incomplete markets compared to complete markets.

the welfare gains are sizable. Replacing capital income tax revenue with consumption tax revenue yields a welfare gain of between 0.4 and 0.6 percent – with the exception of the two good, complete international asset markets open economy model. Using the labor income tax rate delivers welfare gains in the range of 0.14 percent and 0.43 percent. Once again, measuring the welfare benefit across steady states grossly overstates the potential welfare benefit. For the EA7, the short run welfare losses are similar to those recorded for GIIPS, but the long run benefits are larger.

One interesting regularity is that the long run welfare benefits of paying for the capital income tax cut with a consumption tax exceed those associated with using the labor income tax. In the earlier discussion of the effective tax on labor income (which combines the effects of the labor income tax with those of the consumption tax), it was shown that when the change in the labor income and consumption taxes is the same, the change in this effective tax rate is smaller under the consumption tax. Consequently, the larger welfare benefit of replacing capital income tax revenue with consumption tax revenue can be attributed to the smaller economic disruptions associated with the long run increase in the consumption tax relative to the labor income tax. An alternative way of viewing these relative welfare results is by noting that, as shown in Figures 1(a) and 1(b), the long run Laffer curve associated with the consumption tax is much steeper than that of the labor income tax.

4.4 Sensitivity

The baseline calibration has the government adopting a kind of 'cold turkey' approach in that it immediately adopts its long run debt-output target. What if the government implements this target more gradually? This issue is explored for our preferred model, the two good, incomplete international assets markets small open economy model. Larger values of ρ_d, which imply a more gradual response of the government debt-output target to its long run value, serve to moderate the macroeconomic effects of debt reductions. The welfare implications of alternative values of ρ_d are explored in Table 6. Specifically, the columns labeled II set $\rho_d = 0.5$ (implying moderate adjustment in the debt-output target to its long run value) in (23) while the label III corresponds to $\rho_d = 0.9$ (and so fairly slow adjustment in the debt-output target).[11] Except at fairly short horizons, the welfare results are quite insensitive to these changes in ρ_d. At very short horizons, the welfare benefit associated with using the labor income tax becomes smaller. In the case of the consumption tax, the short run welfare cost is moderated. There is remarkably little change when the capital income tax rate is the instrument of policy.

The parameter ϕ^f appears in the world real interest rate equation for the incomplete international asset markets version of the model. Its low value – 0.001 – in the baseline parameterization implies that the world real interest rate paid responds very little to domestic macroeconomic developments. Instead, set $\phi^f = 0.025$, which strengthens the response of the world real interest rate to domestic developments. Relative to the baseline calibration, such a parameter change has relatively little effect on the model's dynamics, except when the consumption tax is the instrument of policy – in which case the responses of macroeconomic variables are somewhat amplified. The columns labeled IV in Table 6 report the welfare implications of setting $\phi^f = 0.025$. As with ρ_d, the welfare results associated with using the capital income tax rate are quite insensitive to ϕ^f. For the labor income tax rate, it is only at very short horizons that the reported welfare numbers change much, switching from a modest benefit under the baseline calibration to a very modest welfare cost. In the case of the consumption tax, the larger value of ϕ^f tends to moderate the short term welfare costs recorded for the baseline model.

Finally, what if some New Keynesian features are added to the model? Specifically, suppose that prices are sticky and the central bank follows a conventional interest rate rule.

[11] Similar results are obtained by setting ω, the feedback parameter from government debt to its primary deficit, to smaller values.

Table 6: Welfare benefit of debt reduction experiments, in percent

	τ_h					τ_c					τ_k				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
GIIPS															
4	0.12	0.05	−0.05	0.01	0.12	−0.55	−0.36	−0.02	−0.39	−0.52	0.31	0.33	0.29	0.30	0.34
16	0.05	0.05	−0.00	−0.05	0.05	−0.48	−0.45	−0.22	−0.29	−0.46	0.18	0.19	0.25	0.17	0.18
40	−0.03	−0.03	−0.02	−0.12	−0.03	−0.25	−0.25	−0.21	−0.09	−0.24	−0.01	−0.01	0.05	−0.03	0.00
∞	−0.04	−0.04	−0.03	−0.07	−0.03	0.02	0.01	0.01	0.06	0.01	0.13	0.13	0.09	0.12	0.06
EA7															
4	0.08	0.02	−0.06	0.07	0.09	−0.46	−0.30	−0.02	−0.38	−0.44	0.26	0.27	0.25	0.26	0.28
16	0.03	0.02	−0.02	0.00	0.03	−0.41	−0.38	−0.19	−0.31	−0.39	0.15	0.16	0.21	0.12	0.15
40	−0.05	−0.05	−0.03	−0.08	−0.04	−0.22	−0.22	−0.19	−0.14	−0.21	−0.01	−0.01	0.03	−0.08	−0.01
∞	−0.05	−0.04	−0.03	−0.05	−0.03	0.01	0.01	0.00	0.02	0.00	0.26	0.26	0.20	0.23	0.08

Notes: I: benchmark model, II: more gradual implementation of long run debt reduction, III: even more gradual implementation of long run debt reduction, IV: more debt-elastic world real interest rate, V: sticky price model.

