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Assessing the Impact of Fiscal Measures on the Czech Economy

Róbert Ambriško, Jan Babecký, Jakub Ryšánek, and Vilém Valenta *

Abstract

We build a satellite DSGE model to investigate the transmission of fiscal policy to the real economy in the Czech Republic. Our model shares features of the Czech National Bank's current g3 forecasting model (Andrle, Hlédik, Kameník, and Vlček, 2009), but contains a more comprehensive fiscal sector. Crucial fiscal parameters, related mainly to the specified fiscal rule, are estimated using Bayesian techniques. We calculate a set of fiscal multipliers for individual revenue and expenditure items of the government budget. We find that the largest real GDP fiscal multipliers in the first year are associated with government investment (0.4) and social security contributions paid by employers (0.3), followed by government consumption (0.2).

JEL Codes: C11, E32, E62, F41.
Keywords: Bayesian estimation, DSGE, fiscal multipliers, fiscal policy, fiscal rule, open economy.

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Nontechnical Summary

The government influences the real economy by setting fiscal policy, which essentially involves adjusting taxes and expenditures. Each tax or expenditure category can have a different impact on the economy (depending, for example, on the timing, scope, and direction of the response). Therefore, in order to properly analyze the impact of fiscal measures on the economy, it is essential to work with a model that allows us to distinguish between individual fiscal categories. This is not fully possible with the Czech National Bank's current g3 model (Andrle, Hlédik, Kameník, and Vlček, 2009), so in this paper we propose an extension to include a more comprehensive fiscal sector.

Our proposed satellite DSGE model contains several important fiscal features. (i) It incorporates a rich set of individual fiscal categories, which include: government consumption, government investment, unemployment benefits, other social benefits, a consumption tax, a wage tax, a capital tax, social security contributions paid by employers, and a lump-sum tax. (ii) The model takes into account that some households do not save, but consume all their income. (iii) Furthermore, unemployment is incorporated into the model, and the unemployment rate affects the amount of unemployment benefits paid. (iv) Government consumption and government capital are allowed to be productive, which means that government consumption yields utility to the households, and government capital is freely available to the firms, which are able to use it in production. (v) Finally, the responses of individual fiscal categories are carefully set through the specified fiscal rule, whose coefficients are estimated on Czech data using Bayesian techniques.

To study the effects of fiscal policy on the Czech economy, it is beneficial to show the values of the fiscal multipliers, which measure the change in the variable of interest (e.g. real GDP, domestic output) with respect to the change in the corresponding fiscal instrument (e.g. government consumption) over some time period, where both changes are expressed in Czech crowns. We provide a set of fiscal multipliers obtained from our DSGE model and assess the robustness of our results to the underlying assumptions. We find that the largest real GDP fiscal multipliers in the first year are associated with government investment (0.4) and social security contributions paid by employers (0.3), followed by government consumption (0.2). In other words, fiscal consolidations based on cuts in government investment and increases in social security contributions paid by employers are most costly in terms of the real GDP loss in the short run.

The relatively low values of the multipliers obtained can be interpreted in the context of a meta analysis of fiscal multipliers from 89 studies by Gechert and Will (2012). According to this analysis, the size of fiscal multipliers depends on the method chosen (e.g. lower values of multipliers for DSGE models compared to macroeconometric models, single equation approaches or VARs), on the fiscal instrument (e.g. the highest multipliers are associated with government investment), and on the share of households who just consume all their disposable income (the higher the share of such households, the higher the fiscal multipliers). These are features we also observe in our results. In addition, the meta analysis reveals that economies with a high import intensity of GDP are characterized by lower fiscal multipliers. This is relevant for the Czech economy, which is particularly dependent on international trade.

In the last part of our paper, we perform a partial evaluation of the impact of selected fiscal measures on the real economy. The term "partial" means that only some of the supply-side aspects are considered, the underlying fiscal shocks are modeled as temporary, and the calculated impacts are deviations of the economy from its equilibrium. Conditional on the model's set of simplifying assumptions, numerical simulations using our DSGE model suggest that selected fiscal measures often discussed in relation to the ongoing fiscal consolidation might imply a tightening of 0.2, 0.4, and 0.5 percentage points of real GDP in 2013, 2014, and 2015, as compared to the baseline scenario of no change in fiscal policy.

1. Introduction

Fiscal policy has received considerable attention since the global economic and financial crisis began in 2008. This attention has also fallen on central banks, since fiscal measures often significantly affect economic activity (real GDP, inflation) and consequently monetary policy interest rates need to be set appropriately. Governments frequently introduce several fiscal measures at once, in so-called fiscal packages, which consist of various measures on both the expenditure and revenue sides of the government budget. Depending on the model used, fiscal measures might not be easily implemented into the model to produce macroeconomic forecasts fully consistent with the fiscal policy settings. This applies also to the practice in the Czech National Bank (CNB).

The CNB's core g3 model, developed and described in Andrle et al. (2009), currently lacks sufficient detail with respect to the fiscal sector. Hence, the objective of this paper is to address this deficiency by building a satellite DSGE model with an extended fiscal sector. To concentrate mainly on fiscal policy variables, we proceed with some simplification of the g3 model; to be more specific, stochastic trends are omitted from the model, but on the other hand we enrich the model with several important fiscal channels. First, we introduce into our model so-called "rule-of-thumb" households, in the manner of Galí, López-Salido, and Vallés (2007). These households do not accumulate any savings and consume all their disposable income. Second, we allow government consumption and government capital to be productive; in other words, government consumption brings some utility to households and government capital contributes to firms' production. These two productive features are often neglected in the mainstream DSGE literature, although the possibility of productive government consumption and government capital has been discussed in the past (Bailey, 1971; Barro, 1981; Baxter and King, 1993). Third, our model contains an extensive set of fiscal instruments, namely, four instruments on the expenditure side (government consumption, government investment, unemployment benefits, and other social benefits) and five instruments on the revenue side (a consumption tax, a wage tax, a capital tax, social security contributions paid by employers, and a lump-sum tax). Fourth, we extend our model to include unemployment, in a tractable way proposed by Galí (2011), which helps to partly endogenize unemployment benefits. Fifth, we specify the government's fiscal rule with feedback coefficients for domestic output and debt, as found, for example, in Leeper, Plante, and Traum (2010), and estimate its coefficients for Czech data using Bayesian techniques.

Given the absence of a consensus in the literature regarding the precise value of the fiscal multipliers,[1] one of our objectives is to provide the CNB with the values of the fiscal multipliers for the Czech economy. Our DSGE model with its extended fiscal sector allows us to produce a rich set of multipliers, by several fiscal instrument categories, and also to assess the robustness of the multipliers to the underlying model assumptions. Recent estimates of fiscal multipliers for the Czech economy based on the structural VAR approach (Valenta, 2011) indicate an output fiscal multiplier of between 0.3 and 0.6 in the first year after a shock to government spending. The real GDP fiscal multipliers implied by our DSGE model attain their largest values in the case of government investment and social security contributions paid by employers, where the fiscal multipliers reach values of 0.4 and 0.3, respectively, in the first year. These are followed by the fiscal multipliers for government consumption, the wage tax, and the consumption tax (all roughly 0.2) and other social benefits and lump-sum taxes (both 0.1). Unemployment benefits and the capital tax have negligible fiscal multipliers. Our results suggest that the most costly, in terms of the real GDP loss in the first year, are fiscal consolidations based on cuts in government investment and increases in social security contributions paid by employers, followed by cuts in government consumption.

[1] Histograms of fiscal multipliers, obtained from many studies, are reported by Gechert and Will (2012).

Comparing our estimates of fiscal multipliers with the results reported in a meta analysis by Gechert and Will (2012) based on the examination of 89 studies suggests that the relatively low values of the fiscal multipliers for the Czech economy could be attributed to its high import intensity of GDP. Furthermore, in what follows our DSGE-based fiscal multipliers should be viewed as lower bound estimates compared to those produced by macroeconometric models, single equation approaches or VARs. Nevertheless, our sensitivity checks demonstrate that the higher is the share of "rule-of-thumb" households, the higher are the values of fiscal multipliers, which corresponds to the evidence from the meta analysis.

For practical purposes, using our proposed DSGE model we evaluate the partial impact of selected fiscal measures on the Czech economy (that is, not accounting for all supply-side effects and assuming that fiscal shocks are of a temporary nature and the economy starts from its equilibrium). We find that the selected fiscal consolidation measures, related to the ongoing process of fiscal consolidation in the Czech Republic, might slow real GDP growth down by 0.2, 0.4, and 0.5 percentage points in 2013, 2014, and 2015, respectively, as compared to the baseline with unchanged fiscal policy.

The paper is structured as follows. Section 2 reviews relevant literature, Section 3 presents our satellite DSGE model with the extended fiscal sector, and Section 4 discusses the transmission of fiscal shocks to the economy, provides estimates of fiscal multipliers and several robustness checks, and quantifies the impact of the selected fiscal measures on the Czech economy. The last section summarizes our findings and outlines suggestions for future research.

2. Related Literature Review

Generally, the empirical literature provides a variety of estimates of fiscal multipliers. (These are often based on (S)VAR techniques, but Dynamic Stochastic General Equilibrium (DSGE) model estimates have gained in prominence recently.) For example, for the euro area, Ratto, Roeger, and in 't Veld (2006) estimate the value of the government spending multiplier on output to be 0.6 over the first year. Using US data, Galí et al. (2007) find the government spending multiplier for output to be 0.8 at the beginning, rising to 1.7 after two years, in line with previous estimates by Baxter and King (1993). Blanchard and Perotti (2002), using the SVAR methodology, estimate the government spending multiplier for output at around 0.8–0.9. Some studies give puzzling results. For example, de Castro and de Cos (2006), using Spanish data, report the expected positive effect of government spending on output in the short run, but a negative relationship in the medium and long run. A recent meta regression analysis of around 90 studies by Gechert and Will (2012) shows that the values of fiscal multipliers are rather dependent on the chosen modeling approach and its settings; nonetheless, the underlying studies suggest that the average fiscal multiplier is less than one.

There is a growing number of models which examine the interactions of monetary and fiscal policies using the DSGE approach. A number of comprehensive models, including the IMF Global Integrated and Fiscal Model (see Kumhof et al., 2010) and the Czech Ministry of Finance HUBERT model (Štork, Závacká, and Vávra, 2009), usually assume a combination of active monetary and passive fiscal policies.[2] There are a few exceptions. Kim (2003) shows that under passive monetary policy and active fiscal policy higher government spending can generate a rise in both output and consumption. Davig and Leeper (2011) investigate government spending multipliers under alternative monetary-fiscal policy combinations. Their results indicate that the government spending multiplier for output fluctuates be-

[2] Passive fiscal policy means that higher taxes are expected to finance higher government spending, and conversely under active fiscal policy higher taxes are not expected to fully finance higher government spending. Passive monetary policy does not satisfy the Taylor principle (i.e., the monetary authority does not raise interest rates in response to rising inflation), but active monetary policy does.

tween values slightly below 1 to almost 2 depending on the specific monetary-fiscal policy combination, where each of the policies can be active or passive. Modeling of active monetary and fiscal policy rules is performed within QUEST III, a large-scale global DSGE model developed by the European Commission (Ratto, Roeger, and in 't Veld, 2009). The New Area-Wide Model (NAWM) of the euro area, elaborated by the European Central Bank, is another state-of-the-art framework, enabling, inter alia, interactions between fiscal and monetary policies.[3] The NAWM model was recently extended by Coenen, Straub, and Trabandt (2012b) to include a richer specification of the fiscal sector, and identified a significant role of discretionary fiscal policies for real GDP growth during the Great Recession. An interesting comparison of structural models, in terms of fiscal policy effectiveness, was performed by Coenen et al. (2012a). These authors found considerable agreement across models on both the absolute and relative sizes of different types of fiscal multipliers.

Further studies on the interactions of monetary and fiscal policies include Annicchiarico, Giammarioli, and Piergallini (2009), where the authors point out that the effects of fiscal shocks crucially depend on the type of monetary policy. Their model suggests that fiscal expansions increase output in the short run, but have negative effects on output in the medium run. Batini, Levine, and Pearlman (2009) argue that an optimal combination of monetary and fiscal policies has a stronger stabilization role compared to the situation where monetary stabilization is considered alone, and such a combination of monetary and fiscal policies has an even stronger effect in the presence of financial frictions. Leith and Wren-Lewis (2008) study fiscal and monetary policy interactions using a two-country model. The authors show that lax fiscal policy in one country can have adverse macroeconomic effects on another country. There are also studies which examine monetary and fiscal policy interactions within a currency union (e.g. Allsopp and Vines, 2008; Duarte and Wolman, 2008; Galí and Monacelli, 2008). The above studies suggest that the interactions between monetary and fiscal policies can be quite complex, and therefore one has to be careful when building a model intended for fiscal policy analysis.[4]

Regarding the Czech Republic, the first comprehensive evidence on the main features of Czech fiscal policy is presented by Bezděk, Dybczak, and Krejdl (2003). The authors assess the impact of the economic cycle on budget balances. Barrell et al. (2004) examine the impacts of economic policies in several EU countries, including the Czech Republic, for which they estimate a fiscal multiplier of 0.4. A somewhat higher fiscal multiplier of 0.6 is obtained by Hřebíček, Král, and Říkovský (2005) using both regression analysis and structural simulation. Recently, Prušvic (2010) determines the government expenditure multiplier at 0.5, in line with previous estimates. An attempt to examine the cyclical effects of fiscal policy employing the structural vector error correction (SVEC) model is made by Radkovský and Štiková (2008). While the authors manage to specify and estimate the SVEC representation, its impulse responses look rather inconclusive. Bulíř (2004) and Krejdl (2006) discuss policy sustainability from the viewpoint of external and fiscal sustainability. Dybczak (2006) and Babecký and Dybczak (2009) examine the long-term perspective of fiscal policy sustainability. Czech fiscal policy is argued to be unsustainable unless demographic trends, in particular population ageing, are properly taken into account. An evaluation of the macroeconomic effects of personal tax reform is provided by Bičáková, Slačálek, and Slavík (2006). There is ongoing work on modeling the fiscal sector in the Ministry of Finance HUBERT model (Štork and Závacká, 2010). At the current stage this model suffers from some drawbacks, i.e., there is no capital, a shock to government consumption leads to an unrealistic deflationary response, and the incorporated fiscal rule is rather simple, reacting to government expenditure only. An extensive set of various fiscal multipliers for the Czech Republic is provided by Klyuev and Snudden (2011), where the authors calibrate the IMF's GIMF model for the Czech data. These multipliers are used by Ambriško et al. (2012) to quantify the impacts of Czech fiscal policy on real GDP in the period 2001–2011. Their

[3] See Christoffel, Coenen, and Warne (2008) for the latest description of the NAWM and related references therein.

[4] Another line of research focuses on examining the cyclical effects of fiscal policy. An excellent collection of analytical material on the cyclicality of fiscal policy is provided in World Economic Outlook (IMF, 2008).

results also indicate little evidence of countercyclical fiscal policy in the Czech Republic. The latest empirical evidence on the effects of fiscal policy on the Czech economy is provided by Valenta (2011) and Franta (2012). These studies explore VAR-based identification approaches and apply classical (Valenta, 2011) and Bayesian (Franta, 2012) estimation techniques. According to Valenta (2011), the output fiscal multiplier is estimated in the range of 0.3–0.6 in the first year following a shock to government spending, while in Franta (2012) the value of the corresponding multiplier is close to one.

3. Structural DSGE Model

Our structural model is built along the lines of the models by Andrle et al. (2009), Coenen et al. (2012b), Galí (2011), and Galí et al. (2007). The small open economy is populated by two types of representative households, the first type called optimizers or Ricardian households, who can save, and the second type called "rule-of-thumb" consumers or non-Ricardian households, who cannot save and consume all their disposable income. The households consume a final consumption good, which is made from private consumption and government consumption goods. So, we allow government consumption to be productive, i.e., it yields utility to the households. The members of households monopolistically supply a differentiated unit of labor to an employment agency, and wage setting follows Calvo contracts. Besides private capital, there is government (public) capital, which freely enters intermediate domestic goods production. Government expenditures are divided into government consumption, government investment, unemployment benefits, and other social benefits. Government revenues come from consumption, labor, capital, dividend and lump-sum taxes, and social security contributions paid by employers. The government balances its budget by issuing bonds or by adjusting taxes. In the fiscal rules, fiscal instruments (taxes or expenditures) react to the deviations of government debt, output or government consumption from their respective targets. The central bank operates under an inflation targeting regime and follows a standard Taylor interest rate rule. The features of the model are shown in Figure 3.1, where black parts overlap with the g3 model, red parts represent the fiscal sector, and green parts depict tax revenues.

3.1 Households

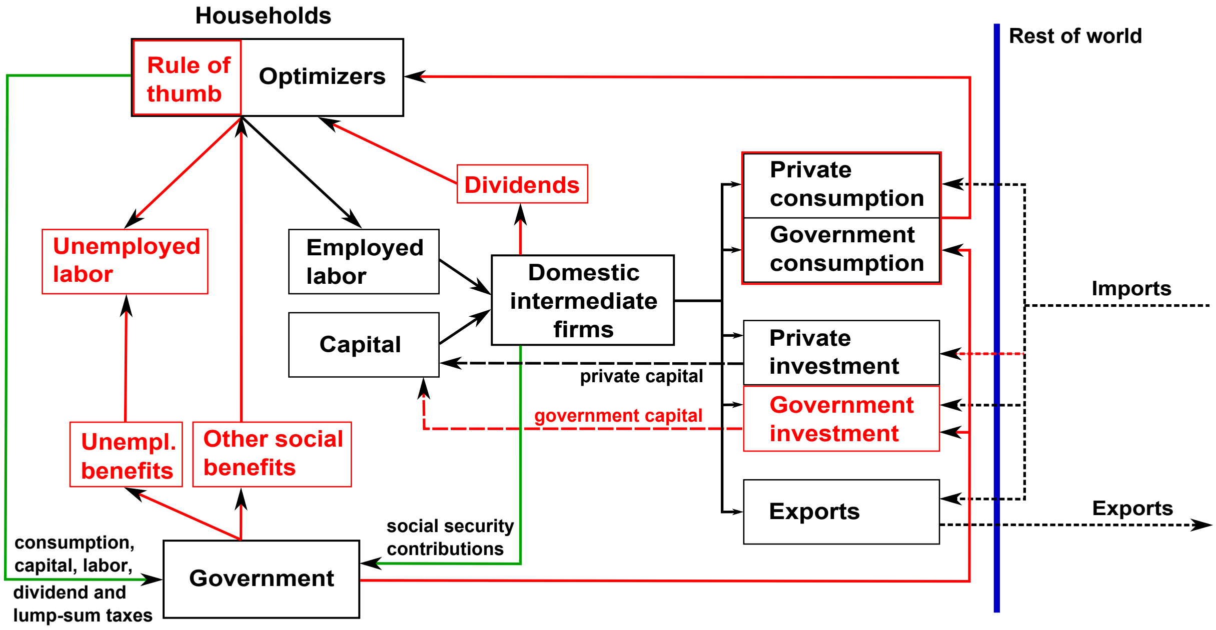
The economy is populated by a continuum of households indexed by $h \in [0,1]$. The households on the interval $[0,\gamma]$ are rule-of-thumb households, and those on $(\gamma,1]$ are Ricardian households. Each household has a continuum of members indexed by a pair $(i,j) \in [0,1] \times [0,1]$, where index i stands for the labor type and index j determines the disutility of work, specified as j^{ϕ_n} when the member is employed and zero otherwise, where $\phi_n \geq 0$ is the elasticity of the marginal disutility of work. Both types of households maximize their lifetime utility function given by:

$$\begin{aligned} E_o \sum_{t=o}^{\infty} \beta^t U_{h,t}^k &= E_o \sum_{t=o}^{\infty} \beta^t \left[\log(C_{h,t}^k - \chi_t^k C_{t-1}) - \theta \int_0^1 \int_0^{L_t^k(i)} j^{\phi_n} dj di \right] = \\ &= E_o \sum_{t=o}^{\infty} \beta^t \left[\log(C_{h,t}^k - \chi_t^k C_{t-1}) - \frac{\theta}{1+\phi_n} \int_0^1 L_t^k(i)^{1+\phi_n} di \right] \end{aligned} \tag{3.1}$$

where $\beta \in (0,1)$ is the discount factor, superscript $k \in \{r,o\}$ distinguishes rule-of-thumb and optimizer households, $C_{h,t}^k$ is the household-specific consumption aggregate, C_{t-1} is the lagged economy-wide level of consumption, $L_t^k(i) \in [0,1]$ is the fraction of members of type i who are employed in households of type k, $\theta > 0$ is a parameter associated with the disutility of labor supply, and $\chi_t^k = \chi^k \exp(\varepsilon_t^{hk})$ is an exogenous process which determines the degree of internal habit formation,[5] with $\chi^k \in [0,1)$ and

[5] Internal habits are preferred to external ones because of more reasonable impulse responses to news shocks, as argued by Nutahara (2010).

