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BoGGEM: A DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODEL FOR POLICY SIMULATIONS

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ABSTRACT

This paper presents the theoretical foundations and dynamic properties of a dynamic stochastic general equilibrium (DSGE) model designed for quantitative policy analysis and counterfactual exercises. The approach of the paper can be summarized as follows. First, we present the model's theoretical framework and building blocks. Then, we calibrate the model to the Greek economy and examine the dynamic properties of the model by inspecting the sample moments produced by the model, reporting impulse response functions to a number of shocks, and by performing variance decomposition analysis. The results indicate that the model performs quite well in these contexts.

JEL Classification Codes: E27, E30, E52, E60
Keywords: Dynamic stochastic general equilibrium model, Small open economy, Greece.

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1. Introduction

The objective of this paper is to present the theoretical foundations and dynamic properties of *BoGGEM*, a Dynamic Stochastic **G**eneral **E**quilibrium (DSGE) **M**odel developed at the **B**ank **o**f **G**reece as a quantitative tool for policy analysis. The approach of the paper can be summarized as follows. First, we present the model's theoretical framework and building blocks. Then, we calibrate the model to the Greek economy and examine its dynamic properties by inspecting the sample moments generated by the model, reporting impulse response functions to a number of shocks, and by performing variance decomposition analysis.

In light of the recent sovereign debt crisis and the ongoing economic adjustment programme in Greece, the need for quantitative answers to questions related to the effects that policy reforms may have on the macroeconomy is more imperative than ever. With few exceptions, applied macroeconomic research based on micro-founded DSGE models is limited in Greece.[1] The goal of this paper is to remedy this omission by developing a DSGE model of the Greek economy designed for quantitative policy analysis and counterfactual exercises.[2]

DSGE models are micro-founded models in which economic outcomes arise as an equilibrium outcome of rational economic agents whose micro decision problems are fully dynamic and produce the aggregate, macroeconomic dynamics observed in the data. They integrate both growth and fluctuations and are established as a useful and credible framework in which modern macroeconomic theory and policy are conducted (for reviews, see e.g. King and Rebelo (1999), Rebelo (2005), McGrattan (2006), Kydland (2006) and Cristiano et al. (2010)). Important work from Smets and and Wouters (2003, 2007) showed that DSGE models can also provide a suitable and credible tool for forecasting. Nowadays, many central banks and policy-making international institutions have developed their own DSGE models that are used for policy analysis and forecasting.[3]

[1] DSGE models calibrated to the Greek economy include Kollintzas and Vassilatos (2000), Angelopoulos et al. (2009), Papageorgiou (2009), Papageorgiou et al. (2011), Papageorgiou (2012) and Papageorgiou and Kazanas (2013).

[2] An earlier version of this model was used for fiscal policy simulations in the Working Group on Econometric Modeling (WGEM team on fiscal policy analysis) of the European System of Central Banks.

[3] Some examples include the Bank of England Quarterly Model (see Harrison et al. (2005)), the BEMOD model of the Bank of Spain (see Andres et al. (2006)), the SIGMA model of the Federal Reserve Board (see Erceg et al. (2006)), the New Area Wide Model (NAWM) of the European Central

The model we employ is a small open economy DSGE model and aims at capturing main features of the Greek economy. It is built in the tradition of New Keynesian models in the sense that includes nominal rigidities and imperfect competition in the product and labour markets. At its core is a neoclassical growth model with optimizing agents and technology driven long-run growth. The model shares main standard characteristics of the models used by most central banks and international institutions, but also includes some features that are important to adapt the model to Greece. We would like to highlight the following features of the model.

First, it incorporates a small open economy structure by allowing households and the government to participate in international financial markets. The domestic economy is modeled as a small open economy that belongs to a currency area in the sense that the nominal exchange rate is exogenous and there is no monetary policy independence. In the absence of autonomous monetary policy, the domestic nominal interest rate is determined by an exogenously given risk-free foreign nominal interest rate and a risk-premium component. Thus, fiscal policy is the only available business cycle stabilization tool, which is a feature that characterizes the Greek economy after its entrance into the euro area. The open economy framework makes the model suitable for analyzing the impact of domestic and foreign shocks on key macroeconomic variables related to the external sector. This is of particular importance for the Greek economy, where external imbalances are not an unusual feature of the recent past (see e.g. Kollintzas et al. (2012) for a discussion).

Second, the model includes a highly detailed fiscal policy block. In particular, fiscal policy is summarized by the paths of the three main types of tax rates (consumption, capital income and labour income tax rates) and the paths of five key types of public spending (government purchases on goods and services, public investment, public sector wages, public employment and government transfers). Thus, the model is well suited for simulating the effects of the fiscal measures that have been implemented recently in Greece, such as cuts in public sector wages and increases in income taxes.

Bank (see Christoffel et al. (2008)), the QUEST model of the European Commission (see Ratto et al. (2009)), the Euro Area and Global Economy (EAGLE) of the European Central Bank (see Gomes et al. (2010)), the GIMF model of the International Monetary Fund (see Kumhof et al. (2010)), and many others.

Third, the model features financial market imperfections in the form of financially constrained households and sovereign risk-premia on public debt. The presence of liquidity constrained households has been found to be an important determinant of the impact of fiscal policy shocks, particularly in periods of tight financial conditions (see e.g. Coenen et al. (2012, 2013)). The introduction of risk-premia on public debt reflects the risk of a sovereign default and introduces a sovereign risk channel through which sovereign default risk is transmitted to the real economy, in line with the recent evidence provided in European Commission (2012) and Corsetti et al. (2013).

Fourthly, the model includes a number of nominal and real frictions, such as price stickiness, price indexation, habit formation in consumption, investment adjustment costs and variable capital utilization, that have been empirically identified as playing an important role for the transmission of structural shocks in the short run (see e.g. Cristiano et al. (2005) and Mertens and Ravn (2011)). Finally, the model features a number of market imperfections and frictions that have been found to characterize the Greek economy, such as real wage rigidities and imperfect competition in the product and labour markets. These features make the model well suited for examining the macroeconomic effects of structural reforms.

We calibrate the model to the Greek economy at a quarterly frequency over the period 2000:1-2011:4. Our approach in examining the dynamic properties of the model can be summarized as follows. First, we investigate the descriptive power of the model by examining the sample moments produced by the model. Second, we report impulse response functions to a number of shocks and analyze the main transmission mechanisms through which these shocks influence the macroeconomy. Given the ongoing fiscal consolidation effort and the implementation of structural reforms in products and labour markets in Greece, we are particularly interested in examining the responses of key macroeconomic variables to fiscal shocks, technology shocks and shocks to the degree of competition in the product and labour markets. Finally, we perform variance decomposition analysis in order to quantify the relative importance of each of the shocks in the variation of key macroeconomic variables. The results indicate that the model performs quite well.

The rest of this paper is as follows: Section 2 presents the model. Section 3 discusses calibration and long-run solution. Section 4 presents the model's descriptive power, impulse response and variance decomposition analysis. Section 5 concludes.

2. The theoretical model

BoGGEM is a DSGE model of a small open economy that belongs to a currency area in the sense that the nominal exchange rate is exogenous and there is no monetary policy independence. In the absence of autonomous monetary policy, the domestic nominal interest rate is determined by an exogenously given risk-free foreign nominal interest rate and a risk-premium component. As in Gali and Monacelli (2005) and Adolfson et al (2007), we assume that the domestic country is of negligible size relative to the rest of the world (referred as foreign economy) and developments in the domestic economy do not have any impact on the rest of the world variables.

The domestic economy consists of a large number of households, firms and a government. In particular, there are two types of households, differing in the ability to participate in asset markets. The first type of households has access to the financial markets and can transfer wealth intertemporally by trading bonds and accumulating physical capital, whereas the second type of households is assumed to be liquidity constrained in the sense that it cannot lend or borrow. Both types of households receive labour income by working in the private and public sector. As regards the labour market in the private sector, households supply differentiated labour services and act as wage setters in monopolistically competitive markets. Concerning firms, we distinguish between monopolistically competitive firms that produce tradable differentiated goods that are sold domestically and in the rest of world, and perfectly competitive final good firms that produce four non-tradable final goods, namely a private consumption good, a private investment good, a public consumption good and a public investment good. There are also importing firms that import differentiated goods from abroad and operate under monopolistic competition. In addition, there is a foreign final good firm that combines the exported domestic intermediate goods.

The government hires labour and combines public consumption and public employment to produce public goods that provide direct utility to households. It levies taxes on consumption, on income from labour and capital earnings, lump-sum taxes, and issues one-period government bonds in the domestic bond market and the international markets. Total tax revenues plus the issue of new government bonds are used to finance public purchases of goods and services, public investment, government transfers and public sector wages.

2.1. Households

The economy is populated by a continuum of households indexed by $h \in [0,1]$, of which a fraction indexed by $i \in \left[0,1-\lambda\right]$ are referred to as Ricardian or optimizing households and a fraction indexed by $j \in (1-\lambda,1]$ are referred to as non-Ricardian or liquidity constrained households. Optimizing households have unrestricted access to the capital or financial markets, where they can invest in the form of physical capital, government bonds and internationally traded bonds. Liquidity constrained households are not able to lend or borrow and they just consume their after-tax disposable income in each period. Both households supply differentiated labour services and act as wage setters in monopolistically competitive markets.

2.1.1. Ricardian Households

Each Ricardian household i has preferences over consumption and hours worked that are represented by the intertemporal utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(C_{i,t} - \xi^c \overline{C}_{i,t-1}, H_{i,t}, Y_t^g\right) \tag{1}$$

where E_0 is the expectations operator conditional on period-0 information, $\beta \in \left(0,1\right)$ is the discount factor, $C_{i,t}$ is the effective consumption (defined below) of Ricardian households at t, $H_{i,t}$ is total hours worked at t, $\xi^c \in [0,1)$ is a parameter that measures the degree of external habit formation in consumption, $\overline{C}_{i,t-1}$ is average (per household i) lagged-once effective consumption and Y_t^g is per-capita public goods and services produced by the government (such as education, justice, hospitals, etc). Effective consumption $C_{i,t}$ is defined as:

$$C_{i,t} = C^p_{i,t} + \vartheta Y^g_t \qquad (2)$$

where $C^p_{i,t}$ is private consumption at time t. Thus, public goods and services influence the private utility through the parameter $\vartheta \in [-1,1]$.[4]

The instantaneous utility function is increasing and concave in its arguments and is assumed to be of the form:

$$U\left(C_{i,t} - \xi^c \overline{C}_{i,t-1}, H_{i,t}, Y^g_t\right) = \log\left(C_{i,t} - \xi^c \overline{C}_{i,t-1}\right) - \kappa \frac{H^{1+\gamma}_{i,t}}{1+\gamma} \qquad (3)$$

where γ is the inverse of Frisch labour supply elasticity and $\kappa > 0$ is a preference parameter related to work effort.

Each household i supplies hours worked in the private sector, $H^p_{i,t}$, and the public sector, $H^g_{i,t}$. As in Ardagna (2001) and Forni et al. (2009), hours of work can be moved costlessly across the two sectors and are perfect substitutes in the utility function. Thus, $H_{i,t} = H^p_{i,t} + H^g_{i,t}$ in each period t. The household can save in the form of physical capital, $I_{i,t}$, domestic government bonds, $B_{i,t}$, and foreign bonds, $F^p_{i,t}$. It receives labour income from working in the private sector, $W^p_{i,t} H^p_{i,t}$, and the public sector, $W^g_{i,t} H^g_{i,t}$, where $W^p_{i,t}$ and $W^g_{i,t}$ are the respective real wage rates in the private and public sector. The households also receive capital income, $r^k_t u_{i,t} K^p_{i,t}$, where r^k_t is the real return to the effective amount of private capital services, $u_{i,t} K^p_{i,t}$, $K^p_{i,t}$ is the physical private capital stock and $u_{i,t} > 0$ is the intensity of use of capital. They also earn interest income from domestic government and internationally traded bonds that pay a gross nominal interest R_t and R^H_t at time $t+1$, respectively. Two additional sources of income are the firm's profits that are distributed in the form of dividends, $Div_{i,t}$, and lump-sum government transfers, $G^{tr}_{i,t}$.

[4] See also e.g. Christiano and Eichenbaum (1992), Forni et al. (2010) and Economides et al. (2011, 2012) for a similar formulation.

The household pays taxes on consumption, $0 \le \tau_t^c < 1$, on income from labour, $0 \le \tau_t^l < 1$, capital earnings and dividends, $0 \le \tau_t^k < 1$, and lump-sum taxes, T_t . Thus, the budget constraint of each Ricardian household i is:

$$\begin{aligned}
&\left(1+\tau_t^c\right)C_{i,t}^p + \frac{P_t^i}{P_t^c} I_{i,t} + \frac{B_{i,t+1}}{P_t^c} + \frac{S_t F_{i,t+1}^p}{P_t^c} = \\
&\qquad = \left(1-\tau_t^l\right)\left(W_{i,t}^p H_{i,t}^p + W_{i,t}^g H_{i,t}^g\right) + \left(1-\tau_t^k\right)\left(r_t^k u_{i,t} K_{i,t}^p + Div_{i,t}\right) + \\
&\qquad\qquad + R_{t-1}\frac{B_{i,t}}{P_t^c} + R_{t-1}^H \frac{S_t F_{i,t}^p}{P_t^c} + G_{i,t}^{tr} - T_t
\end{aligned} \tag{4}$$

where P_t^c and P_t^i are the prices of a unit of the private consumption final good and the investment final good, respectively, and S_t is the nominal exchange rate, expressed in terms of the domestic currency per unit of foreign currency.

The private capital stock is assumed to evolve over time according to the following law of motion:

$$K_{i,t+1}^p = \left(1-\delta^p\left(u_{i,t}\right)\right)K_{i,t}^p + \eta_t^I\left[1 - S\left(\frac{I_{i,t}}{I_{i,t-1}}\right)\right]I_{i,t} \tag{5}$$

where S is a convex adjustment cost function of the form proposed by Christiano et al. (2005) that satisfies $S\left(\gamma_{z^+}\right) = S'\left(\gamma_{z^+}\right) = 0$, $S''(\cdot) > 0$, where γ_{z^+} is the rate that private investment grows along the balance growth path. We adopt the following specification for S:

$$S\left(\frac{I_{i,t}}{I_{i,t-1}}\right) = \frac{\xi^k}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - \gamma_{z^+}\right)^2 \tag{6}$$

where $\xi^k \ge 0$ is an adjustment cost parameter. As in Greenwood et al. (1988), we assume that the depreciation rate of private capital depends on the rate of capacity utilization and is a convex function that satisfies $\delta'^p > 0$, $\delta''^p > 0$. The modelling choice is motivated by the fact that variable capital utilization has been found to be important determinant for the transmission of fiscal policy shocks; see e.g. Mertens and Ravn (2011). The depreciation function is of the form:

$$\delta^{p}\left(u_{i,t}\right)=\delta^{p}u_{i,t}^{\phi} \tag{7}$$

where $\delta^{p}\in\left(0,1\right)$ and $\phi>0$ are respectively the average rate of depreciation of private capital and the elasticity of marginal depreciation costs. In the law of motion of capital we also include an investment-specific technology shock, η_{t}^{I}, that affects the efficiency of the newly installed investment good. Investment-specific shocks have been found important driving forces for generating aggregate fluctuations (see e.g. Greenwood et al. (2000)).

Taking prices $\left\{r_{t}^{k},R_{t},R_{t}^{H},P_{t}^{c},P_{t}^{i}\right\}_{t=0}^{\infty}$ and fiscal policy $\left\{\tau_{t}^{c},\tau_{t}^{l},\tau_{t}^{k},W_{i,t}^{g},H_{i,t}^{g},G_{i,t}^{tr},T_{t}\right\}_{t=0}^{\infty}$ as given, each Ricardian household i chooses a sequence $\left\{C_{i,t}^{p},B_{i,t+1},F_{i,t+1}^{p},u_{i,t},I_{i,t},K_{i,t+1}^{p}\right\}_{t=0}^{\infty}$ in order to maximize (1) subject to the constraints (4)-(5), the initial conditions for $K_{i,0}^{p},B_{i,0},F_{i,0}^{p}$ plus the non-negatively constraints for $C_{i,t}^{p},B_{i,t+1},F_{i,t+1}^{p},u_{i,t},I_{i,t},K_{i,t+1}^{p}$. Defining $\Lambda_{i,t}$ to be the Langrange multiplier associated with the household's budget constraint, and $Q_{i,t}$ the Langrange multiplier associated with the private capital accumulation equation, the first-order conditions for $C_{i,t}^{p},B_{i,t+1},F_{i,t+1}^{p},u_{i,t},I_{i,t},K_{i,t+1}^{p}$ include the constraints and the following conditions:

$$\Lambda_{i,t}=\frac{\left(C_{i,t}-\xi^{c}\bar{C}_{i,t-1}\right)^{-1}}{\left(1+\tau_{t}^{c}\right)} \tag{8a}$$

$$\Lambda_{i,t}=\beta E_{t}\left[\Lambda_{i,t+1}\frac{R_{t}}{\Pi_{t+1}^{c}}\right] \tag{8b}$$

$$\Lambda_{i,t}=\beta E_{t}\left[\Lambda_{t+1}\frac{R_{t}^{H}}{\Pi_{t+1}^{c}}s_{t+1}\right] \tag{8c}$$

$$\left(1-\tau_{t}^{k}\right)r_{t}^{k}=q_{i,t}\delta^{p\prime}\left(u_{i,t}\right) \tag{8d}$$

$$\frac{P_{t}^{i}}{P_{t}^{c}}=q_{i,t}\eta_{t}^{I}\left(1-S\left[\frac{I_{i,t}}{I_{i,t-1}}\right]-S'\left[\frac{I_{i,t}}{I_{i,t-1}}\right]\frac{I_{i,t}}{I_{i,t-1}}\right)+\beta E_{t}q_{i,t+1}\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\eta_{t+1}^{I}S'\left[\frac{I_{i,t+1}}{I_{i,t}}\right]\left(\frac{I_{i,t+1}}{I_{i,t}}\right)^{2} \tag{8e}$$

$$q_{i,t} = \beta E_t \frac{\Lambda_{i,t+1}}{\Lambda_{i,t}} \left[\left(1-\tau_{t+1}^k\right) r_{t+1}^k u_{i,t+1} + q_{i,t+1} \left(1-\delta^p \left(u_{i,t+1}\right)\right) \right] \tag{8f}$$

where $\Pi_t^c = P_t^c / P_{t-1}^c$ is the gross rate of consumer price index (CPI) inflation, $s_t = S_t / S_{t-1}$ is the gross growth rate of the nominal exchange rate and $q_{i,t} = \frac{Q_{i,t}}{\Lambda_{i,t}}$ is the shadow price of a unit of capital (i.e. the Tobin's Q). The optimality conditions are completed with the transversality conditions for the three assets, $\lim_{t\to\infty} \beta^t \frac{\partial U_t(.)}{\partial C_{i,t}^p} K_{i,t+1}^p = 0$, $\lim_{t\to\infty} \beta^t \frac{\partial U_t(.)}{\partial C_{i,t}^p} B_{i,t+1} = 0$ and $\lim_{t\to\infty} \beta^t \frac{\partial U_t(.)}{\partial C_{i,t}^p} F_{i,t+1}^p = 0$.

Condition (8a) states that the Lagrange multiplier equals the marginal utility of consumption. Conditions (8b), (8c) and (8e) are the standard Euler equations for B_{t+1}, F_{t+1}^p and I_{t+1}, respectively. Condition (8d) states that the marginal benefit of raising utilization must equal the associated marginal cost. Finally, condition (8f) states that the relative price of capital is equal to the expected return of capital.

2.1.2. Non-Ricardian households

Liquidity constrained households have the same preferences as optimizing households that are represented by an equation symmetric to (3), with $i = j$. They receive labour income from working in the private and public sector, but they have no access to the capital or financial markets. Therefore, they cannot lend or borrow and each period they consume their after-tax disposable wage income plus lump-sum government transfers. The period-by-period budget constraint of each household j is:

$$\left(1+\tau_t^c\right) C_{j,t} = \left(1-\tau_t^l\right)\left(W_{j,t}^p H_{j,t}^p + W_{j,t}^g H_{j,t}^g\right) + G_{j,t}^{tr} \tag{9}$$

where $H_{j,t}^p$ and $H_{j,t}^g$ are respectively hours worked in the private and public sector and $G_{j,t}^{tr}$ are lump-sum government transfers. As in Coenen et al. (2013), we allow for a possible uneven distribution of government transfers amongst Ricardian and Non-Ricardian households. The corresponding marginal utility of consumption is given by:

$$\Lambda_{j,t} = \frac{\left(C_{j,t} - \xi^c \overline{C}_{j,t-1}\right)^{-1}}{\left(1+\tau_t^c\right)} \tag{10}$$

2.2 Wage setting and the evolution of wages in the private sector

We assume that wages in the private sector are set by monopolistic unions, following the approach in Gali et al. (2007) and Forni et al. (2009). More specifically, households supply the differentiated labour inputs to a continuum of unions $h \in [0,1]$ each of which represents workers of the same type. Each union h represents $1-\lambda$ Ricardian and λ non-Ricardian households, and in each period it sets the wage rate for their workers by trading off the utility value of the labour income obtained by working in the private sector and the disutility of the total work effort. In doing so, unions take the demand for the differentiated labour input h as given. Additionally, they take into account the fact that firms and the public sector allocate labour demand uniformly across different types h of workers, independently of them being Ricardian or non-Ricardian, which means that hours worked by the two types of households are equal: $H_{j,t}^{h,p} = H_{i,t}^{h,p} \equiv H_{h,t}^{p}$ and $H_{j,t}^{h,g} = H_{i,t}^{h,g} \equiv H_{h,t}^{g}$. Therefore, each period a typical union h chooses the wage rate, $W_{h,t}^{p}$, in order to maximize the following objective function:

$$L_w = \lambda\left[\Lambda_{h,t}^{NR}\left(1-\tau^l\right)W_{h,t}^{p}H_{h,t}^{p}\right] + (1-\lambda)\left[\Lambda_{h,t}^{R}\left(1-\tau^l\right)W_{h,t}^{p}H_{h,t}^{p}\right] - \kappa\frac{\left(H_{h,t}\right)^{1+\gamma}}{1+\gamma} \tag{11}$$

subject to

$$H_{h,t}^{p} = \left(\frac{W_{h,t}^{p}}{W_{t}^{p}}\right)^{-\frac{\mu_t^w}{\mu_t^w - 1}} H_t^p \tag{12}$$

$$H_{h,t} = H_{h,t}^{p} + H_{h,t}^{g} \tag{13}$$

where equation (12) is the demand for the differentiated labour input h (derived formally later in Section 2.3.2.), H_t^p is total labour demand in the private sector, W_t^p is the aggregate wage rate in the private sector, $\Lambda_{h,t}^{NR}$, $\Lambda_{h,t}^{R}$ are respectively the marginal utilities of consumption of non-Ricardian and Ricardian households of type h that are used as weights for the labour income earned by working in the private sector. Also, $\mu_t^w / \left(\mu_t^w - 1\right) > 1$ is the elasticity of substitution across the differentiated labour services. As we demonstrate below, the time varying parameter, $\mu_t^w > 1$, has a natural interpretation as a markup in the private labour market.