To flesh out this variation, suppose that domestic goods are a composite of local varieties,

$$y_t = \left[\int_0^1 y_t(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}},$$

where j indexes the local varieties. From this, one obtains the 'usual' expressions for the demand for variety j and the aggregate price level:

$$y_t(j) = \left[\frac{p_{ht}(j)}{p_{ht}} \right]^{-\theta} y_t, \tag{38}$$

$$p_{ht} = \left[\int_0^1 p_{ht}(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}}. \tag{39}$$

Sticky prices are introduced as in Rotemberg (1982). Producer j's problem is to maximize the value of the firm,

$$\sum_{t=0}^{\infty} \beta^t \Lambda_t d_t(j),$$

subject to (38) and $y_t(j) = F[k_{t-1}(j), a_t h_t(j)]$ where Λ_t is the household's marginal value of a unit of output, and real dividends or profits are given by

$$d_t(j) = (1+\tau_y)\frac{p_{ht}(j)}{p_{ht}} y_t(j) - w_t h_t(j) - r_{kt} k_{t-1}(j) - \frac{\phi_\pi}{2} \left[\frac{p_{ht}(j)}{p_{h,t-1}(j)} - \overline{\pi} \right]^2 y_t.$$

Above, τ_y is a subsidy to production, introduced to eliminate the steady state distortions associated with monopolistic pricing, and $\overline{\pi}$ is the steady state rate inflation rate. Following the approach in Ireland (1997) eventually leads to an equation that determines the evolution of inflation over time,

$$0 = \Lambda_t \left\{ (1+\tau_y)(1-\theta) - \phi_\pi \left[\pi_t - \overline{\pi} \right] \pi_t + \mu_t \theta \right\} + \beta \Lambda_{t+1} \phi_\pi \left[\pi_{t+1} - \overline{\pi} \right] \pi_{t+1} \frac{y_{t+1}}{y_t}, \tag{40}$$

where π_t is the inflation rate.

The final ingredient is monetary policy, specified as an interest rate rule:

$$\ln i_t = (1 - \rho_i) \ln \bar{\imath} + \rho_i \left[\ln i_{t-1} + d_\pi \left(\ln \pi_t - \ln \overline{\pi}\right)\right], \tag{41}$$

where 'bars' denote long run values or targets. In other words, the central bank responds only to domestic inflation.

The sticky price model is parameterized as follows. $\theta = 6$ which implies a steady state markup of 20 percent. This parameter value requires setting $\tau_y = 0.2$. Set $\overline{\pi} = 1.0048$ which corresponds to a steady state inflation rate of 1.9 percent *per annum*, in line with European data. In the price adjustment term, $\phi_\pi = 80$. For the parameters in the monetary policy interest rate rule, $\rho_i = 0.7$ and $d_\pi = 1.5$. These last three parameter values are as in Ireland (1997).

The model's responses to labor income tax- or consumption tax-financed debt reductions are not terribly sensitive to the introduction of sticky prices. On the other hand, the impact response to a capital income tax-financed debt reduction are strengthened. The welfare implications of introducing sticky prices in this way are summarized under the columns labeled V in Table 6. Relative to the baseline model, introducing sticky prices has remarkably little effect on the recorded welfare benefits.

The implications of these deviations from the baseline model for the tax substitution experiments are summarized in Table 7. Since the target debt-output ratio is held fixed under these experiments, varying how fast the government adjusts its target (ρ_d) has no effects and so these results are omitted. Making the world real interest rate more responsive to domestic developments increases the short- to medium-term welfare losses, but has only a modest impact on the long run welfare benefits. Similar results are obtained in the sticky price model when the labor income tax rate is used to replace the lost capital income tax revenue; when using the consumption tax, both the short- to medium-term welfare costs and long run benefits are moderated.