Figure 3.1: The Scheme of the Model



Note: Black parts show overlap with the g3 model, red parts represent the fiscal sector, and green parts depict tax revenues.

$\varepsilon_t^{hk} \sim N(0, \sigma^{hk})$. Households' consumption is made up of private and government consumption goods as follows:

$$C_t^k = \left[(\alpha_C)^{\frac{1}{v_C}} \left(C_t^{pk} \right)^{\frac{v_C - 1}{v_C}} + (1 - \alpha_C)^{\frac{1}{v_C}} \left(G_t^k \right)^{\frac{v_C - 1}{v_C}} \right]^{\frac{v_C}{v_C - 1}}, \tag{3.2}$$

where $\alpha_C \in (0, 1]$ is the share of the private good in the consumption aggregate, and $v_C > 0$ is the elasticity of substitution between the private and government consumption good. The government good is equally available to all households, hence $G_t^o = G_t^r = G_t$, and is provided free of charge.

The households of **optimizers** respect the following budget constraint:

$$\begin{aligned} (1 + \tau_t^C) P_t^C C_t^{po} + P_t^I I_t^{po} + B_t^o \quad \leq \quad & (1 - \tau_t^W) \int_0^1 W_t(i) L_t^o(i) di + \\ & + \left[(1 - \tau_t^K) P_t^K + \tau_t^K \delta^p P_t^I \right] K_{t-1}^{po} + \\ & + R_{t-1} B_{t-1}^o + P_t^C SB_t^o - P_t^C T_t^o + (1 - \tau_t^D) D_t^o, \end{aligned} \tag{3.3}$$

where C_t^o is the optimizers' consumption; I_t^{po} denotes optimizers' investment in private capital K_t^{po}; P_t^C, P_t^I are the unit prices of consumption and investment goods; P_t^K is the rental rate of capital; R_t is the domestic nominal gross interest rate; $W_t(i)$ is the nominal wage for labor of type i; τ_t^C, τ_t^W, τ_t^K, τ_t^D are consumption, wage, capital, and dividend taxes, respectively; SB_t^o are social benefits (the sum of unemployment benefits and other social benefits); δ^p is the depreciation rate of private capital; B_t^o are domestic bonds issued by the government and held by optimizers; T_t^o are lump-sum taxes; and D_t^o are dividends from monopolistic firms in the production sectors.

Optimizers own and accumulate a private stock of capital. The capital law of motion involves the type of intertemporal adjustment costs found in Kim (2003):

$$K_t^{po} = \left(K_{t-1}^{po}\right)^{1-\delta^p} \left(ME_t^{po} \frac{I_t^{po}}{\delta^p}\right)^{\delta^p} - \frac{\eta}{2} \left(\frac{I_t^{po}}{I_{t-1}^{po}} - 1\right)^2 K_{t-1}^{po}, \tag{3.4}$$

where $\eta \geq 0$ is the investment adjustment cost parameter and $ME_t^{po} = \left(ME_{t-1}^{po}\right)^{\rho_{mep}} \exp(\varepsilon_t^{mep})$ is an exogenous marginal efficiency booster of investment with persistence $\rho_{mep} \in (0,1)$ and normal innovation $\varepsilon_t^{mep} \sim N(0, \sigma^{mep})$. Furthermore, the depreciation of capital is exempted from capital tax, as stated in the budget constraint for optimizers.

Rule-of-thumb households spend their entire budget on consumption:

$$(1+\tau_t^C) P_t^C C_t^{pr} \leq (1-\tau_t^W) \int_0^1 W_t(i) L_t^r(i) di + P_t^C SB_t^r - P_t^C T_t^r, \tag{3.5}$$

where C_t^r is the rule-of-thumbs' consumption, SB_t^r are social benefits, and T_t^r are lump-sum taxes.

3.2 Production Sectors

There are several production sectors in the economy. All monopolistic firms are owned by optimizers, and firms' profits are rebated to them as dividends, which are subject to dividend tax.

3.2.1 Domestic Intermediate Goods

There is a continuum of domestic intermediate goods firms $z \in [0,1]$, who combine capital $K_{t-1}(z)$ and labor $L_t(z)$ inputs into a single variety of intermediate good according to Cobb-Douglas production technology:

$$Y_t(z) = \varsigma_t \left(A_t L_t(z)\right)^{1-\alpha} K_{t-1}(z)^{\alpha}, \tag{3.6}$$

where ς_t and A_t are the total factor productivity shock and labor-augmenting technology process, and labor input is defined as $L_t(z) = (\int_0^1 [L_t(z,i)]^{\frac{\epsilon_W - 1}{\epsilon_W}} di)^{\frac{\epsilon_W}{\epsilon_W - 1}}$, where ϵ_W is the elasticity of substitution for labor services between individual households. Firm z's labor demand for labor type i is downward sloping:

$$L_t(z,i) = \left[\frac{W_t(i)}{W_t}\right]^{-\epsilon_W} L_t(z), \tag{3.7}$$

where $W_t = (\int_0^1 [W_t(i)]^{1-\epsilon_W} di)^{\frac{1}{1-\epsilon_W}}$ is the aggregate wage index. Due to common production technology, sector-wide production equals:

$$\int_0^1 Y_t(z) dz = \varsigma_t \left(A_t L_t\right)^{1-\alpha} {K_{t-1}}^{\alpha} \tag{3.8}$$

Total capital K_t is the CES aggregate of private (K_t^p) and exogenously given government capital (K_t^g):

$$K_t = \left[(\alpha_K)^{\frac{1}{v_K}} \left(K_t^p\right)^{\frac{v_K - 1}{v_K}} + (1-\alpha_K)^{\frac{1}{v_K}} \left(K_t^g\right)^{\frac{v_K - 1}{v_K}}\right]^{\frac{v_K}{v_K - 1}}, \tag{3.9}$$

where $\alpha_K \in [0,1]$ is the share of private capital in the capital aggregate and $v_K > 0$ is the elasticity of substitution between private and government capital.

Intermediate firms minimize the total costs of production $P_t^K K_{t-1}^p(z) + (1+\tau_t^S)W_t L_t(z)$, given their production function in (3.6). Note that labor costs include social security contributions paid by employers, represented by the implicit tax rate τ_t^S. Cost minimization yields the following factor demands:

$$\frac{P_t^K}{P_t^Y} = RMCY_t \alpha \frac{Y_t}{K_{t-1}} \left(\frac{\alpha_K K_{t-1}}{K_{t-1}^p} \right)^{\frac{1}{v_K}} \tag{3.10}$$

$$(1+\tau_t^S)\frac{W_t}{P_t^Y} = RMCY_t(1-\alpha)\frac{Y_t}{L_t}, \tag{3.11}$$

where the firm's index z is omitted because of symmetry, and $RMCY_t$ denotes real marginal costs in intermediate production.

The prices of intermediate goods are sticky *à la* Calvo (1983). In each period, firm z has the opportunity to optimally adjust prices with probability $1-\xi_Y$. The remaining firms, which are not allowed to optimally adjust their prices in a given period, automatically index prices using the last-known sector-wide inflation Π_t^Y (e.g. $P_t^Y(z) = P_{t-1}^Y(z)\Pi_{t-1}^Y$). This pricing implies the following Phillips curve:

$$\log \frac{\Pi_t^Y}{\Pi_{t-1}^Y} = \beta \log \frac{\Pi_{t+1}^Y}{\Pi_t^Y} + \frac{(1-\xi_Y)(1-\beta\xi_Y)}{\xi_Y} \log(RMCY_t \Theta^Y) + \varepsilon_t^Y, \tag{3.12}$$

where Θ^Y is the price markup and ε_t^Y is the cost-push shock.[6]

Intermediate production is sold to the consumption, investment, government, and export-producing sectors as inputs for further production:

$$Y_t = Y_t^C + Y_t^I + Y_t^G + Y_t^X \tag{3.13}$$

3.2.2 Imported Goods

A continuum of imported goods firms $z^N \in [0,1]$ imports varieties of foreign intermediate goods according to the CES production technology:

$$N_t(z^N) = a_t^N \left[\int_0^1 [o_t(f)]^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, \tag{3.14}$$

where a_t^N is a stationary productivity shock, $o_t(f)$ denotes the imported CES bundle from country $f \in [0,1]$, and $\theta > 1$ is the elasticity of substitution across imported bundles. Sector-wide imported goods production is sold on to the consumption, investment, and export sectors:

$$\int_0^1 N_t(z^N) dz^N = N_t^C + N_t^I + N_t^X \tag{3.15}$$

Sticky prices of intermediate goods result in a standard Phillips curve analogous to the one in the domestic intermediate goods sector.

[6] When estimating the model we also tried a version with simple indexation to the previous price level, but the results turned out in favor of inflation indexation based on the value of the marginal likelihood.

3.2.3 Consumption Goods

There is a continuum of consumption goods firms $z^C \in [0,1]$, who combine imported and domestic intermediate goods into the private consumption good with the CES technology. Sector-wide private consumption equals:

$$\int_0^1 C_t^p(z^C)dz^C = \left[(\omega_C)^{\frac{1}{\eta_C}}\left(N_t^C\right)^{\frac{\eta_C-1}{\eta_C}} + (1-\omega_C)^{\frac{1}{\eta_C}}\left(Y_t^C\right)^{\frac{\eta_C-1}{\eta_C}}\right]^{\frac{\eta_C}{\eta_C-1}}, \tag{3.16}$$

where ω_C is the share of imported goods in the private consumption bundle and $\eta_C > 0$ is the elasticity of substitution between domestic and imported intermediate goods. The prices of private consumption goods are sticky, and a similar Phillips curve as in other production sectors can be obtained.

3.2.4 Investment Goods

Similarly to consumption goods firms, investment goods firms $z^I \in [0,1]$ buy imported and domestic intermediate inputs and produce varieties of investment goods. Sector-wide investment goods production is defined as:

$$\int_0^1 I_t(z^I)dz^I = a_t^I\left[(\omega_I)^{\frac{1}{\eta_I}}\left(N_t^I\right)^{\frac{\eta_I-1}{\eta_I}} + (1-\omega_I)^{\frac{1}{\eta_I}}\left(Y_t^I\right)^{\frac{\eta_I-1}{\eta_I}}\right]^{\frac{\eta_I}{\eta_I-1}}, \tag{3.17}$$

where ω_I is the share of imported inputs in the investment bundle, $\eta_I > 0$ is the elasticity of substitution between domestic and imported intermediate goods, and a_t^I is the stationary investment-specific technology shock. Investment goods production is sold to households and government, that is, $I_t = I_t^p + I_t^g$. Prices of investment goods are sticky as in the other production sectors.

3.2.5 Export Goods

Export goods firms $z^X \in [0,1]$ put together imported and domestic intermediate goods into varieties of export goods using the CES technology. Sector-wide export goods production is equal to:

$$\int_0^1 X_t(z^X)dz^X = \left[(\omega_X)^{\frac{1}{\eta_X}}\left(N_t^X\right)^{\frac{\eta_X-1}{\eta_X}} + (1-\omega_X)^{\frac{1}{\eta_X}}\left(Y_t^X\right)^{\frac{\eta_X-1}{\eta_X}}\right]^{\frac{\eta_X}{\eta_X-1}}, \tag{3.18}$$

where ω_X is the share of imported goods in the export goods bundle, and $\eta_X > 0$ is the elasticity of substitution between domestic and imported intermediate goods. In contrast to other production sectors, the prices of export goods are sticky in foreign currency, which gives the following Phillips curve:

$$\log\frac{\widetilde{\Pi}_t^X}{\widetilde{\Pi}_{t-1}^X} = \beta\log\frac{\widetilde{\Pi}_{t+1}^X}{\widetilde{\Pi}_t^X} + \frac{(1-\xi_X)(1-\beta\xi_X)}{\xi_X}\log\left(RMCX_t\Theta^X\right) + \varepsilon_t^X, \tag{3.19}$$

where $\xi_X > 0$ is the Calvo signal parameter, Θ^X is the export price markup, $RMCX_t$ are real marginal costs in the export goods sector, ε_t^X is the export cost-push shock, and the link $\Pi_t^X = \frac{S_t}{S_{t-1}}\widetilde{\Pi}_t^X$ holds between export goods inflation in domestic currency and export goods inflation in foreign currency, with S_t denoting the nominal exchange rate (defined as the price of foreign currency expressed in the domestic currency).

Demand for domestic export goods moves in line with foreign demand as follows:

$$X_t = \left(\frac{P_t^X}{P_t^*}\right)^{-\theta_X} N_t^*, \tag{3.20}$$

where $\theta_X > 0$ is the price elasticity of exports, N_t^* is exogenous foreign demand, and P_t^* is the exogenously given foreign price level (expressed in the domestic currency).

3.2.6 Government Goods

Government goods firms $z^G \in [0,1]$ transform domestic intermediate inputs into varieties of government goods. Sector-wide government goods production equals:

$$\int_0^1 G_t(z^G)dz^G = a_t^G Y_t^G, \tag{3.21}$$

where a_t^G is the stationary government technology shock. Government goods are freely available to all households; one can think of roads, hospitals, the police, the fire brigade, and other public goods and services that yield some utility to households. The pricing of government goods involves nominal rigidities similarly to the other production sectors.

3.3 Wage Contracts

We assume that both types of households supply their labor services to an employment agency, which costlessly bundles labor services into the CES aggregate. Wages are set by the employment agency in the Calvo manner, so each period the employment agency is able to renegotiate nominal wages for its workers with probability $1-\xi_W$. Nominal wages for the remaining workers, for which the employment agency did not have the chance to renegotiate wages, are automatically indexed to the last-known sector-wide wage inflation. Having determined wages, the employment agency distributes workers to the firms according to their demand, sending those workers with the lowest disutility of work first. At the end, the employment agency collects the wage income and pools it equally among all households. Therefore, the wage is common to both types of households, i.e., $W_t = W_t^o = W_t^r$, and together with the assumption of same preferences across households this implies that the employed labor supply of optimizers and rule-of-thumb households is $L_t^o = L_t^r = L_t$.

Formally, when renegotiating wages, the employment agency chooses the new nominal wage $W_t^*(i)$ for workers of type i to maximize the following objective function:

$$\max_{W_t^*(i)} E_t \sum_{s=0}^{\infty} (\beta\xi_W)^{t+s} \left\{ \begin{array}{c} (1-\gamma)\left[\lambda_{t+s}^{co}(i)(1-\tau_{t+s}^W)W_t^*(i)\frac{W_{t+s-1}}{W_{t-1}}L_{t+s}^o(i)\right] \\ +\gamma\left[\lambda_{t+s}^{cr}(i)(1-\tau_{t+s}^W)W_t^*(i)\frac{W_{t+s-1}}{W_{t-1}}L_{t+s}^r(i)\right] \\ -\left[(1-\gamma)\theta\frac{\left(L_{t+s}^o(i)\right)^{1+\phi_n}}{1+\phi_n} + \gamma\theta\frac{\left(L_{t+s}^r(i)\right)^{1+\phi_n}}{1+\phi_n}\right] \end{array} \right\} \tag{3.22}$$

subject to the labor demand condition:

$$L_t(i) = \left[\frac{W_t(i)}{W_t}\right]^{-\epsilon^W} L_t \tag{3.23}$$

The first order condition gives the following expression:

$$E_t \sum_{s=0}^{\infty} (\beta\xi_W)^{t+s} \frac{\left(L_{t+s}^o(i)\right)^{1+\phi_n}}{W_t^*(i)} \left[\begin{array}{c} \left(\frac{1-\gamma}{MRS_{t+s}^o(i)} + \frac{\gamma}{MRS_{t+s}^r(i)}\right)(1-\tau_{t+s}^W)W_t^*(i)\frac{W_{t+s-1}}{W_{t-1}} \\ -\Theta^W \end{array} \right] = 0, \tag{3.24}$$

where $\Theta^W = \frac{\epsilon^W}{\epsilon^W - 1}$ is the desired (flexible) wage markup and $MRS_t^o(i)$, $MRS_t^r(i)$ are the marginal rates of substitution between labor and consumption for labor type i in the optimizers' and rule-of-thumb households. Log-linearizing this condition, and using the definition for the aggregate wage index W_t (defined in Section 3.2.1), one can obtain the following wage Phillips curve:

$$\log\frac{\Pi_t^W}{\Pi_{t-1}^W} = \beta\log\frac{\Pi_{t+1}^W}{\Pi_t^W} - \frac{(1-\xi_W)(1-\beta\xi_W)}{\xi_W(1+\epsilon^W\phi_n)}\log\frac{\Theta_t^W}{\Theta^W} + \varepsilon_t^W, \tag{3.25}$$

where $\Theta_t^W = \frac{(1-\tau_t^W)W_t}{P_t MRS_t}$ is the average wage markup (the ratio of the after-tax real wage to the average marginal rate of substitution between labor and consumption for both types of households MRS_t) and ε_t^W is the wage cost-push shock. Wage inflation is rising with expected higher wage inflation in the next period, and is decreasing with deviation of the average wage markup from the desired/flexible wage markup.

The household-relevant marginal rate of substitution between consumption and employment for type i workers in households of type k can be expressed as:

$$MRS_t^k(i) = -\frac{U_{n(i),t}^k}{U_{c,t}^k} = \frac{\theta \left[L_t^k(i)\right]^{\phi_n}}{\lambda_t^{ck}}, \tag{3.26}$$

where λ_t^{ck} is the shadow price of consumption (the Lagrange multiplier associated with the budget constraint for the respective type of household k). Taking logs and integrating over all labor and household types:

$$mrs_t = \log\theta + \phi_n l_t - \tilde{\lambda}_t^c, \tag{3.27}$$

where $mrs_t = \int_0^1 mrs_t(i)di$ is the log average marginal rate of substitution, $l_t = \int_0^1 l_t(i)di$ is log aggregate employment, and $\tilde{\lambda}_t^c = \gamma \log \lambda_t^{cr} + (1-\gamma)\log\lambda_t^{co}$ is the log average shadow price of consumption.

3.3.1 Unemployment

The unemployment introduced into this model uses the framework of Galí (2011), where unemployment is a result of workers' market power, i.e., wages are set above their competitive levels, and unemployment fluctuations arise because of slow adjustment of nominal wages. For any member of the household it is optimal to participate in the labor market if his after-tax real wage is higher than his disutility of work, deflated by the shadow price of consumption:

$$\frac{(1-\tau_t^W)W_t(i)}{P_t^C} \geq \frac{\theta j^{\phi_n}}{\lambda_t^c} \tag{3.28}$$

For a marginal supplier of labor type i, who is indifferent to working and not working and is denoted as $L_t^P(i)$, the following holds:

$$\frac{(1-\tau_t^W)W_t(i)}{P_t^C} = \frac{\theta \left[L_t^P(i)\right]^{\phi_n}}{\lambda_t^{ck}} \tag{3.29}$$

Taking logs and integrating over all labor types i and households k:

$$\log(1-\tau_t^W) + w_t - p_t^c = \log\theta + \phi_n l_t^P - \tilde{\lambda}_t^c, \tag{3.30}$$

where $w_t = \int_0^1 w_t(i)di$ is the log aggregate wage index and $l_t^P = \int_0^1 l_t^P(i)di$ is the log aggregate participation or labor force. The unemployment rate is defined as the difference between the log aggregate labor force and employment:

$$u_t = l_t^P - l_t \tag{3.31}$$

Combining equations (3.27) and (3.30) with the expression for the average wage markup, the following simple relationship between the wage markup and the unemployment rate arises:

$$\log\Theta_t^W = \phi_n u_t \tag{3.32}$$

This expression can be substituted back into the wage Phillips curve (3.25), so wage inflation can be directly related to unemployment fluctuations. Wage inflation is decreasing when the unemployment rate is high. In the absence of wage rigidities, we can define the concept of the natural rate of unemployment u_t^n. Assuming a constant desired wage markup Θ^W, it follows that the natural rate of unemployment is constant as well and can be expressed as:

$$u^n = \frac{\log \Theta^W}{\phi_n} \tag{3.33}$$

3.4 Foreign Block

The model features a version of the uncovered interest rate parity (UIP) condition as follows:

$$S_t R_t = (E_t S_{t+1})^{\rho_s} (S_{t-1})^{1-\rho_s} R_t^* prem_t \exp(\varepsilon_t^{uip}) \tag{3.34}$$

$$prem_t = (prem_{t-1})^{\rho_p} \exp(-\zeta_B B_t^* + \varepsilon_t^{prem}), \tag{3.35}$$

where S_t is the nominal exchange rate, R_t^* is the foreign gross nominal interest rate, $prem_t$ is the foreign debt-elastic risk premium, $\rho_s \in [0, 1]$ is a parameter that introduces partial sluggishness into the UIP relationship, $\rho_p \in [0, 1)$ is the persistence parameter in the risk premium, B_t^* denotes holdings of foreign currency bonds expressed in the domestic currency, $\zeta_B > 0$ is the parameter measuring the elasticity of the risk premium with respect to holdings of foreign bonds, and $\varepsilon_t^{uip}, \varepsilon_t^{prem}$ are normally distributed shocks.