Restricting our attention on a symmetric equilibrium in which all unions choose the same wage, the first order condition for the above problem is:

$$W_t^{*p}\left(\frac{\lambda}{MRS_t^{NR}} + \frac{1-\lambda}{MRS_t^{R}}\right) = \mu_t^w \tag{14}$$

where W_t^{*p} is the optimal wage rate chosen by the unions, and $MRS_t^{NR} = \dfrac{\kappa H_t^{\gamma}}{\left(1-\tau^l\right)\Lambda_t^{NR}}$ and $MRS_t^{R} = \dfrac{\kappa H_t^{\gamma}}{\left(1-\tau^l\right)\Lambda_t^{R}}$ are respectively the marginal rates of substitution between consumption and leisure of the non-Ricardian and Ricardian households. Also, note that in the case in which $\lambda = 0$ (i.e. all households are Ricardian), the time varying parameter μ_t^w represents a markup of the optimally chosen real wage rate over the marginal rate of substitution between consumption and leisure.

Following Hall (2005) and Blanchard and Gali (2007), we introduce rigidities in the labour market by assuming that real wages respond sluggishly to labour market conditions as a result of some unmodeled imperfections or frictions in the labour market. In particular, the real wage rate in the private sector is a weighted average of the past wage rate and the optimal wage rate chosen by unions:

$$W_t^{p} = \left(W_{t-1}^{p}\right)^{n}\left(W_t^{*p}\right)^{1-n} \tag{15}$$

where $0 \le n \le 1$ denotes the degree of real wage rigidities and W_t^{*p} is given by (14).

The above formulation aims at capturing a number of possible sources of imperfection that have been found to characterize the Greek labour market, e.g. institutional and legal rigidities, safety nets etc; see European Commission (2010) and Lapatinas (2009) for a further discussion regarding rigidities in the Greek labour market. In addition, as found in Uhlig (2007), Malley et al. (2009) and Kliem and

Uhlig (2013), this specification works quite well in capturing the aggregate dynamics of hours worked and real wages in the data.[5]

2.3. Firms

The production sector of the economy is as follows: there is a continuum of monopolistically competitive domestic intermediate good firms, indexed by $f \in [0,1]$, each of which produces a differentiated output that is sold domestically or abroad. There is also a set of four representative perfectly competitive final good firms that combine purchases of domestically produced intermediate goods with purchases of imported intermediate goods to produce four non-tradable goods, namely, private consumption, private investment, public consumption and public investment. In addition, there is a continuum of importing firms, indexed by $f^m \in [0,1]$, that import differentiated intermediate goods in a monopolistically competitive environment. Finally, there is a foreign final good firm that combines purchases of the exported domestic intermediate goods.

2.3.1. Domestic final good firms

There are four representative perfectly competitive final good firms that combine purchases of domestically produced intermediate goods with purchases of imported intermediate goods to produce four non-tradable final goods: a private consumption good, C_t^c, a private investment good, I_t^i, a public consumption good, G_t^{gc} and a public investment good, G_t^{gi}.

Let us first discuss the production of the private final consumption good. The representative producer of the private consumption good combines a bundle of domestically produced intermediate goods, C_t^d, with a bundle of imported intermediate goods, C_t^m, to generate a composite non-tradable consumption good, C_t^c, by using a constant elasticity of substitution (CES) production function:

[5] Microfoundations for Equation (15) can be found e.g. in Petrongolo and Pissarides (2001), Hall (2003) and Christoffel and Linzert (2010).

$$C_t^c = \left[\omega_c^{\frac{1}{\varepsilon_c}} \left(C_t^d \right)^{\frac{\varepsilon_c - 1}{\varepsilon_c}} + (1-\omega_c)^{\frac{1}{\varepsilon_c}} \left(C_t^m \right)^{\frac{\varepsilon_c - 1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c - 1}} \tag{16}$$

where $\omega_c \in [0,1]$ measures the home bias in the production of the final private consumption good that determines the degree of openness in the long run, and $\varepsilon_c > 0$ is the elasticity of substitution between domestic and imported consumption goods.

Domestic and foreign intermediate good bundles combine differentiated goods from each intermediate good firm f, $C_{f,t}^d$, and each importing firm f^m, $C_{f,t}^m$, via the CES functions:

$$C_t^d = \left(\int_0^1 \left(C_{f,t}^d \right)^{\frac{1}{\mu_t^d}} df \right)^{\mu_t^d} \tag{17}$$

$$C_t^m = \left(\int_0^1 \left(C_{f^m,t}^m \right)^{\frac{1}{\mu_t^m}} df^m \right)^{\mu_t^m} \tag{18}$$

where the time varying parameters $\mu_t^d, \mu_t^m > 1$ are related to the intratemporal elasticities of substitution between the differentiated outputs supplied by the domestic intermediate good and importing firms, respectively. As we demonstrate later, μ_t^d and μ_t^m represent price markups in the markets of domestic and imported intermediate goods.

The producer of the final private consumption good solves a two stages problem. In the first stage, it takes as given the prices of the domestic and imported intermediate goods $P_{f,t}^d, P_{f^m,t}^m$, and chooses the optimal amounts of the differentiated goods $C_{f,t}^d$ and $C_{f,t}^m$ in order to minimize total expenditures for the bundles of differentiated goods, $\int_0^1 P_{f,t}^d C_{f,t}^d df$ and $\int_0^1 P_{f^m,t}^m C_{f^m,t}^m df$, subject to the aggregation constraints (17) and (18). The solutions of the cost minimization problems give the demand functions for the intermediate goods f and f^m:

$$C_{f,t}^d = \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} C_t^d \tag{19}$$

$$C^m_{f^m,t} = \left(\frac{P^m_{f^m,t}}{P^m_t}\right)^{-\frac{\mu^m_t}{\mu^m_t - 1}} C^m_t \tag{20}$$

where

$$P^d_t = \left(\int_0^1 \left(P^d_{f,t}\right)^{\frac{1}{1-\mu^d_t}} df\right)^{1-\mu^d_t} \tag{21}$$

$$P^m_t = \left(\int_0^1 \left(P^m_{f^m,t}\right)^{\frac{1}{1-\mu^m_t}} df^m\right)^{1-\mu^m_t} \tag{22}$$

are respectively the aggregate price indices of the domestic and imported intermediate goods. Note that $\mu^d_t / \left(\mu^d_t - 1\right) > 1$ and $\mu^m_t / \left(\mu^m_t - 1\right) > 1$ are the intratemporal elasticities of substitution between the differentiated outputs supplied by the domestic intermediate good producers and importing firms, respectively.

In the second stage, the final consumption good firm takes as given the aggregate price indices of the domestic and imported intermediate goods, P^d_t, P^m_t, as well as the aggregate price index of the final private consumption good P^c_t, and chooses output, C^c_t, and inputs, C^d_t, C^m_t, to maximize profits:

$$\Pi^c_t = P^c_t C^c_t - P^d_t C^d_t - P^m_t C^m_t \tag{23}$$

subject to equation (16). The first-order conditions are:

$$\frac{C^d_t}{C^c_t} = \omega_c \left(\frac{P^d_t}{P^c_t}\right)^{-\varepsilon_c} \tag{24}$$

$$\frac{C^m_t}{C^c_t} = \left(1 - \omega_c\right)\left(\frac{P^m_t}{P^c_t}\right)^{-\varepsilon_c} \tag{25}$$

which give the demand functions for the domestic and imported intermediate consumption goods bundles, respectively. From the zero profit condition we get the price index of a unit of the private consumption final good (i.e. the consumer's price index), which is a weighted sum of the price indices of the domestic and imported intermediate goods:

$$P_t^c = \left[\omega_c \left(P_t^d \right)^{1-\varepsilon_c} + \left(1-\omega_c\right)\left(P_t^m\right)^{1-\varepsilon_c} \right]^{\frac{1}{1-\varepsilon_c}} \tag{26}$$

The production of the final private investment good is modeled in an analogous manner. In particular, the representative producer combines a bundle of domestically produced intermediate goods, I_t^d, with a bundle of imported intermediate goods, I_t^m, to generate a composite non-tradable private investment good, I_t^i, by using a CES production function:

$$I_t^i = \left[\omega_i^{\frac{1}{\varepsilon_i}} \left(I_t^d \right)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} + (1-\omega_i)^{\frac{1}{\varepsilon_i}} \left(I_t^m \right)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right]^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \tag{27}$$

where $\omega_i \in [0,1]$ measures the home bias in the production of the final private investment good and $\varepsilon_i > 0$ is the elasticity of substitution between domestic and imported investment goods. The producer of the final private investment good solves a problem similar to that of the final consumption good producer. It can be shown that the demand functions for the intermediate goods, $I_{f,t}^d$, $I_{f^m,t}^m$ are:

$$I_{f,t}^d = \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} I_t^d \tag{28}$$

$$I_{f^m,t}^m = \left(\frac{P_{f^m,t}^m}{P_t^m} \right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} I_t^m \tag{29}$$

Accordingly, the demand functions for the bundles of the domestically produced intermediate goods, I_t^d, and imported intermediate goods, I_t^m, are:

$$\frac{I_t^d}{I_t^c} = \omega_i \left(\frac{P_t^d}{P_t^i} \right)^{-\varepsilon_i} \tag{30}$$

$$\frac{I_t^m}{I_t^c} = \left(1-\omega_i\right) \left(\frac{P_t^m}{P_t^i} \right)^{-\varepsilon_i} \tag{31}$$

where

$$P_t^i = \left[\omega_i \left(P_t^d \right)^{1-\varepsilon_i} + \left(1-\omega_i \right) \left(P_t^m \right)^{1-\varepsilon_i} \right]^{\frac{1}{1-\varepsilon_i}} \tag{32}$$

is the aggregate investment price index.[6]

Regarding the final public consumption and investment goods, G_t^{gc} and G_t^{gi}, we follow Christoffel et al. (2008) and Stahler and Thomas (2012) and assume them to be composites made only from domestic intermediate goods. Hence, $G_t^{gc} = GC_t^d$ and $G_t^{gi} = GI_t^d$ where

$$GC_t^d = \left(\int_0^1 \left(GC_{f,t}^d \right)^{\frac{1}{\mu_t^d}} df \right)^{\mu_t^d} \tag{33}$$

$$GI_t^d = \left(\int_0^1 \left(GI_{f,t}^d \right)^{\frac{1}{\mu_t^d}} df \right)^{\mu_t^d} \tag{34}$$

The optimal demand functions for the domestic intermediate good f are:

$$GC_{f,t}^d = \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} GC_t^d \tag{35}$$

$$GI_{f,t}^d = \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} GI_t^d \tag{36}$$

Finally, aggregating across the four final good firms, we get the respective aggregate demand functions for the domestic and imported intermediate goods f and f^m:

$$Y_{f,t}^d = C_{f,t}^d + I_{f,t}^d + GC_{f,t}^d + GI_{f,t}^d = \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} Y_t^d \tag{37}$$

$$Y_{f^m,t}^m = C_{f^m,t}^m + I_{f^m,t}^m = \left(\frac{P_{f^m,t}^m}{P_t^m} \right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} Y_t^m \tag{38}$$

[6] Note that this price might be different from the aggregate price index of the final consumption good P_t^c due to differences in the home bias parameters.

where $Y_t^d = C_t^d + I_t^d + GC_t^d + GI_t^d$ is total domestic demand for domestically produced goods and $Y_t^m = C_t^m + I_t^m$ is total demand for imports.

2.3.2. Intermediate good firms

The intermediate goods sector is composed by a continuum of monopolistically competitive intermediate goods firms indexed by $f \in [0,1]$. Each firm f produces a single tradable differentiated intermediate good, $Y_{f,t}$, by using as inputs private capital services, $K_{f,t}$, private labour services, $H_{f,t}$, and by making use of average (per firm f) public capital $\bar{K}_t^g$. The production technology of each firm is:

$$Y_{f,t} = A_t \left(K_{f,t}\right)^a \left(z_t H_{f,t}\right)^{1-a} \left(\bar{K}_t^g\right)^{a_g} - z_t^+ \Phi \tag{39}$$

where $a > 0$ is the output elasticity of gross capital services, $a_g > 0$ is the productivity of public capital and z_t is labour augmenting technology. Note that the production function exhibits increasing returns to scale with respect to public capital, as in Baxter and King (1993) and Leeper et al. (2010). The presence of public capital in the production function provides production externalities to private sector firms and introduces a channel through which fiscal policy affects output. Also, $\Phi > 0$ corresponds to the fixed cost of production that is scaled by the variable z_t^+ so that fixed costs grow at the same rate as output. It can be shown that in a balance-growth path, real output grows by a factor given by $z_t^+ = z_t^{\frac{1-a}{1-a-a_g}}$. Fixed costs are introduced in order to rule out the entry and exit of intermediate good producers.

The variable A_t characterizes the stochastic total factor productivity. In addition, following e.g. Christiano et al. (2005) and Garcia-Cicco et al. (2010), we assume that the logarithm of the gross rate of labour augmenting productivity growth, $\gamma_{z,t} = z_t / z_{t-1}$, is stochastic. Note that A_t represents a transitory technology shock, while innovations in $\gamma_{z,t}$ have permanent effects on the level of z_t and introduce long-run risks about future growth developments. Both technology shocks are common across intermediate goods firms and their stochastic processes are specified in the next Section.

We note that the labour input employed by each firm, $H_{f,t}$, is a composite of household specific varieties, $H_{f,t}^{h}$ indexed by $h \in [0,1]$, that are supplied in monopolistically competitive markets via the aggregator:

$$H_{f,t} = \left(\int_0^1 \left(H_{f,t}^{h} \right)^{\frac{1}{\mu_t^w}} dh \right)^{\mu_t^w} \tag{40}$$

Regarding the demand for variety h, each firm takes the real wage rate $W_{h,t}^{p}$ as given and minimizes the total labour cost, $\int_0^1 W_{h,t}^{p} H_{f,t}^{h} dh$, subject to the constraint (40). The optimal demand by each firm f for labour of type h is:

$$H_{f,t}^{h} = \left(\frac{W_{h,t}^{p}}{W_t^{p}} \right)^{-\frac{\mu_t^w}{\mu_t^w - 1}} H_{f,t} \tag{41}$$

where $\mu_t^w / \left(\mu_t^w - 1 \right) > 1$ is the elasticity of substitution across the differentiated labour services and W_t^{p} is the aggregate real wage index in the private sector that is given by:[7]

$$W_t^{p} = \left(\int_0^1 \left(W_{h,t}^{p} \right)^{\frac{1}{1-\mu_t^w}} dh \right)^{1-\mu_t^w} \tag{42}$$

Aggregating over the continuum of firms, we get the aggregate demand for labour of type h in the private sector:

$$H_{h,t}^{p} = \int_0^1 H_{f,t}^{h} df = \left(\frac{W_{h,t}^{p}}{W_t^{p}} \right)^{-\frac{\mu_t^w}{\mu_t^w - 1}} H_t^{p} \tag{43}$$

[7] The aggregate wage index is obtained by substituting (40) into the demand function (41) and aggregating over the continuum of households.

Intermediate good firms solve a two stages problem. In the first stage, each firm takes as given the factor prices, r_t^k and W_t^p and chooses $K_{f,t}, H_{f,t}$ in order to minimize total real input cost:

$$\min_{K_{f,t},H_{f,t}} r_t^k K_{f,t} + W_t^p H_{f,t} \tag{44}$$

subject to equation (39). The first-order conditions are:

$$W_t^p = (1-a)\frac{Y_{f,t} + z_t^+ \Phi}{H_{f,t}} mc_{f,t} \tag{45}$$

$$r_t^k = a\frac{Y_{f,t} + z_t^+ \Phi}{K_{f,t}} mc_{f,t} \tag{46}$$

where $mc_{f,t}$ is the Langrange multiplier associated with the technology constraint, that is, the real marginal cost in terms of the consumer prices, P_t^c. Note that since all firms rent inputs at the same input prices and since they have all access to the same technology, the real marginal cost will be the same across the different firms: $mc_{f,t} = mc_t$.

In the second stage, intermediate good firms choose the price that maximizes discounted real profits. As in Christoffel et al. (2008), firms charge different prices at home and abroad, setting prices in producer currency. The choice of producer currency pricing, is guided by the work of Antoniades (2012), who provides evidence that Greek firms exhibit producer currency pricing.

In both markets, we assume that prices are sticky à la Calvo (1983). In particular, each period $t \geq 0$, the firm f can optimally reset its prices with a constant probability $1-\theta_p^d$ when it sells its differentiated product in the domestic market, and with probability $1-\theta_p^x$ when it sells its product abroad. Those firms that cannot reoptimize partially index their prices to aggregate past inflation according to the following price indexation schemes:

$$P_{f,t}^d = P_{f,t-1}^d \left(\Pi_{t-1}^d\right)^{x_d} \tag{47}$$

$$P_{f,t}^x = P_{f,t-1}^x \left(\Pi_{t-1}^x\right)^{x_x} \tag{48}$$

where $P_{f,t}^{d}$ denote the domestic price of good f and $P_{f,t}^{x}$ its foreign price, P_t^d, P_t^x are the aggregate domestic and export price indices (defined below), respectively and $\Pi_t^d = P_t^d / P_{t-1}^d$, $\Pi_t^x = P_t^x / P_{t-1}^x$. The indexation parameters $x_d, x_x \in [0,1]$ determine the weights given to past inflation, where $x_d, x_x = 0$ denotes no indexation and $x_d, x_x = 1$ is total indexation. Therefore, the price of a firm that has not been able to reoptimize for τ periods in the domestic market is $P_{f,t+\tau}^{d} = P_{f,t}^{d} \prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^{d}\right)^{x_d}$. Similarly, in the foreign markets the price is $P_{f,t+\tau}^{x} = P_{f,t}^{x} \prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^{x}\right)^{x_x}$.

Each firm f that reoptimize its price in the domestic market in period t, knows the probability θ_p^d that the price it sets will still be in effect τ periods ahead, and chooses the optimal price $P_{f,t}^{*d}$ in order to maximize the discounted sum of expected real profits (in terms of the consumer prices P_t^c), by taking aggregate domestic demand, Y_t^d, and the aggregate price index in the domestic market, P_t^d, as given. Thus, each firm f maximizes:

$$\max_{P_{f,t}^{d}} E_t \sum_{\tau=0}^{\infty} \left(\beta\theta_p^d\right)^{\tau} \frac{\Lambda_{t+\tau}^{R}}{\Lambda_t^{R}} \left\{ \frac{P_{t+\tau}^{d}}{P_{t+\tau}^{c}} \left(\prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^{d}\right)^{x_d} \frac{P_{f,t}^{d}}{P_{t+\tau}^{d}} - mc_{t+\tau}^{d} \right) Y_{f,t+\tau}^{d} \right\} \tag{49}$$

subject to

$$Y_{f,t}^{d} = \left(\prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^{d}\right)^{x_d} \frac{P_{f,t}^{d}}{P_{t+\tau}^{d}} \right)^{-\frac{\mu_{t+\tau}^{d}}{\mu_{t+\tau}^{d}-1}} Y_{t+\tau}^{d} \tag{50}$$

where $mc_t^d = P_t^c mc_t / P_t^d$ is the average real marginal cost in terms of the domestic price index and $\Lambda_{t+\tau}^{R} / \Lambda_t^{R}$ is the ratio of the marginal utilities of consumption of Ricardian households - that are the owners of the firms - according to which firms value future profits.[8] Since all firms face the same marginal cost and take aggregate variables as given, any firm that reoptimizes will set the same price, $P_{f,t}^{*d} = P_t^{*d}$. Thus, the first-order condition of the above problem is:

[8] Note that in equilibrium the marginal utility of consumption is equal across all Ricardian households, that is, $\Lambda_{i,t} = \Lambda_t^R$.

$$E_t\left(\beta\theta_p^d\right)^{\tau}\frac{\Lambda_{t+\tau}^R}{\Lambda_t^R}\left(\prod_{s=1}^{\tau}\left(\frac{\left(\Pi_{t+s-1}^d\right)^{x_d}}{\Pi_{t+s}^d}\right)\frac{P_t^{*d}}{P_t^d}\right)^{-\frac{\mu_{t+\tau}^d}{\mu_{t+\tau}^d-1}}Y_{t+\tau}^d\frac{P_{t+\tau}^d}{P_{t+\tau}^c}\left[\prod_{s=1}^{\tau}\left(\frac{\left(\Pi_{t+s-1}^d\right)^{x_d}}{\Pi_{t+s}^d}\right)\frac{P_t^{*d}}{P_t^d}-\mu_{t+\tau}^d mc_{t+\tau}^d\right]=0 \quad (51)$$

According to the above expression firms set nominal prices so as to equate the average future expected marginal revenues to average future expected marginal costs. Note that in the case of fully flexible prices, $\theta_p^d = 0$, the above condition reduces to the static relation, $P_t^{*d} = \mu_{t+\tau}^d P_t^c mc_{t+\tau}$, which states that the price is equal to a markup over the nominal marginal cost. It is convenient to express Equation (51) in recursive form. To this end, we define $g_t^{d_1}$ and $g_t^{d_2}$:

$$g_t^{d_1} = \mu_t^d mc_t^d Y_t^d \Lambda_t^R \frac{P_t^d}{P_t^c} + \left(\beta\theta_p^d\right)E_t\left[\frac{\left(\Pi_t^d\right)^{x_d}}{\Pi_{t+1}^d}\right]^{-\frac{\mu_t^d}{\mu_t^d-1}} g_{t+1}^{d_1} \quad (52)$$

$$g_t^{d_2} = \Pi_t^{*d} Y_t^d \Lambda_t^R \frac{P_t^d}{P_t^c} + \left(\beta\theta_p^d\right)E_t\left[\frac{\left(\Pi_t^d\right)^{x_d}}{\Pi_{t+1}^d}\right]^{1-\frac{\mu_t^d}{\mu_t^d-1}} \frac{\Pi_t^{*d}}{\Pi_{t+1}^{*d}} g_{t+1}^{d_2} \quad (53)$$

where $\Pi_t^{*d} = P_t^{*d} / P_t^d$. In turn, Equation (51) is equivalent to:

$$g_t^{d_1} = g_t^{d_2} \quad (54)$$

In addition, given the Calvo pricing, the aggregate domestic index evolves according to:

$$P_t^d = \left(\left(1-\theta_p^d\right)\left(P_t^{*d}\right)^{\frac{1}{1-\mu_t^d}} + \theta_p^d\left(P_{t-1}^d\left(\Pi_{t-1}^d\right)^{x_d}\right)^{\frac{1}{1-\mu_t^d}}\right)^{1-\mu_t^d} \quad (55)$$