Table 7: Welfare benefit of tax substitution experiments, in percent

	τ_h			τ_c		
	I	IV	V	I	IV	V
GIIPS						
4	−1.05	−1.24	−1.21	−1.26	-1.30	−1.00
16	−1.07	−1.39	−1.16	−1.24	-1.38	−1.09
40	−0.75	−1.07	−0.81	−0.79	-0.98	−0.73
∞	0.24	0.19	0.15	0.40	0.39	0.33
EA7						
4	−0.96	−1.60	−1.17	−1.30	-1.76	−0.94
16	−0.96	−1.67	−1.08	−1.23	-1.77	−1.02
40	−0.61	−1.18	−0.70	−0.69	-1.13	−0.60
∞	0.58	0.48	0.44	0.77	0.70	0.68

Notes: I: benchmark model, IV: more debt-elastic world real interest rate, V: sticky price model.

5 Conclusion

Debt levels in the Euro zone have risen over the past decade. In the case of the GIIPS group, the increase has been quite large. Once the fiscal crises have resolved themselves, it is likely that European governments will want to reduce their debt levels. This paper focused on the use of tax instruments to implement such a debt reduction. Fiscal policy was assumed to follow a feedback rule that renders government debt stable. More specifically, the government is required to run a larger primary budget surplus when its debt-output ratio is above its long run target. Debt reductions involve higher taxes in the short run so that the government runs larger budget surpluses; in the longer term taxes fall as the government's debt servicing costs decline.

Four models were developed. For reasons discussed at length in the Introduction, our preferred model is the incomplete markets, two good small open economy model. The policy experiment was a ten percentage point reduction in the annual debt-output ratio. Evaluating the welfare gain using the entire transition path, the capital income tax is the preferred tax instrument. For the GIIPS model, the welfare gain is 0.16 percent of consumption; for the

EA7, the gain is 0.36 percent. The surprise nature of the increase in the capital income tax operates much like a lump-sum tax, and so is less distortionary in the short term than the other taxes. The long term benefits of lowering the capital income tax rate are reminiscent of the results from the optimal taxation literature that typically call for very low taxes on capital in the long run.

Using the consumption tax as the policy instrument delivers very modest welfare gains. In this case, the long term gains are largely offset by the short term economic disruptions. Implementing debt reductions through the labor income tax was found to be welfare-reducing, suggesting that if this were the only instrument open to the government, it would be better off leaving its debt-output ratio unchanged.

Having lowered the debt-output ratio by raising the capital income tax rate, it may be politically tempting to keep the capital income tax rate high, reducing instead one of the other taxes. Our model suggests that this would be a bad idea. Indeed, as shown in Section 4.3, holding fixed the long run government debt-output ratio, a ten percentage point *reduction* in the capital income tax rate, financed by either the consumption tax or the labor income tax, raises welfare. Once more focusing on the preferred two good, incomplete asset markets small open economy model, implementing such a policy through the labor income tax rate produces a welfare gain of either 0.24 percent for the GIIPS group, or 0.58 for the EA7. Using the consumption tax leads to larger welfare gains: 0.40 percent for GIIPS or 0.77 percent for the EA7.

Appendix A

A.1 Dynamic Solution Method

The solution method is based on the one described by Juillard (1996), adapted to solving a Robin Kind of two point boundary problem. Denote the vector of endogenous variables by

$$Y = \begin{bmatrix} y_0' & y_1' & y_2' & \cdots & y_T' \end{bmatrix}',$$

where T is the number of periods that we solve the model for. We seek a solution Y^* that satisfies a set of Euler equations and other constraints; denote this solution by $F(Y^*) = 0$. The usual procedure is to take a first-order Taylor series approximation around a guess, Y, to obtain the Newton step, ΔY, from

$$F(Y^*) \simeq F(Y) + J(Y)\Delta Y,$$

where $J(Y)$ is the Jacobian (matrix of first-order derivatives) of $F(Y)$. Since the objective is to find a Y^* such that $F(Y^*) = 0$, we need to solve the following set of equations for ΔY:

$$J(Y)\Delta Y = -F(Y).$$

The time dimension to the model imposes considerable structure on the Jacobian, $J(Y)$. Write

$$F(Y) = \begin{bmatrix} F_0(Y)' & F_1(Y)' & F_2(Y)' & \cdots & F_T(Y)' \end{bmatrix}',$$

where $F_0(Y)$ is an initial condition, $F_0(Y) = f_0(y_0) = y_0 - y_0^*$; $F_T(Y) = 0$ represents the terminal, no change condition; and the remaining $F_t(Y)$ are the 'time t' Euler equations and constraints. For ease of presentation (and consistent with our model), assume that at most one lead and one lag of the endogenous variables appear in $F_t(Y) = f_t(y_{t-1}, y_t, y_{t+1})$.[12] In