The trade balance equals the value of exports less the value of imports:

$$TB_t = P_t^X X_t - P_t^* N_t, \tag{3.36}$$

where P_t^* is the foreign price level expressed in domestic currency, i.e., $P_t^* = S_t \widetilde{P}_t^*$, where $\widetilde{P}_t^*$ is the foreign price level in foreign currency.

The net foreign debt law of motion is given by the following relationship:

$$B_t^* = \frac{S_t}{S_{t-1}} B_{t-1}^* R_{t-1}^* + TB_t \tag{3.37}$$

As we are modeling a small open economy, the foreign variables – specifically foreign inflation, the foreign gross nominal interest rate, and foreign demand – are exogenously given:

$$\begin{aligned} \widetilde{\Pi}_t^* &= \left(\widetilde{\Pi}_{t-1}^*\right)^{\rho_{ps}} \exp(\varepsilon_t^{ps}) \\ \frac{R_t^*}{\bar{R}} &= \left(\frac{R_{t-1}^*}{\bar{R}}\right)^{\rho_{rs}} \exp(\varepsilon_t^{rs}) \\ \frac{N_t^*}{\bar{N}^*} &= \left(\frac{N_{t-1}^*}{\bar{N}^*}\right)^{\rho_{ns}} \exp(\varepsilon_t^{ns}), \end{aligned} \tag{3.38}$$

where $\widetilde{\Pi}_t^* = \widetilde{P}_t^* / \widetilde{P}_{t-1}^*$, the steady states for foreign inflation and foreign nominal interest rates equal the steady states of their domestic counterparts, the ρ's from $[0, 1)$ measure the persistences of the exogenous processes, and ε's are normally distributed shocks.

3.5 Fiscal Block

Government expenditures comprise government consumption, government investment, unemployment benefits and other social benefits provided to households, and interest payments paid on issued debt. The government can issue bonds to finance its expenditures. Government revenues are made up of consumption, labor, capital, dividend and lump-sum taxes, and social security contributions paid by employers. The total government budget balance can be computed by subtracting government expenditures from government revenues:

$$\begin{aligned} BB_t &= \tau_t^C P_t^C C_t^p + \left(\tau_t^W + \tau_t^S\right) W_t L_t + \tau_t^K \left(P_t^K - \delta^p P_t^I\right) K_{t-1}^p + \tau_t^D D_t + P_t^C T_t \\ &\quad - P_t^G G_t - P_t^I I_t^g - P_t^C SB_t - (R_{t-1} - 1) B_{t-1} \end{aligned} \tag{3.39}$$

The primary government budget balance equals the total government budget balance plus interest payments:

$$PB_t = BB_t + (R_{t-1} - 1) B_{t-1} \tag{3.40}$$

The government's budget constraint follows:

$$B_{t-1} - BB_t = R_{t-1} B_{t-1} - PB_t = B_t \tag{3.41}$$

Note that in equilibrium the level of government debt is stable and the government's budget is balanced. Government capital evolves according to a similar law of motion as private capital, but a different depreciation rate δ^g is allowed for government capital:

$$K_t^g = \left(K_{t-1}^g\right)^{1-\delta^g} \left(ME_t^g \frac{I_t^g}{\delta^g}\right)^{\delta^g} - \frac{\eta}{2} \left(\frac{I_t^g}{I_{t-1}^g} - 1\right)^2 K_{t-1}^g, \tag{3.42}$$

where $ME_t^g = \left(ME_{t-1}^g\right)^{\rho_{meg}} \exp(\varepsilon_t^{meg})$ is an exogenous marginal efficiency booster of government investment with $\rho_{meg} \in (0,1)$ and $\varepsilon_t^{meg} \sim N(0, \sigma^{meg})$.

The government sets all fiscal instruments on the expenditure and revenue side. For modeling purposes these are assumed to follow two alternative fiscal rules. In the first version, we adopt a simple fiscal rule as in Galí et al. (2007) where only lump-sum transfers adjust to deviations of real debt and government consumption from their targets (steady states):

$$\frac{T_t - \bar{T}}{\bar{Y}} = \phi_b \frac{b_t - \bar{b}}{\bar{Y}} + \phi_g \frac{G_t - \bar{G}}{\bar{Y}} + \varepsilon_t^{tt}, \tag{3.43}$$

where $b_t = \frac{B_t}{P_t^Y}$ is real debt, $\phi_b, \phi_g > 0$ are feedback coefficients, and $\varepsilon_t^{tt} \sim N(0, \sigma^{tt})$ is a normally distributed shock. The remaining fiscal instruments follow simple exogenous autoregressive processes. On the expenditure side we have:

$$\begin{aligned} G_t &= \left(\bar{G}\right)^{1-\rho_g} \left(G_{t-1}\right)^{\rho_g} \exp(\varepsilon_t^g) \\ I_t^g &= \left(\bar{I}^g\right)^{1-\rho_{ig}} \left(I_{t-1}^g\right)^{\rho_{ig}} \exp(\varepsilon_t^{ig}) \\ UB_t &= \left(\bar{UB}\right)^{1-\rho_{ub}} \left(UB_{t-1}\right)^{\rho_{ub}} \left(\frac{u_t}{u^n}\right)^{\phi_u} \exp(\varepsilon_t^{ub}), \\ OB_t &= \left(\bar{OB}\right)^{1-\rho_{ob}} \left(OB_{t-1}\right)^{\rho_{ob}} \exp(\varepsilon_t^{ob}), \end{aligned} \tag{3.44}$$

where $\phi_u > 0$ is the feedback coefficient for deviations of the unemployment rate from its steady state. On the revenue side, fiscal instruments are represented by implicit tax rates:

$$\begin{aligned}
\tau_t^C &= \left(\bar{\tau}^C\right)^{1-\rho_{tc}} \left(\tau_{t-1}^C\right)^{\rho_{tc}} \exp(\varepsilon_t^{tc}) \\
\tau_t^K &= \left(\bar{\tau}^K\right)^{1-\rho_{tk}} \left(\tau_{t-1}^K\right)^{\rho_{tk}} \exp(\varepsilon_t^{tk}) \\
\tau_t^W &= \left(\bar{\tau}^W\right)^{1-\rho_{tw}} \left(\tau_{t-1}^W\right)^{\rho_{tw}} \exp(\varepsilon_t^{tw}) \\
\tau_t^S &= \left(\bar{\tau}^S\right)^{1-\rho_{ts}} \left(\tau_{t-1}^S\right)^{\rho_{ts}} \exp(\varepsilon_t^{ts}) \\
\tau_t^D &= \left(\bar{\tau}^D\right)^{1-\rho_{td}} \left(\tau_{t-1}^D\right)^{\rho_{td}} \exp(\varepsilon_t^{td}),
\end{aligned} \tag{3.45}$$

where for each $x \in \{g, ig, sb, tc, tk, tw, ts, td\}$ autoregressive coefficients $\rho_x \in [0, 1)$, shocks ε_t^x have normal distributions, and the hats denote steady states.

In the alternative version, a richer specification of fiscal rules is used, as found, for example, in Leeper et al. (2010). All fiscal instruments react to deviations of output and debt from their steady states. The only exception is the consumption tax, which has no feedback to output or debt. Allowing for feedback effects, fiscal instruments can act procyclically or countercyclically on the economy. Furthermore, on the revenue side shocks affecting one tax can affect other taxes as well. The motivation for such shocks is that the government often adjusts taxes jointly. The set of fiscal rules is as follows:

$$\begin{aligned}
\frac{G_t}{\bar{G}} &= \left(\frac{Y_t}{\bar{Y}}\right)^{-\phi_{yg}} \left(\frac{b_t}{\bar{b}}\right)^{-\phi_{bg}} u_t^g \\
\frac{I_t^g}{\bar{I}^g} &= \left(\frac{Y_t}{\bar{Y}}\right)^{-\phi_{yig}} \left(\frac{b_t}{\bar{b}}\right)^{-\phi_{big}} u_t^{ig} \\
\frac{UB_t}{\bar{UB}} &= \left(\frac{Y_t}{\bar{Y}}\right)^{-\phi_{yub}} \left(\frac{b_t}{\bar{b}}\right)^{-\phi_{bub}} \left(\frac{u_t}{u^n}\right)^{\phi_u} u_t^{ub} \\
\frac{OB_t}{\bar{OB}} &= \left(\frac{Y_t}{\bar{Y}}\right)^{-\phi_{yob}} \left(\frac{b_t}{\bar{b}}\right)^{-\phi_{bob}} u_t^{ob}
\end{aligned} \tag{3.46}$$

$$\begin{aligned}
\frac{\tau_t^C}{\bar{\tau}^C} &= \left(u_t^{tk}\right)^{\phi_{kc}} \left(u_t^{tw}\right)^{\phi_{wc}} \left(u_t^{ts}\right)^{\phi_{sc}} \left(u_t^{td}\right)^{\phi_{dc}} u_t^{tc} \\
\frac{\tau_t^K}{\bar{\tau}^K} &= \left(\frac{Y_t}{\bar{Y}}\right)^{\phi_{ytk}} \left(\frac{b_t}{\bar{b}}\right)^{\phi_{btk}} \left(u_t^{tc}\right)^{\phi_{kc}} \left(u_t^{tw}\right)^{\phi_{kw}} \left(u_t^{ts}\right)^{\phi_{sk}} \left(u_t^{td}\right)^{\phi_{dk}} u_t^{tk} \\
\frac{\tau_t^W}{\bar{\tau}^W} &= \left(\frac{Y_t}{\bar{Y}}\right)^{\phi_{ytw}} \left(\frac{b_t}{\bar{b}}\right)^{\phi_{btw}} \left(u_t^{tc}\right)^{\phi_{wc}} \left(u_t^{tk}\right)^{\phi_{kw}} \left(u_t^{ts}\right)^{\phi_{sw}} \left(u_t^{td}\right)^{\phi_{dw}} u_t^{tw} \\
\frac{\tau_t^S}{\bar{\tau}^S} &= \left(\frac{Y_t}{\bar{Y}}\right)^{\phi_{yts}} \left(\frac{b_t}{\bar{b}}\right)^{\phi_{bts}} \left(u_t^{tc}\right)^{\phi_{sc}} \left(u_t^{tk}\right)^{\phi_{sk}} \left(u_t^{tw}\right)^{\phi_{sw}} \left(u_t^{td}\right)^{\phi_{ds}} u_t^{ts} \\
\frac{\tau_t^D}{\bar{\tau}^D} &= \left(\frac{Y_t}{\bar{Y}}\right)^{\phi_{ytd}} \left(\frac{b_t}{\bar{b}}\right)^{\phi_{btd}} \left(u_t^{tc}\right)^{\phi_{dc}} \left(u_t^{tk}\right)^{\phi_{dk}} \left(u_t^{tw}\right)^{\phi_{dw}} \left(u_t^{ts}\right)^{\phi_{ds}} u_t^{td} \\
\frac{T_t}{\bar{T}} &= \left(\frac{Y_t}{\bar{Y}}\right)^{\phi_{ytt}} \left(\frac{b_t}{\bar{b}}\right)^{\phi_{btt}} u_t^{tt} \\
u_t^x &= \left(u_{t-1}^x\right)^{\rho_x} \exp(\varepsilon_t^x), \; x \in \{g, ig, ub, ob, tc, tk, tw, ts, td, tt\},
\end{aligned} \tag{3.47}$$

where $\phi_{yx}, \phi_{bx}, \phi_u$ are the feedback coefficients for output, debt, and unemployment, respectively. If ϕ_{yx} is positive (negative), then a given fiscal instrument has a countercyclical (procyclical) component. The shocks u_t^x are serially correlated, $\rho_x \in [0, 1)$, and ε_t^x are normal innovations. The remaining "cross-tax" co-movement coefficients $\phi_{[..]}$ (powering the u_t^x shocks) measure how much an unexpected movement in one tax affects another tax.

As we have two types of households in the model, lump-sum taxes might not necessarily adjust equally for the two types of households. Therefore, we allow the following redistribution of lump-sum taxes:

$$T_t^o - \bar{T}^o = \phi_l \left(T_t^r - \bar{T}^r \right) \tag{3.48}$$

where $\phi_l > 0$ measures the relative degree of lump-sum taxation of optimizers compared to rule-of-thumb households. If $\phi_l = 1$ and some stochastic shock hits the economy, then the relative change in the lump-sum taxation of the two types of households is the same.

3.6 Monetary Policy

The central bank operates under a regime of inflation targeting and sets the nominal gross interest rate according to the following Taylor rule:

$$R_t = (R_{t-1})^{\rho_i} \left[\bar{R} \left(\frac{\Pi_{t+4}^{C4}}{\overline{\Pi}} \right)^{\phi_\pi} \right]^{1-\rho_i} \exp(\varepsilon_t^M), \tag{3.49}$$

where $\bar{R}$ is the steady state nominal gross interest rate, $\Pi_t^{C4} = P_t^C / P_{t-4}^C$ is year-on-year CPI inflation, which excludes changes in indirect taxation, $\overline{\Pi}$ is the inflation target, $0 \leq \rho_i < 1$ is the interest rate smoothing parameter, $\phi_\pi > 1$ is the feedback coefficient for inflation deviations from the inflation target, and ε_t^M is a normally distributed monetary policy shock. The central bank targets the year-on-year deviation of CPI inflation from its target four periods ahead.

3.7 Aggregation

The aggregate per-capita level of household-relevant variables is given by $X_t = \int_0^1 X_t(h)dh$, which can be translated into the following individual relationships:

$$\begin{aligned}
C_t &= \gamma C_t^r + (1-\gamma) C_t^o \\
C_t^p &= \gamma C_t^{pr} + (1-\gamma) C_t^{po} \\
G_t &= \gamma G_t^r + (1-\gamma) G_t^o \\
UB_t &= \gamma UB_t^r + (1-\gamma) UB_t^o \\
OB_t &= \gamma OB_t^r + (1-\gamma) OB_t^o \\
SB_t &= UB_t + OB_t \\
T_t &= \gamma T_t^r + (1-\gamma) T_t^o \\
L_t &= \gamma L_t^r + (1-\gamma) L_t^o,
\end{aligned} \tag{3.50}$$

and because only optimizers save, accumulate private capital, and own firms, the remaining aggregate quantities are defined as:

$$\begin{aligned}
B_t &= (1-\gamma) B_t^o \\
K_t^p &= (1-\gamma) K_t^{po} \\
I_t^p &= (1-\gamma) I_t^{po} \\
D_t &= (1-\gamma) D_t^o
\end{aligned} \tag{3.51}$$

Nominal GDP can be calculated by evaluating the individual expenditure components:

$$GDP_t = P_t^C C_t^p + P_t^I I_t + P_t^G G_t + P_t^X X_t - P_t^* N_t \tag{3.52}$$

As we have several production sectors in the model with their own price levels, there is no single-good counterpart of real GDP. Nonetheless, to study the dynamics of real GDP it is possible to use some sort of approximation; for example, we construct real GDP as:

$$\log RGDP_t = \frac{P^C C^p}{GDP} \log C_t^p + \frac{P^I I}{GDP} \log I_t + \frac{P^G G}{GDP} \log G_t + \frac{P^X X}{GDP} \log X_t - \frac{P^* N}{GDP} \log N_t \tag{3.53}$$

3.8 Calibration

The parameters of the model were either calibrated or estimated on Czech data. In this section we describe the parameters of the model which were calibrated. For comparison purposes, our calibration mainly follows Andrle et al. (2009) and Galí et al. (2007). The complete list of calibrated parameters and steady state ratios can be found in Table A.1 in the Appendix.

Discount factor β is set so that the annualized equilibrium real interest rate equals 3%. The disutility of labor supply parameter θ was set to 5 to pin down the steady state labor supply at a value of roughly 1/3. The habit parameter is same for both types of households and equals 0.75. The capital share α equals 1/3. The share of the private good in the consumption good α_C is assumed to be 0.8, and the share of private capital in the capital composite α_K equals 0.9. The depreciation of capital, both private and government, is set to an annualized value of 6%. The investment adjustment cost parameter η equals 0.2.

Concerning monetary policy, the inflation feedback parameter ϕ_π is set to 2, interest rate smoothing ρ_i equals 0.75, and the gross inflation target is unitary since the model works with detrended variables. The parameters of the simple fiscal rule are set according to Galí et al. (2007), that is, government consumption feedback $\phi_g = 0.1$ and debt feedback $\phi_b = 0.33$. The parameters of the alternative richer fiscal rules were estimated. However, some of the coefficients – specifically the co-movement coefficient between consumption and capital taxes and the co-movement coefficients for the dividend tax – turned out to be insignificantly different from zero, so these were set to zero. On top of that, the co-movement coefficient between consumption and the wage tax was set to zero, which somewhat helped to improve the inflation responses to the consumption tax shock.[7] The coefficient ϕ_l, which drives lump-sum tax allocation between optimizers and rule-of-thumb households, is set to 1.

On the revenue side, the model works with implicit (or effective) tax rates, and their steady states are based on OECD data, which are discussed in detail later (in Section 3.10.1). Specifically, the equilibrium implicit tax rates were set as follows: the consumption tax at 20%, the wage tax at 10%, the capital tax at 19%, and social security contributions paid by employers at 24%. The dividend tax was turned off, because the impulse response functions to the dividend shock lacked economic intuition; to be more specific, an increase in the dividend tax led to an increase in real GDP. The steady state value for the unemployment rate, also denoted as the natural rate of unemployment, is set to 6.5%, which is the long-run average for the Czech Republic.

The share of rule-of-thumb households is calibrated to 40%.[8] A roughly similar share of 37% was used by Štork and Závacká (2010). The share of imported goods in private consumption was set to 15%, the

[7] This generated a stronger inflationary response, whereas before there had been an inflationary response followed by an anti-inflationary response of roughly the same magnitude.

[8] This share can also be justified by a recent Gallup poll, where 40% of approximately 1,000 Czechs questioned said that they did not expect to make ends meet (Ipsos Tambor, 2012).

share of imported inputs, which feeds into the total investment composite, equals 70%, and the share of imported goods in the export good was calibrated to 55%. The ratio of government consumption to domestic intermediate output was set to 25%, the share of government investment in output equals 3%, unemployment benefits represents 0.3% of output, other social benefits make up 14% of output, and the debt (bonds) is calibrated to 60% of output. These ratios can be expressed in nominal terms and with respect to the model's implied nominal GDP value, and the resulting ratios are in line with Czech data. For example, the steady state nominal debt to GDP ratio is roughly 45%, close to the government's current level of indebtedness.

There is a significant degree of stickiness in each production sector, with the Calvo signaling parameters ranging between 0.5 and 0.8. The elasticities between goods varieties are set to 6, implying 17% mark-ups in production sectors. The elasticity between labor varieties is pinned down from equation (3.33) – substituting the steady state value of the natural rate of unemployment and the estimated value of the inverse of the Frisch elasticity gives a wage markup of approximately 20%, which can be translated into an elasticity of labor varieties of 5.9. The elasticity η_C between domestic and imported goods in the consumption composite good is set to 2.1, and the elasticities η_I, η_X between domestic and imported goods in investment and export composite goods are both set to 0.5. The price elasticity of exports θ_X equals 1.2, and the elasticity of the risk premium with respect to foreign bonds is 0.005.

Exogenous processes involve different degrees of persistence captured by the ρ coefficients. The exact values are provided in the Appendix.

3.9 Estimation

As our model contains quite a large number of parameters, it would be a tedious task to estimate all of them at once. We intend to keep approximately half of the model parameters fixed, for which we have two reasons. First, some of our model structures overlap with the CNB's g3 model, which can serve as a reference point for calibration. Second, convergence of the estimation is of course a function of the magnitude of the parameter space, and thus to avoid the curse of dimensionality we concentrate only on a parameter subset. On the other hand, we have a rich data set of various fiscal measures. This enables us to identify the parameters in the fiscal feedback rules that are most relevant to us in this study.

Many of the modeled variables have reasonable counterparts in real data,[9] so it is possible to add a block of measurement equations and inspect the solution of the model via Kalman filtering. This technique also provides the value of the logarithm of the likelihood function for a given parametrization of the model, which is useful when estimating the model parameters using Bayesian methods. Parameters in autoregressive processes measuring the persistences and volatility are estimated, where possible, equation by equation on real data (this is the case, for example, with the foreign AR(1) processes).

Estimation of the model parameters is carried out in the Dynare Toolbox.[10] The prior distributions of a subset of the model parameters get combined with the likelihood function based on the observed data. This results in the posterior distributions for particular parameters. First, we instruct Dynare to use numerical optimization techniques to search for the posterior modes. Next, we draw from the posterior distributions around these modes with help of the random walk Metropolis-Hastings algorithm. To make sure that convergence of the posterior simulations has been achieved, we run two parallel MH blocks of length 200,000 draws. Both simulations result in acceptance rates of just over 56%. Half of the

[9] Data treatment is discussed further in a separate section.
[10] This Matlab-based toolbox is a suitable framework for Bayesian estimations. For further information see www.dynare.org.

draws get thrown away as a burn-in. Figures A.1 through A.4 show the comparison of the prior/posterior distributions and the results of the multivariate convergence diagnostic test.