Similarly, the maximization problem of each firm f that reoptimize its price in the foreign markets in period t, is:

$$\max_{P_{f,t}^x} E_t\sum_{\tau=0}^{\infty}\left(\beta\theta_p^x\right)^{\tau}\frac{\Lambda_{t+\tau}^R}{\Lambda_t^R}\left\{\frac{P_{t+\tau}^x}{P_{t+\tau}^c}\left(\prod_{s=1}^{\tau}\left(\Pi_{t+s-1}^x\right)^{x_x}\frac{P_{f,t}^x}{P_{t+\tau}^x}-mc_{t+\tau}^x\right)Y_{f,t+\tau}^x\right\} \quad (56)$$

subject to

$$Y_{f,t}^{x} = \left(\prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^{x} \right)^{x_x} \frac{P_{f,t}^{x}}{P_{t+\tau}^{x}} \right)^{-\frac{\mu_{t+\tau}^{x}}{\mu_{t+\tau}^{x}-1}} Y_{t+\tau}^{x} \tag{57}$$

where $mc_t^x = P_t^c mc_t / P_t^x$ is the average real marginal cost in terms of the aggregate export price index, P_t^x. The associated first-order condition of this problem is:

$$E_t \left(\beta \theta_p^x \right)^{\tau} \frac{\Lambda_{t+\tau}^R}{\Lambda_t^R} \left(\prod_{s=1}^{\tau} \left(\frac{\left(\Pi_{t+s-1}^{x} \right)^{x_x}}{\Pi_{t+s}^{x}} \right) \frac{P_t^{*x}}{P_t^x} \right)^{-\frac{\mu_{t+\tau}^{x}}{\mu_{t+\tau}^{x}-1}} Y_{t+\tau}^{x} \frac{P_{t+\tau}^{x}}{P_{t+\tau}^{c}} \left[\prod_{s=1}^{\tau} \left(\frac{\left(\Pi_{t+s-1}^{x} \right)^{x_x}}{\Pi_{t+s}^{x}} \right) \frac{P_t^{*x}}{P_t^x} - \mu_{t+\tau}^{x} mc_{t+\tau}^{x} \right] = 0 \tag{58}$$

Expressing (58) recursively, we get:

$$g_t^{x_1} = \mu_t^x mc_t^x y_t^x \Lambda_t^R \frac{P_t^x}{P_t^c} + \left(\beta \theta_p^x \right) E_t \left[\frac{\left(\Pi_t^x \right)^{x_x}}{\Pi_{t+1}^x} \right]^{-\frac{\mu_t^x}{\mu_t^x - 1}} g_{t+1}^{x_1} \tag{59}$$

$$g_t^{x_2} = \Pi_t^{*x} y_t^x \Lambda_t^R \frac{P_t^x}{P_t^c} + \left(\beta \theta_p^x \right) E_t \left[\frac{\left(\Pi_t^x \right)^{x_x}}{\Pi_{t+1}^x} \right]^{1-\frac{\mu_t^x}{\mu_t^x - 1}} \frac{\Pi_t^{*x}}{\Pi_{t+1}^{*x}} g_{t+1}^{x_2} \tag{60}$$

$$g_t^{x_1} = g_t^{x_2} \tag{61}$$

where $\Pi_t^{*x} = P_t^{*x} / P_t^x$. The aggregate export price index evolves according to:

$$P_t^x = \left(\left(1 - \theta_p^x \right) \left(P_t^{*x} \right)^{\frac{1}{1-\mu_t^x}} + \theta_p^x \left(P_{t-1}^x \left(\Pi_{t-1}^x \right)^{x_x} \right)^{\frac{1}{1-\mu_t^x}} \right)^{1-\mu_t^x} \tag{62}$$

2.3.3. Importing firms

There is a continuum of importing firms $f^m \in [0,1]$, each of which imports a single differentiated intermediate good, $Y_{f^m,t}^m$. Following Monacelli (2005), these firms operate under monopolistic competition and are assumed to have a small degree of pricing power. This creates a wedge between the price at which the importing firms buy the foreign differentiated goods in the world markets, $S_t P_t^{*y}$, and the price at which they sell these goods to domestic households, $P_{f^m,t}^m$.

As in the case of intermediate good producers, importing firms face price stickiness à la Calvo, with $1-\theta_p^m$ being the probability that a firm f^m can optimally reset its price in the domestic market in any given period $t \geq 0$. Importing firms that cannot reoptimize, index their prices to past inflation according to the indexation rule:

$$P_{f^m,t}^m = P_{f^m,t-1}^m \left(\Pi_{t-1}^m\right)^{x_m} \tag{63}$$

where $P_{f^m,t}^m$ is the price of the imported good f^m, P_t^m is the aggregate import price index (defined below), $\Pi_t^m = P_t^m / P_{t-1}^m$, and $x_m \in [0,1]$ is the indexation parameter to past inflation.

Accordingly, the maximization problem of each firm f^m that reoptimize its price in period t, is:

$$\max_{P_{f^m,t}^m} E_t \sum_{\tau=0}^{\infty} \left(\beta\theta_p^m\right)^{\tau} \frac{\Lambda_{t+\tau}^R}{\Lambda_t^R} \left\{ \frac{P_{t+\tau}^m}{P_{t+\tau}^c} \left(\prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^m\right)^{x_m} \frac{P_{f,t}^m}{P_{t+\tau}^m} - mc_{t+\tau}^m \right) Y_{f^m,t+\tau}^m \right\} \tag{64}$$

subject to

$$Y_{f^m,t}^m = \left(\prod_{s=1}^{\tau} \left(\Pi_{t+s-1}^m\right)^{x_m} \frac{P_{f^m,t}^m}{P_{t+\tau}^m} \right)^{-\frac{\mu_{t+\tau}^m}{\mu_{t+\tau}^m - 1}} Y_{t+\tau}^m \tag{65}$$

where $mc_t^m = S_t P_t^{*y} / P_t^m$ is the average real marginal cost. The associated first-order condition for this problem is:

$$E_t \left(\beta\theta_p^m\right)^{\tau} \frac{\Lambda_{t+\tau}^R}{\Lambda_t^R} \left(\prod_{s=1}^{\tau} \left(\frac{\left(\Pi_{t+s-1}^m\right)^{x_m}}{\Pi_{t+s}^m} \right) \frac{P_t^{*m}}{P_t^m} \right)^{-\frac{\mu_{t+\tau}^m}{\mu_{t+\tau}^m - 1}} Y_{t+\tau}^m \frac{P_{t+\tau}^m}{P_{t+\tau}^c} \left[\prod_{s=1}^{\tau} \left(\frac{\left(\Pi_{t+s-1}^m\right)^{x_m}}{\Pi_{t+s}^m} \right) \frac{P_t^{*m}}{P_t^m} - \mu_{t+\tau}^m mc_{t+\tau}^m \right] = 0 \tag{66}$$

We express (66) recursively as:

$$g_t^{m_1} = \mu_t^m mc_t^m y_t^m \Lambda_t^R \frac{P_t^m}{P_t^c} + \left(\beta\theta_p^m\right) E_t \left[\frac{\left(\Pi_t^m\right)^{x_m}}{\Pi_{t+1}^m} \right]^{-\frac{\mu_t^m}{\mu_t^m - 1}} g_{t+1}^{m_1} \tag{67}$$

$$g_t^{m_2} = \Pi_t^{*m} y_t^m \Lambda_t^R \frac{P_t^m}{P_t^c} + \left(\beta\theta_p^m\right) E_t \left[\frac{\left(\Pi_t^m\right)^{x_m}}{\Pi_{t+1}^m}\right]^{1-\frac{\mu_t^m}{\mu_t^m-1}} \frac{\Pi_t^{*m}}{\Pi_{t+1}^{*m}} g_{t+1}^{m_2} \tag{68}$$

$$g_t^{m_1} = g_t^{m_2} \tag{69}$$

Where $\Pi_t^{*m} = P_t^{*m} / P_t^m$. Finally, the aggregate import price index evolves according to:

$$P_t^m = \left(\left(1-\theta_p^m\right)\left(P_t^{*m}\right)^{\frac{1}{1-\mu_t^m}} + \theta_p^m \left(P_{t-1}^m \left(\Pi_{t-1}^m\right)^{x_m}\right)^{\frac{1}{1-\mu_t^m}}\right)^{1-\mu_t^m} \tag{70}$$

2.4. Foreign final good firms and foreign demand

There is a representative foreign final good firm that combines the purchases of the differentiated exported goods, $Y_{f,t}^x$, produced by the domestic intermediate good firms f, and transforms them into a homogeneous final good Y_t^x via the CES technology:

$$Y_t^x = \left(\int_0^1 \left(Y_{f,t}^x\right)^{\frac{1}{\mu_t^x}} df\right)^{\mu_t^x} \tag{71}$$

where the time varying parameter $\mu_t^x > 1$ is related to the elasticity of substitution between the differentiated outputs supplied by the domestic intermediate good firms, $\mu_t^x / \left(\mu_t^x - 1\right) > 1$.

The foreign firm takes the prices of the exported differentiated goods $P_{f,t}^x / S_t$ (expressed in terms of the foreign currency) as given, and chooses the optimal amounts of differentiated inputs to minimize the total input costs, $\int_0^1 \left(P_{f,t}^x / S_t\right) Y_{f,t}^x df$, subject to (71). From the solution of the cost minimization problem we get the demand function for each input $Y_{f,t}^x$:

$$Y_{f,t}^x = \left(\frac{P_{f,t}^x}{P_t^x}\right)^{-\frac{\mu_t^x}{\mu_t^x-1}} Y_t^x \tag{72}$$

where

$$P_t^x = \left(\int_0^1 \left(P_{f,t}^x \right)^{\frac{1}{1-\mu_t^x}} df \right)^{1-\mu_t^x} \tag{73}$$

is the aggregate price index of the exported domestic intermediate goods and Y_t^x is total foreign demand for domestic intermediate goods. The latter is assumed to be given by an equation analogous in structure to the demand equations for the domestic and imported intermediate goods:

$$Y_t^x = \left(\frac{P_t^x / S_t}{P_t^{x^*}} \right)^{-\varepsilon_x} Y_t^* \tag{74}$$

where $P_t^{x^*}$ is the price of foreign competitors in the export markets and Y_t^* is a measure of aggregate foreign demand.

2.5. Government

The government levies taxes on consumption, on income from labour and capital earnings, lump-sum taxes, and issues one-period government bonds in the domestic bond market, B_{t+1}^g, and the international markets, F_{t+1}^g. Total tax revenues plus the issue of new government bonds are used to finance government purchases of goods and services, G_t^c, government investment, G_t^i, government transfers allocated to optimizing and liquidity constrained households, G_t^{tr}, and total compensation of public employees, $W_t^g H_t^g$. Moreover, the government pays interest payments on past domestic public debt, R_t, and foreign public debt, R_t^H. The within-period government budget constraint written in per-capita terms is:

$$\begin{aligned} &\frac{B_{t+1}^g}{P_t^c} + \frac{S_t F_{t+1}^g}{P_t^c} + \tau_t^c C_t^p + \tau_t^l \left(W_t^p H_t^p + W_t^g H_t^g \right) + \tau_t^k \left(r_t^k u_t K_t^p + Div_t \right) + T_t = \\ &\qquad = \frac{P_t^d}{P_t^c} G_t^c + \frac{P_t^d}{P_t^c} G_t^i + G_t^{tr} + W_t^g H_t^g + \left(R_{t-1} \frac{B_t^g}{P_t^c} + R_{t-1}^H \frac{S_t F_t^g}{P_t^c} \right) \end{aligned} \tag{75}$$

We follow most of the literature (see e.g. Coenen et al. (2012)), by allowing lump-sum taxes as share of GDP to react systematically to the public debt-to-GDP ratio in order to ensure fiscal solvency:

$$\tau_t = \varphi^T \left(\frac{D_t}{P_{t-1}^y Y_{t-1}^{GDP}} - s^d \right) \tag{76}$$

where $\tau_t = \dfrac{P_t^c T_t}{P_t^y Y_t^{GDP}}$ are lump-sum taxes as share of GDP, s^d is the long-run value of the public debt-to-GDP ratio, $\varphi^T > 0$ and Y_t^{GDP} is real GDP that is defined formally later. Thus, the government has ten policy instruments, $\tau_t^c, \tau_t^l, \tau_t^k, W_t^g, H_t^g, G_t^c, G_t^i, G_t^{tr}, B_{t+1}^g, F_{t+1}^g$, out of which only nine can be exogenously set. It is convenient to assume that $B_{t+1}^g = v_t D_{t+1}$ and $S_t F_{t+1}^g = (1-v_t) D_{t+1}$, where $0 \le v_t \le 1$ is the share of total public debt held by domestic agents at the end of period t, and $D_{t+1} = B_{t+1}^g + S_t F_{t+1}^g$ is the end-of-period total public debt issued by the government. Following usual practice, the policy instrument that adjusts to satisfy the period budget constraint is total public debt, D_{t+1}, while the other nine policy instruments, $\tau_t^c, \tau_t^l, \tau_t^k, W_t^g, H_t^g, G_t^c, G_t^i, G_t^{tr}, v_t$, are set exogenously by the government. The processes of the exogenous policy instruments are specified below.

On the production side, following e.g. Forni et al. (2010) and Economides et al. (2013), it is assumed that the government combines public spending on goods and services, G_t^c, and public employment, H_t^g, to produce public goods Y_t^g by using the following production function:

$$Y_t^g = A_t \left(G_t^c \right)^{\chi} \left(z_t^+ H_t^g \right)^{1-\chi} \tag{77}$$

where $0 \le \chi \le 1$ is a technology parameter.

The law of motion of public capital in per-capita terms is:

$$K_{t+1}^g = \left(1-\delta^g\right) K_t^g + G_t^i \tag{78}$$

where $\delta^g \in (0,1)$ is the depreciation rate of public capital stock and $K_0^g > 0$ is given.

2.6. World capital markets and sovereign spreads

We introduce a sovereign risk channel through which sovereign default risk influence economic activity by assuming that domestic households and the government pay a risk-premium when they participate in the international markets. In particular, following the approach e.g. in Schmitt-Grohe and Uribe (2003) and Forni and Pissani (2013), the interest rate at which the home country borrows from the international markets, R_t^H, is the sum of an exogenously given risk-free foreign nominal interest rate, R_t^*, and a risk-premium term, $\tilde{\psi}_t$:

$$R_t^H = R_t^* + \tilde{\psi}_t \tag{79}$$

As in Christiano et al. (2010) and Garcia-Cicco et al. (2010), the risk-premium term is a function of fundamentals of the domestic economy and exogenous risk-premium shocks. We impose the following structure on the risk-premium term:

$$\tilde{\psi}_t = \psi_t + \rho_\psi \psi_{t-1} \tag{80}$$

where $0 \le \rho_\psi \le 1$, and ψ_t is the risk-premium component that has the following form:

$$\psi_t = \psi^d \left(\exp\left(\frac{D_{t+1}}{P_t^y Y_t^{GDP}} - \bar{d} \right) - 1 \right) + \psi^f \left(-\exp\left(\frac{S_t F_{t+1}^p}{P_t^y Y_t^{GDP}} - \bar{f} \right) + 1 \right) + \left(\exp\left(\varepsilon_t^R \right) - 1 \right) \tag{81}$$

where $\psi^d, \psi^f \ge 0$ are parameters and $\bar{d}$, $\bar{f}$ are the target values of the public debt-to-GDP ratio and the net foreign private asset position-to-GDP ratio, respectively. The first component in the right hand side of (81) reflects the risk of a sovereign default and constitutes a sovereign risk channel through which sovereign default risk affects the real economy, in line with the recent evidence provided in Corsetti et al. (2013). In particular, the term includes changes in the total public debt-to-GDP ratio, where increases in this ratio above a threshold level lead to a rise in spreads, consistent with the recent empirical evidence (see e.g. Ardagna et al. (2008) and Roeger and in't Veld (2013)). The second term in (81) is introduced to ensure that foreign private assets are a stationary variable.[9] Finally, $\varepsilon_t^R \sim i.i.d.\ N(0, \sigma_R)$ is a country premium shock that induces stochastic shifts in the risk-premium that are uncorrelated with the

[9] Note that when households are borrowers (i.e. $F_{t+1}^p < 0$), there is a premium on the interest rate, while when households are lenders (i.e. $F_{t+1}^p > 0$), there is a remuneration. This specification ensures that foreign private assets are stationary; see Schmitt-Grohe and Uribe (2003) for details.

fundamentals of the domestic economy. As discussed in Garcia-Cicco et al. (2010), exogenous risk-premium shocks play an important role in explaining fluctuations in the trade balance and the current account balance, and can be thought as coming from financial imperfections in the domestic market.

2.7. Monetary policy regime

We model the domestic economy as being a member of a currency union in the sense that the nominal exchange rate, S_t, is exogenously set, and at the same time, there is no monetary policy independence. In turn, we choose the domestic nominal interest rate on government bonds, R_t, to be endogenously determined by the risk-free foreign nominal interest rate and the risk-premium component.[10]

2.8. Aggregation, market clearing conditions and resource constraint

The model is closed by defining household and firm-specific variables in per-capita terms, imposing market clearing conditions and deriving the evolution of the economy's net foreign assets.

2.8.1. Aggregation

The aggregate quantity, expressed in per-capita terms, of any household specific variable $X_{h,t}$, is given by $X_t = \int_0^1 X_{h,t} dh = (1-\lambda) X_{i,t} + \lambda X_{j,t}$. Note that in equilibrium all optimizing households make identical decisions. The same holds and for the non-Ricardian households. Thus, we can drop the household specific indexes i, j. Hence, per-capita private consumption is given by

$$C_t^p = (1-\lambda) C_t^{p,R} + \lambda C_t^{p,NR} \tag{82}$$

where we have replaced the indexes i, j with the superscripts R and NR, respectively.

[10] This can be seen by combining the log-linearized versions of Equations (A2) and (A3) (see Appendix A). See Philippopoulos et al. (2013) and the references therein for a discussion on this issue.

Since only optimizing households have access to the capital, bond, dividend and international markets, the per-capita quantities for private capital, private investment, domestic government bonds, foreign private assets and profits are respectively:

$$K_t^p = (1-\lambda) K_{i,t}^p \tag{83}$$

$$I_t = (1-\lambda) I_{i,t} \tag{84}$$

$$B_t = (1-\lambda) B_{i,t} \tag{85}$$

$$F_t^p = (1-\lambda) F_{i,t}^p \tag{86}$$

$$Div_t = (1-\lambda) Div_{i,t} \tag{87}$$

Per-capita government transfers are:

$$G_t^{tr} = (1-\lambda) G_t^{tr,R} + \lambda G_t^{tr,NR} \tag{88}$$

where total transfers are allocated between liquidity constrained and optimizing households according to the following rules: $G_t^{tr,NR} = \overline{\lambda} G_t^{tr}$ and $G_t^{tr,NR} = \left(1-\overline{\lambda}\right) G_t^{tr}$, with $0 \leq \overline{\lambda} \leq 1$.

2.8.2. Market clearing conditions

Market clearing in the labour market

For the labour market to clear, total labour supply needs to equal the amount of labour employed by the private and public sectors:

$$H_t = \int_0^1 H_{h,t} dh = \int_0^1 H_{h,t}^p dh + \int_0^1 H_{h,t}^g dh = \int_0^1 \left(\frac{W_{h,t}^p}{W_t^p} \right)^{-\frac{\mu_t^w}{\mu_t^w - 1}} H_t^p dh + H_t^g = H_t^p + H_t^g \tag{89}$$

where H_t is total labour supply.[11]

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[11] In deriving (89) we have used the fact that in a symmetric equilibrium, $W_{h,t}^p / W_t^p = 1$.

Market clearing in the capital market

Market clearing for capital services implies that the supply of utilized private capital stock from households satisfies the demand for private capital services by intermediate good firms:

$$u_t \int_0^1 K_{h,t}^p dh = u_t K_t^p = \int_0^1 K_{f,t} df \tag{90}$$

Market clearing in the intermediate goods sector

The supply of each differentiated good f needs to meet domestic and foreign demand:

$$Y_{f,t} = Y_{f,t}^d + Y_{f,t}^x \tag{91}$$

Aggregating over the continuum of intermediate good firms we get the aggregate resource constraint:

$$Y_t = \int_0^1 Y_{f,t} df = \int_0^1 Y_{f,t}^d df + \int_0^1 Y_{f,t}^x df = \int_0^1 \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} Y_t^d df + \int_0^1 \left(\frac{P_{f,t}^x}{P_t^x} \right)^{-\frac{\mu_t^x}{\mu_t^x - 1}} Y_t^x df$$

or

$$Y_t = u_t^d Y_t^d + u_t^x Y_t^x \tag{92}$$

where $u_t^d = \int_0^1 \left(\frac{P_{f,t}^d}{P_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} df$ and $u_t^x = \int_0^1 \left(\frac{P_{f,t}^x}{P_t^x} \right)^{-\frac{\mu_t^x}{\mu_t^x - 1}} df$ measure the degree of price dispersion across the differentiated goods that are sold in the domestic and foreign markets, respectively. The two measures of price dispersion evolve according to:

$$u_t^d = \left(1 - \theta_p^d\right) \left(\Pi_t^{*d}\right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} + \theta_p^d \left(\frac{\left(\Pi_{t-1}^d\right)^{\chi_d}}{\Pi_t^d} \right)^{-\frac{\mu_t^d}{\mu_t^d - 1}} u_{t-1}^d \tag{83}$$

$$u_t^x = \left(1 - \theta_p^x\right) \left(\Pi_t^{*x}\right)^{-\frac{\mu_t^x}{\mu_t^x - 1}} + \theta_p^x \left(\frac{\left(\Pi_{t-1}^x\right)^{\chi_d}}{\Pi_t^x} \right)^{-\frac{\mu_t^x}{\mu_t^x - 1}} u_{t-1}^x \tag{94}$$

where $\Pi_t^{*d} = P_t^{*d} / P_t^d$, $\Pi_t^{*x} = P_t^{*x} / P_t^x$, $\Pi_t^d = P_t^d / P_{t-1}^d$ and $\Pi_t^x = P_t^x / P_{t-1}^x$.

Also, by making use of the market clearing conditions in the labour and capital markets, the production function written in per-capita terms is:

$$Y_t = A_t \left(u_t K_t^p\right)^a \left(z_t H_t^p\right)^{1-a} \left(K_t^g\right)^{a_G} - z_t^+ \Phi \tag{95}$$

Market clearing in the market of imported intermediate goods

The supply of each differentiated importing good f^m needs to meet domestic demand:

$$M_t = \int_0^1 Y_{f^m,t}^m df^m = \int_0^1 \left(\frac{P_{f^m,t}^m}{P_t^m}\right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} Y_t^m df^m = u_t^m Y_t^m \tag{96}$$

where $Y_t^m = C_t^m + I_t^m$ is total demand for imports and $u_t^m = \int_0^1 \left(\frac{P_{f^m,t}^m}{P_t^m}\right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} df^m$ measures the degree of price dispersion across the differentiated imported goods f^m that evolves according to:

$$u_t^m = \left(1 - \theta_p^m\right)\left(\Pi_t^{*m}\right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} + \theta_p^m \left(\frac{\left(\Pi_{t-1}^m\right)^{x_m}}{\Pi_t^m}\right)^{-\frac{\mu_t^m}{\mu_t^m - 1}} u_{t-1}^m \tag{97}$$

where $\Pi_t^{*m} = P_t^{*m} / P_t^m$ and $\Pi_t^m = P_t^m / P_{t-1}^m$.