[12] It is easy to accommodate additional leads or lags through the introduction of auxiliary variables.

this case, the Jacobian is

$$
J(Y) = \begin{bmatrix} I & & & & & \\ J_{1,0} & J_{1,1} & J_{1,2} & & & \\ & J_{2,1} & J_{2,2} & J_{2,3} & & \\ & & \ddots & \ddots & \ddots & \\ & & & J_{T-1,T-2} & J_{T-1,T-1} & J_{T-1,T} \\ & & & & -I & I \end{bmatrix}, \tag{42}
$$

where $J_{t,s}$ denotes the block of the Jacobian corresponding to $\partial f_t(y_{t-1}, y_t, y_{t+1})/\partial y_s$ for $s \in \{t-1, t, t+1\}$ and $t \in \{2, 3, 4, \ldots, T-1\}$. The last 'line' in (42) corresponds to the terminal condition, $y_T = y_{t-1}$ from which it follows $\Delta y_T = \Delta y_{T-1}$.

The idea now is to simplify (42). The first 'line' in (42) corresponds to $\Delta y_0 = 0$ – that is, there is no change in the initial condition. The second line reads

$$
J_{1,0}\Delta y_0 + J_{1,1}\Delta y_1 + J_{1,2}\Delta y_2 = -f_1(y_0, y_1, y_2).
$$

Since $\Delta y_0 = 0$, this equation can be rearranged to read

$$
\Delta y_1 + \underbrace{J_{1,1}^{-1} J_{1,2}}_{C_1} \Delta y_2 = \underbrace{-J_{1,1}^{-1} f_1(y_0, y_1, y_2)}_{d_1}.
$$

Proceeding to subsequent 'lines' of (42) yields

$$
\Delta y_t + \underbrace{[J_{t,t} - J_{t,t-1}C_{t-1}]^{-1} J_{t,t+1}}_{C_t} \Delta y_{t+1} = \underbrace{-[J_{t,t} - J_{t,t-1}C_{t-1}]^{-1}[J_{t,t-1}d_{t-1} + f_t(y_{t-1}, y_t, y_{t+1})]}_{d_t},
$$

for $t = 2, 3, \ldots, T-1$. Notice that, in addition to elements of the Jacobian and the function evaluations, each step only requires the previous solutions, C_{t-1} and d_{t-1}.

The Newton step now looks like

$$J(Y) = \begin{bmatrix} I & & & & & \\ & I & C_1 & & & \\ & & I & C_2 & & \\ & & & \ddots & \ddots & \\ & & & & I & C_{T-1} \\ & & & & -I & I \end{bmatrix} \begin{bmatrix} \Delta y_0 \\ \Delta y_1 \\ \Delta y_2 \\ \vdots \\ \Delta y_{T-1} \\ \Delta y_T \end{bmatrix} = \begin{bmatrix} y_0 - y_0^* \\ d_1 \\ d_2 \\ \vdots \\ d_{T-1} \\ 0 \end{bmatrix}.$$

The steps, $\{\Delta y_t\}$, are obtained as follows. Start with the last 'line',

$$\Delta y_T = \Delta y_{T-1},$$

which corresponds to the 'no change' terminal condition. The second last 'line' reads

$$\Delta y_{T-1} + C_{T-1}\Delta y_T = d_{T-1},$$

from which it follows

$$\Delta y_{T-1} = \Delta y_T = [I + C_{T-1}]^{-1} d_{T-1}.$$

Continuing backwards, the generic step is

$$\Delta y_t = d_t - C_t \Delta y_{t+1}.$$

Notice that the 'forward pass' only requires temporarily storing a small part of the Jacobian and that this pass requires keeping the matrices $\{C_t\}_{t=1}^{T-1}$ and vectors $\{d_t\}_{t=1}^{T-1}$. Furthermore, this pass requires solving relatively small blocks of equations since the matrices involved have dimensions equal to the number of date t endogenous variables. For the most part, the 'backward pass' involves matrix-vector multiplications.

In our experience, using this method to solve our full model for 1200 periods with 14 endogenous variables per period is roughly two orders of magnitude faster than naïvely applying a nonlinear equation solver. Depending on the exact experiment, solving the model for 2000 periods takes a few seconds using Fortran code on an Intel i7 980 running at 3.33 GHz.