The prior distributions for the estimated parameters were chosen as follows. We assume the normal distribution type for all model parameters except for the standard deviations of the shocks. Due to the zero lower bound, we impose an inverse gamma distribution on these parameters. Along the lines of Galí (2011) we calibrate the mean value of the inverse Frisch elasticity at around 2. The elasticities of substitution between the private and government inputs in the CES aggregates for consumption and capital, υ_C and υ_K, both have prior means calibrated to a value of 1. This induces a Cobb-Douglas production function with constant returns to scale in the process of generation of the final aggregate. The prior means of the feedback multipliers in the fiscal rules are calibrated to 0 since we leave the econometric significance of these parameters to the subsequent estimation. The parameters that measure the pair co-movements between the fiscal rules should be positive by definition, as we think that an increase in one tax is not systematically connected to a decrease of another tax. Therefore, the prior mean values of the co-movement parameters are strictly positive and the underlying normal distributions are truncated at 0. We also have a strong belief that unemployment benefits are positively correlated with the unemployment rate. This leads us to shift the appropriate co-movement parameter to a higher value (0.5). The prior distributions of the standard deviations of the shock disturbances are non-informative, as we keep the means at 0.01.

As for the posterior outcomes from the Bayesian routine, the inverse Frisch elasticity estimation exceeded our prior calibration, pointing to a lower elasticity of hours worked to the wage rate. Compared to the prior setting, the lower posterior value of υ_C induces complementarity between the input factors in the consumption CES aggregate. The opposite is true for υ_K, which is shifted upwards during the estimation, making the inputs of the appropriate CES aggregate rather mutual substitutes. Not all the feedback coefficients in the fiscal rules came out significantly different from zero from the estimation, so we keep some of them turned off, as is pointed out in the section focused on calibration. On the other hand, the data provide strong information on the coefficients capturing the reaction of fiscal measures to deviations of the gaps in the economy's intermediate output and government indebtedness. High government indebtedness moves in line with lower expenditure on other social benefits, transfers, and government consumption (parameters ϕ_{bob}, ϕ_{btt}, and ϕ_{bg}). Unemployment benefits and government investment also negatively co-moves in line with indebtedness, although to a much smaller extent. Except for social security contributions paid by employers, the posterior means of the debt feedback coefficients are positive, helping to stabilize government debt outside of equilibrium. A positive output gap is connected with higher taxation, except in the case of the capital tax, which seems to be negatively correlated with the output gap (parameter ϕ_{ytk}).

A comparison of the prior and posterior distributions for the estimated parameters can be found in the Appendix (see Table A.3).

3.10 Data

Our DSGE model is stationary in levels, which is consistent with steady state growth rates of all model variables at zero. To map the model onto real data we therefore use stationarized time series, i.e., series from which the linear trends are extracted before actual estimation. Thus, only the business cycle information is retained for the subsequent analysis.

Our core data sample ranges from 1996Q1 to 2011Q4 and consists of time series for the Czech Republic. Specifically, the data set covers a complete set of the GDP expenditure components from the national accounts, including both real variables and their respective deflators, domestic financial variables, labor market variables, a block of EU variables, and a rich set of fiscal variables. A complete overview of the data that we feed into the model can be found in Table A.2 in the Appendix.

3.10.1 Quality of Fiscal Data

Fiscal data, as they are published in the national accounts, do not usually represent a good basis for macroeconomic analysis, even in developed countries. There are several reasons for this. First, a complete set of government statistics is often available only on an annual basis, while quarterly government accounts are available only for certain government variables or for a shorter period, as is the case in the Czech Republic. To study the business cycle properties of an economy, one commonly works with quarterly data. Especially in the case of the Czech Republic, it would be very inconvenient to work with annual data because of the short data sample. A full set of quarterly data for the government sector exists only since 1999Q1, and the period from 1996Q1 to 1998Q4 needs to be interpolated from annual figures.

Second, we use ESA 95-based fiscal data to ensure methodological consistency with the national accounts' real-economy aggregates. These data should, in principle, also better reflect the position of the economy in the business cycle. However, cash data are usually more closely linked to changes in fiscal policy and better reflect budgetary execution (this is the case, for example, with monthly collection of taxes).

Third, government sector revenues and expenditures are substantially affected by one-off operations that have only a temporary effect on the rest of the economy and in some cases may have no effect at all. It is important to analyze government variables adjusted for operations which do not represent a fiscal shock or the recording of which does not coincide with the definition of fiscal shock in the sense of the model (e.g., debt assumptions and write-offs, recording of privatization proceeds as negative expenditures, and reclassifications of entities to and from the government sector). Since the Czech Republic has gone through a long process of economic transition and privatization in its recent history, adjustment for these effects plays a critical role.

Finally, there are distinct discrepancies between the evolution of government aggregate variables on the one hand and the changes to the parameters of the fiscal system (e.g. tax rates) on the other hand. As a result, fiscal shocks are often visible in the fiscal data at a different time than when they occur in reality. Traditional econometric exercises using models that include fiscal variables therefore often result in insignificant estimates of the model parameters or in biased estimates. To bypass these discrepancies, Mendoza, Razin, and Tesar (1994) and Jones (2002) suggest computing effective tax rates, which are more in line with economic developments, and this approach is also taken in this paper. The reason for this is that a reliable database on the history of tax policy measures is not available and state tax revenues mostly do not coincide with the settings of the various tax rates. Mendoza et al. (1994) makes computations based on the OECD database and Jones (2002) uses the NIPA tables for the US economy. They both provide the same results. The OECD database is a very convenient data source because it contains data for all member countries, including the Czech Republic, and facilitates cross-country comparison.

Figure A.5 depicts the annual time series for consumption tax rates, labor tax rates, and capital tax rates. We also include the household tax for total income, which is used to compute the labor and capital tax rates. With the exception of the average tax rate on total income, the implied Czech rates resemble those in Germany. Labor income of employees is taxed at a higher rate than in the USA. On the other hand, implied taxation of corporate profits is higher in the USA than in both Germany and the Czech Republic. The labor tax comprises both employees' and employers' wage tax and social security tax.

3.10.2 Adjusted Kalman Filter

Some of the observed variables are known only with annual frequency or are not known on the entire history (as is the case with the tax rates). Kalman filtering provides consistent estimates of all variables on a quarterly basis and thus bypasses the problem of sparse input data. Unlike the usual interpolation procedures, such as cubic splines, the Kalman filter returns interpolated series which are consistent with the underlying economic model.

The usual Kalman filtering problem can be defined in the state space as

$$\begin{aligned} x_t &= F(\phi)x_{t-1} + G(\phi)\epsilon_t, \qquad && \epsilon_t \sim N(0, E), \\ y_t &= A(\phi)x_t + \omega_t, && \omega_t \sim N(0, \Omega), \end{aligned} \tag{3.54}$$

where x_t is the vector of state variables and y_t is the vector of observed data. All the model matrices depend on the parameterization ϕ. While structural shocks, ϵ_t, are usually contemporaneously correlated, the measurement errors, ω_t, are independent of each other.

Since we work with fiscal data that are known only with annual frequency, we need to introduce some unobserved variables that will be used to estimate the quarterly figures of appropriate series. Then we linearly map these unobserved variables onto the data we have at hand. Of course, we need to distinguish between stock and flow variables:

$$\begin{aligned} \text{Stocks:} \quad & y_t = 4(x_t + x_{t-1} + x_{t-2} + x_{t-3}) + \omega_t, \\ \text{Flows:} \quad & y_t = x_t + x_{t-1} + x_{t-2} + x_{t-3} + \omega_t. \end{aligned}$$

This is not enough for the Kalman filter to work properly, because the structure of the state space is always one period ahead. Hence, if we move, say, to the second quarter of a year, such aggregation of quarterly estimates would be mapped onto an annual figure that we do not have for the second quarter.

For that matter, we can adjust the standard Kalman filter algorithm to account for time-varying measurement errors so that the matrix Ω in equation (3.54) now becomes time dependent, or Ω_t. If we are in a period of aggregation we impose some justifiable measurement error, and if we move away from that period, we impose a sufficiently large measurement error so that the Kalman filter computations are not influenced by the measurement equation:

$$y_t = 4(x_t + x_{t-1} + x_{t-2} + x_{t-3}) + \omega_t, \begin{cases} std(\omega_t) = \infty, & t = \text{within year}, \\ std(\omega_t) \ll \infty, & t = \text{end of year}. \end{cases} \tag{3.55}$$

3.10.3 Model and Data Properties

The overall performance of the model with respect to the available data is presented in the Appendix (see Figures A.6–A.8, where each graph depicts a particular observed time series and the time series filtered by the model). The interpolation of the data based on consistent model filtration is clearly visible in cases where only sparse data with annual frequency exist or where the sample size is shortened. Since the model contains a sufficient number of structural shocks, the filtered series coincide with the observed data. Only for private/government consumption, investment, and the deflators is a much higher degree of smoothing identified. The perfect overlay of the filtered/observed data in the case of interest rates and the exchange rate arises from the fact that these variables are measured without uncertainty, so zero measurement errors for the filtration are assumed.

To further depict the behavior of the model in comparison to the data, we calculate auto- and cross-correlations among a subset of the observed variables. Figures A.9 and A.10 show the correlations between the core domestic variables (the interest rate, the consumption deflator as a proxy for inflation, the exchange rate, and the GDP components) and the correlations between the fiscal sector variables, respectively. The results are structured in a matrix of graphs where each graph $[x, y]$ displays the correlation between the variable in row $[x]$ and various lags of the variable listed in column $[y]$, with a maximum lag of six quarters assumed. The correlations based on the observed data (blue lines in the graphs) and the correlations based on the simulated (artificial) time series generated by the model (red lines in the graphs) are plotted over each other for the sake of easy comparison between the model properties and the observed data. Since the correlation estimates are subject to uncertainty, the results in the graphs are complemented with 99% confidence bands. While the uncertainty in the correlations between the observed data emanates from the limited sample size, the uncertainty regarding the model correlations emerges rather from the Bayesian estimation of the model parameters. Since the correlation structure of the model stays within the confidence bands of the data correlations for most of the variables, the data correlations are captured by the model quite well.

3.11 Steady State

Given the calibrated and estimated parameters of the model, we compute the steady state of the model. Since the model involves several price levels in production sectors, we start by taking one price level as a numeraire and express the remaining prices with respect to the numeraire, which ensures stationarity of the model. Using substitutions within the system of steady state versions of the optimality conditions, we were able to numerically compute steady state values for all the model variables. Having computed the steady state, we log-linearize the system of optimality conditions around the steady state and solve it using the IRIS toolbox.[11]

Since the model works with detrended variables, there is no inflation in the steady state. Furthermore, we allow the steady state consumption of the two types of households to differ, with the consumption of optimizers being higher than the consumption of rule-of-thumb households; specifically, $\frac{C^r}{C^o} = 0.8$, the value used by Coenen, Straub, and Trabandt (2011). The desired level of the steady state consumption ratio is delivered by adjusting lump-sum taxes for rule-of-thumb households in the steady state. In our model, the actual steady state lump-sum taxes for rule-of-thumb households are negative, which means that rule-of-thumb households are subsidized by lump-sum transfers in the equilibrium.

4. The Results

In this section we investigate the effects of fiscal instruments on the economy in terms of impulse responses, then we present the fiscal multiplier values implied by our structural DSGE model, and finally we use our model to evaluate the impact of the selected fiscal measures on the economy.

4.1 Transmission of Fiscal Shocks to the Economy

We discuss the effects of government spending and tax shocks on the economy by investigating the DSGE model's impulse response functions, which are reported in Figures A.11–A.19 in the Appendix. The impulse responses are reported as percentage point deviations from the steady state values. The unexpected shocks to government spending variables and lump-sum taxes are in the magnitude of 1% of the corresponding fiscal variable. Tax shocks are in the magnitude of 1 percentage point of the cor-

[11] IRIS is a toolbox for macroeconomic modeling and forecasting in MATLAB developed by Beneš (2012). Further information on the IRIS toolbox is available at www.iris-toolbox.com.

responding tax rate. The deviations represent quarterly changes, except for inflation and the nominal interest rate, which are expressed in annualized terms.

4.1.1 Spending Shocks

Several similar patterns can be identified when we inspect the shocks to government consumption, government investment, unemployment benefits, and other social benefits. Spending shocks raise real GDP; demand pressures induce firms to produce more, so firms need more labor inputs and the unemployment rate drops. The real marginal costs of firms producing domestic intermediate goods increase. This translates into higher CPI inflation, to which the central bank reacts by raising the nominal interest rate. As a result of higher government spending, which is financed by issuing new debt and raising lump-sum taxes, the government budget balance worsens.

On the other hand, there are some significant differences between the effects of the four fiscal instruments considered on the expenditure side with respect to total consumption. Government consumption, unemployment benefit, and other social benefit shocks raise total consumption in the economy, whereas an increase in government investment crowds out total consumption. For the government consumption shock the nominal exchange rate appreciates, but in the case of the government investment shock the nominal exchange rate depreciates. This is because government investment goods also have a foreign component, while for the production of government consumption goods only domestic inputs are needed. Next, the trade balance worsens in the case of both government consumption and government investment shocks, but for the latter it drops immediately and the decrease is more pronounced. The channels underlying the worsening trade balance are therefore different: a decrease in exports and an increase in imports in reaction to the government consumption shock, and an improvement in both exports and imports (the rise in imports being twice as strong) following the government investment shock.

The responses of unemployment benefits and other social benefits are qualitatively very similar. This is given by their construction, as they similarly enter the budget constraint of households and the only difference resides in the specification of the fiscal rule for unemployment benefits, which react to unemployment fluctuations, whereas other social benefits do not. For both shocks, the nominal exchange rate depreciates slightly on impact. This supports exports and the trade balance gradually improves over time.

Notice that a positive demand effect is the main channel through which an increase in unemployment benefits and other social benefits leads to a decrease in unemployment. However, the optimal timing of the corresponding policy action would be during the downward phase of the business cycle, and this measure should be of a temporary nature in order to avoid subsequent adverse effects of unemployment and other social benefits on labor supply.

4.1.2 Tax Shocks

Our model allows us to examine the effects of five tax shocks, namely, a consumption tax shock, a wage tax shock, a social security contribution tax shock, a capital tax shock, and a lump-sum tax shock. As expected, higher tax revenues improve the government budget balance and lower the government debt. Higher tax revenues also make it possible to increase government consumption. However, any positive tax shock in our model causes overall consumption and real GDP to decline. Except for social security contributions paid by employers, taxes affect households' budget constraint directly. On the other hand, social security contributions paid by employers increase labor costs in production, firms reduce their demand for labor, and households' income shrinks along with their lower wage income. So, in all cases of tax shocks, higher taxes decrease households' disposable income, leading to a drop in consumption. The decrease in consumption induces firms to demand less labor, hence the unemployment rate increases and real wages fall. Except for lump-sum taxes, higher taxes cause real marginal costs to increase. This is manifested in inflationary pressures and the central bank responds to the inflation by raising the nominal interest rate.

Initially, for all the five tax shocks considered, the nominal exchange rate appreciates. This contributes to a decline in exports (for the consumption tax only in the first year), and for the shocks to the capital tax, the wage tax and social security contributions, the nominal exchange rate appreciation is high enough to induce higher imports, reflected in a worse trade balance as well. In addition, for all the tax shocks overall investment is crowded in by lower overall consumption (despite higher government consumption). With higher lump-sum taxes the inflation rate declines. This initially helps somewhat to increase the real wage, but soon after the real wage starts to decline similarly as in the case of other tax shocks.

4.2 Fiscal Multipliers

The model's implied fiscal multipliers are listed in Tables A.4–A.11 in the Appendix. The fiscal multipliers are calculated according to Uhlig (2010), so these are net-present-value multipliers accumulated over time, discounted by the steady state real interest rate. We list fiscal multipliers with effects on real GDP for individual revenue and expenditure items of the government budget. The fiscal multipliers are calculated for the case of a temporary, one-year fiscal stimulus and for the case of a longer-lasting 10-year fiscal stimulus. The unexpected shocks to the fiscal instruments are set so that the worsening of the government budget balance in the first year equals 1% of nominal GDP, and the value of the corresponding fiscal instrument is kept constant during the affected period. Moreover, the estimated fiscal rule is initially turned off for two years (keeping unaffected fiscal instruments at their steady states) so as to isolate the effects of affected fiscal instruments. Otherwise, keeping the fiscal rule turned on from the beginning could result in our results being somewhat blurred by co-movements of fiscal instruments as defined in the fiscal rule. We treat the estimated fiscal rule as a good approximation of the fiscal policy settings in the long run, hence we decided to turn off the fiscal rule at the beginning of the simulations. This also means that the fiscal stimuli in the first two years are fully debt financed. The role of alternative assumptions, concerning the model or the simulations, is demonstrated later in the robustness of the results.

Regarding the effect of a temporary fiscal stimulus on real GDP (see Table A.4), the largest effects after the first year occur with government investment, with the fiscal multiplier reaching roughly 0.4. Next, social security contributions paid by employers have a fiscal multiplier of 0.3, followed by government consumption with a corresponding fiscal multiplier of 0.2. The fiscal multipliers for the wage tax and the consumption tax attain values of roughly 0.2. Other social benefits and lump-sum taxes have fiscal multipliers of approximately 0.1. Negligible fiscal multipliers are recorded for unemployment benefits and the capital tax. All the values of the fiscal multipliers with effects on real GDP are below 1.

Our values of the overall expenditure multipliers are somewhat lower than the CNB estimates of around 0.6 reported in Hřebíček, Král, and Říkovský (2005), which are obtained from empirical estimates using regression analysis and structural simulation. This corroborates the finding from a meta analysis of 89 studies by Gechert and Will (2012) that DSGE-based multipliers are somewhat lower than multipliers from macroeconometric models and single equation approaches. On the other hand, our fiscal multiplier values are not very far from the ones estimated by Klyuev and Snudden (2011) for the Czech Republic using the GIMF model. However, there are some differences. The one-year temporary fiscal multiplier for government consumption is lower in our case (0.2) compared to their estimate (0.4). On the revenue side, our one-year fiscal multipliers for the consumption tax (0.2) and the wage tax (0.2) are roughly double the estimates based on the GIMF model. Our temporary fiscal multipliers for government investment and the capital tax are quite similar to those reported by Klyuev and Snudden (2011). Also, according to our model the capital tax has a negligible fiscal multiplier. In the study by Klyuev and Snudden (2011), the capital tax has the lowest multiplier: 0.03 (see p. 17). This is within the range found by Coenen et al. (2012b) for the USA (0.01–0.11) and for the euro area (0.03–0.06).

The fiscal multipliers for a 10-year fiscal stimulus have similar values in the short run as in the case of a temporary, one-year fiscal stimulus. In the long run, the fiscal multipliers for the 10-year fiscal stimulus are somewhat lower, and for government investment the effect on real GDP is slightly negative. Lower fiscal multiplier values for permanent stimuli is confirmed by several other structural models (Coenen et al., 2012a).

The long-run effects of a temporary fiscal stimulus on real GDP (see the last column in the tables) suggest that it is desirable to support the domestic economy mainly by increasing other social benefits, and further by decreasing taxes associated with wages (the wage tax and social security contributions paid by employers). Lump-sum taxes have a similar temporary fiscal multiplier in the long run as taxes associated with wages, but lump-sum taxes are hard to find in the real economy. For a longer-lasting fiscal stimulus, the highest effects on real GDP are recorded for taxes associated with wages and government consumption. Conversely, as regards an appropriate, growth-friendly fiscal consolidation strategy, cuts in unemployment benefits and hikes in capital taxes seem desirable given the low values of the fiscal multipliers for these fiscal instruments. However, the scope for cutting unemployment benefits is very limited, since their share in GDP is rather small in the Czech Republic. These long-run suggestions should be taken with care, since they are more or less prone to the specification of the fiscal rule, as will be demonstrated in the robustness of the results.

4.2.1 Robustness

To investigate the robustness of the results, we calculate several alternative fiscal multipliers. We inspect how the fiscal multipliers change with: (i) a smaller/larger share of rule-of-thumb households, (ii) a simplified type of fiscal rule, (iii) a different elasticity of labor supply, (iv) passive monetary policy, and (v) anticipated shocks.

The share of rule-of-thumb households matters for the size of fiscal multipliers, as can be seen from Tables A.6–A.7 in the Appendix. Additionally to the 40% share of rule-of-thumb households in the baseline, shares of 20% and 60% are considered here. Generally, with a higher share of rule-of-thumb households the fiscal multipliers take higher values, in line with evidence from other literature summarized in the meta analysis of 89 studies by Gechert and Will (2012). One notable exception in our case is the behavior of other social benefits in the long run, which is bit puzzling. The estimated fiscal rule is probably responsible for this response. Low variation in fiscal multipliers is visible for social security contributions paid by employers. This can be explained by the fact that this kind of tax is incurred by firms and does not directly affect employees' net labor income. In the short run, all the fiscal multipliers behave according to economic intuition; that is, the higher is the share of rule-of-thumb households in the economy, the stronger are the demand effects generated by consumers in response to fiscal stimuli.