Market clearing in the final goods markets

Market clearing in the final goods markets implies:

$$C_t^c = C_t^p \tag{98}$$

$$I_t^i = I_t^p \tag{99}$$

$$G_t^{gc} \equiv GC_t^d = G_t^c \tag{100}$$

$$G_t^{gi} \equiv GI_t^d = G_t^i \tag{101}$$

Note that by combining the market clearing conditions in the intermediate goods and the final goods sectors, we obtain the following interpretation for the nominal private output that determines the implicit price index of domestic production (i.e. the GDP deflator), P_t^y:

$$P_t^y Y_t = P_t^d Y_t^d + P_t^x Y_t^x \tag{102}$$

where $Y_t^d = C_t^d + I_t^d + G_t^c + G_t^i$ is total domestic demand for domestically produced goods.

Definition of Gross Domestic Product

Consistent with national accounts statistics, we define the domestic country's GDP as the sum of private sector production, Y_t, and the gross government wage bill, $W_t^g H_t^g$, following the approach in Forni et al. (2010) and Stahler and Thomas (2012). Thus, real per-capital GDP is defined as:

$$Y_t^{GDP} = Y_t + \frac{P_t^c}{P_t^y} W_t^g H_t^g \tag{103}$$

Market clearing in the dividend market

Real profits of the intermediate good f, expressed in terms of the price of the final consumption good P_t^c, can be written as:

$$Div_{f,t} = Div_{f,t}^d + Div_{f,t}^x = \frac{P_{f,t}^d}{P_t^c} Y_{f,t}^d + \frac{P_{f,t}^x}{P_t^c} Y_{f,t}^x - mc_t Y_{f,t}$$

Aggregating over the continuum of intermediate good producers, and using the corresponding demand functions for the intermediate good f, and the definition of nominal private output, we get the real per-capita profits of the intermediate goods sector:

$$Div_t^f = \int_0^1 Div_{f,t} df = \frac{P_t^y}{P_t^c} Y_t - mc_t \left(Y_t + z_t^+ \Phi \right) \tag{104}$$

Real profits of the importing firm f^m (in terms of the price of the final consumption good, P_t^c), are written as:

$$Div_{f^m,t} = \frac{P_t^m}{P_t^c}\left(\frac{P_{f,t}^m}{P_t^m}Y_{f,t}^m - \frac{q_t P_t^y}{P_t^m}Y_{f^m,t}\right)$$

where $q_t^{ex} = \frac{S_t P_t^{*y}}{P_t^y} = q_{t-1}^{ex}\frac{s_t \Pi_t^{*y}}{\Pi_t^y}$, is the real effective exchange rate, P_t^{*y} is the implicit price deflator in the foreign country and $\Pi_t^{*y} = P_t^{*y} / P_{t-1}^{*y}$, $\Pi_t^y = P_t^y / P_{t-1}^y$. Aggregating over the continuum of importing firms we obtain the real per-capita profits of importing firms:

$$Div_t^m = \frac{P_t^m}{P_t^c}\left(Y_t^m - \frac{q_t P_t^y}{P_t^m}u_t^m Y_t^m\right) \tag{105}$$

Total profits are:

$$Div_t = Div_t^f + Div_t^m \tag{106}$$

Evolution of net private foreign assets

The evolution of the net foreign private assets is derived from the optimizing households' budget constraint, after imposing the budget constraint of the liquidity constrained households, the government budget constraint, the definition of profits of intermediate goods producers and importing firms, and by making use of the zero profit conditions of the final good firms:

$$\frac{S_t F_{t+1}^p}{P_t^c} = R_{t-1}^H \frac{S_t F_t^p}{P_t^c} + \frac{S_t F_{t+1}^g}{P_t^c} - R_{t-1}^H \frac{S_t F_t^g}{P_t^c} + \frac{P_t^x}{P_t^c}Y_t^x - q_t \frac{P_t^y}{P_t^c}u_t^m Y_t^m \tag{107}$$

2.9. Decentralized competitive equilibrium

We solve for a decentralized competitive equilibrium (DCE) in which: (i) Ricardian households maximize welfare; (ii) a fraction $1-\theta_p^d$ and $1-\theta_p^x$ of intermediate good firms maximize profits in the domestic and foreign markets, respectively, a fraction $1-\theta_p^m$ of importing firms maximize profits in the domestic market, and the rest of the firms set their prices according to the respective indexation schemes (47), (48) and (63); (iii) final good firms maximize profits; (iv) all constraints are satisfied; and (v) all markets clear.

Note that all real variables, with the exception for hours worked, in a balance growth path, grow by the factor $z_t^+ = z_t^{\frac{1-a}{1-a-a_g}}$. To solve for a DCE we have to make all the relevant real variables stationary by scaling them with z_t^+. Thus, for any per-capita variable X_t, we define its stationary level with a lowercase letter as $x_t \equiv X_t / z_t^+$. Note that the endogenous state variables that are predetermined in period t, as e.g. the private capital stock, are scaled with z_{t-1}^+, that is, $k_t^p \equiv K_t^p / z_{t-1}^+$. In addition, we divide all price indices with the price index of the consumption good in order to make them stationary. For instance, the relative price of domestically produced and sold goods is defined as $p_t^d = P_t^d / P_t^c$. Note that foreign GDP is assumed to grow at the same rate as the domestic economy, z_t^+, while the price of foreign competitors in the export markets, $P_t^{x^*}$, is stationarized by dividing it with the foreign GDP deflator P_t^{y*}. The stationary DCE is analytically presented in Appendix A.

2.10. The world economy

We assume that the home country is of negligible size relative to the rest of the world and developments in the domestic economy do not have any impact on foreign (i.e. the rest of the world) variables. Following Adolfson et al. (2007) and Cristiano et al. (2010), the foreign economy is modeled as a structural vector autoregressive model (SVAR):

$$F_0 X_t^* = F\left(L\right) X_{t-1}^* + \varepsilon_t^{X^*} \tag{108}$$

where $X_t^* \equiv [\ln y_t^*, \Pi_t^*, R_t^*, \ln p_t^{x^*}]$ and $\varepsilon_t^{X^*} \sim N\left(0, \Sigma_{X^*}\right)$.

2.11. Stochastic environment

We now summarize the exogenous stochastic processes of the exogenous variables. The model features twenty two exogenous disturbances, out of which four are related to the foreign variables. In particular, nine shocks arise from the stochastic fiscal policy instruments, $\left(\tau_t^c, \tau_t^l, \tau_t^k, w_t^g, h_t^g, g_t^c, g_t^i, g_t^{tr}, v_t\right)$, three from technology $\left(A_t, \gamma_{z,t}, \eta_t^I\right)$, and four from the markups in the labour and product markets $\left(\mu_t^w, \mu_t^d, \mu_t^x, \mu_t^m\right)$. There is also a risk premium shock, ε_t^R, and a shock to the growth rate of the nominal exchange rate, s_t. It is assumed that $\tau_t^c, \tau_t^l, \tau_t^k, g_t^c, g_t^i, g_t^{tr}$, $w_t^g, h_t^g, A_t, \gamma_{z,t}, \eta_t^I, \mu_t^w, \mu_t^d, \mu_t^x, \mu_t^m$ follow independent first-order autoregressive (AR(1)) stochastic processes of the form:

$$\ln F_t = \left(1-\rho_F\right)\ln F + \rho_F \ln F_{t-1} + \varepsilon_t^F \tag{109}$$

where $F_t \equiv g_t^c, g_t^i, g_t^{tr}, w_t^g, \tau_t^c, \tau_t^l, \tau_t^k, h_t^g, A_t, \gamma_{z,t}, \eta_t^I, \mu_t^w, \mu_t^d, \mu_t^x, \mu_t^m$ denotes the respective exogenous variables and $\varepsilon_t^F \sim i.i.d.\, N\left(0, \sigma_F\right)$. The share of domestically held public debt, v_t, and the risk premium shock, ε_t^R, follow an AR(1) process in levels. Finally, the growth rate of the nominal exchange rate, s_t, is assumed to follow a white noise process.

3. Calibration and long-run solution

The model is calibrated for the Greek economy at a quarterly frequency. The data source is Eurostat, unless otherwise stated. The data set comprises quarterly data and covers the period 2000:1-2011:4.[12] We compute quarterly effective tax rates on consumption, labour income and capital income based on the methodology of Mendoza et al. (1994). Series for the two capital stocks are constructed following the approach in Conesa et al. (2007). We also construct a measure of the real effective exchange rate using data on the nominal effective exchange rate, the domestic and the foreign GDP deflator. Details about the data used are in Appendix B.

[12] We focus on the period during which Greece is part of the euro area. Greece joined the euro area in 1 January 2001. We start our sample period in 2000, when Greece qualified to join the euro area by assuming that agents anticipated that the entry in the euro area will occur. Another reason to start our sample in 2000 is that quarterly non-interpolated data are available only since 2000.

3.1. Calibration

Our calibration strategy involves assigning values for the structural parameters according to the following criteria: (i) to match key first moments of the data; (ii) to reproduce certain second moments of the data; (iii) based on a priori information; and (iv) based on econometric estimation. Table 1 reports the calibrated parameters and the average values of the fiscal policy variables in the data.

As in most studies, the inverse of the Frisch elasticity of labour supply, γ, is set equal to 1. Following the study of Fiorito and Kollintzas (2004), the preference parameter, ϑ, which measures the degree of substitutability/complementarity between private and public goods in consumption, is set equal to 0.05. The preference parameter κ, is calibrated for a given total labour allocation equal to 21.9% of time. The habit persistence parameter, ξ^c, is set equal to 0.60, which is in the midpoint of the values reported in Smets and Wouters (2003) and Forni et al. (2009) for the euro area. We set the fraction of liquidity constrained households equal to the fraction of firms that do not have access to bank loans.[13] This gives a value for λ equal to 0.35, which is broadly in line with the values reported in previous studies (see e.g. Forni et al. (2009) and Coenen et al. (2012)).

The level of long-run aggregate productivity, A, is set equal to one since it is a scale parameter, which affects only the scale of the economy; see King and Rebelo (1999). We also normalize the long-run value of the investment-specific technology, η^I to unity. The gross growth rate of technological process, γ_z, is calibrated from the equation $\gamma_{z^+,t} = \gamma_{z,t}^{\frac{1-a}{1-a-a_g}}$, where $\gamma_{z^+,t} = z^+_{t+1} / z^+_t$ is the gross growth rate of real per-capita GDP. We set γ_{z^+} equal to 1.003, which is the average gross growth rate of real per-capita GDP found in the data, and we solve the previous equation for γ_z.

We set the gross inflation rates of the final private consumption good, Π^c, and the foreign implicit price deflator, Π^{y^*}, equal to one, and we normalize the relative

[13] Our measure of the firms that do not have access to bank loans, corresponds to the number of firms that applied for a bank loan that was rejected plus the number of firms that did not apply for a bank loan because of possible rejection. The data source is European Central Bank, Statistical Data Warehouse and covers the period 2009-2011.

price of imported goods, p^m to unity. This implies that $\Pi^y = \Pi^d = \Pi^x = \Pi^m = 1$, $p^d = 1$, $p^i = 1$ and $s = 1$. In turn, the discount factor, β, is calibrated as $\beta = \gamma_{z^+} / R^*$, assuming a quarterly foreign nominal interest rate equal to 1.075% (4.3% annually).

The average value of the physical depreciation rate in the private sector, δ^p, and the elasticity of marginal depreciation costs, ϕ, are jointly calibrated by constructing series for the private capital stock consistent with the model's assumption that the depreciation rate varies with capacity utilization (see Appendix B for details). The calibrated values of δ^p and ϕ are found to be 0.0172 (0.0688 annually) and 1.625, respectively. Similarly, we calibrate the depreciation rate in the public sector, δ^g, by constructing series for the public capital stock. This yields $\delta^g = 0.0107$ (0.0428 annually). The steady-state value of capital utilization is normalized to unity, as is usual the case in similar studies (see e.g. Adolfson et al. (2007)). The exponent of public capital in the production function, a_g, is set at 0.0316, which is the average public investment-to-GDP ratio in the data (see also Baxter and King (1993)). The capital share in output, a, is calibrated to match the average value of the private investment-to-GDP ratio found in the data. This yields $a = 0.3677$, similar to the findings in Papageorgiou (2012). The value of the adjustment cost parameter in private capital, ξ^k, is chosen so as to pin down as close as possible the volatility of private investment found in data. The fixed cost parameter in production, Φ, is chosen to ensure zero profits in the steady state so as to rule out the entry and exit of intermediate good producers.

The calibration of the steady-state markup on private sector wages, μ_t^w, is based on observed wage differentials across Greek industries, as reported in Du Caju et al. (2010) and Nicolitsas (2011). In particular, following the approach in Bayoumi et al. (2004), we compare wages in sectors that face high competition from abroad, and in which labour unions are assumed to have little bargaining power, to the average wage in the economy as a whole. The results imply a wage markup equal to 15%.[14] To

[14] The sectors we consider are textiles, clothing and leather. The average wage differential observed in these sectors vis-à-vis the average wage in the whole economy is around 9% for the years 2002 and 2006. Similar results for Greece are also reported in Jean and Nicoletti (2002). As in Bayoumi et al. (2004), this number is scaled by a factor of 0.06 in order to correct for the degree of the regulatory impediments in the product market and the level of public ownership that have been found to affect the level of wage markups.

calibrate steady-state price markups, we first calculate the net profit margin for the whole economy, defined as the net operating surplus as share of GDP.[15] The markup is then calculated as $NPM_t / (1 - NPM_t)$, where NPM_t denotes the net profit margin. The average price markup for the economy level is found to be 38%, in line with the results reported in Papageorgiou and Kazanas (2013), who use a different approach to compute markups. As in Coenen et al. (2008), we assume that the markup is the same in the importing sector, $\mu_t^w = \mu_t^d$. We consider the exporting sector as the most competitive sector, and we set the price markup equal to $\mu^x = 1.1$ in order to match as close as possible the exports share in GDP found in data.

We set the Calvo parameter in the domestic market, θ_p^d, equal to 0.7059, based on the study of Druant et al. (2009), who report that firms in Greece adjust their prices every 3.4 quarters. We choose the same value for the Calvo parameter of the importing firms, θ_p^m. The degree of price stickiness in the foreign markets, θ_p^x, is set at 0.697. This means that firms adjust prices about every 3.3 quarters, which is the average duration of price adjustment for euro area firms (see Druant et al. (2009)). The indexation parameters of the intermediate good firms, x_d, x_x, x_m, are set equal to 0.26, which roughly corresponds to the fraction of firms in Greece that consider past inflation when adjusting prices or wages (see Druant et al. (2009) and Nikolitsas (2013)).

The risk-premium coefficient on public debt, ψ^d, is set equal to 0.04 on annual basis. This means that a one percentage point increase in the debt-to-GDP ratio leads to an increase in risk-premia by 4 basis point, which is within the range of recent empirical estimates.[16] We choose a value for the risk-premium coefficient on net private foreign assets, ψ^f, so that to guarantee that the equilibrium solution is stationary (see e.g. Schmitt-Grohe and Uribe (2003)). The target level for the debt-to-GDP ratio, $\bar{d}$, is set equal to 4 (100% annually), which corresponds to the average value of the public debt-to-GDP ratio during the pre-sovereign debt crisis period

[15] The net operating surplus is derived as the gross operating surplus and mixed income of the total economy minus consumption of fixed capital. In addition, we subtract an imputed wage of the self-employed. The latter is computed as the average wage rate per employee multiplied with the number of the self-employed (see Appendix B for details).
[16] See e.g. Ardagna et al. (2008), Alper and Forni (2011), Poghosyan (2012).

2000-2009. This value is broadly in line with the threshold levels found in many empirical studies above which public debt has a negative effect on the macroeconomy.[17]

The home bias parameters, ω_c, ω_i, are respectively set in order to match the ratios of imported consumption and investment goods to total imported goods in the data. The elasticities of substitution between imported and domestically produced consumption and investment goods, $\varepsilon_c, \varepsilon_i$, as well as the elasticity of exports, ε_x, are estimated via OLS from the log-linear versions of equations (A34), (A37) and (74), respectively.[18] The estimated values are $\varepsilon_c = 3.351$, $\varepsilon_i = 6.352$ and $\varepsilon_x = 1.4630$, broadly in line with previous estimates reported in similar studies (see e.g. Adolfson et al. (2007) and Burriel et al. (2010)). Similarly, we obtain the wage persistent parameter, n, via OLS estimation of the log-linear version of Equation (15).[19] The estimated value is 0.6491, which implies a rather moderate level of real wage rigidities in the private sector, and appears to be in line with previous estimates in similar studies (see Malley et al. (2009) for EU countries and Kliem and Uhlig (2013) for the US economy).

Regarding fiscal policy instruments, the long-run values of public spending on goods and services and public investment as shares of output are respectively set equal to 0.0638 and 0.0316, which are the average values in the data. The average values of the constructed quarterly effective tax rates on consumption, labour income and capital income are found to be $\tau_t^c = 0.18$, $\tau_t^l = 0.30$ and $\tau_t^k = 0.20$. Hours worked in the public sector, h_t^g, and the share of domestic public debt to total public debt, v_t, are set equal to their data averages. The average wage rate in the public sector, w_t^g, is set so that the wage premium of the public-to-private sector wages to be 30%, in line

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[17] See Rainhart and Rogoff (2009), Kumar and Woo (2010) and Baum et al. (2012).

[18] In estimating Equations (A34) and (A37), we use as a proxy for the price of the domestically produced and sold goods data on the producer price in industry in the domestic market. Similarly, as a proxy for the price of imported goods we use data on the import price index in industry. For the estimation of Equation (74), we use as proxy for the price of competitors in foreign markets data on the average export price index of the EU-28 countries. As a proxy for foreign demand we use average real GDP of the EU-28 countries. All variables were quadratically detrended to obtain their stationary components that more closely correspond to the model's stationary variables.

[19] We use data on compensation per hours worked in the private sector for the dependent variable. As a proxy for the optimal wage rate, w_t^*, we use labour productivity in the private sector, defined as the ratio between real per-capita output (excluding government wages) and per-capita hours worked in the private sector.

with recent empirical evidence (see e.g. De Castro et al. (2013) and Giordano et al. (2011)). The productivity of public spending on goods and services in the public sector's production function, χ, is calibrated at 0.3547, which is the data average value of public spending on goods and services as a share of total government consumption expenditures. We set the share of government transfers that is allocated to liquidity constrained households, $\bar{\lambda}$, equal to 0.5, which means that government transfers are equally split between Ricardian and non-Ricardian households. The feedback coefficient of lump-sum taxes on the debt ratio, φ_t^T, is set to 0.20 to ensure stability of public debt.

The persistence parameters and the standard deviations of the exogenous variables, $\tau_t^c, \tau_t^l, \tau_t^k, g_t^c, g_t^i, g_t^{tr}, w_t^g, h_t^g, v_t, A_t, \eta_t^I$, were estimated via OLS from their respective stochastic processes.[20] Note that, in line with the model's assumptions, we compute utilization-adjusted series for the total factor productivity, A_t, as a residual from the production function, given the calibrated parameters for a and a_g. The resulting series are H-P filtered and then we fit the AR(1) model on the cyclical component of A_t, to obtain the persistence and the standard deviation of the utilization-adjusted Solow residual. We set the persistence and volatility of the wage markup shock in order to replicate the volatility and the persistence of private sector real wages found in data. We set the persistence and volatility of the price markup shocks equal to the persistence and volatility of the residual obtained from fitting an AR(1) model on the constructed series for the price markup of the whole economy. The persistence and the standard deviation of the risk premium shock ε_t^R is set so that to pin down as close as possible the persistence and volatility of the current account balance-to-GDP ratio. In a similar manner, we set the persistence of the shock to the gross growth rate of technological process, γ_z, equal to the first-order autocorrelation coefficient of the gross growth rate of real per-capita GDP, and we choose the standard deviation of the shock so that the model to replicate the variance of actual real GDP. We set the standard deviation of the shock in the growth rate of the nominal

[20] The time series on $\tau_t^c, \tau_t^l, \tau_t^k, g_t^c, g_t^i, g_t^{tr}, w_t^g, h_t^g, v_t, \eta_t^I$ were quadratically detrended to obtain their stationary components that more closely correspond to the model's stationary variables. We use as a measure for the investment-specific technology, η_t^I, the inverse of the ratio of the private investment deflator to the deflator of private consumption expenditures (see also Greenwood et al. (2010)).

exchange rate, s_t, equal to the standard deviation of the respective series in the data.[21] Finally, the SVAR system is estimated with OLS and the indentifying scheme is based on a Choleski orthogonalization of the shocks.[22]

[Table 1 about here]

3.2. Long-run solution

Table 2 reports the model's long-run solution. In this solution, we exogenously set the long-run level of the debt-to-GDP ratio equal to the target level $\bar{d}$. Given the calibrated value of the discount factor, it follows that the long-run value of the net private foreign asset position is pinned down by the parameter $\bar{f}$, and that the interest rate premium is nil. As is common in similar studies, the parameter $\bar{f}$ is set equal to zero, which implies a zero net foreign asset position for the private sector. One of the remaining fiscal policy instruments should be residually determined to satisfy the long-run government budget constraint. We choose government transfers as share of GDP to play that role. Notice that, in order to satisfy the government budget constraint, the share of transfers has to fall below its value in the data (from 0.1936 to 0.1428).

[Table 2 about here]

3.3. Linearization and approximate solution

Equations (A1)-(A68), which describe the Decentralized Competitive Equilibrium (DCE) of the model economy, are linearized around the logarithms of steady state. Variables in the log-linearized system are expressed as percentage deviations from the respective steady state values, $\hat{x}_t \equiv \ln x_t - \ln x$, where x is the steady-state value of x_t The final system is solved using the generalized Schur decomposition method proposed by Klein (2000).

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[21] We use data on the nominal effective exchange rate vis-à-vis 37 trading partners.

[22] The ordering of the variables is $\ln y_t^*, \Pi_t^*, R_t^*, \ln p_t^{x^*}$. In estimating the SVAR we also add a constant, a linear and a quadratic trend. As proxies for the rest of the world variables we use EU-28 averages, with the exception of the foreign interest rate that corresponds to the euro area (17 countries) average interest rate on ten-year government bonds.