A.2 Data

All our data come from the OECD Economic Outlook and Tax databases from 2005 to 2010. There are 12 countries: Austria, Belgium, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, the Netherlands, Portugal and Spain.

- GDP growth for the Euro Area is based on GDP levels, in volume (real) at market prices. We build an aggregate measure of GDP and compute the average quarterly growth rate.

- Subgroup measures of hours worked per employee are computed using series on average annual hours worked per employee and employment levels. We first compute time-varying weights based on employment series for each subgroup, and compute weighted averages of hours worked per employee for each year and for each subgroup, before taking the mean and expressing the mean as a proportion of total awake time.

- Subgroup aggregates of imports, in volume (real) at market prices, and subgroup GDP measures are used to compute the imports to GDP ratios for each year, before taking the mean.

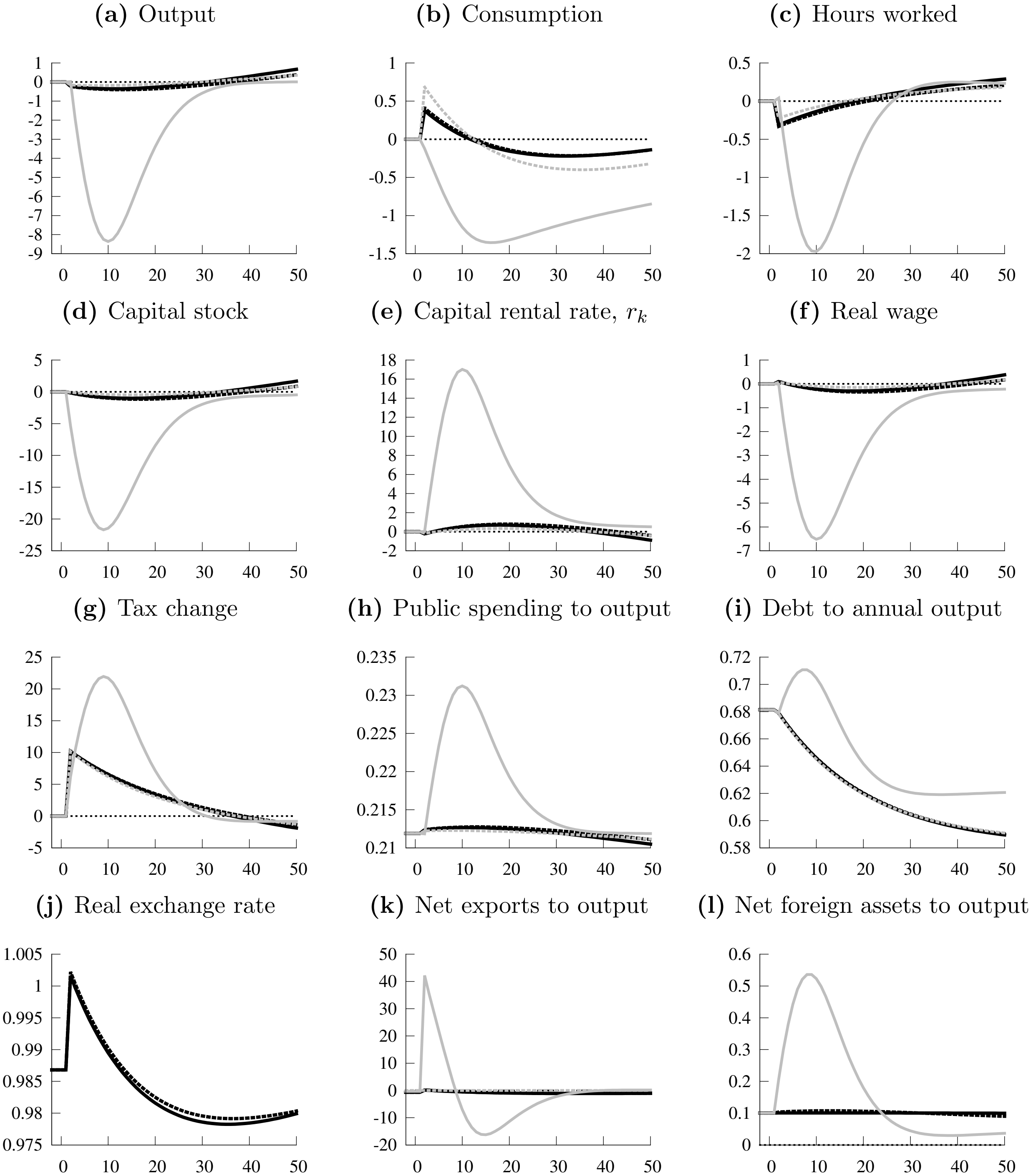
- We proceed similarly for debt to annual GDP, using the gross public debt measure (Maastricht criteria) to GDP provided by the OECD Economic Outlook database, and for public spending to GDP ratios, using government final consumption expenditure, in volume (real) at market prices.