Next, we checked the robustness of the fiscal multipliers with respect to the specification of the fiscal rule when the model contains only a simple calibrated fiscal rule (see equation 3.43 and the results in Table A.8). With a simple fiscal rule the model's implied fiscal multipliers in the short run are very similar to those obtained with a more comprehensive estimated fiscal rule. This is due to the fact that the fiscal rule is switched off for the initial two years by assumption. So, again, the highest temporary one-year fiscal multipliers are found for government investment, social security contributions paid by employers, and government consumption. As to the cumulative long-run gains in the case of a one-year fiscal stimulus, the situation changes. Here, the largest effects are attained for lump-sum taxes and taxes associated with wages (social security contributions paid by employers and the wage tax). The relevance of lump-sum taxes in this case is the result of the fiscal rule used, as only lump-sum taxes can adjust in response to rising government debt and government consumption, in contrast to the comprehensive estimated fiscal rule, where all fiscal instruments can adjust to variations in government debt and intermediate production.

Originally, in the g3 model the utility function is linear in labor supply, implying an infinitely elastic supply of labor. By contrast, in our model we estimated the inverse of the Frisch elasticity of labor supply ϕ_n at a value of roughly 3. Therefore, we check the sensitivity of this parameter on the values of the fiscal multipliers. Due to the inclusion of unemployment in our model, we are unable to set this parameter to 0 as in the g3 model; nevertheless, we can set the value of parameter ϕ_n close to zero, e.g. 0.25. For this case, we list the fiscal multipliers in Table A.9. On inspecting the results, we see that the fiscal multipliers have increased. This is due to a greater willingness of households to supply labor to firms, which want to cover the higher demand generated by the fiscal stimuli. The ordering of the first three fiscal instruments, in terms of GDP growth contribution, has changed slightly. In the short run the most significant are government investment and taxes associated with wages, and in the long run other social benefits are followed by the wage tax and government investment.

Furthermore, the fiscal multipliers change when monetary policy is passive, which means that monetary policy does not follow the Taylor rule, i.e., the central bank does not raise interest rates in response to rising inflation. We simulate the effects of fiscal stimuli with temporarily passive monetary policy, when the interest rate is kept constant for two years at its steady state level and thereafter adjusts according to the model's Taylor rule. This simulation is different from the situation where interest rates hit the zero lower bound; nonetheless, the direction of real effects might be similar. The fiscal multipliers with passive monetary policy are reported in Table A.10. Many of the fiscal multipliers have increased, with the highest one-year multipliers being attained by government investment, government consumption, and the wage tax. The increase in the fiscal multipliers when monetary policy is passive is due to the fact that the monetary conditions are looser in the first two years compared to the baseline. The results for social security contributions paid by employers and other social benefits in the long run are puzzling, as the fiscal multipliers have decreased compared to the baseline.

As a last robustness check, fiscal multipliers with anticipated shocks are calculated in Table A.11. The majority of the fiscal multipliers have decreased compared to the baseline. One exception concerns social security contributions paid by employers in the short run. The highest one-year fiscal multipliers are recorded by social security contributions paid by employers (0.3), government investment, and government consumption (both roughly 0.2). The lower real GDP effects might be explained by the fact that households fully expect the tax cuts or expenditure increases to be temporary and choose rather to smooth their consumption profiles. Another explanation might be that all the fiscal instruments have substantial backward-looking elements by definition.

4.3 The Impact of Selected Fiscal Measures

Having built and estimated our model, we try to illustrate its use with a real-world example from the Czech economy. In April 2012, the Czech government announced a new fiscal consolidation package of various measures for 2013–2015. We focus on selected, already approved measures from this consolidation package, with further details provided in Table A.12 in the Appendix. Obviously, it is interesting to quantify the macroeconomic effects of such consolidation measures on the Czech economy.

Firstly, in order to simulate the effects of the selected fiscal measures, we mapped these measures onto the models' fiscal instruments; this is done in the last column of the table. Afterwards, the estimated impacts of the individual measures on the government budget balance, expressed in percent of nominal GDP, were transformed into desired deviations of the relevant fiscal revenues/expenditures using the steady state value of the model's nominal GDP. Adjusting the paths of the affected fiscal revenues/expenditures for the calculated deviations, it is possible to simulate the macroeconomic effects of the fiscal measures considered. The remaining unaffected fiscal instruments (unemployment benefits and lump-sum transfers) were kept at their steady state levels for two years; thereafter, the estimated fiscal rule is switched on, serving as a good approximation of the fiscal policy settings in the long run.

The results given by our model show that the selected consolidation measures planned in the Czech Republic for 2013–2015 might imply a tightening of real GDP by 0.2, 0.4, and 0.5 percentage points in the respective years compared to the baseline scenario with unchanged fiscal policy. Given the size of the consolidation measures selected, the implicit fiscal multiplier of the simulated measures is roughly 0.2. Nonetheless, these results should be taken with care, since our simplified simulation starts in a situation where the economy is in equilibrium, which is obviously not the case in the current period, when interest rates have virtually hit the zero lower bound. A further simplification is that the fiscal shocks in our model are treated as temporary (i.e., as having only temporary effects which do not affect the steady state of the model), whereas some of the above-mentioned fiscal measures might be valid permanently, thus pushing the economy toward a new equilibrium.

5. Conclusion

In this paper we presented a satellite DSGE model for the Czech Republic to study the effects of fiscal policy on the economy. Our DSGE model shares key features of the CNB's core g3 model, developed by Andrle et al. (2009), and contains a comprehensive fiscal block. The most distinctive fiscal features of our DSGE model are due to the inclusion of "rule-of-thumb" consumers, detailed specification of the revenue and expenditure fiscal instruments, productive government spending, productive government capital, unemployment dynamics, and the estimated fiscal rule.

The real GDP fiscal multipliers from our DSGE model suggest that the largest multipliers after the first year of a temporary fiscal stimulus are associated with government investment (0.4) and social security contributions paid by employers (0.3), followed by government consumption (0.2), then by the wage tax and the consumption tax (each roughly 0.2), then by other social benefits and lump-sum taxes (both 0.1), and lastly by unemployment benefits and the capital tax (close to zero). Thus, our results imply that the strongest effects, in terms of real GDP, are associated with an increase in government investment and a decrease in social security contributions paid by employers; or, to put it differently, fiscal consolidations based on cuts in government investment and increases in social security contributions paid by employers would be associated with substantial real costs, at least in the short to medium run. Conversely, a less costly way to consolidate public finance is to raise capital taxes, because of their low impact on GDP growth.

For practical purposes, we used our model to perform a partial evaluation of the effects on the real economy of selected consolidation measures related to the ongoing process of fiscal consolidation in the Czech Republic. Conditional on the model's set of simplifying assumptions (inter alia, limited supply-side aspects and the assumption of temporary fiscal shocks) we found rather small impacts on real GDP dynamics, specifically impacts of 0.2, 0.4, and 0.5 percentage points in 2013, 2014, and 2015, as compared to the baseline with unchanged fiscal policy.

This paper could be extended in several directions. The robustness of our results could be further checked in terms of the underlying model mechanisms and assumptions. For example, what is the role of complementarity/substitutability between private and government consumption/capital in the measured values of fiscal multipliers? And what is the size of the fiscal multipliers if the zero lower bound on nominal interest rates is reached? One could also further refine the fiscal sector; for instance, it is possible to further elaborate government labor services and model them explicitly as a production input. Another possible extension would be to build a DSGE-VAR model, that is, to simulate the priors from our DSGE model and use them afterwards in the estimation of the Bayesian VAR model.

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Appendix A

Table A.1: Calibrated Parameters and Steady State Ratios

Parameter / Ratio	Description	Value
Preferences		
β	Discount factor	0.9938
θ	Disutility of labor supply	5
χ^o	Habit parameter optimizers	0.75
χ^r	Habit parameter: rule-of-thumb households	0.75
α_C	Share of private good in consumption good	0.8
Technology		
α	Capital share	0.3333
α_K	Share of private capital in capital composite	0.90
δ^p	Depreciation rate: private capital	0.0153
δ^g	Depreciation rate: government capital	0.0153
η	Investment adjustment cost	0.2
Monetary policy		
ϕ_π	Inflation feedback	2
ρ_i	Interest rate smoothing	0.75
$\bar{R}$	Nominal gross interest rate	1.0062
$\overline{\Pi}$	Inflation target	1
Fiscal rule		
ϕ_g	Government consumption feedback	0.1
ϕ_b	Debt feedback	0.33
ϕ_l	Lump-sum transfers allocation	1
ϕ_{kc}, ϕ_{wc}	Co-movement consumption tax with capital and wage tax	0
ϕ_{dc}, ϕ_{dw}	Co-movement dividend tax with capital and wage tax	0
ϕ_{ds}	Co-movement dividend tax and social security contributions	0
Tax rates, unemployment		
τ^C	Consumption tax rate	0.20
τ^W	Wage tax rate	0.10
τ^K	Capital tax rate	0.19
τ^S	Social security contributions paid by employers	0.24
τ^D	Dividend tax rate	0
u^n	Natural rate of unemployment	0.065
Shares		
γ	Share of rule-of-thumb households	0.4
ω_C	Share of imported goods in private consumption	0.15
ω_I	Share of imported inputs in investment	0.70
ω_X	Share of imported goods in exports	0.55

Table A.1 – Continued from Previous Page

Parameter / Ratio	Description	Value
Ratios		
G/Y	Government consumption to output	0.25
I^g/Y	Government investment to output	0.03
UB/Y	Unemployment benefits to output	0.003
OB/Y	Other social benefits to output	0.14
B/Y	Government debt to output	0.60
Calvo setting		
ξ_Y	Intermediate good stickiness	0.50
ξ_C	Consumption good stickiness	0.65
ξ_I	Investment good stickiness	0.40
ξ_G	Government good stickiness	0.75
ξ_X	Export good stickiness	0.60
ξ_N	Import good stickiness	0.60
ξ_W	Wage stickiness	0.80
Elasticity		
ϵ^W	Between labor varieties	5.9
$\epsilon^Y, \epsilon^C, \epsilon^I, \epsilon^G, \epsilon^X, \epsilon^N$	Between goods varieties	6
η_C	Between domestic and imported goods for consumption good	2.1
η_I	Between domestic and imported goods for investment good	0.5
η_X	Between domestic and imported goods for export good	0.5
θ_X	Price elasticity of exports	1.2
ζ_B	Risk premium w.r.t. foreign bonds	0.005
Persistence		
ρ_a	Technology	0.9
ρ_g	Government consumption	0.9
ρ_{ig}	Government investment	0.75
ρ_{ub}	Unemployment benefits	0.75
ρ_{ob}	Other social benefits	0.75
ρ_{tc}	Consumption tax	0.95
ρ_{tk}	Capital tax	0.95
ρ_{tw}	Wage tax	0.95
ρ_{ts}	Social security contributions	0.9
ρ_{td}	Dividend tax	0.9
ρ_s	UIP sluggishness	0.7
ρ_p	Risk premium	0
ρ_{ps}	Foreign inflation	0.3
ρ_{rs}	Foreign gross nominal interest rate	0.8
ρ_{ns}	Foreign demand	0.75
ρ_{mep}	Marginal efficiency booster of private investment	0.5
ρ_{meg}	Marginal efficiency booster of government investment	0.5

Table A.2: Input Data

Time series	Frequency	Range	Source
Real GDP expenditure components			
Private consumption	Q	1996Q2 – 2011Q4	CZSO
Private investment	Q	1999Q2 – 2011Q4	CZSO
Government consumption	Q	1996Q2 – 2011Q4	CZSO
Government investment	Q	1999Q2 – 2011Q4	CZSO
Exports	Q	1996Q2 – 2011Q4	CZSO
Imports	Q	1996Q2 – 2011Q4	CZSO
Deflators			
Consumption deflator	Q	1997Q1 – 2011Q4	CZSO
Investment deflator	Q	1997Q1 – 2011Q4	CZSO
Government cons. deflator	Q	1997Q1 – 2011Q4	CZSO
Export deflator	Q	1996Q2 – 2011Q4	CZSO
Import deflator	Q	1996Q2 – 2011Q4	CZSO
Labor market			
Wages (nominal)	Q	1996Q1 – 2011Q4	CZSO
Unemployment rate	Q	1996Q1 – 2011Q4	CZSO
Implicit tax rates			
Consumption tax rate	Y	1996 – 2010	OECD
Capital tax rate	Y	1996 – 2010	OECD
Labor tax rate	Y	1996 – 2010	OECD
Government expenditures			
Social benefits	Q	1996Q1 – 2011Q3	CZSO
Unemployment benefits	Q	1996Q1 – 2011Q4	CZSO
Government balance and debt			
Primary deficit	Q	1999Q1 – 2011Q3	CZSO
Government debt	Y Q	1996 – 2000 2001Q1 – 2011Q3	CZSO
Domestic financial variables			
3M PRIBOR	Q	1996Q1 – 2011Q4	CNB
CZK/EUR exchange rate	Q	1996Q1 – 2011Q4	CNB
Foreign variables			
3M EURIBOR	Q	1996Q1 – 2011Q4	EUROSTAT
GDP (EMU)	Q	1996Q1 – 2011Q4	EUROSTAT
PPI (EMU)	Q	1996Q1 – 2011Q4	EUROSTAT

Note: Q = Quaterly, Y = Yearly. Implicit tax rates are based on Mendoza et al. (1994) methodology and OECD data.

Table A.3: Estimated Parameters

Parameter		Prior distribution	Posterior distribution			
equation / figure			mode	mean	10%	90%
Inverse of Frisch elasticity						
ϕ_n	phin	N(2.5,0.2)	2.84	2.84	2.63	3.07
Elasticities in CES aggregates:						
v_C	vC	N(1,0.2)	0.86	0.86	0.58	1.14
v_K	vK	N(1,0.2)	1.10	1.09	0.82	1.35
Output feedback coefficients in fiscal rules:						
ϕ_{yg}	phi_yg	N(0,0.2)	0.08	0.07	-0.16	0.32
ϕ_{yig}	phi_yig	N(0,0.2)	0.07	0.07	-0.13	0.26
ϕ_{yub}	phi_yub	N(0,0.2)	0.03	0.02	-0.22	0.27
ϕ_{yob}	phi_yob	N(0,0.2)	-0.04	-0.03	-0.26	0.19
ϕ_{ytk}	phi_yk	N(0,0.2)	-0.22	-0.23	-0.48	0.04
ϕ_{ytw}	phi_yw	N(0,0.2)	0.33	0.31	0.08	0.55
ϕ_{yts}	phi_ys	N(0,0.2)	0.19	0.19	-0.07	0.44
ϕ_{ytd}	phi_yd	N(0,0.2)	-0.13	-0.11	-0.36	0.14
ϕ_{ytt}	phi_yt	N(0,0.2)	0.13	0.12	-0.13	0.38
Debt feedback coefficients in fiscal rules:						
ϕ_{bg}	phi_bg	N(0,0.2)	0.46	0.46	0.29	0.62
ϕ_{big}	phi_big	N(0,0.2)	0.06	0.06	-0.01	0.14
ϕ_{bub}	phi_bub	N(0,0.2)	0.10	0.10	-0.11	0.31
ϕ_{bob}	phi_bob	N(0,0.2)	0.34	0.33	0.22	0.44
ϕ_{btk}	phi_bk	N(0,0.2)	0.40	0.40	0.15	0.66
ϕ_{btw}	phi_bw	N(0,0.2)	-0.02	0.01	-0.21	0.24
ϕ_{bts}	phi_bs	N(0,0.1)	-0.07	-0.06	-0.20	0.07
ϕ_{btd}	phi_bd	N(0,0.2)	0.28	0.27	0.03	0.52
ϕ_{btt}	phi_bt	N(0,0.2)	0.30	0.30	0.08	0.51
Unemployment feedback coefficient in fiscal rule						
ϕ_u	phi_u	N(0.5,0.2)	0.44	0.44	0.35	0.53
Co-movement coefficients in fiscal rules:						
ϕ_{wc}	phi_wc	N^{tr}(0.25,0.05,0)	0.24	0.24	0.17	0.31
ϕ_{sc}	phi_sc	N^{tr}(0.25,0.05,0)	0.08	0.10	0.03	0.17
ϕ_{kw}	phi_kw	N^{tr}(0.25,0.05,0)	0.22	0.22	0.17	0.27
ϕ_{sk}	phi_sk	N^{tr}(0.25,0.05,0)	0.20	0.20	0.14	0.26
ϕ_{dk}	phi_dk	N^{tr}(0.25,0.05,0)	0.21	0.21	0.16	0.26
ϕ_{sw}	phi_sw	N^{tr}(0.25,0.05,0)	0.22	0.22	0.16	0.28

Table A.3 – Continued from Previous Page

Parameter		Prior distribution	Posterior distribution			
equation / figure			mode	mean	10%	90%
Standard errors of shocks:						
ε_t^M	emp	IG(0.01,0.1)	0.01	0.01	0.01	0.01
ε_t^{prem}	eprem	IG(0.01,0.1)	0.01	0.01	0.01	0.02
ε_t^{import}	eimport	IG(0.01,0.1)	0.02	0.02	0.02	0.03
ε_t^Y	ecostpushPY	IG(0.01,0.1)	0.03	0.03	0.03	0.04
ε_t^C	ecostpushPC	IG(0.01,0.1)	0.01	0.01	0.01	0.01
ε_t^I	ecostpushPI	IG(0.01,0.1)	0.04	0.04	0.03	0.05
ε_t^G	ecostpushPG	IG(0.01,0.1)	0.03	0.03	0.02	0.03
ε_t^N	ecostpushPN	IG(0.01,0.1)	0.03	0.03	0.02	0.03
ε_t^X	ecostpushPX	IG(0.01,0.1)	0.04	0.05	0.04	0.05

Table A.4: Fiscal Multipliers: One-Year Stimulus on Real GDP

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.23	0.21	0.20	0.17	0.23	0.12
Government investment	0.31	0.36	0.40	0.32	0.40	0.15
Unemployment benefits	0.01	0.01	0.01	0.01	0.02	0.02
Other social benefits	0.13	0.13	0.13	0.10	0.85	0.85
Taxes (-):						
Consumption tax	0.16	0.17	0.18	0.13	0.18	0.12
Wage tax	0.15	0.19	0.21	0.18	0.21	0.20
Social contributions employers	0.11	0.25	0.24	0.14	0.26	0.19
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.14	0.14	0.13	0.09	0.20	0.20

Note: These are cumulative net-present-value fiscal multipliers calculated as the discounted cumulative change in real GDP over the discounted cumulative change in the corresponding fiscal instrument in real terms. The fiscal stimulus lasts for one year and is set so that the budget balance worsens by 1% of nominal GDP in the first year.

Table A.5: Fiscal Multipliers: 10-year Stimulus on Real GDP

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.23	0.21	0.20	0.16	0.23	0.10
Government investment	0.31	0.36	0.39	0.27	0.39	-0.05
Unemployment benefits	0.01	0.01	0.01	0.00	0.01	0.00
Other social benefits	0.13	0.13	0.13	0.06	0.13	0.02
Taxes (-):						
Consumption tax	0.16	0.17	0.18	0.12	0.18	0.06
Wage tax	0.15	0.19	0.21	0.18	0.21	0.19
Social contributions employers	0.11	0.25	0.24	0.14	0.26	0.16
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.14	0.14	0.13	0.06	0.14	0.01

Note: The fiscal stimulus lasts for 10 years and is set so that the budget balance worsens by 1% of nominal GDP in the first year.

Table A.6: Fiscal Multipliers: One-Year Stimulus on Real GDP, Rule-of-Thumb Households 20%

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.18	0.17	0.16	0.15	0.18	0.11
Government investment	0.28	0.31	0.34	0.28	0.34	0.09
Unemployment benefits	0.01	0.01	0.01	0.01	0.02	0.02
Other social benefits	0.07	0.08	0.08	0.07	1.26	1.26
Taxes (-):						
Consumption tax	0.09	0.12	0.13	0.11	0.13	0.10
Wage tax	0.10	0.15	0.17	0.16	0.19	0.19
Social contributions employers	0.11	0.24	0.23	0.13	0.25	0.18
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.07	0.08	0.09	0.06	0.18	0.18

Note: See Table A.4 for a detailed description.

Table A.7: Fiscal Multipliers: One-Year Stimulus on Real GDP, Rule-of-Thumb Households 60%

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.29	0.26	0.24	0.21	0.29	0.14
Government investment	0.35	0.43	0.49	0.37	0.49	0.22
Unemployment benefits	0.01	0.01	0.01	0.01	0.01	0.01
Other social benefits	0.21	0.19	0.18	0.14	0.65	0.65
Taxes (-):						
Consumption tax	0.25	0.25	0.25	0.17	0.25	0.14
Wage tax	0.22	0.24	0.25	0.20	0.25	0.21
Social contributions employers	0.11	0.25	0.25	0.14	0.28	0.19
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.22	0.20	0.18	0.12	0.22	0.20

Note: See Table A.4 for a detailed description.