4. Model properties

In this Section we investigate the dynamic properties of the model by: (i) inspecting the sample moments produced by the model; (ii) reporting the impulse response functions to the stochastic shocks and analyzing the main transmission channels through which the shocks influence the macroeconomy; and (iii) performing variance decomposition analysis.

4.1. Descriptive power of the model economy

The descriptive power of the model is evaluated by comparing the second moment properties generated by the model to those in the actual Greek data over the period 2000:1-2011:4. Table 3 summarizes results for standard deviations (relative to GDP), first-order autocorrelations and cross-correlations with GDP. This is done both for the actual and the simulated series.[23]

[Table 3 about here]

As Table 3 reveals, the model does quite well in predicting the variability of most variables. On the one hand, the model is able to reproduce the high volatility of private consumption, while it matches well the volatilities of hours worked, the real effective exchange rate and the CPI inflation rate. The volatilities of the private and public capital stocks are also well captured. On the other hand, the model underpredicts the volatility of exports and, to a lesser extent, the volatilities of imports and the trade balance-to-GDP ratio. Finally, the model correctly predicts that the current account balance-to-GDP ratio fluctuates more than the trade balance-to-GDP ratio.

As regards persistence properties, the model produces satisfactory results for most of the macroeconomic variables. In addition, the model does well in reproducing the cross-correlations of the various variables with GDP in terms of signs and, to some extent magnitude.

[23] The model has been simulated 1000 times, with each simulation being 148 periods long, where the first 100 observations has been discarded to ensure that the simulated series start from an ergodic distribution. To get the business cycle behavior of the series, both the actual and simulated data were logged and then filtered by using the Hodrick-Prescott filter with a smoothing parameter of 1600. The trade balance-to-GDP ratio and the current account balance-to-GDP ratio are H-P filtered in levels. The moments summarizing the cyclical behavior are computed from the filtered data and averaged across the 1000 simulations.

Overall, the above findings suggest that the model does quite well in explaining the key stylized facts of the Greek business cycle over the sample period.

4.2. Impulse response analysis

In this Section we investigate the dynamic properties of the model by reporting the impulse response functions to a number of stochastic shocks and analyzing the main transmission channels through which the shocks influence the macroeconomy. To save on space, we focus our attention to shocks in fiscal policy instruments, technology shocks, as well as shocks to the price and wage markups. Impulse responses for the rest exogenous variables are presented in Appendix C.

The series plotted are percentage deviations from the steady-state. Exceptions are the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are reported as percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations.

4.2.1. Effects of shocks to government spending instruments

We first discuss the dynamic effects of transitory shocks to government spending instruments. We focus on shocks to government purchases of goods and services, g_t^c, government investment, g_t^i, public sector wages, w_t^g, and public sector employment, h_t^g.[24] The magnitude of the shocks to government purchases of goods and services and government investment is set in order to have a decrease in the respective components of public spending at time $t=0$ equal to 1% of steady-state GDP (i.e. including the government wage bill). The shock in the public wage rate is set in order to have a decrease in the total public wage bill equal to 1% of steady-state GDP. Similarly, we choose the shock in public sector employment in order to achieve a decrease in the total public wage bill equal to 1% of initial GDP.

[24] Impulse responses for the share of domestic to total public debt, v_t and government transfers, g_t^{tr}, are shown in the Appendix C.

Figure 1 depicts the dynamic responses of some major macroeconomic variables to a temporary shock in government purchases of goods and services equal to a 1% decrease in steady-state GDP.

[Figures 1-4 about here]

The reduction in government purchases produces a positive wealth effect that induces optimizing households to increase current consumption and decrease labour supply in the private sector.[25] At the same time, the fall in aggregate demand leads firms to reduce their demand for labour and capital services. The demand side effect on labour is found to be strong, leading to a decrease in private sector real wages and employment. In turn, the lower labour costs, combined with the reduction in the rental rate on capital, result in a decrease in real marginal costs that allows firms to reduce domestic prices, thereby generating deflationary pressures. In contrast to the optimizing households, liquidity constrained households reduce consumption demand due to the fall in their disposable income. As can be seen from Figure 1, the net effect on total private consumption is negative on impact. This is explained by the presence of liquidity constrained households that partly offset the positive wealth effect of optimizing households, as well as the open economy set-up that allows optimizing households to smooth consumption more effectively than when the economy is closed. This is achieved by reducing the holdings of foreign assets, thereby dampening the response of private consumption in the short run. Nevertheless, the fall in total consumption is short-lived and its dynamic response in the following periods of transition is denominated by the behaviour of optimizing households.

In addition, the increase in the real interest rate along with the decline in the return to capital generate a fall in the price of capital and thus on private investment that further dampens aggregate demand in the short run.[26] Nevertheless, private investment increases in the subsequent periods of transition. As regards the variables related to the external sector, the reduction in domestic prices produces a rise in the

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[25] Optimizing households feel wealthier because the fiscal contraction increases the social resources that are available to the private sector, raising their permanent income.

[26] The rise in the real interest rate results from the fact that there is no monetary policy independence. More specifically, the increase in the public debt-to-GDP ratio due to the adverse effects of the fiscal contraction on GDP along with the decline in private foreign assets, increase risk-premia and hence the nominal domestic interest rate that, in turn, discourages investment. In contrast, under an independent monetary authority that follows a Taylor-type rule, the real interest rate typically decreases after a reduction in government purchases, thereby encouraging investment (see for example Forni et al. (2009) and Pappa (2009)).

real exchange rate in the short run, that is, a real depreciation that signals an improvement in the country's competitiveness. The drop in export prices along with a rise in import prices that is driven by the higher real effective exchange rate, induce an increase in the terms of trade, which means that domestically produced goods are relatively cheaper than imported goods. This in turn boosts exports and dampens imports, leading to an improvement in the trade balance and the current account balance, in line with the results obtained in Erceg et al. (2005) for the US economy. Eventually, the decrease in aggregate demand leads to a fall in real private output. The estimated impact multiplier is found to be 1.01. The corresponding impact multiplier of real GDP, which is defined as the sum of private production and total compensation of public employees, is 0.92.

Figure 2 shows the dynamic responses to a government shock in public investment equal to a 1% decrease in steady-state GDP. The main channels at work are the same as in the case of a decrease in public consumption, but now there are also supply-side effects, as a lower stock of public infrastructure leads to lower marginal products of private inputs. As a result, the adverse effects on aggregate demand and thus on private output and real GDP are stronger and more persistent than when government purchases on goods and services decrease. Nevertheless, the qualitative results are found to be very similar. The impact multiplier for private output and real GDP are estimated at 1.11 and 0.93 respectively.

Figure 3 summarizes the dynamic responses to a shock in the average wage rate of the public sector. Recall that the shock is set in order to have a decrease in the total public wage bill equal to 1% of initial GDP. Cutting public sector wages reduces the disposable income of liquidity constrained households and leads to a reduction in their consumption purchases, which in turn puts downward pressure on private sector wages. Eventually, private sector wages decrease, leading to a fall in labour costs that allows firms to increase the demand for labour. Regarding the behavior of optimizing households, as the impulses show, the decrease in real wages leads them to decrease consumption expenditures on impact, while at the same time the fall in the return to capital forces them to use capital less intensively. Nevertheless, private consumption of optimizing households starts increasing after the second quarter onwards. Moreover, the lower labour costs exert a downward pressure on domestic prices that is translated to a drop in domestic inflation and an improvement in the terms of trade that triggers a rise in exports.

The decrease in aggregate demand, which is mainly driven by the lower demand for goods by liquidity constrained households, results in a small, albeit negligible reduction in private output on impact period by about 0.09%, much lower than in the case of a fiscal contraction in the form of lower public consumption or public investment. The fall in private output is, however, only temporary since private output starts increasing after the second quarter onwards in order to meet the higher foreign demand. Thus, reductions in public wages can be beneficial in stimulating private production and improving external imbalances through its impact on private sector wages. The positive relationship between public and private sector wages implied by the model is consistent with the recent empirical findings of Fernandez-de-Cordoba et al. (2012) and Lamo et al. (2012). On the other hand, real GDP decreases on impact by around 1%. We should note, however, that this effect on real GDP is due to our definition of GDP, namely the sum of private production and public sector wages. Similar results regarding the impact of cuts in public sector wages can also be found in Stahler and Thomas (2012).

Figure 4 illustrates the dynamic effects of a shock in public sector employment. The shock is set in order to achieve a decrease in the total public wage bill equal to 1% of steady state real GDP. The shock to public employment lowers total labour demand and leads to a reduction in both labour income and total employment, whereas it increases the available labour supply for private production. At the same time, it affects the intratemporal choices of optimizing households, leading them to increase consumption purchases, as well as labour supply in the private sector. On the other hand, liquidity constrained households experience a loss in their disposable income that forces them to reduce consumption demand, yielding a decrease in aggregate consumption. Eventually, the lower public employment results in a reduction in private sector wage claims and hence labour costs, allowing firms to increase their demand for labour and reduce domestic prices. In turn, the fall in domestic prices gives rise to an improvement in the terms of trade that triggers an expansion in foreign demand for domestic goods. In contrast to the case of a reduction in public sector wages, private investment increases due to the rise in the price of capital. Overall, the increase in exports and private investment outweighs the negative impact of the lower consumption expenditures on aggregate demand, and results to an increase in private output. By contrast, real GDP decreases by around 1% on impact. As already explained, this is due to the reduction in the total wage bill.

4.2.2. Effects of shocks to tax policy instruments

Figures 5-7 show the dynamic effects of transitory shocks to the tax rates on consumption, labour income and capital income. The shocks to different tax instruments are set so as to achieve an increase in the different categories of tax revenues by 1% of initial GDP.

[Figures 5-7 about here]

Figure 5 depicts the dynamic responses to a shock in the tax rate on labour income that increases labour tax revenues by 1% of initial GDP. The increase in the labour income tax rate causes a negative wealth effect that induces optimizing households to reduce current consumption and increase labour supply. But, at the same time, the higher tax rate reduces the after-tax wage inducing an intratemporal substitution effect that leads optimizing households to reduce current labour supply and consumption. As regards liquidity constrained households, the decrease in the after-tax labour income forces them to reduce consumption demand. Consequently, since both types of households reduce their consumption purchases, total consumption decreases. It is worth noting that real wages in the private sector decrease on impact. This is explained by the lower demand for labour, as well as the sizable reduction of consumption of liquidity constrained households that exerts a downward pressure on wages. Nevertheless, the intratemporal substitution effect dominates the wealth effect in the subsequent periods of transition, leading to a reduction in labour supply that triggers an increase in private sector wages. The latter effect raises real marginal costs and forces firms to substitute labour with capital services and increase domestic prices.

Regarding the impact of the higher labour tax rate on the variables related to the external sector, we observe a deterioration in the terms of trade triggered by the rise in export prices and the fall in import prices. While the loss in competitiveness causes a sizable reduction in the demand for exports, the lower demand for consumption dampens imports and induces an improvement in the trade balance. Eventually, the lower aggregate demand gives rise to a decrease in private production and real GDP. The impact multipliers are respectively 0.30 and 0.26, broadly in line with previous findings in similar studies (see e.g. Coenen et al. (2012) and Forni et al. (2009)).

Figure 6 illustrates the dynamic responses to a shock in the tax rate on consumption. There is again a negative wealth effect, as well as an intratemporal substitution effect that leads optimizing households to decrease current consumption. The consumption demand of liquidity constrained households also decreases due to the fall in the disposable income, leading to a sizable reduction in aggregate consumption. In contrast to the case of an increase in labour taxes, the higher consumption tax rate results in a rise in the price of capital and hence private investment. In addition, we observe an increase in the real exchange rate (that is, a real depreciation), that improves the terms of trade and boosts exports. The rise in exports, in combination with the fall in imports, causes an improvement in the trade balance and the current account balance in the short run. Despite the rise in the demand for exports and investment, both private output and real GDP fall on impact by 0.36% and 0.30%, respectively.

Figure 7 summarizes the dynamic responses to a shock in the tax rate on capital income. An increase in the capital income tax rate has a negative wealth effect that induces optimizing households to decrease current consumption and increase labour supply. At the same time, the fall in the after-tax return to capital along with the decrease in capital utilization reduce private investment and capital over time. The reduction in the supply of capital services, in combination with the higher rental rate of capital, lead firms to substitute away from capital services to labour services. The increase in labour demand exerts an upward pressure on private sector wages in the short run that results in a transient increase in the disposable income of the liquidity constrained households, which in turn, puts a downward pressure in labour supply and enhances the increase in real wages in the short run. Higher labour costs along with higher costs of renting capital services, lead firms to increase domestic prices, which in turn generates inflationary pressures and reduces the real effective exchange rate and the terms of trade. Consequently, domestic products become less competitive and this dampens the demand for exports. Overall, the lower aggregate demand results to a decrease in private production and real GDP on impact period by about 0.28% and 0.23%, respectively. It is interesting to note that private output and real GDP continue decreasing in the subsequent periods of transition due to the adverse effects of the capital tax rate on private investment.

4.2.3. Effects of technology shocks

Figures 8-10 depict the dynamic responses to a temporary one standard deviation increase in the innovations of total factor productivity, investment-specific technology and labour augmenting productivity growth, respectively.

[Figures 8-10 about here]

A positive shock in total factor productivity increases the marginal productivity of private inputs and decreases real marginal costs, allowing firms to reduce the prices of domestically produced goods. Because prices are sticky, aggregate demand responds only sluggishly to the increase in output supply and firms can meet the higher demand by employing less labour and capital services. As a result, there is a decrease in hours worked and private sector wages in the short run, consistent with the empirical evidence provided in Gali (1999). Regarding the response of private consumption, optimizing households face a positive wealth effect that induces them to increase current consumption. On the other hand, the initial decrease in the labour income leads liquidity constrained households to reduce their consumption expenditures in the short run. The net effect on private consumption demand is negative on impact, thereby restraining the increase in demand. The increase in the marginal productivity of capital increases investment demand, while the decrease in export prices results in an improvement in the terms of trade and shifts foreign and domestic demand towards domestic goods, thereby boosting exports.

A positive investment-specific technology shock increases the marginal efficiency of investment and creates incentives to raise future capital formation. Since new capital is now more productive than the current capital stock, this leads households to increase the utilization rate and depreciate the current capital stock. At the same time, optimizing households find it optimal to postpone their consumption in the short run in order to invest more. As Figure 9 shows, in response to the positive investment-specific technology shock, private investment increases in a hump-shaped pattern. In addition, there is a small, albeit negligible decrease in hours worked in the private sector on impact period that puts a downward pressure on private sector wages. Nevertheless, the rise in the marginal productivity of private inputs that is driven by the higher capital services generates an expansion in private sector employment and wages in the following periods, in line with the findings in Justiniano et al. (2010) and Khan and Tsoukalas (2012).

Figure 10 shows the dynamic responses to a shock in labour augmenting technology. Recall that innovations in $\gamma_{z,t}$ have permanent effects on the level of z_t, and hence on the levels of macroeconomic variables that grow along the balanced growth path. The positive productivity shock increases private sector wages and employment and triggers an increase in the consumption demand of both types of households. At the same time, the rise in the return to capital induces optimizing households to increase the utilization of existing capital, whereas the higher price of capital boosts investment demand. The increase in the price of domestically produced goods that is driven by the rise in the real marginal costs generates inflationary pressures that reduce the real effective exchange rate and the terms of trade, leading to a deterioration in the trade balance and the current account balance.

4.2.4. Effects of markup shocks

In this Section we investigate the dynamic responses to temporary reductions in the price and wage markups by 1%.

We first consider the effects of a reduction in the price markups by 1%. Figure 11 displays the dynamic paths resulting from a shock in the domestic price markup, μ_t^d. The first order effect is a decrease in the price of goods that are produced and sold domestically, which increases the domestic demand for these goods, whereas it reduces the demand for imported goods. The higher aggregate demand leads to a rise in the demand for labour and capital services that triggers an expansion in private production and real GDP. However, the higher input costs cause an increase in the real marginal cost and lead domestic firms to increase export prices, which causes the terms of trade to deteriorate and discourages exports. Nevertheless, there is an improvement in the trade balance in the short run that is driven by the lower imports. Finally, note that both the primary deficit-to-GDP ratio and the debt-to-GDP ratio decrease along the dynamic path, which implies that a reduction in the domestic price markup can be beneficial for improving public finances.

[Figures 11-14 about here]

Figure 12 illustrates the effects of a temporary reduction in the export price markup, μ_t^x, by 1%. The decrease in the markup is associated with an improvement in the terms of trade and an expansion in the foreign demand for exports. Firms increase the demand for inputs and this puts upward pressure to the real wages and the return to capital. Eventually, there is an expansion in private production and real GDP.

A different picture emerges regarding the short-run response of private output and real GDP in the case of a reduction in the import price markup. As Figure 13 depicts, the decrease in the import price markup makes imported goods cheaper, which in turn leads to expenditure switching towards imported goods. Given the reduction in the domestic demand for goods that are produced and sold domestically, firms decrease their demand for private inputs, putting downward pressures in the private sector wages and the return to capital. Since both private employment and wages decrease, there is a reduction in consumption expenditures. Eventually, private output and real GDP decrease in the short run.

We now turn our analysis on the effects from a decrease in the wage markup by 1%. As can be seen from Figure 14, the first order effect is a decrease in private sector real wages that creates strong incentives for firms to use labour services. At the same time, lower wages are translated into a lower real marginal cost that allows firms to decrease the prices of both domestically sold and exported goods. Consequently, there is a rise in exports that is accompanied by an improvement in the terms of trade and the trade balance-to-GDP ratio in the short run. At the same time, the decrease in domestic inflation triggers an increase in the real effective rate, that is, a real depreciation. In addition, investment demand increases due to the rise in the price of capital. Eventually, the rise in aggregate demand results to a rise in private production and real GDP. Regarding the impact on public finances, it is worth noting that there is a reduction in the public debt-to-GDP ratio that is mainly driven by the higher real GDP.

4.3. Variance decomposition

In this Section we quantify the contribution of each structural shock to fluctuations in the endogenous variables at different time horizons. More specifically, the total variances of the endogenous variables are decomposed into fractions explained by innovations in the exogenous variables. We report forecast error variances over short-term (1-4 quarters), medium-term (12 quarters) and long-term (20-40 quarters). We focus our attention on the decomposition of real GDP, private output, private sector employment, real exports, real imports and the real effective exchange rate.

[Figures 15-22 about here]

As Figure 15 illustrates, fluctuations in real GDP in the short run are primary driven by government wage shocks, government purchases shocks, total factor productivity shocks and wage markup shocks. In the very short run, shocks to government wages and government consumption explain respectively about 32% and 19% of the variance in real GDP. At the 4-quarter horizon, shocks in total factor productivity, public sector wages and wage markup shocks account respectively for about 22%, 19% and 10% of the variation in real GDP. It is worth noting that shocks to the tax rates, government employment and price markups do not seem to matter for the variability of real GDP in the short run. Over the medium term, shocks in total factor productivity, permanent technology shocks and investment specific shocks become gradually more important. In the long run (after 40 quarters), technology shocks together explain about 47% of the total variance in real GDP, while the remaining variability is mainly explained by shocks in government wages and wage markups.

In the case of private output, shocks in government purchases of goods and services explain about 31% of the total variance in the very short run, but their contribution is relatively short-lived. In contrast to the case of real GDP, the contribution of shocks to government wages is now negligible. On the other hand, the nominal exchange rate explains about 18% of the short-run variations in private output. This is not surprising since, in the absence of monetary policy independence, these shocks directly affect the intertemporal choices of optimizing households. In the medium term, total factor productivity shocks and investment specific shocks are the main forces behind the fluctuations in private output. The remaining variability is mostly explained by wage markup shocks. At longer horizons, technology shocks together can explain about 52% of the total variance of private output.

Turning our analysis to the determinants of private sector employment, it can be seen from Figure 17 that the variability of hours worked in the private sector in the short run is driven by wage markup shocks and total factor productivity. At the 4-quarter horizon, the former shocks explain about 33% of the total variance, while the latter explain about 20%. A similar picture emerges at longer horizons, where shocks in total factor productivity and wage markup shocks together account for about 50% of the total variance in hours worked in the private sector.

As regards short-run fluctuations in private consumption, Figure 18 reveals that they are mainly attributed to shocks in the tax rate on consumption and risk-premium shocks. This is explained by the fact that both shocks have a direct impact on the intertemporal choices of optimizing households. At longer horizons, however, permanent technology shocks also become important, since they explain about 32% of the variability in private consumption.

The contribution of risk-premium shocks is also important in explaining short-run fluctuations in private investment. The reason is that they have a direct impact on the price of capital. As Figure 19 shows, risk-premium shocks along with investment-specific technology shocks explain more that 60% of the short-run variations in private investment. As the time horizon increases, investment-specific technology shocks and labour productivity shocks are the dominant factors behind movements in private investment.

Concerning fluctuations in real exports, Figure 20 illustrates that in the very short run they are mainly driven by shocks to the prices of foreign competitors, foreign demand shocks, as well as shocks in the nominal exchange rate. In the medium term, as well as at longer horizons, foreign demand shocks account for about 33% of the fluctuations in real exports. The remaining variability is mainly due to shocks in the prices of foreign competitors, risk-premium shocks, shocks in the foreign interest rate and shocks in the nominal exchange rate.

As regards fluctuations in real imports in the short run, Figure 21 suggests that they are primary driven by risk-premium shocks. This is in line with the findings in

Kollitzas et al. (2012), who show that the low lending rates after the adoption of euro are associated with higher imports in Greece. At longer horizons, risk-premium shocks account for about 38% of the variability in imports, while the remaining variability can be attributed to permanent technology shocks and investment-specific shocks.

5. Concluding remarks

In this paper we have presented the theoretical foundations and dynamic properties of *BoGGEM* , a Dynamic Stochastic General Equilibrium (DSGE) Model developed at the Bank of Greece as a quantitative tool for policy analysis. We calibrated the model to the Greek economy and examined the dynamic properties of the model by reporting impulse response functions to a number of shocks, performing variance decomposition analysis, and by inspecting the sample moments produced by the model. The results indicate that the model performs quite well along these dimensions.

The current version of the model was calibrated at a quarterly frequency for the Greek economy. Estimating the model and examining its forecasting properties is an important future objective. In addition, adding a banking/financial sector in the current version of the model is an interesting extension.