- We built subgroup measures of net foreign assets to annual GDP based on the updated database of Lane and Milesi-Ferretti (2007).

- We use tax rate time series to construct subgroup GDP-weighted averages of tax rates. The consumption tax rate is essentially the VAT. Factor income tax rates are all-in rates (including social security taxes and personal income taxes). For the labor income tax rate, we have series for single workers and series for workers that are married with two children. We take the mean of both tax rates before computing our subgroup measures of labor income tax rates. Capital income taxes comprise profits, dividend and the capital income portion of personal income taxes.

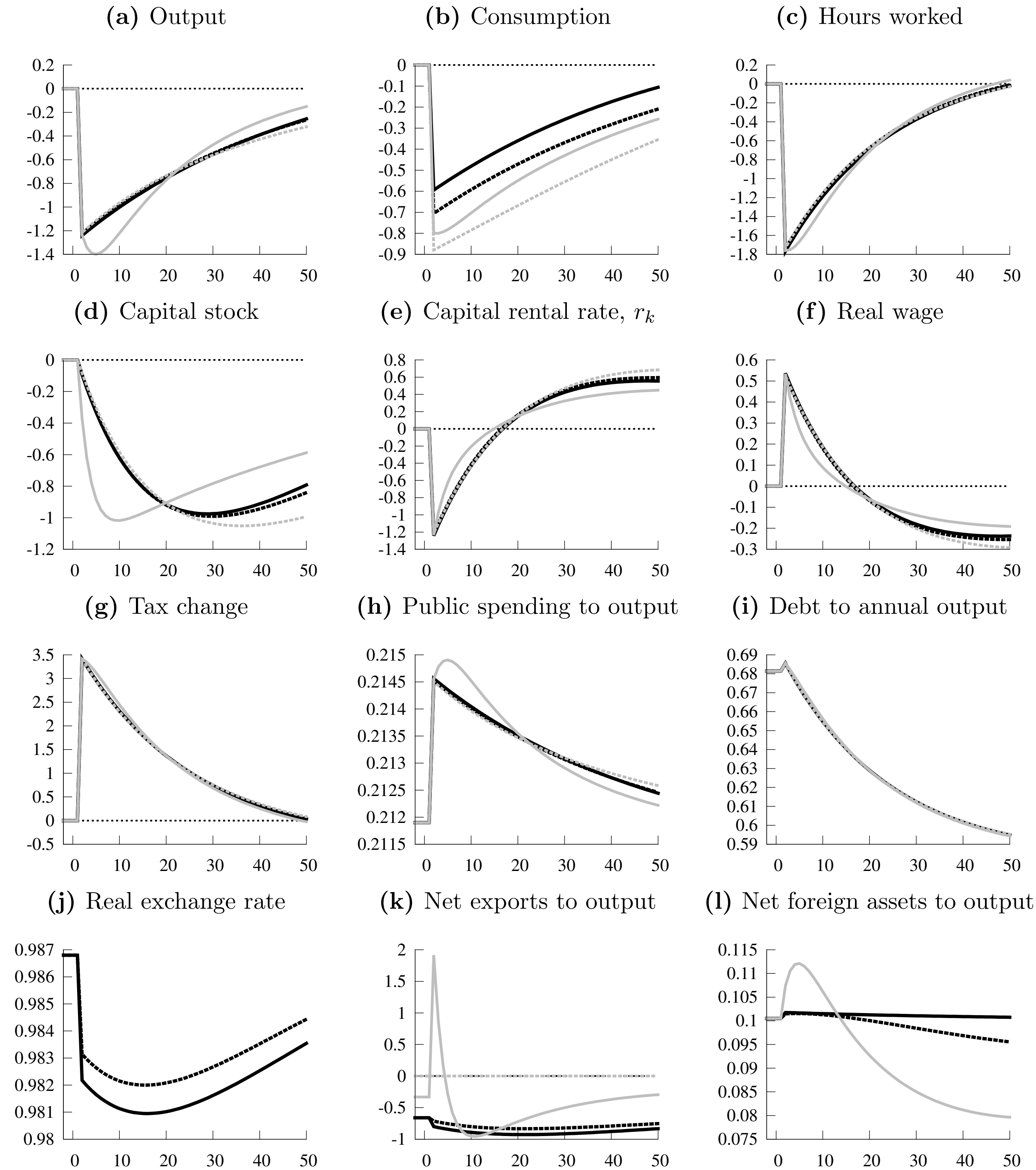
A.3 Additional graphs: Debt reduction experiments for the EA7