Table A.8: Fiscal Multipliers: One-Year Stimulus on Real GDP, Simple Fiscal Rule

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.23	0.22	0.24	0.18	0.24	0.15
Government investment	0.31	0.36	0.48	0.41	0.48	0.17
Unemployment benefits	0.01	0.01	0.02	0.01	0.02	0.02
Other social benefits	0.13	0.14	0.17	0.13	0.17	0.14
Taxes (-):						
Consumption tax	0.15	0.16	0.20	0.14	0.20	0.09
Wage tax	0.13	0.15	0.20	0.17	0.20	0.18
Social contributions employers	0.12	0.27	0.28	0.16	0.30	0.20
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.14	0.16	0.39	1.56	1.60	1.29

Note: See Table A.4 for a detailed description.

Table A.9: Fiscal Multipliers: One-Year Stimulus on Real GDP, $\phi_n = 0.25$

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.24	0.24	0.27	0.29	0.29	0.26
Government investment	0.32	0.39	0.46	0.42	0.57	0.50
Unemployment benefits	0.01	0.01	0.01	0.01	0.03	0.03
Other social benefits	0.13	0.13	0.13	0.11	1.47	1.47
Taxes (-):						
Consumption tax	0.16	0.20	0.23	0.22	0.29	0.29
Wage tax	0.18	0.26	0.33	0.38	0.51	0.51
Social contributions employers	0.13	0.32	0.35	0.26	0.37	0.37
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.14	0.14	0.14	0.09	0.33	0.33

Note: See Table A.4 for a detailed description.

Table A.10: Fiscal Multipliers: One-Year Stimulus on Real GDP, Passive Monetary Policy

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.23	0.23	0.24	0.21	0.24	0.13
Government investment	0.32	0.40	0.47	0.38	0.47	0.18
Unemployment benefits	0.01	0.01	0.01	0.01	0.02	0.02
Other social benefits	0.14	0.15	0.16	0.13	0.60	0.60
Taxes (-):						
Consumption tax	0.16	0.19	0.22	0.17	0.22	0.13
Wage tax	0.16	0.22	0.26	0.21	0.26	0.21
Social contributions employers	0.07	0.11	0.10	0.06	0.14	0.14
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.15	0.16	0.17	0.12	0.20	0.20

Note: See Table A.4 for a detailed description.

Table A.11: Fiscal Multipliers: One-Year Stimulus on Real GDP, Anticipated Shocks

	Quarters				Peak	Long-run
	1	4	8	16		
Expenditures (+):						
Government consumption	0.20	0.15	0.14	0.13	0.20	0.10
Government investment	0.23	0.19	0.21	0.18	0.23	0.02
Unemployment benefits	0.01	0.00	0.00	0.00	0.01	0.01
Other social benefits	0.09	0.05	0.04	0.02	0.78	0.78
Taxes (-):						
Consumption tax	0.10	0.07	0.08	0.07	0.10	0.07
Wage tax	0.09	0.07	0.10	0.13	0.18	0.18
Social contributions employers	0.14	0.28	0.25	0.13	0.29	0.18
Capital tax	0.00	0.00	0.00	0.00	0.00	0.00
Lump-sum tax	0.10	0.05	0.04	0.02	0.11	0.11

Note: See Table A.4 for a detailed description.

Table A.12: Selected Fiscal Consolidation Measures

Consolidation measures (in % of GDP)	2013	2014	2015	Model's instruments
Direct taxes				
7% additional solidarity personal income tax	0.0	0.1	0.1	τ^W
Abolition of basic allowance for working pensioners	0.1	0.1	0.1	τ^W
Reduction of flat-expense deductions for self-employed	0.1	0.1	0.1	τ^W
Increase of withholding tax against tax havens, abolition of health insurance ceiling	0.1	0.1	0.1	τ^W, τ^S
Indirect taxes				
1 pp increase in VAT	0.5	0.5	0.4	τ^C
Abolition of selected excise exemptions	0.0	0.1	0.1	τ^C
Other taxes				
1 pp increase in real estate tax	0.1	0.1	0.1	τ^K
Sales of emission permits	0.1	0.1	0.1	τ^K
Revenue measures	0.9	1.0	0.9	
Expenditure				
Freezing of wages for state employees	-0.1	-0.3	-0.4	G
Savings in state administration	0.0	-0.3	-0.6	G
Lower subsidies	-0.1	-0.1	-0.1	I^g
Lower indexation of pensions, cancelation of some social benefits	-0.3	-0.4	-0.5	OB
Expenditure measures	-0.5	-1.1	-1.6	
Total impact on government budget balance	1.4	2.0	2.5	

Note: Impacts of consolidation measures accumulate over time.
Source: Ministry of Finance of the Czech Republic and CNB estimates.

Figure A.1: Bayesian Estimation: Priors and Posteriors of Estimated Parameters

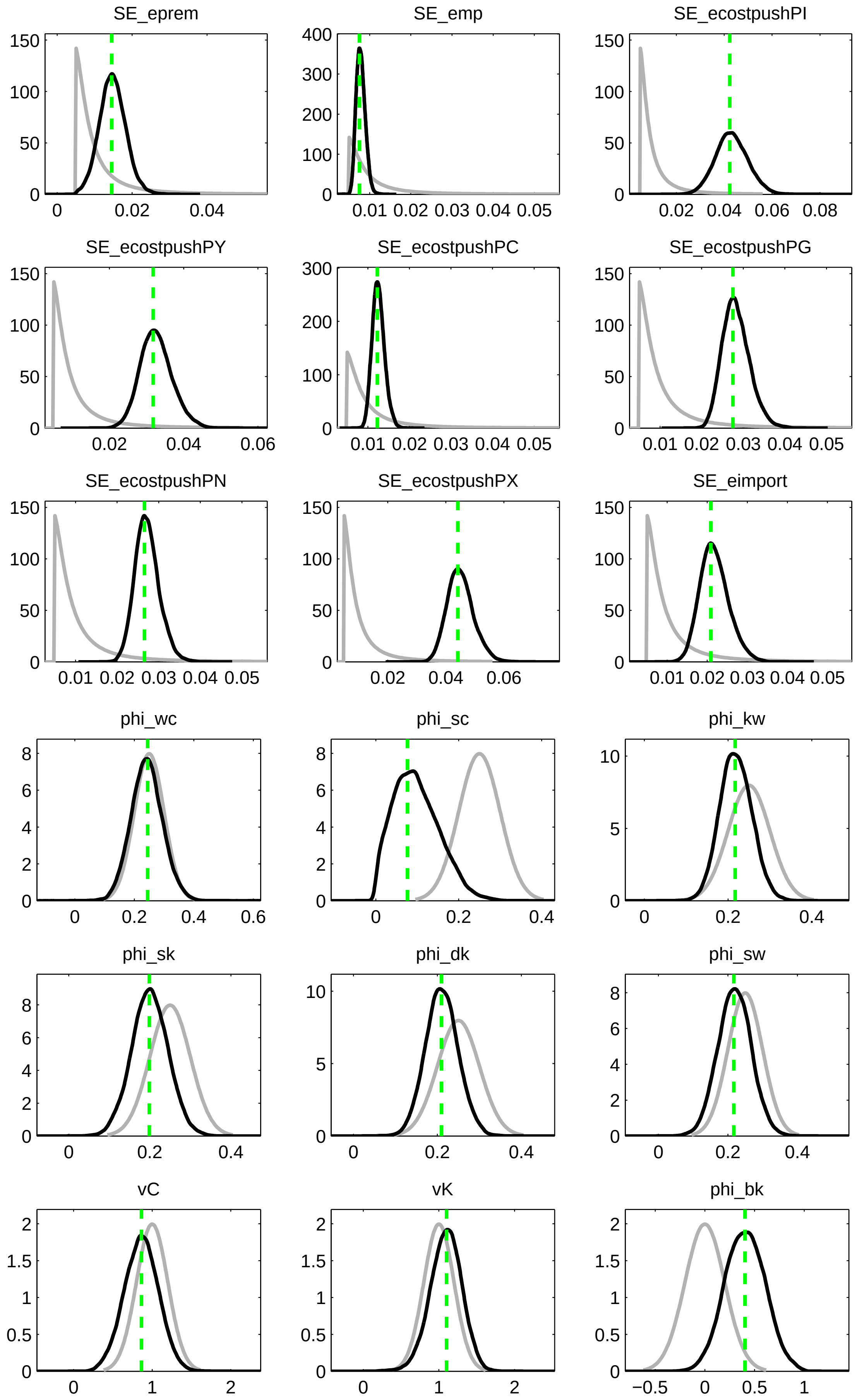


Figure A.2: Bayesian Estimation: Priors and Posteriors of Estimated Parameters (Continued)

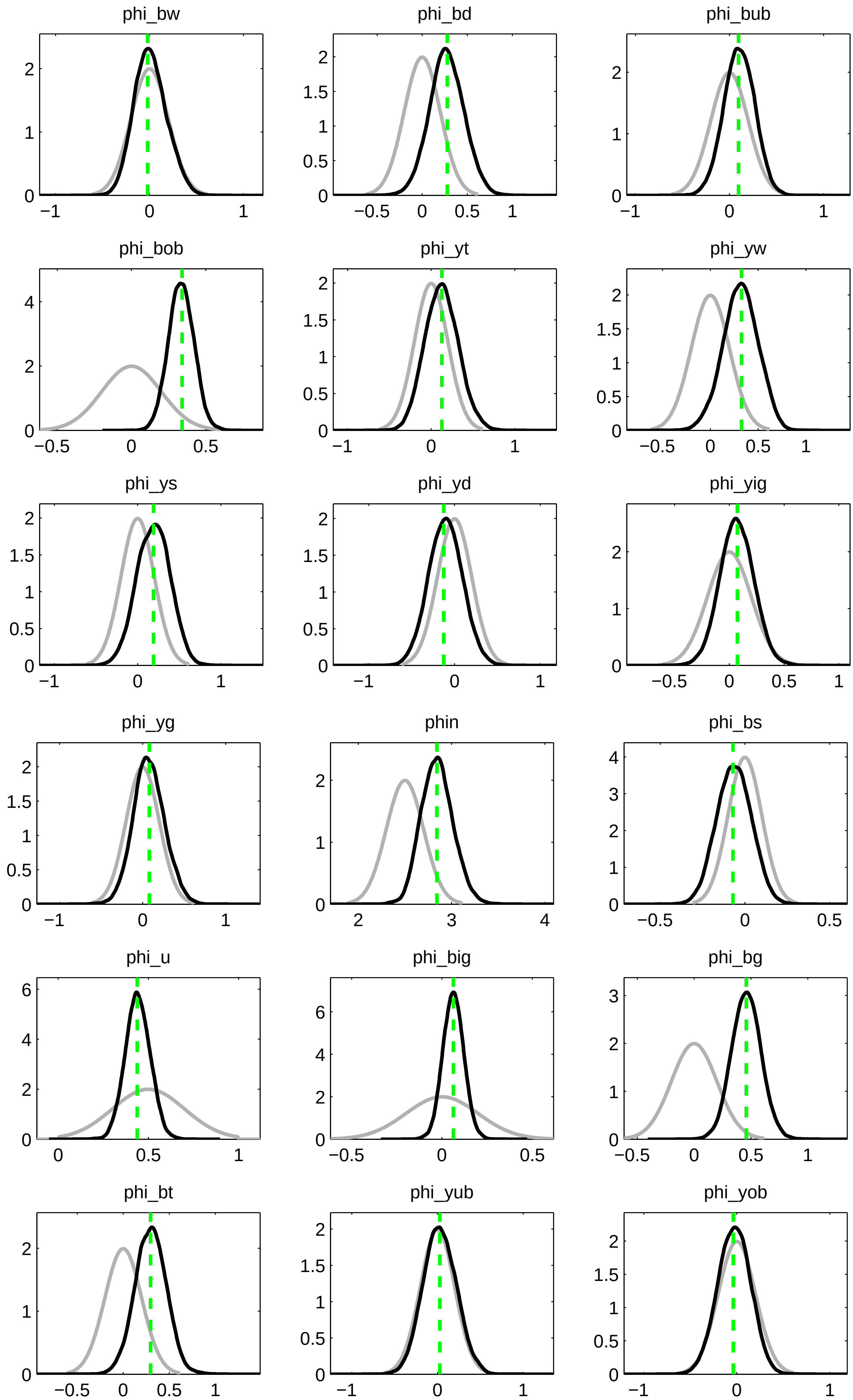


Figure A.3: Bayesian Estimation: Priors and Posteriors of Estimated Parameters (Continued)

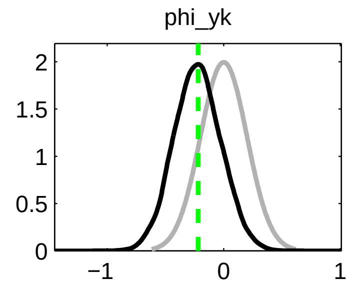


Figure A.4: Bayesian Estimation: Multivariate Convergence Statistics

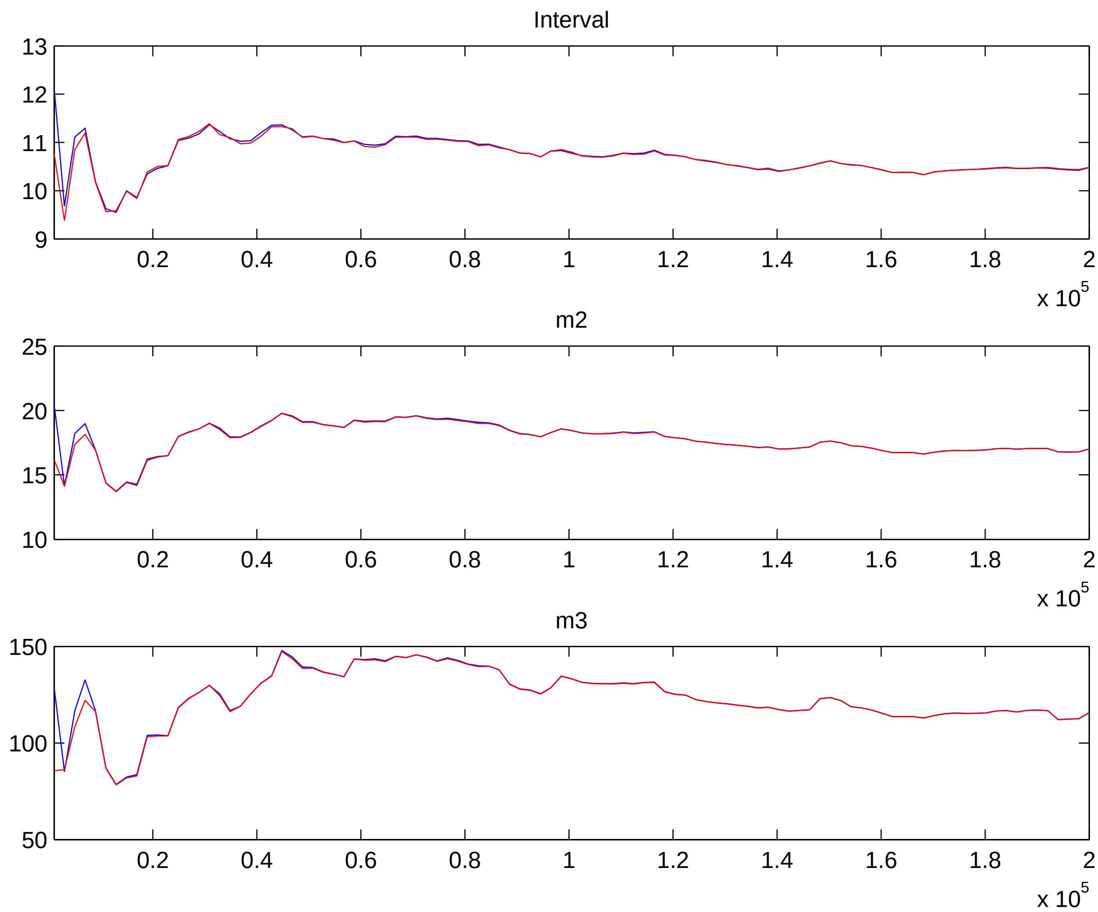


Figure A.5: Tax Rates

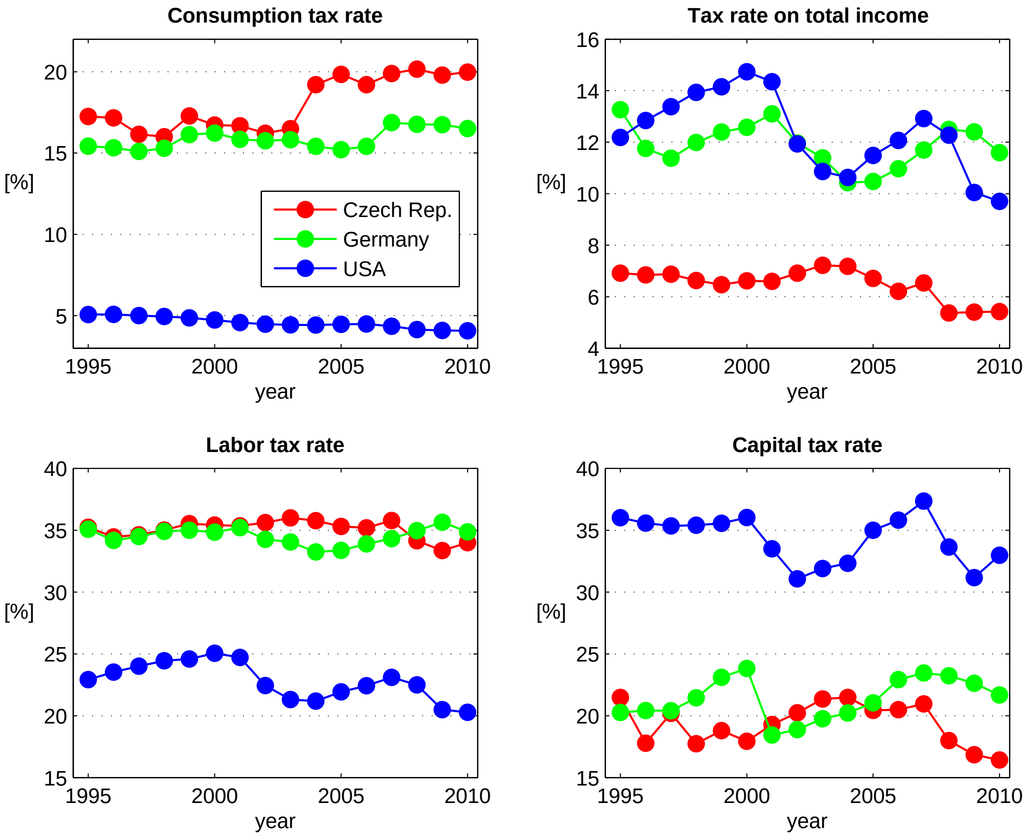


Figure A.6: Data vs. Model

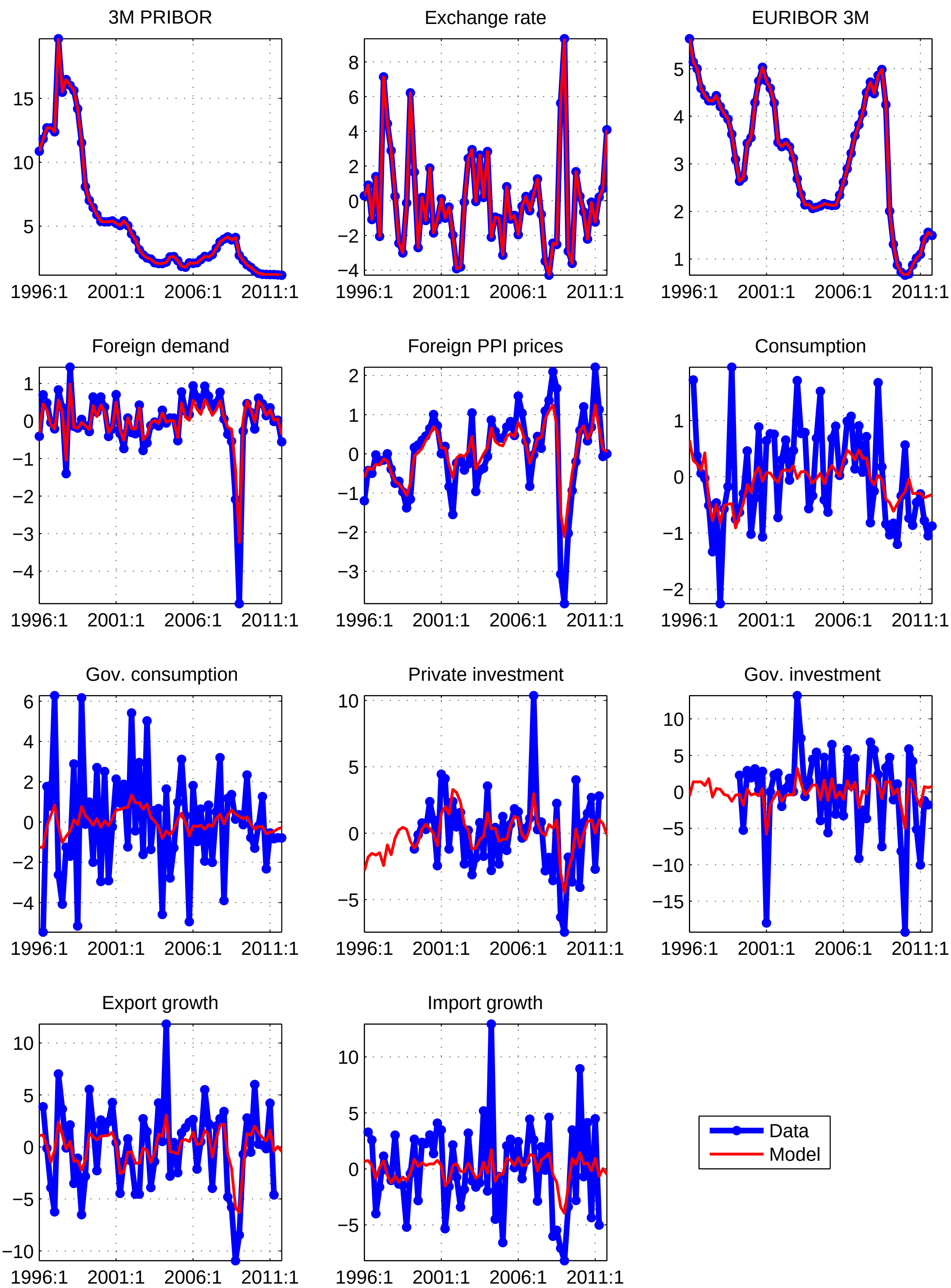


Figure A.7: Data vs. Model (Continued)