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Table 1: Calibration

Parameter or Variable	Description	Value
γ	Inverse of the Frisch elasticity of labour supply	1
ϑ	Substitutability/complementarity between private and public goods	0.05
ξ^c	Habit persistence	0.60
a	Gross capital elasticity in production	0.3677
$1-a$	Labour elasticity in production	0.6323
a_g	Public capital elasticity in production	0.0316
γ_z	Growth rate of labor augmenting technology	1.0028
β	Time discount factor	0.9923
κ	Preference parameter	26.4
λ	Fraction of liquidity constrained households	0.35
A	Long-run aggregate productivity	1
δ^p	Private capital quarterly depreciation rate	0.0172
δ^g	Public capital quarterly depreciation rate	0.0107
ξ^k	Private capital adjustment cost parameter	0.9
ϕ	Elasticity of marginal depreciation costs	1.625
Φ	Fixed cost parameter	0.1367
μ_t^w	Markup on private sector wages	1.15
μ_t^d	Markup - domestic market	1.38
μ_t^x	Markup - foreign markets	1.1
μ_t^m	Markup - importing firms	1.38
θ_p^d	Calvo parameter - domestic market	0.7059
θ_p^x	Calvo parameter - foreign markets	0.697
θ_p^m	Calvo parameter - importing firms	0.7059
x_d	Indexation parameter - domestic market	0.26
x_x	Indexation parameter - foreign markets	0.26
x_m	Indexation parameter - importing firms	0.26
ψ^d	Risk-premium coefficient on total public debt-to-output ratio	0.04/16
ψ^f	Risk-premium coefficient on net private foreign assets-to-GDP ratio	0.01
ρ_ψ	Persistent parameter of risk premium	0.95
$\bar{d}$	Target level of total public debt-to-GDP ratio	4
$\bar{f}$	Target level of net private foreign assets-to-GDP ratio	0
χ	Productivity of public spending on goods and services	0.3547
$\bar{\lambda}$	Share of total government transfers allocated to liquidity constrained households	0.5

Table 1: continued

φ_t^T	Feedback parameter on total public debt-to-GDP ratio	0.2
ω_c	Home bias in the production of consumption goods	0.6697
ω_i	Home bias in the production of investment goods	0.3457
ε_c	Elasticity of substitution between imported and domestic consumption goods	3.3510
ε_i	Elasticity of substitution between imported and domestic investment goods	6.3520
ε_x	Elasticity of exports	1.463
n	Degree of real wage rigidity	0.6491
$p^d g^c / p^y y^{GDP}$	Government purchases of goods and services-to-GDP ratio	0.0638
$p^d g^i / p^y y^{GDP}$	Government investment-to-GDP ratio	0.0316
τ^c	Tax rate on consumption	0.18
τ^l	Tax rate on labor income	0.30
τ^k	Tax rate on capital income	0.20
T_t	Lump-sum taxes	0
h^g	Hours worked in the public sector	0.0372
v	Share of domestic public debt	0.4045
ρ_A	Persistent parameter of A_t	0.6261
ρ_{γ_z}	Persistent parameter of $\gamma_{z,t}$	0.6439
ρ_{η^I}	Persistent parameter of η_t^I	0.907
ρ_{g^c}	Persistent parameter of g_t^c	0.76
ρ_{g^i}	Persistent parameter of g_t^i	0.8557
ρ_{w^g}	Persistent parameter of w_t^g	0.7715
ρ_{h^g}	Persistent parameter of h_t^g	0.7084
$\rho_{g^{tr}}$	Persistent parameter of g_t^{tr}	0.7223
ρ_{τ^c}	Persistent parameter of τ_t^c	0.5623
ρ_{τ^l}	Persistent parameter of τ_t^l	0.6502
ρ_{τ^k}	Persistent parameter of τ_t^k	0.7458
ρ_v	Persistent parameter of v_t	0.537
ρ_{μ^w}	Persistent parameter of μ_t^w	0.5
ρ_{μ^d}	Persistent parameter of μ_t^d	0.7193
ρ_{μ^x}	Persistent parameter of μ_t^x	0.7193
ρ_{μ^m}	Persistent parameter of μ_t^m	0.7193
ρ_{ε^R}	Persistent parameter of ε_t^R	0.30

Table 1: continued

σ_A	Standard deviation of A_t	0.0104
σ_{γ_z}	Standard deviation of $\gamma_{z,t}$	0.0045
ρ_{η^I}	Standard deviation of η_t^I	0.0085
σ_{g^c}	Standard deviation of g_t^c	0.0855
σ_{g^i}	Standard deviation of g_t^i	0.0808
σ_{w^g}	Standard deviation of w_t^g	0.0406
σ_{h^g}	Standard deviation of h_t^g	0.0206
$\sigma_{g^{tr}}$	Standard deviation of g_t^{tr}	0.0315
σ_{τ^c}	Standard deviation of τ_t^c	0.0547
σ_{τ^l}	Standard deviation of τ_t^l	0.0216
σ_{τ^k}	Standard deviation of τ_t^k	0.0462
σ_v	Standard deviation of v_t	0.0307
σ_{μ^w}	Standard deviation of μ_t^w	0.021
σ_{μ^d}	Standard deviation of μ_t^d	0.0092
σ_{μ^x}	Standard deviation of μ_t^x	0.0092
σ_{μ^m}	Standard deviation of μ_t^m	0.0092
σ_{ε^R}	Standard deviation of ε_t^R	0.0059
σ_s	Standard deviation of s_t	0.008

Table 2: Data averages and long-run model solution

Variable	Data Averages	Long Run Solution
Total private consumption-to-GDP ratio	0.7191	0.7175
Private investment-to-GDP ratio	0.1820	0.1820
Total hours at work	0.2193	0.2193
Hours at work in the private sector	0.1821	0.1821
Private capital-to-GDP ratio	10.4769	9.0391
Public capital-to-GDP ratio	1.9035	2.3135
Total public debt-to-GDP ratio	4	4
Foreign public debt-to-GDP ratio	3.1260	2.3820
Domestic public debt-to-GDP ratio	1.6180	1.6180
Government transfers-to-GDP ratio	0.1936	0.1428
Private net foreign asset position-to-GDP ratio	-0.028	0
Total economy's net foreign asset position-to-GDP ratio	3.1540	2.3820
Exports-to-GDP ratio	0.2264	0.2175
Total imports-to-GDP ratio	0.3454	0.2580
Trade balance-to-GDP ratio	-0.1190	-0.0405
Current account-to-GDP ratio	-0.0957	-0.066

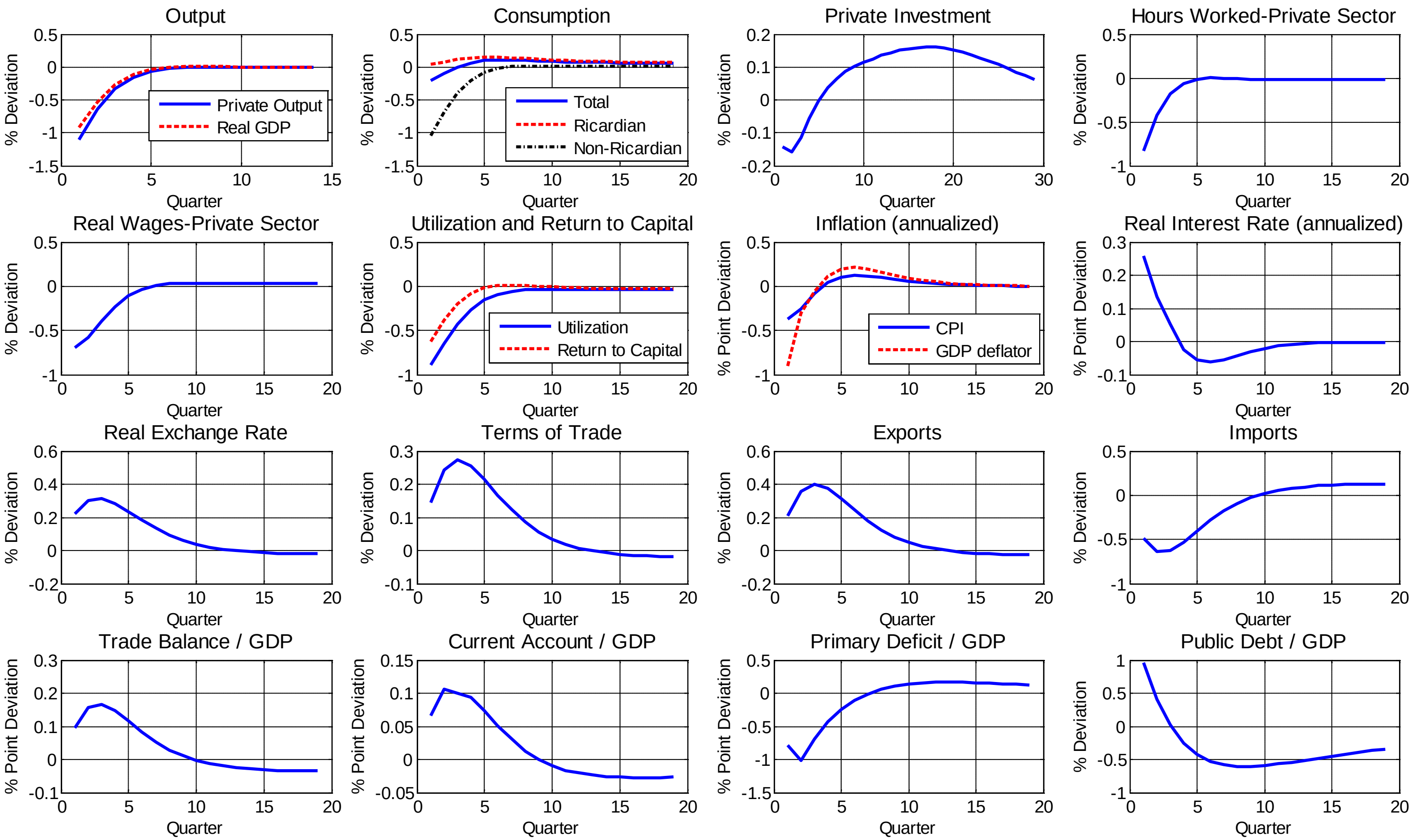
Note: (i) Quarterly data over the period 2000:1-2011:4 (ii) Data averages for the total public debt-to-GDP ratio are over the period 2000-2009, data averages for the domestic public debt-to-GDP ratio, the foreign public debt-to-GDP ratio and the total economy's net foreign asset position-to-GDP ratio are over the period 2002-2011, (iii) A negative value of the private net foreign asset position-to-GDP ratio means that domestic households are net lenders.

Table 3: Simulation results for the model economy

Variable x	Relative Volatility σ_x / σ_y		Persistence $\rho(x_{t-1}, x_t)$		Contemporaneous Correlation $\rho(y_t, x_t)$	
	Actual Data	Simulated Data	Actual Data	Simulated Data	Actual Data	Simulated Data
Real GDP	1	1	0.89	0.68	1	1
Private consumption	1.31	0.94	0.86	0.70	0.78	0.65
Private investment	4.22	4.24	0.75	0.85	0.67	0.50
Total hours of work	0.69	0.72	0.86	0.47	0.65	0.53
Hours worked – Private sector	0.88	0.86	0.86	0.48	0.58	0.50
Wage per hour – Private sector	1.35	1.34	0.64	0.65	0.53	0.50
Private capital stock	0.29	0.31	0.93	0.95	0.57	0.12
Public capital stock	0.39	0.21	0.93	0.92	0.45	0.02
Exports	3.13	1.64	0.90	0.71	0.16	0.52
Imports	3.36	2.4	0.80	0.81	0.60	0.41
Trade balance / GDP	0.85	0.64	0.59	0.78	-0.53	-0.12
Current account balance / GDP	0.95	0.95	0.58	0.41	-0.49	-0.02
Real effective exchange rate	0.67	0.66	0.49	0.67	0.02	0.27
CPI inflation	0.25	0.27	0.12	0.59	0.07	0.38
Standard deviation of GDP, σ_y	0.0182	0.0182				

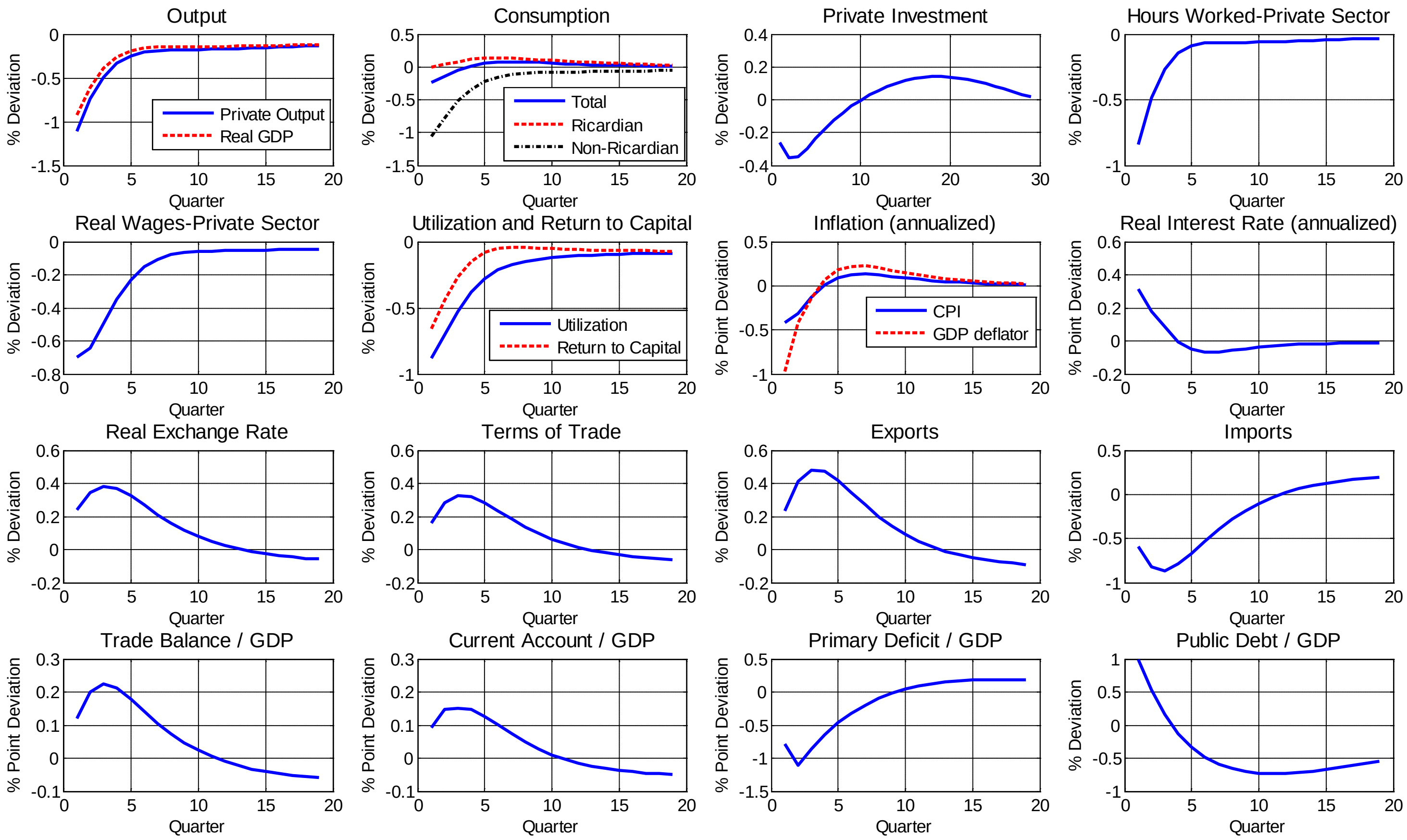
Notes: (i) Quarterly data over the period 2000:1-2011:4, (ii) All variables, with the exception of the trade balance / GDP and the current account balance / GDP, are in logs and have been detrended with the H-P filter with a smoothing parameter of 1600. The trade balance / GDP and the current account balance / GDP have been H-P filtered in levels.

Figure 1: Dynamic responses to a government purchases shock



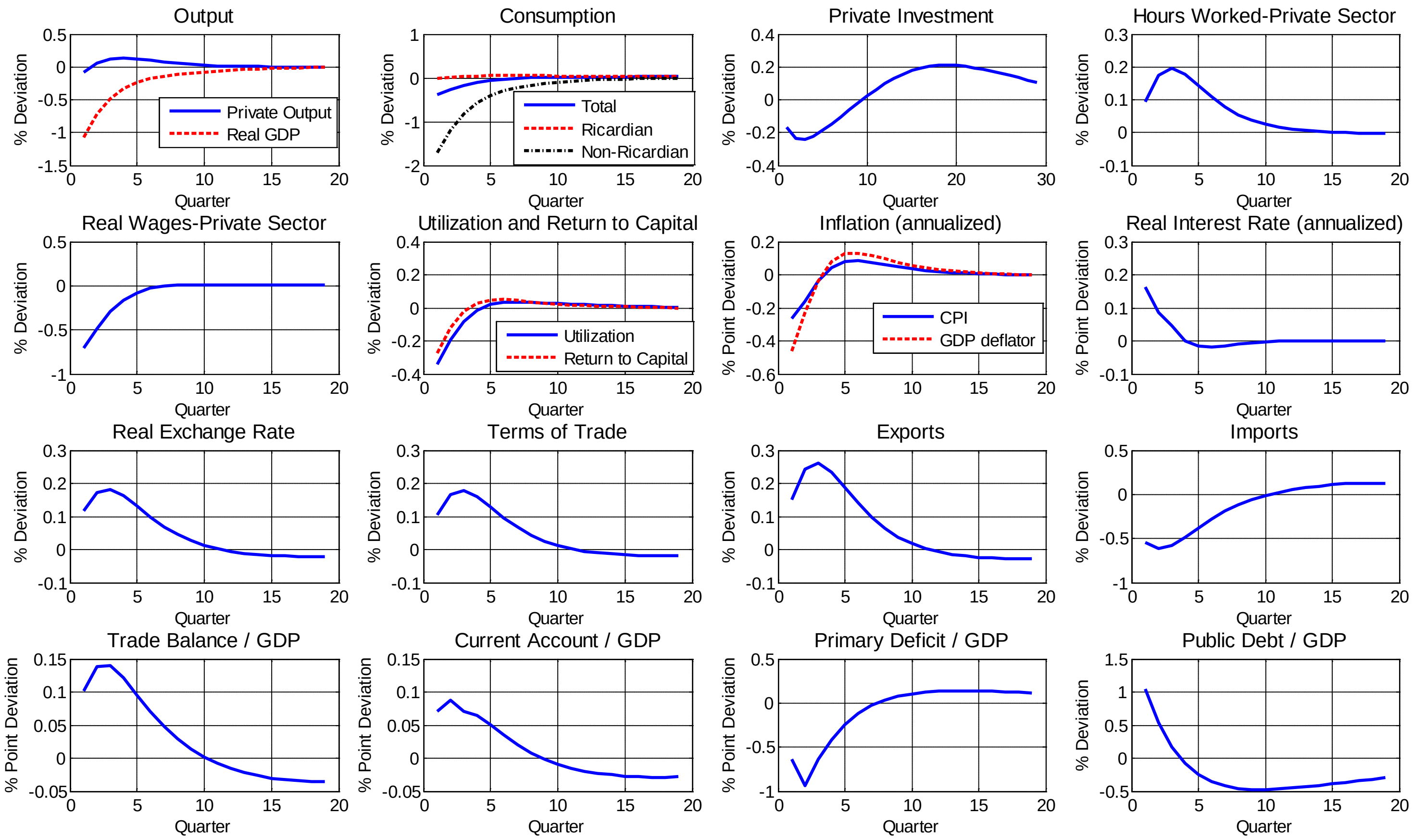
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 2: Dynamic responses to a government investment shock



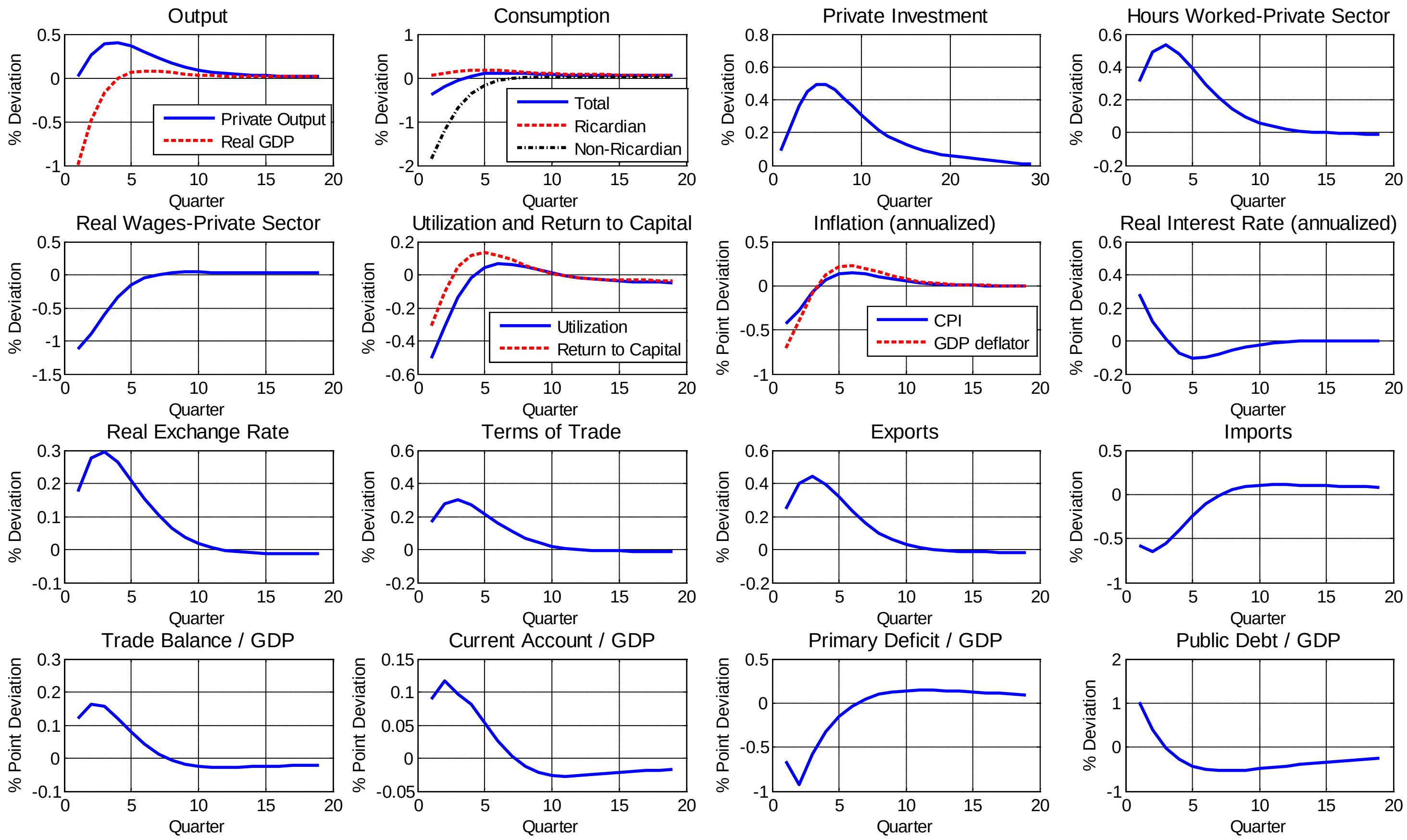
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 3: Dynamic responses to a public sector wage rate shock