Figure 7: Debt reduction experiment in the EA7 through the capital income tax rate



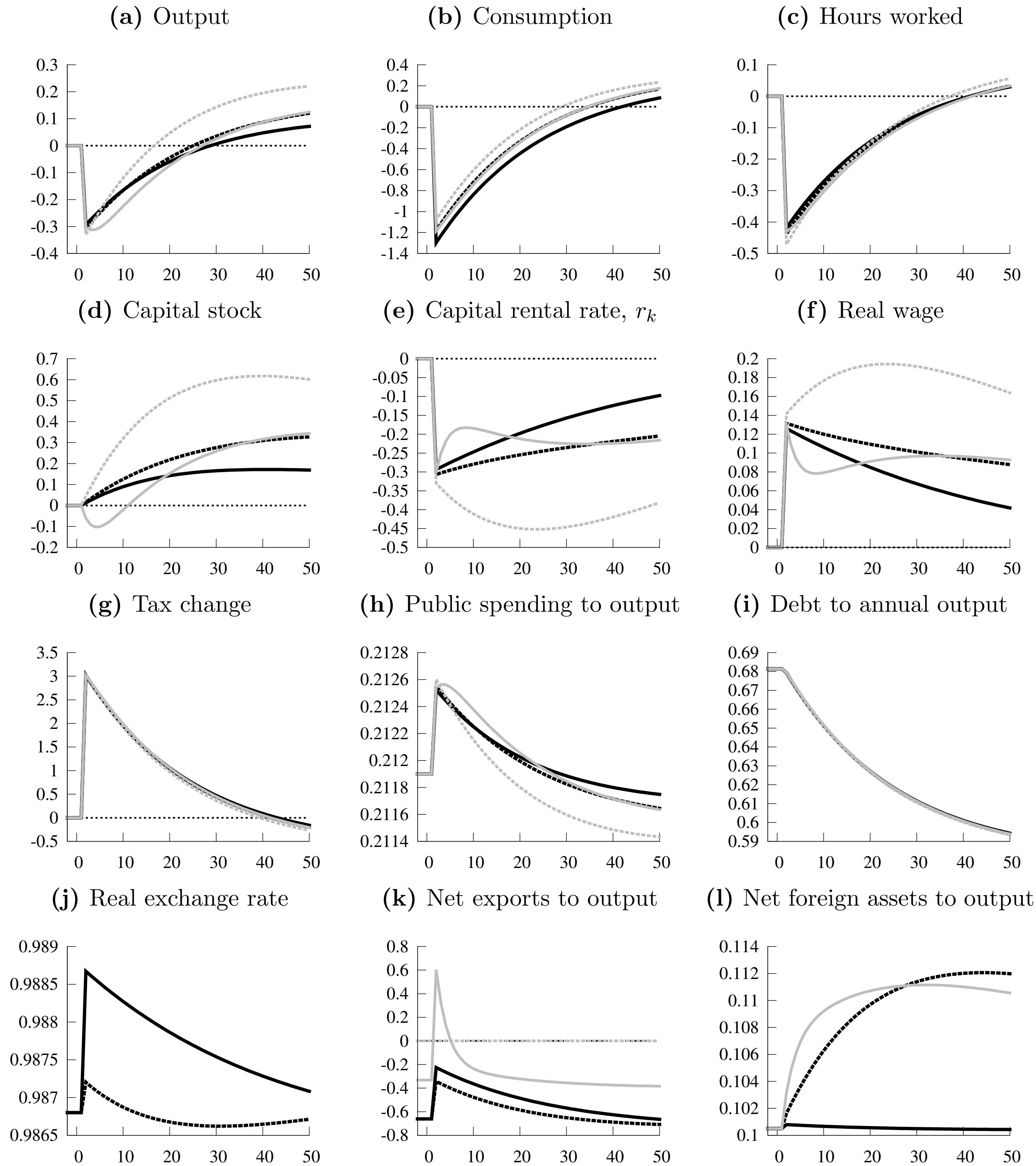
Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

Figure 8: Debt reduction experiment in the EA7 through the labor income tax rate



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

Figure 9: Debt reduction experiment in the EA7 through the consumption tax rate



Legend: Solid black: complete markets. Dotted black: incomplete markets. Solid gray: incomplete markets, one good. Dotted gray: closed economy. Output, consumption, hours, the capital stock, the rental rate for capital and the wage rate are expressed as percentage deviations from the initial steady state.