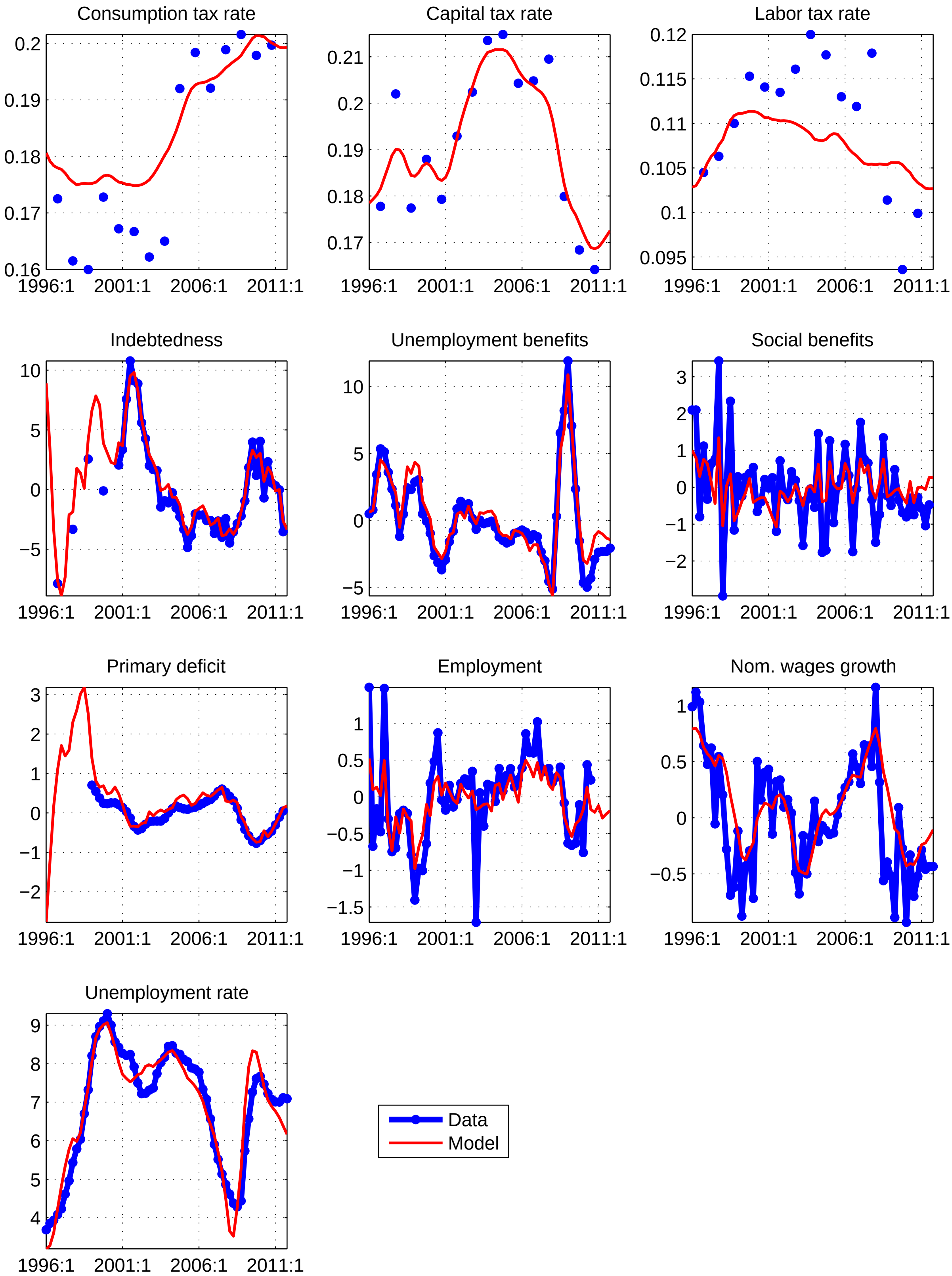


Figure A.8: Data vs. Model (Continued)

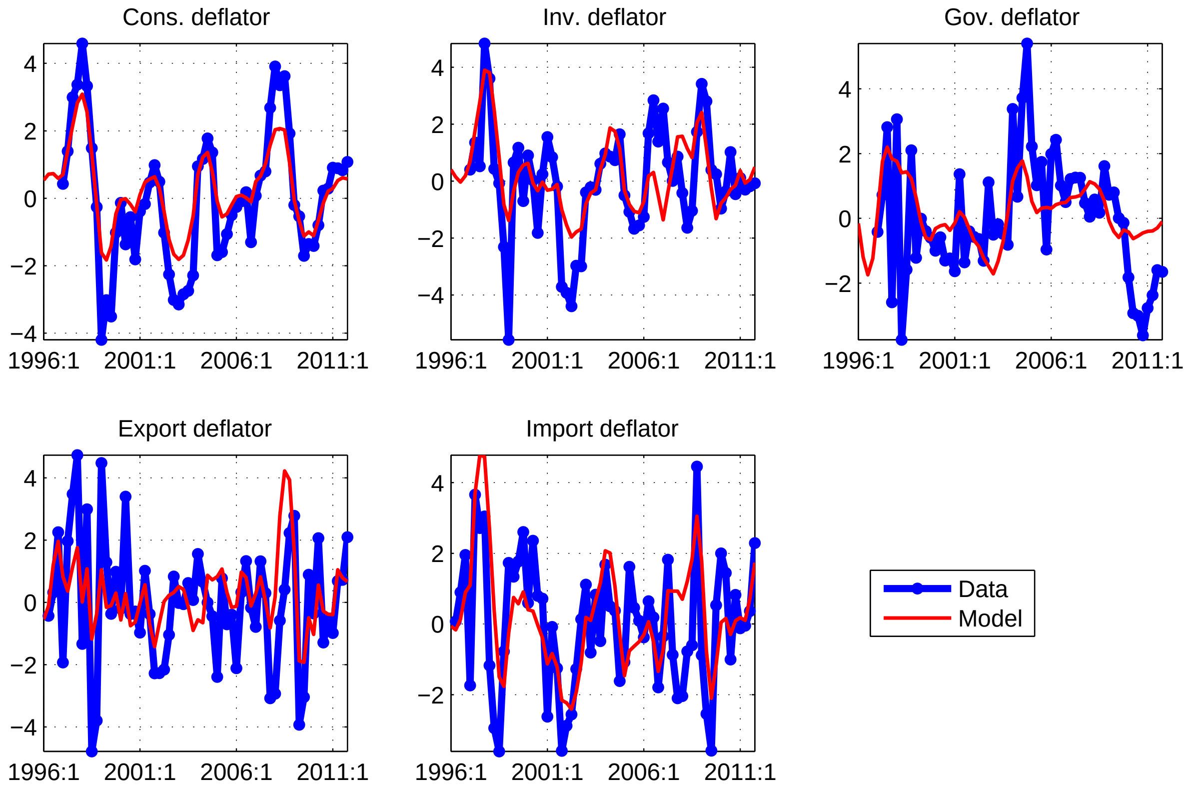
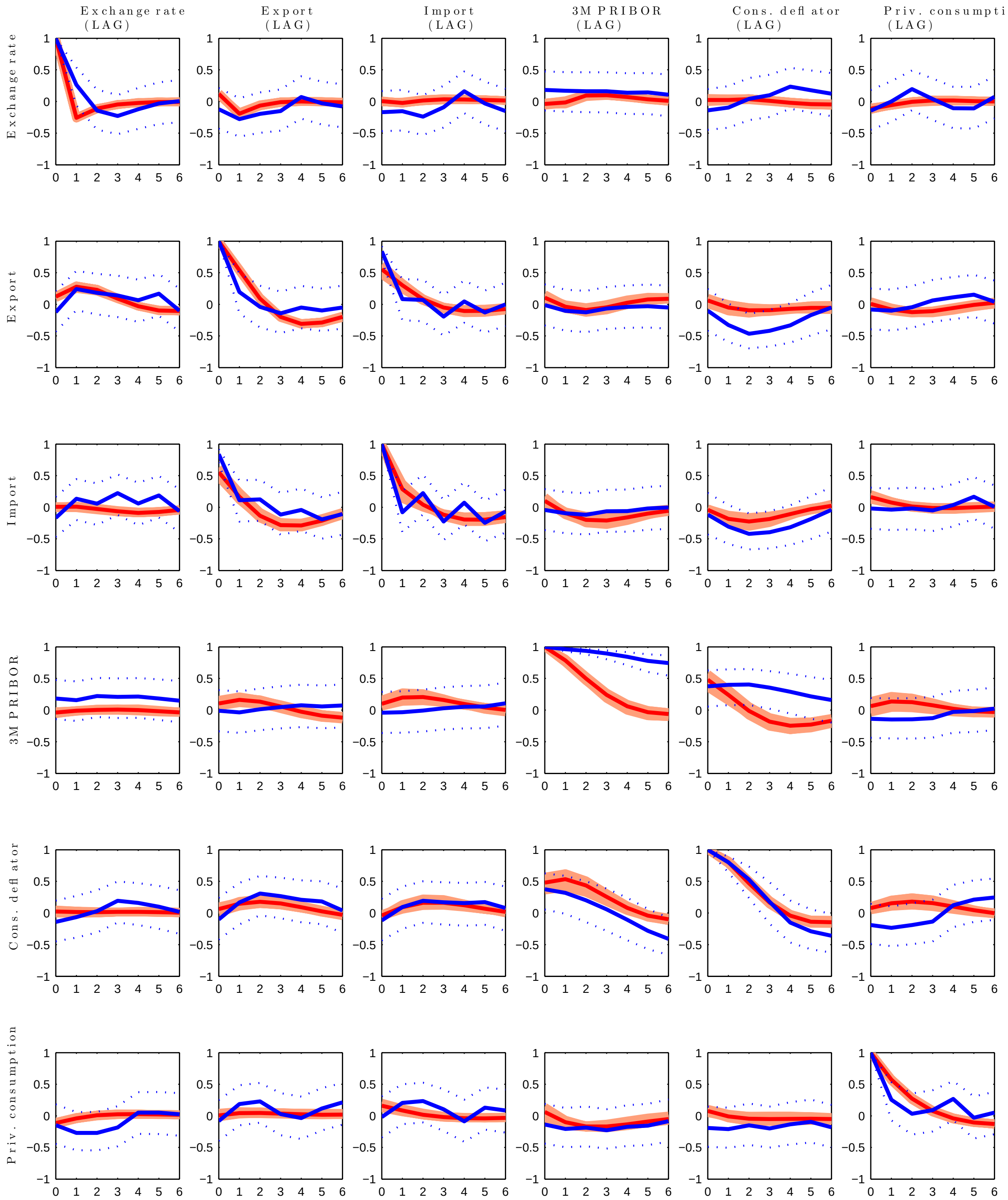
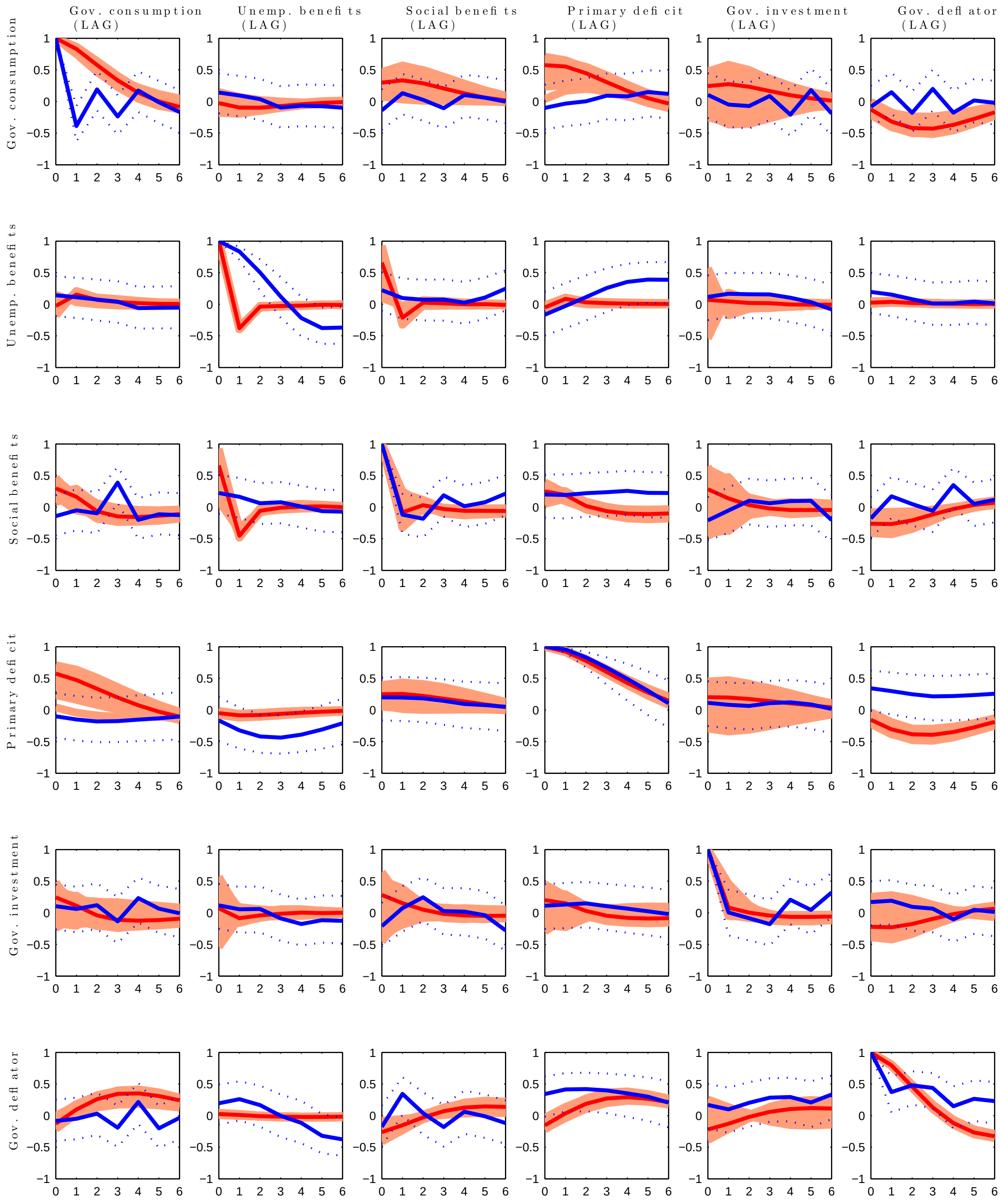


Figure A.9: Comparison of Cross-Correlations (Model vs. Data): Domestic Core Variables



Note: Each graph $[x, y]$ displays the correlation between the variable in row $[x]$ and various lags of the variable listed in column $[y]$, with a maximum lag of 6 quarters assumed. Blue line - correlations of the observed data, including 99% confidence bands; red line - model correlations.

Figure A.10: Comparison of Cross-Correlations (Model vs. Data): Fiscal Variables



Note: See Figure A.9 for a detailed description.