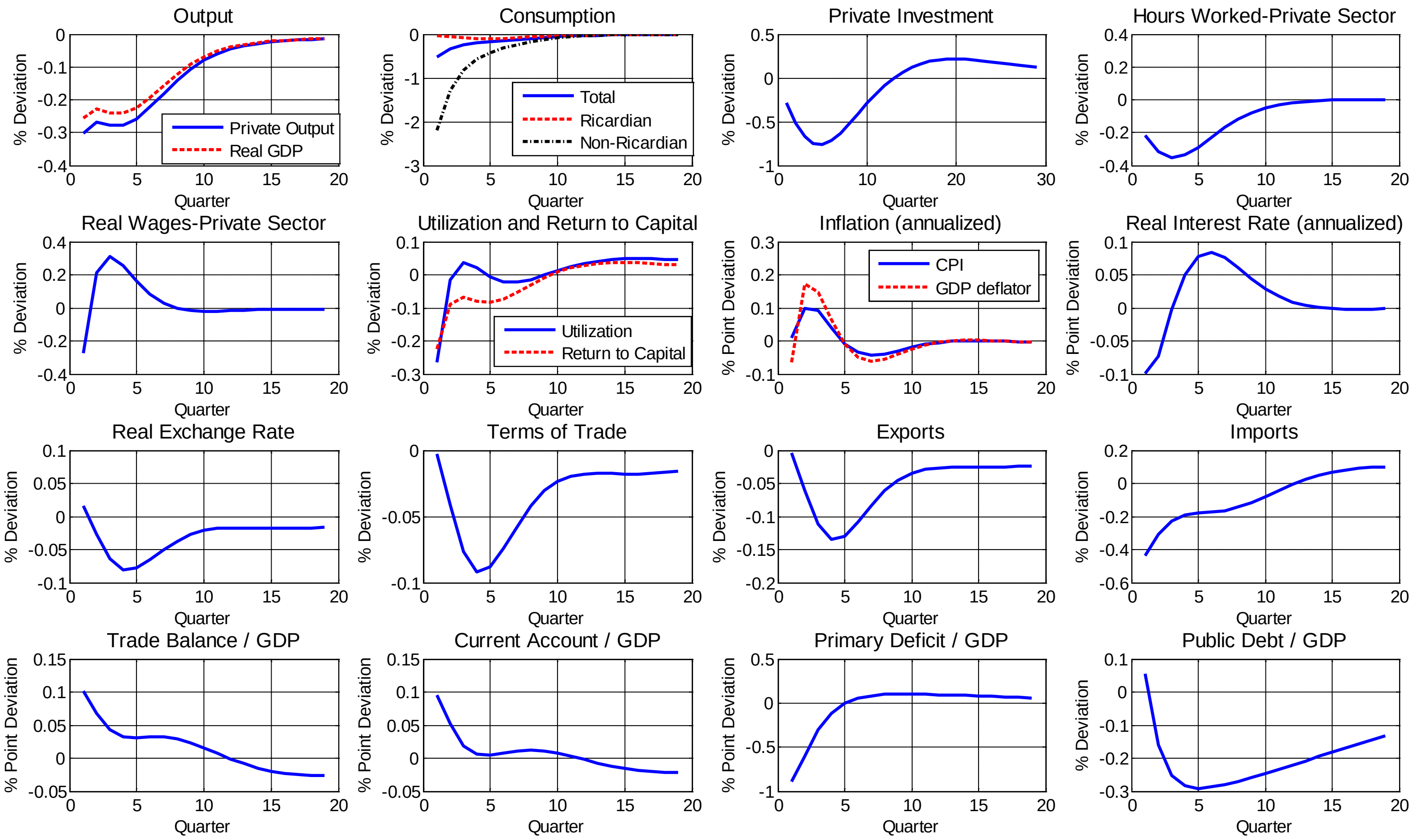
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 4: Dynamic responses to a public sector employment shock



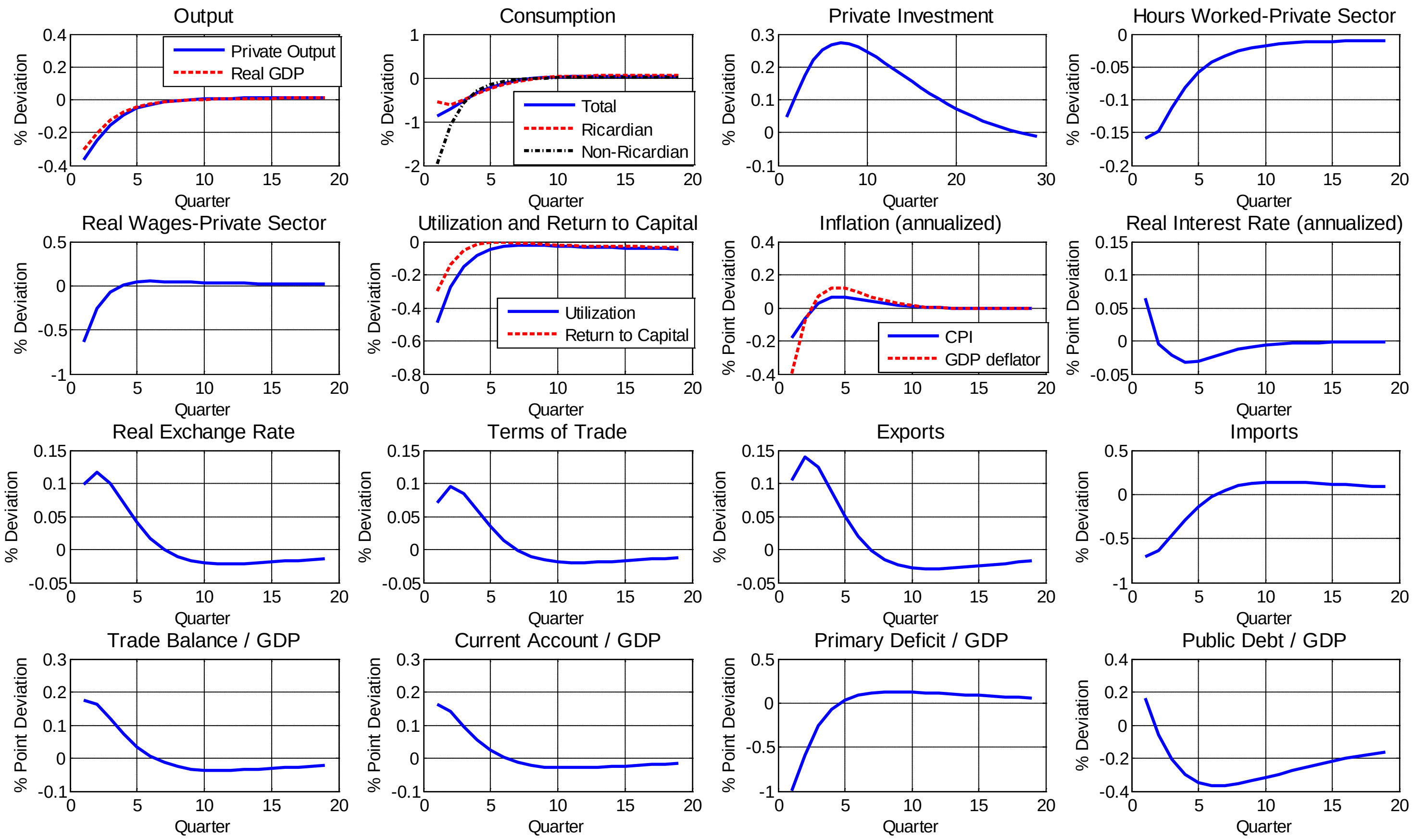
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 5: Dynamic responses to a shock in the tax rate on labour income



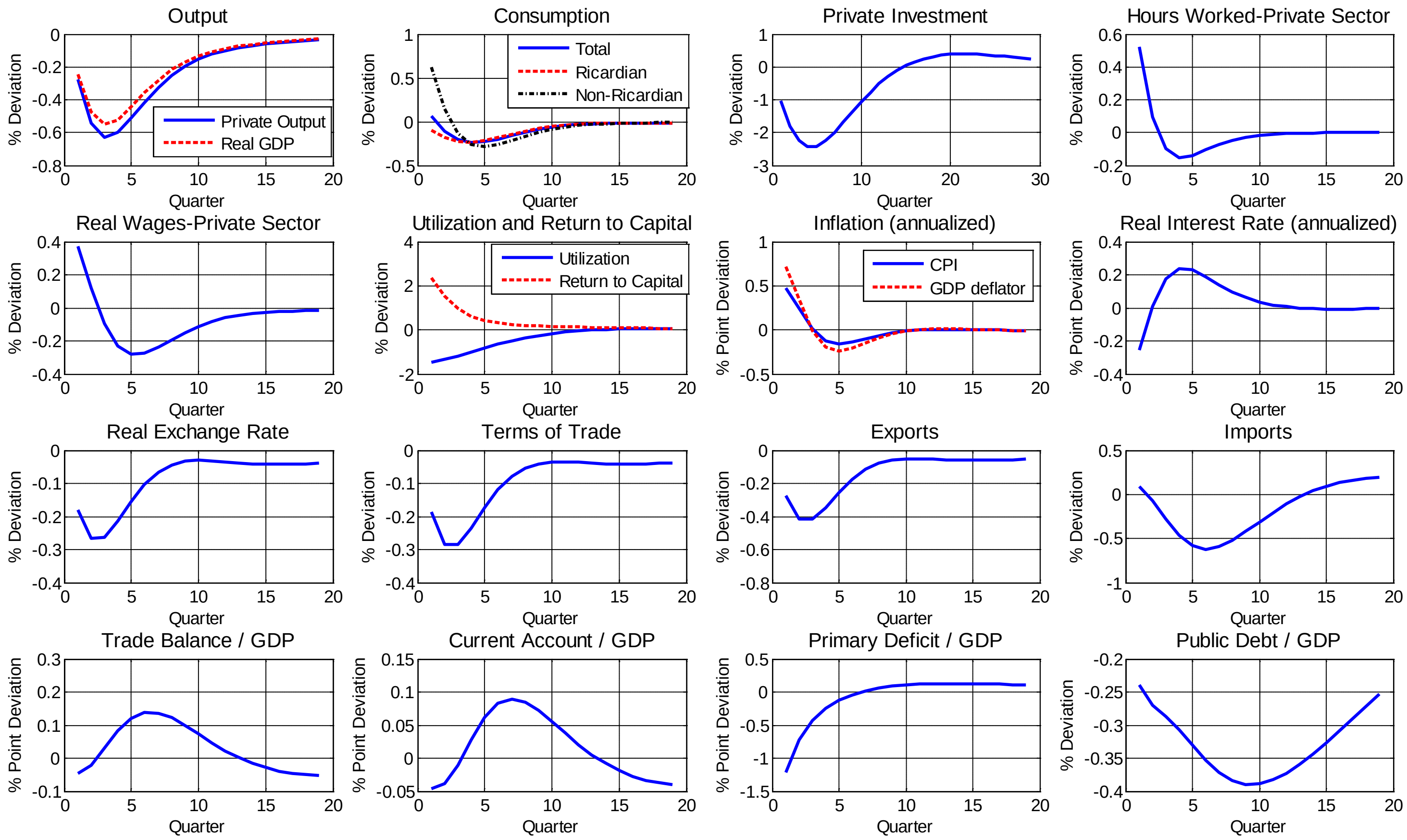
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 6: Dynamic responses to a shock in the tax rate on consumption



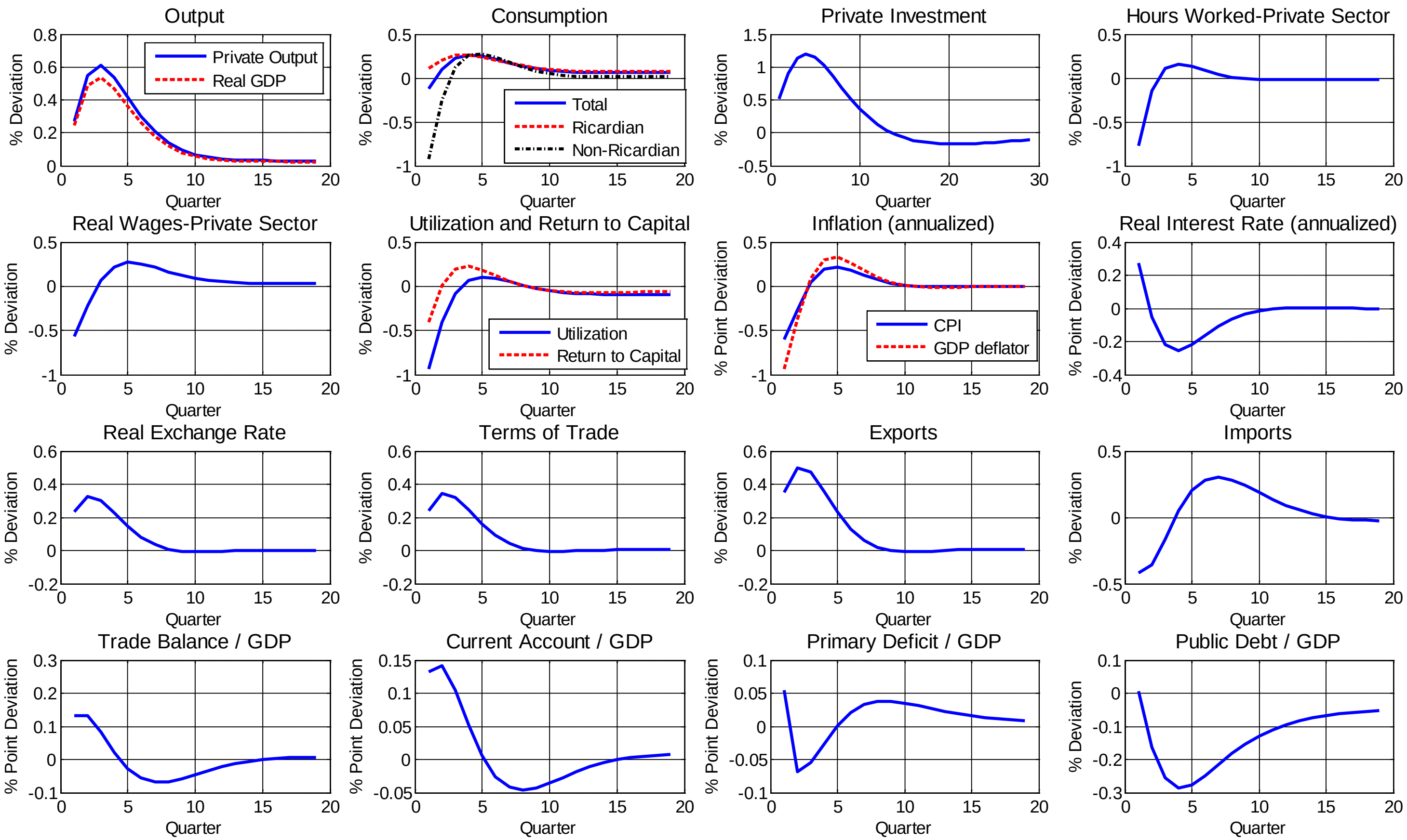
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 7: Dynamic responses to a shock in the tax rate on capital income



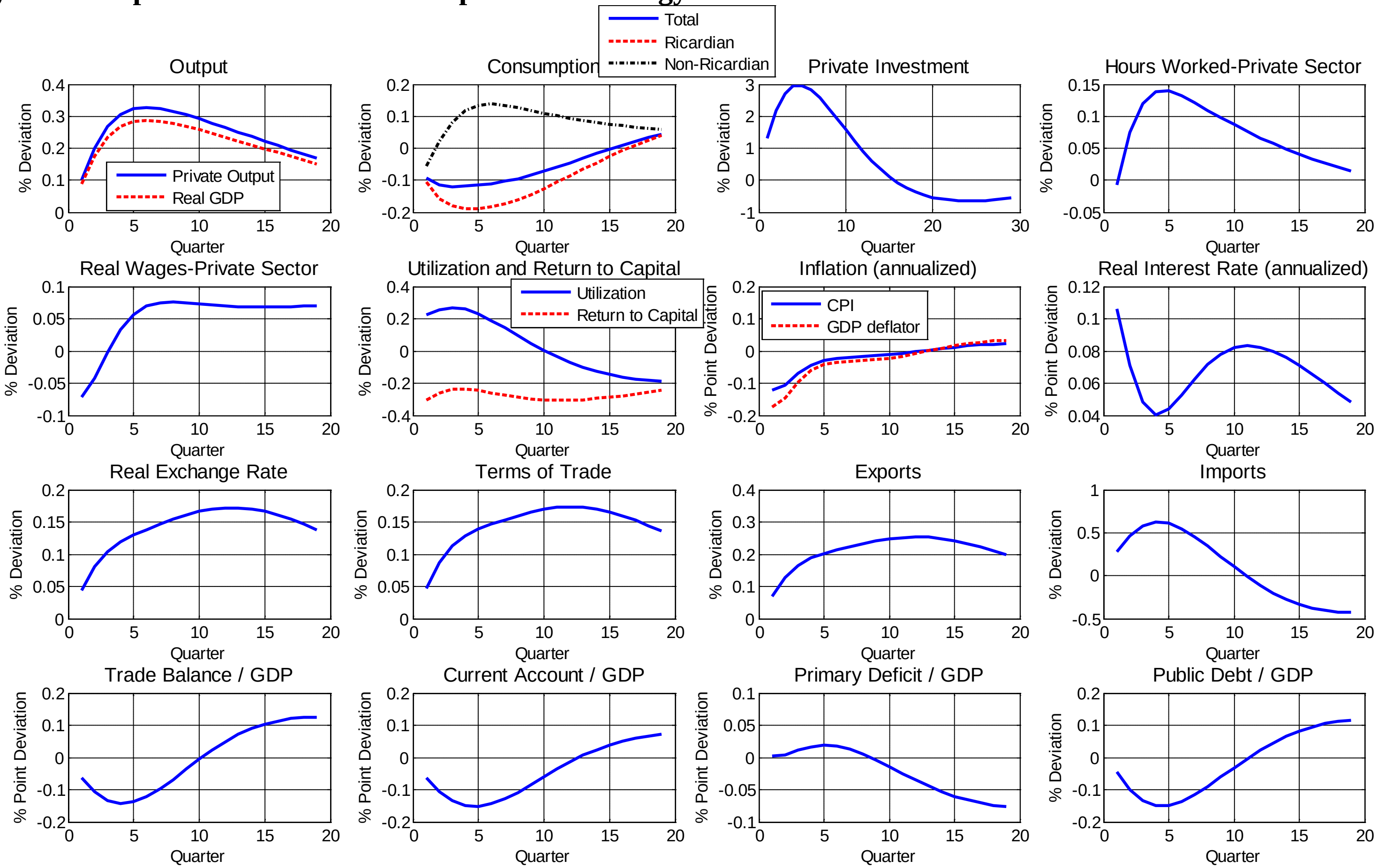
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 8: Dynamic responses to a shock in total factor productivity



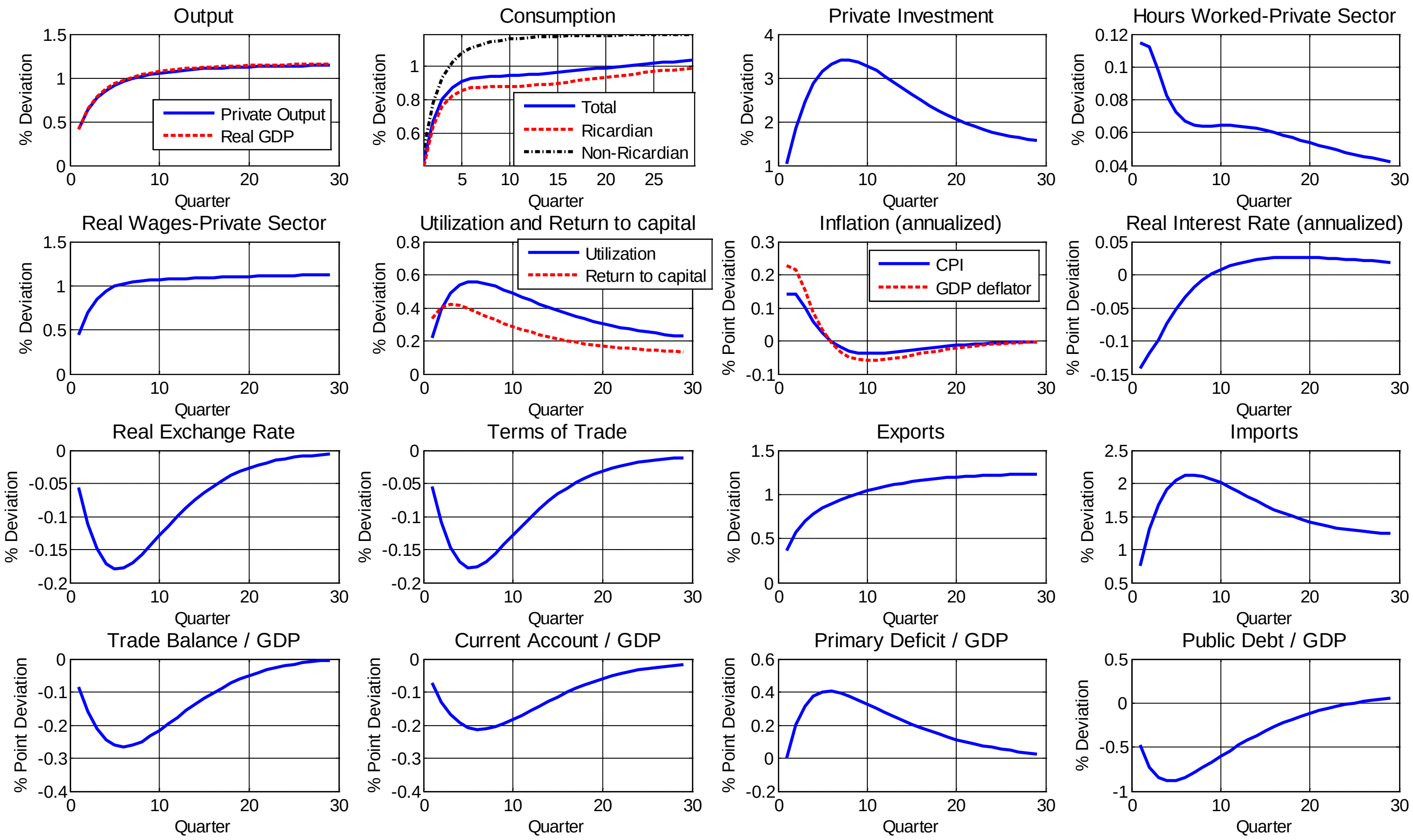
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 9: Dynamic responses to an investment-specific technology shock