References

AURAY, S., B. DE BLAS AND A. EYQUEM, "Ramsey Policies in a Small Open Economy with Sticky Prices and Capital," *Journal of Economic Dynamics and Control* 35 (2011), 1531–1546.

AURAY, S. AND A. EYQUEM, "Welfare Reversals in a Monetary Union," *American Economic Journal: Macroeconomics* 6 (2014), 246–290.

BACKUS, D. K., P. J. KEHOE AND F. E. KYDLAND, "International Business Cycles: Theory vs. Evidence," *Federal Reserve Bank of Minneapolis Quarterly Review* Fall (1993), 14–29.

BENIGNO, G. AND B. DE PAOLI, "On the International Dimension of Fiscal Policy," *Journal of Money, Credit and Banking* 42 (December 2010), 1523–1542.

BENIGNO, P., "Price Stability with Imperfect Financial Integration," *Journal of Money, Credit and Banking* 41 (2009), 121–149.

BERKA, M., M. B. DEVEREUX AND C. ENGEL, "Real Exchange Rate Adjustment in and out of the Eurozone," *American Economic Review* 102 (May 2012), 179–85.

BERNHARDSEN, T., "The Relationship between Interest Rate Differentials and Macroeconomic Variables: A Panel Data Study for European Countries," *Journal of International Money and Finance* 19 (2000), 289–308.

BOUAKEZ, H. AND A. EYQUEM, "Government Spending, Monetary Policy, and the Real Exchange Rate," *Journal of International Money and Finance* 56 (2015), 178–201.

CHAMLEY, C., "Optimal Taxation of Capital Income in General Equilibrium with Infinite Lives," *Econometrica* 54 (May 1986), 607–622.

CHARI, V. V. AND P. J. KEHOE, "Optimal Fiscal and Monetary Policy," in J. B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics* (Elsevier, 1999), 1671–1745.

De Paoli, B., “Monetary Policy and Welfare in a Small Open Economy,” *Journal of International Economics* 77 (February 2009), 11–22.

Gomme, P. and P. Rupert, “Theory, Measurement, and Calibration of Macroeconomic Models,” *Journal of Monetary Economics* 54 (March 2007), 460–497.

Ireland, P. N., “A Small Structural, Quarterly Model for Monetary Policy Evaluation,” *Carnegie-Rochester Conference Series on Public Policy* 47 (December 1997), 83–108.

Judd, K. L., “Redistributive Taxation in a Simple Perfect Foresight Model,” *Journal of Public Economics* 28 (October 1985), 59–83.

Juillard, M., “Dynare: A program for the resolution and simulation of dynamic models with forward variables through the use of a relaxation algorithm,” No: 9602, CPREMAP Working Papers (Couverture Orange), 1996.

Lane, P. R. and G. M. Milesi-Ferretti, “Long-Term Capital Movements,” in *NBER Macroeconomics Annual 2001, Volume 16*NBER Chapters (National Bureau of Economic Research, Inc, 2002), 73–136.

———, “The external wealth of nations mark II: Revised and extended estimates of foreign assets and liabilities, 1970-2004,” *Journal of International Economics* 73 (November 2007), 223–250.

Lucas, R. E., Jr. and N. L. Stokey, “Optimal Fiscal and Monetary Policy in an Economy without Capital,” *Journal of Monetary Economics* 12 (1983), 55–93.

Mendoza, E. G., “Real Business Cycles in a Small Open Economy,” *American Economic Review* 81 (September 1991), 797–818.

Mendoza, E. G. and L. L. Tesar, “The Interntaional Ramifications of Tax Reforms: Supply-Side Economics in a Global Economy,” *American Economic Review* 88 (March 1998), 226–245.

Mendoza, E. G., L. L. Tesar and J. Zhang, "Saving Europe?: The Unpleasant Arithmetic of Fiscal Austerity in Integrated Economies," NBER Working Papers 20200, National Bureau of Economic Research, June 2014.

Rotemberg, J. J., "Monopolistic Price Adjustment and Aggregate Output," *Review of Economic Studies* 49 (1982), 517–531.

Schmitt-Grohé, S. and M. Uribe, "Closing Small Open Economy Models," *Journal of International Economics* 61 (October 2003), 163–185.

Trabandt, M. and H. Uhlig, "The Laffer Curve Revisited," *Journal of Monetary Economics* 58 (May 2011), 305–327.