Figure A.11: Impulse Responses to 1% Government Consumption Shock

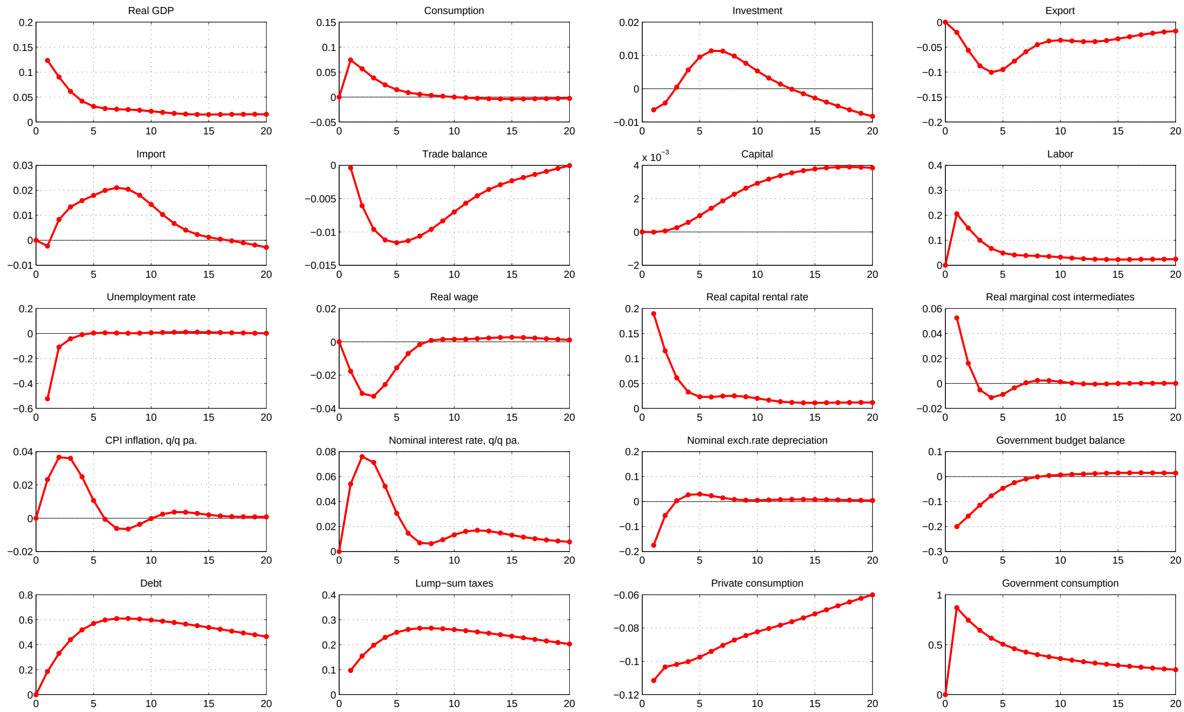


Figure A.12: Impulse Responses to 1% Government Investment Shock

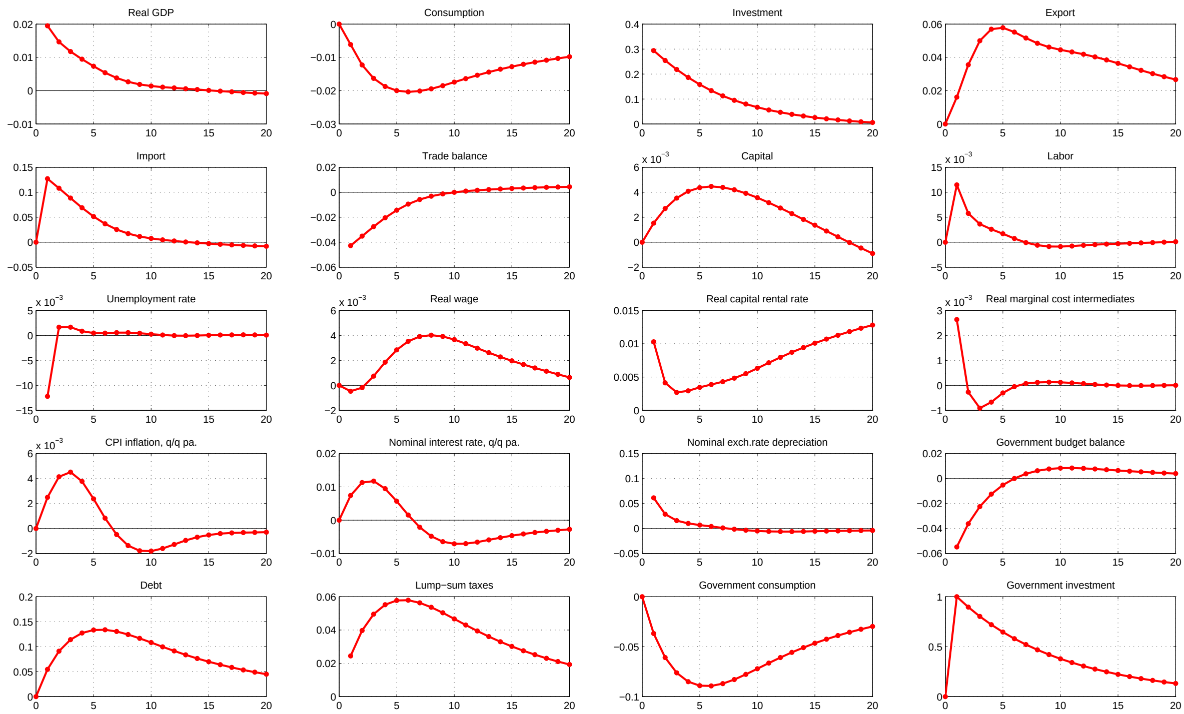


Figure A.13: Impulse Responses to 1% Unemployment Benefits Shock

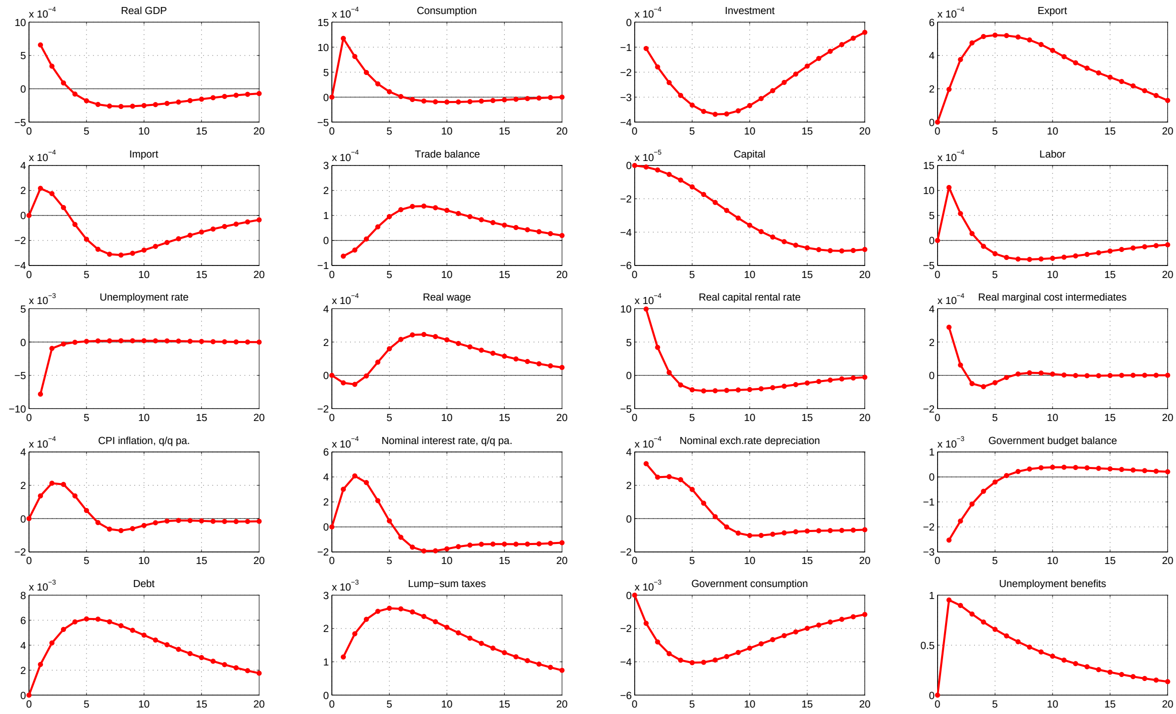


Figure A.14: Impulse Responses to 1% Other Social Benefits Shock

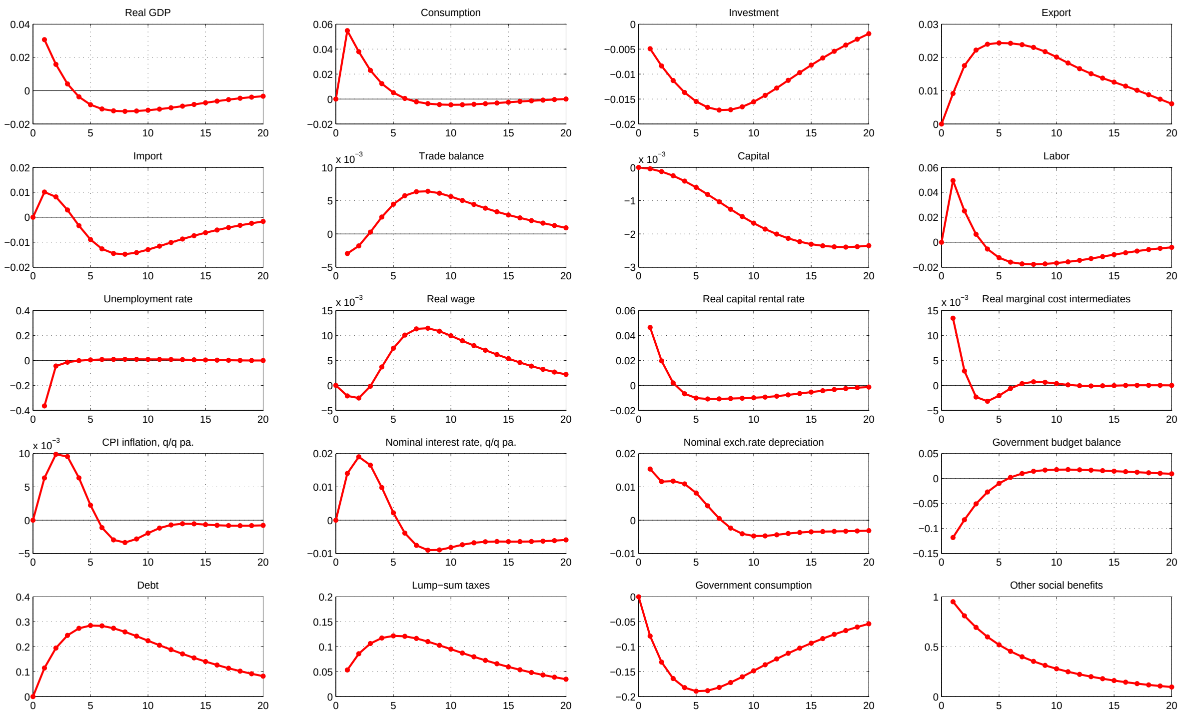


Figure A.15: Impulse Responses to 1 pp Consumption Tax Shock

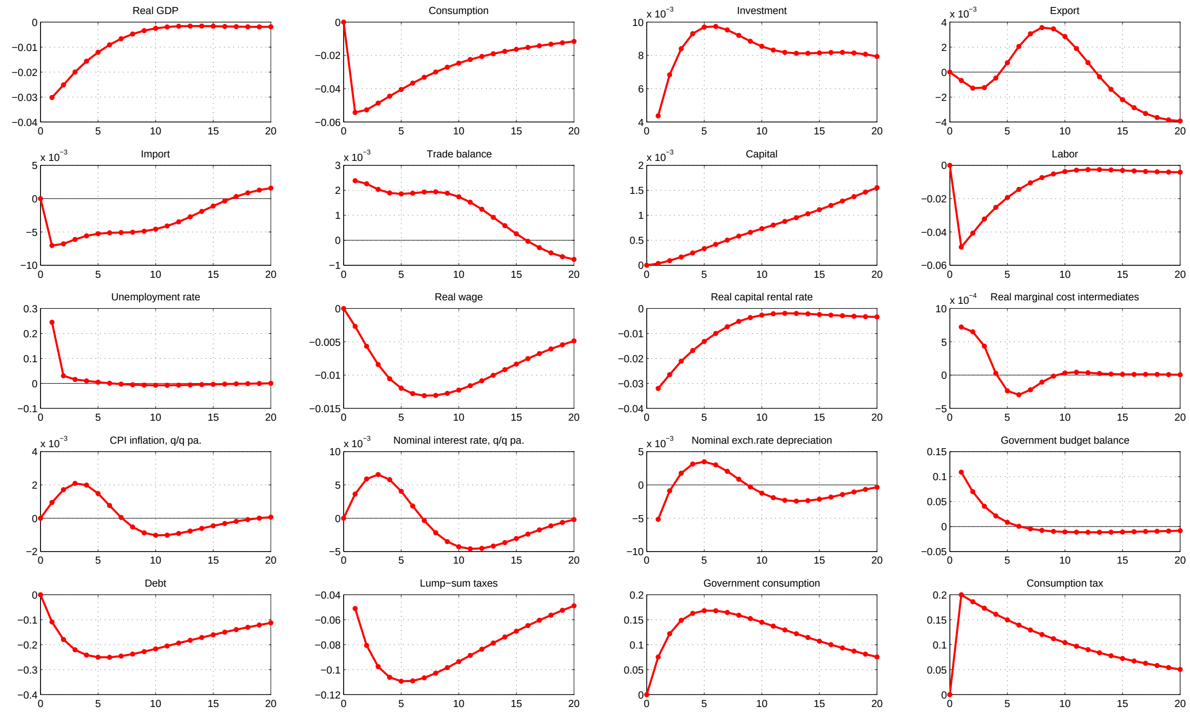


Figure A.16: Impulse Responses to 1 pp Wage Tax Shock

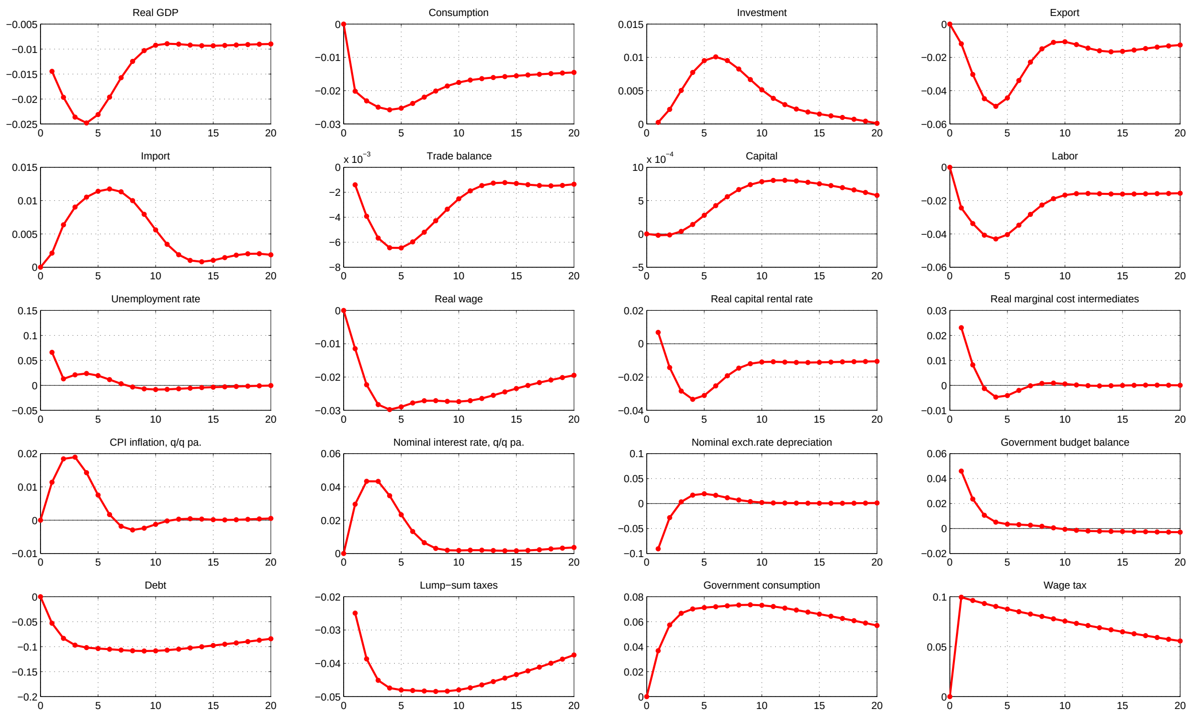


Figure A.17: Impulse Responses to 1 pp Social Security Contributions Shock

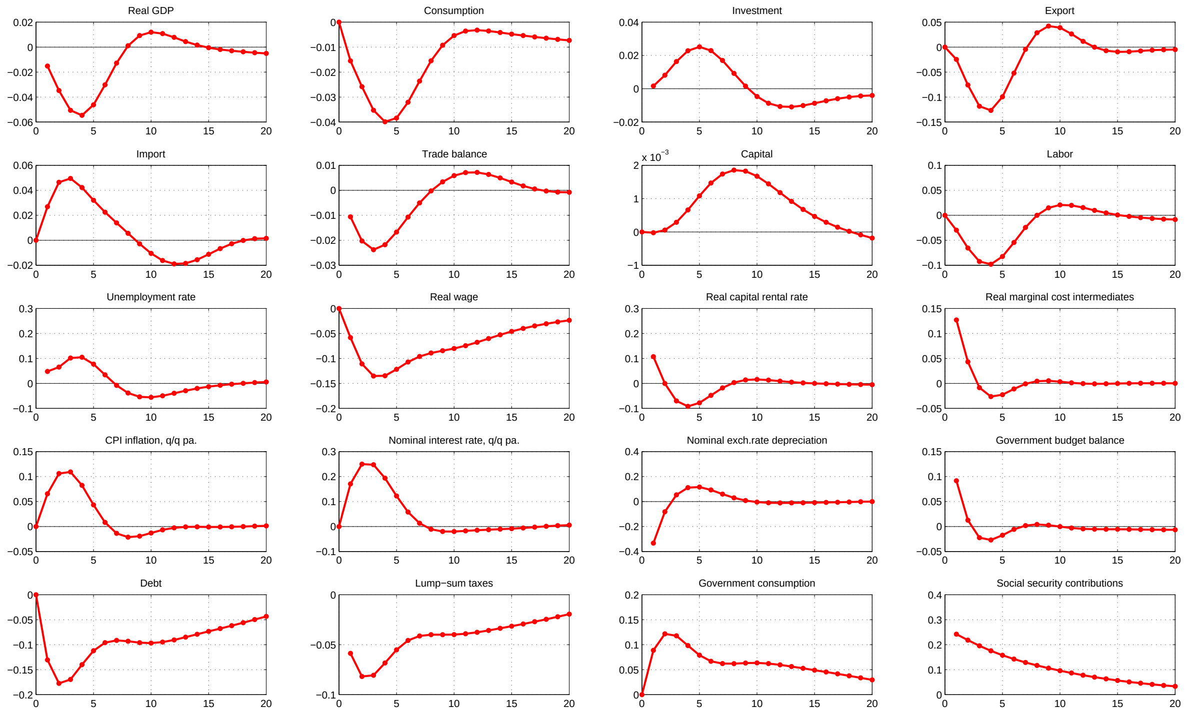


Figure A.18: Impulse Responses to 1 pp Capital Tax Shock

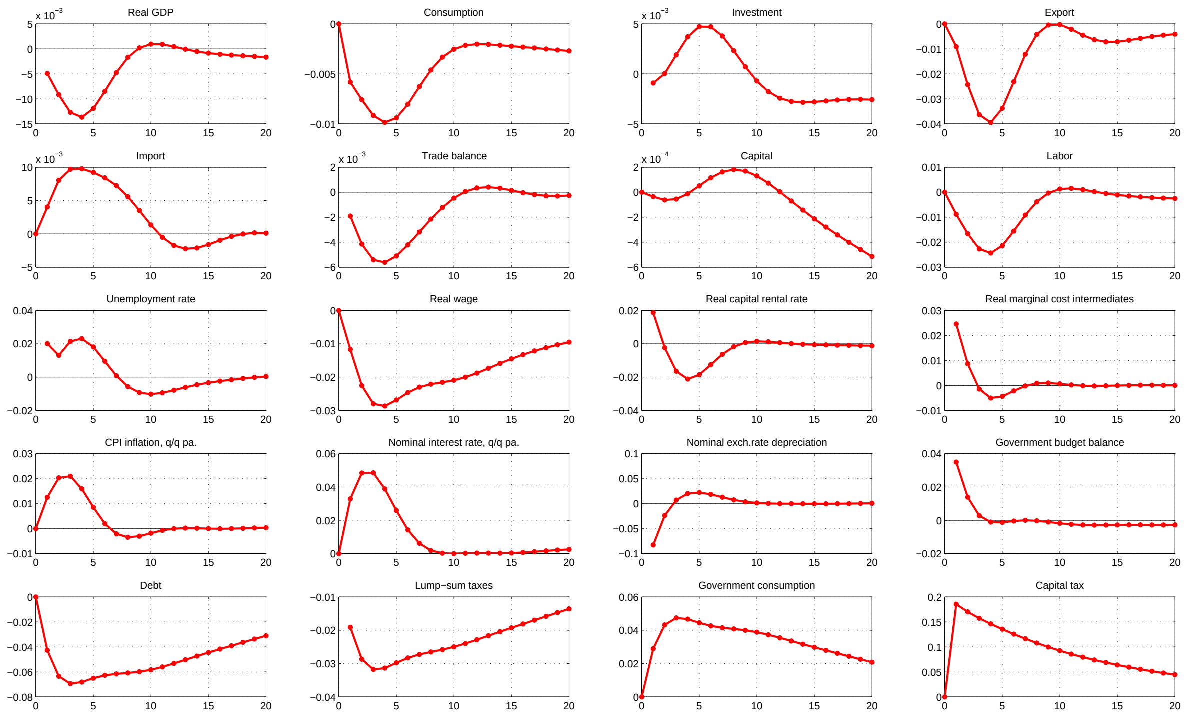
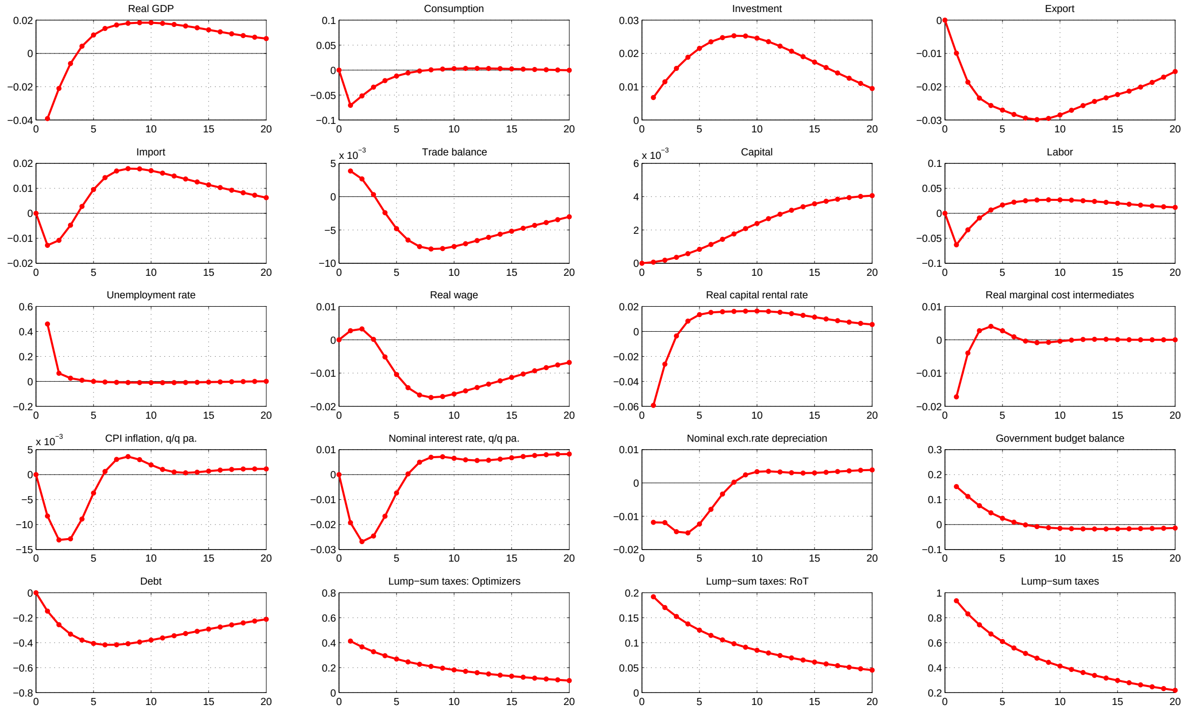


Figure A.19: Impulse Responses to 1% Lump-Sum Taxes Shock



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