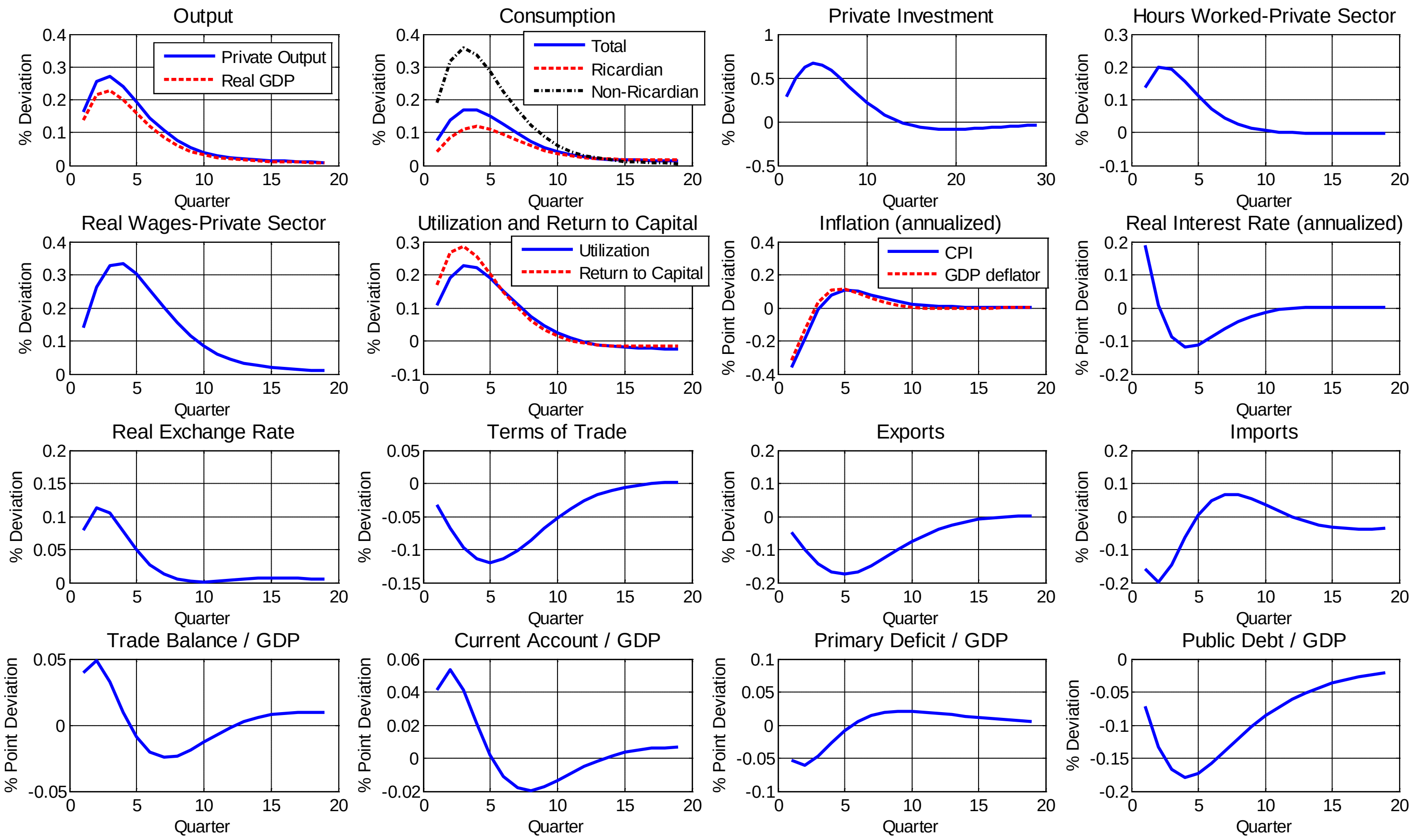
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 10: Dynamic responses to a shock in labour augmenting technology



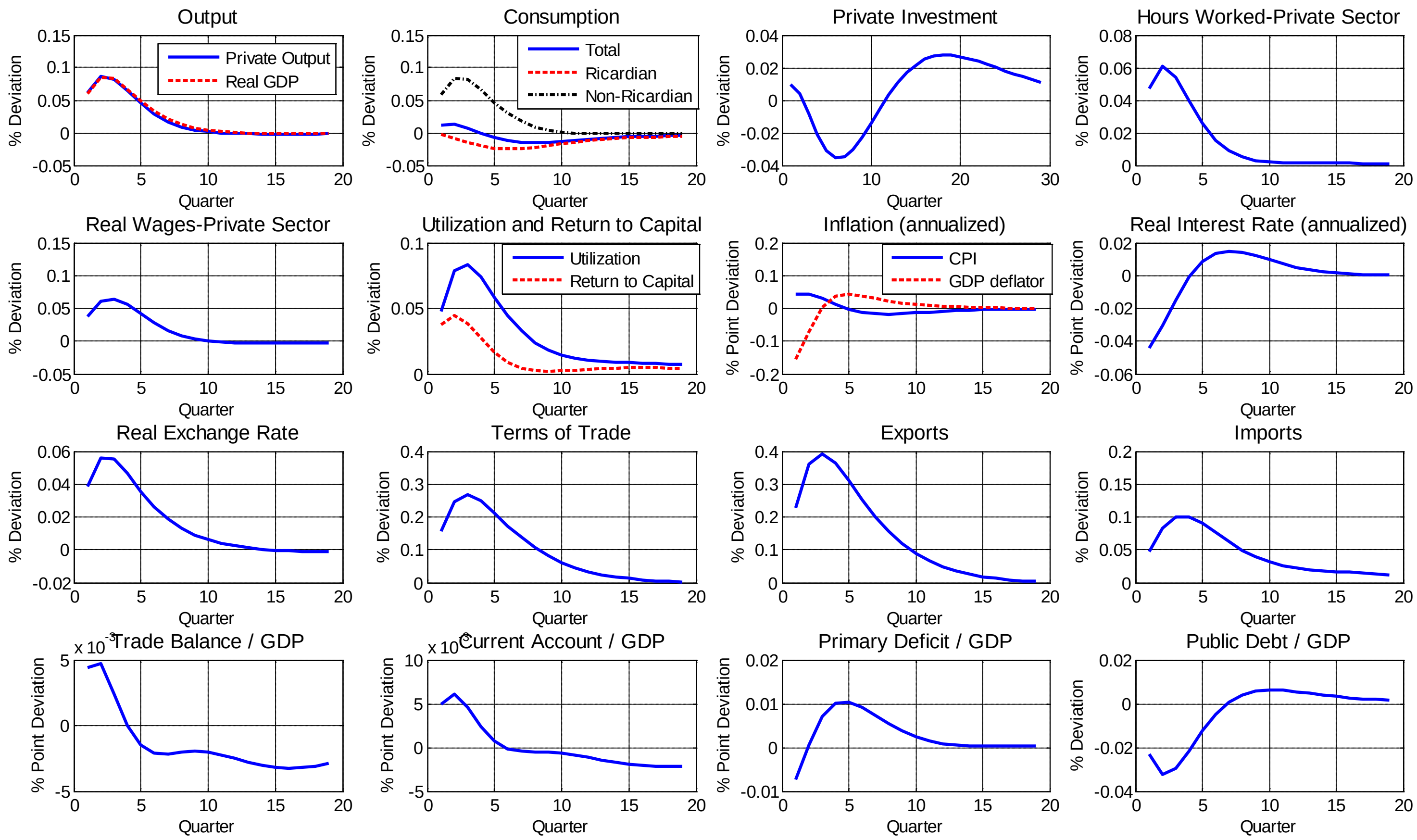
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 11: Dynamic responses to a domestic price markup shock



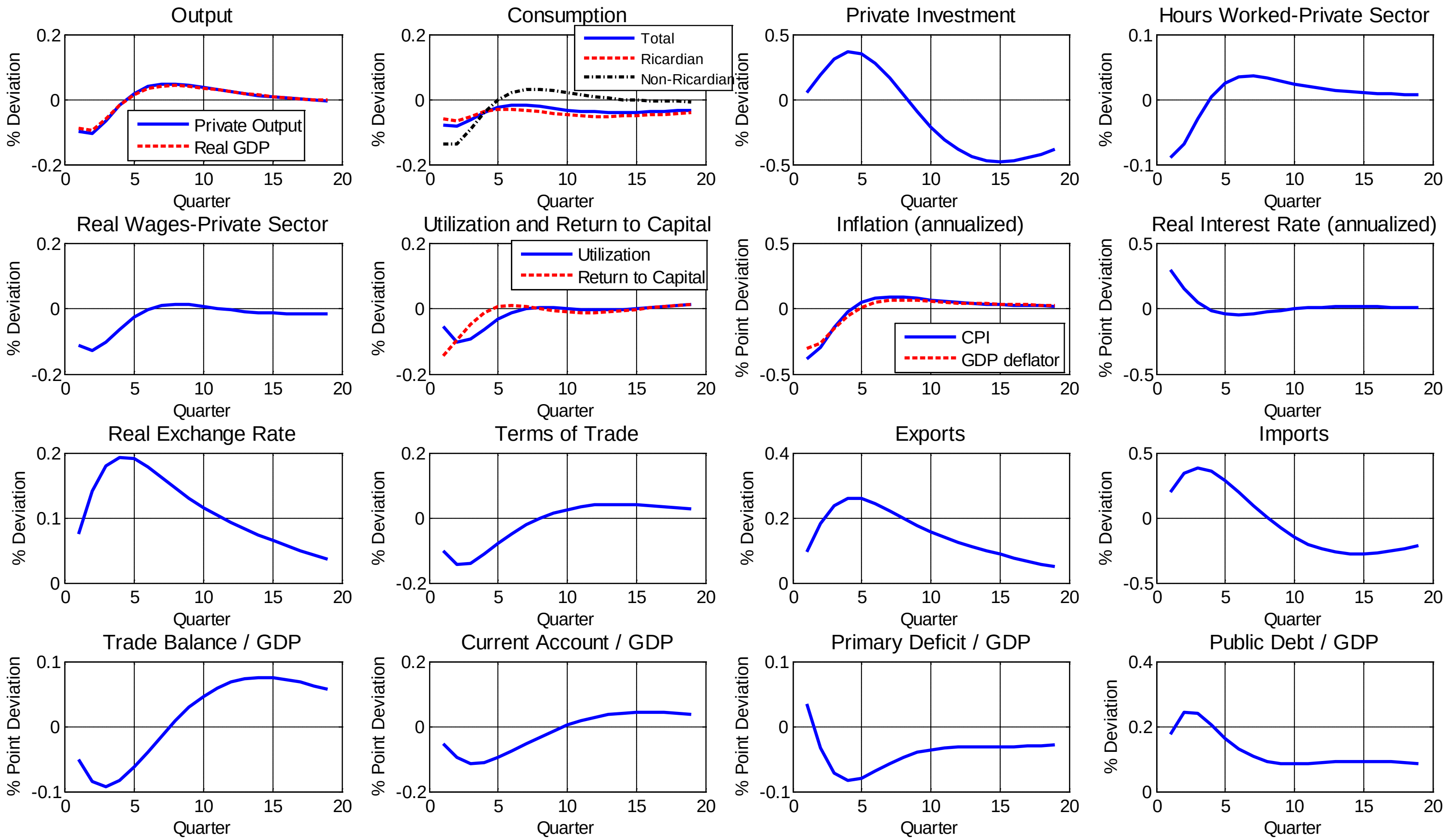
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 12: Dynamic responses to an export price markup shock



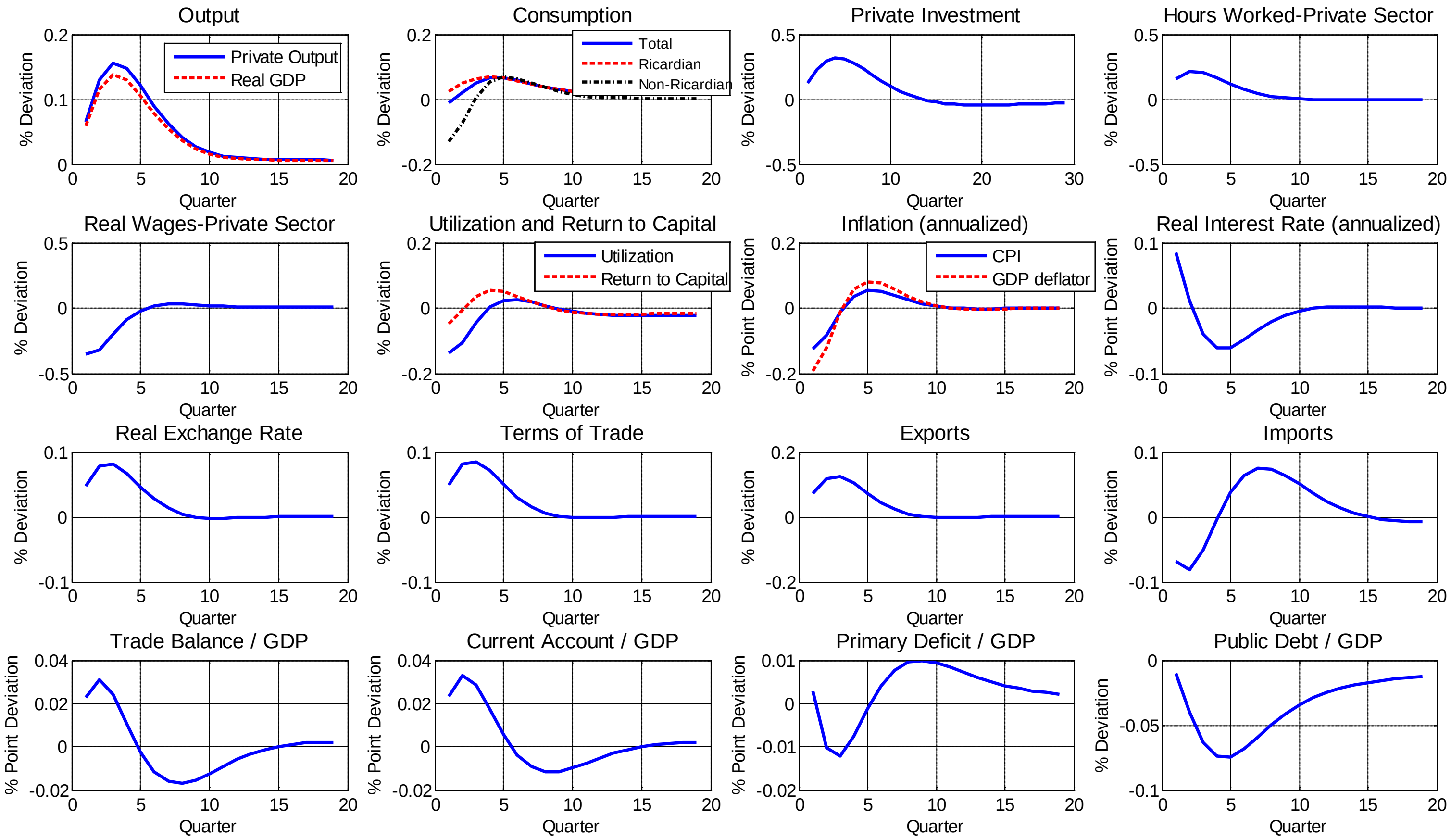
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 13: Dynamic responses to an import price markup shock



Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 14: Dynamic responses to a wage markup shock



Notes: (i) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure 15: Forecast error variance decomposition – Real GDP

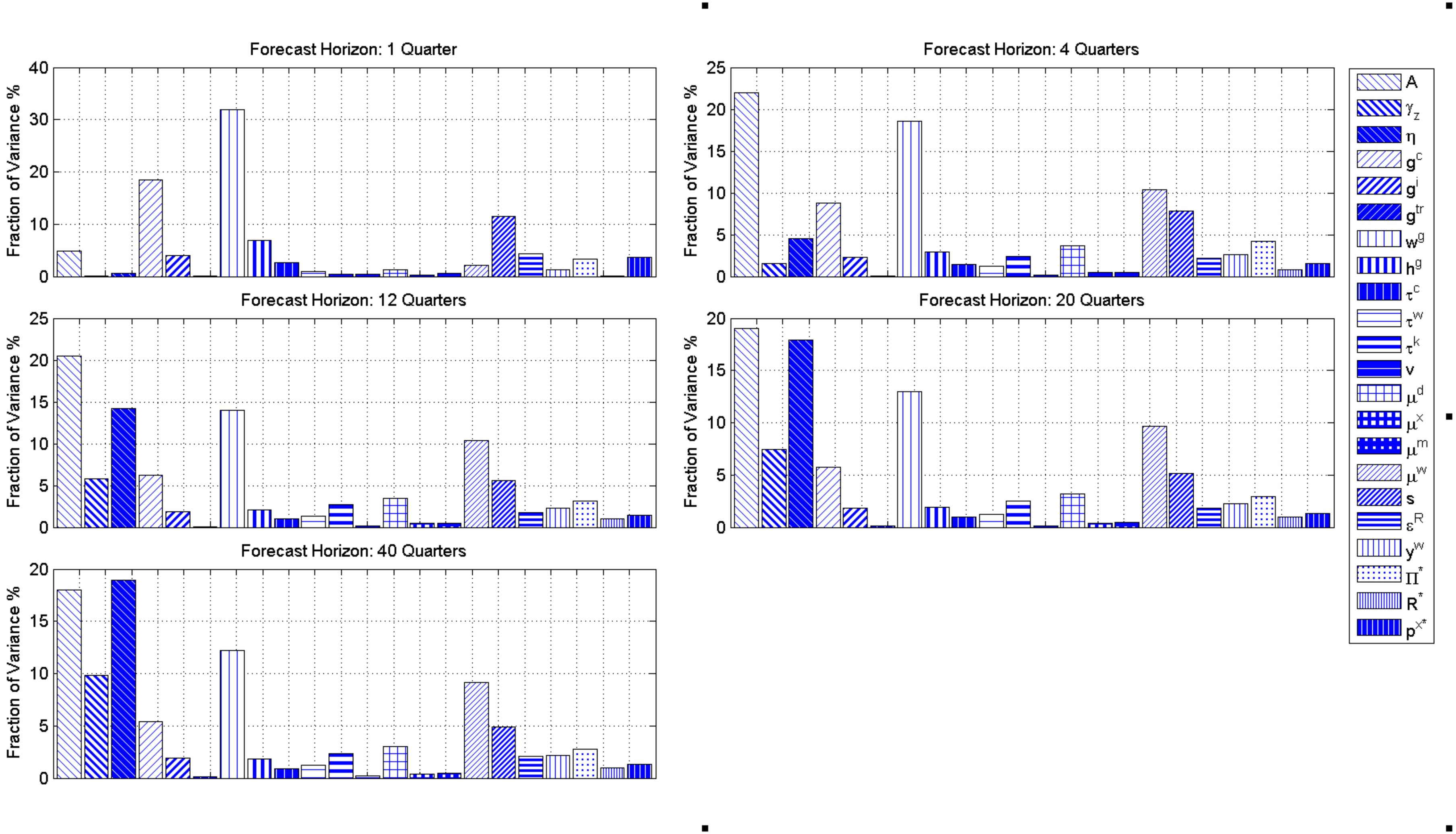


Figure 16: Forecast error variance decomposition – Private output

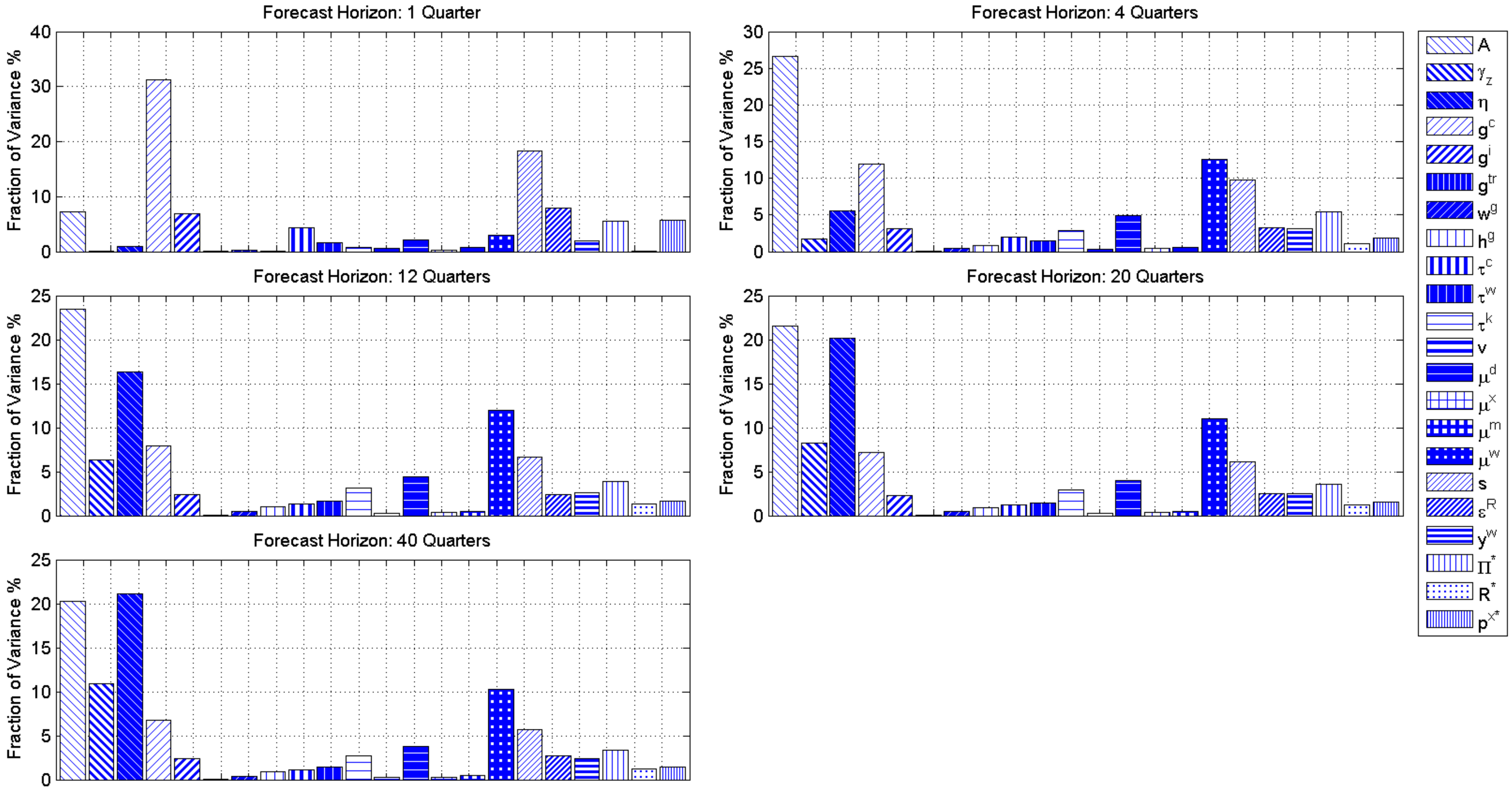


Figure 17: Forecast error variance decomposition – Hours worked in the private sector

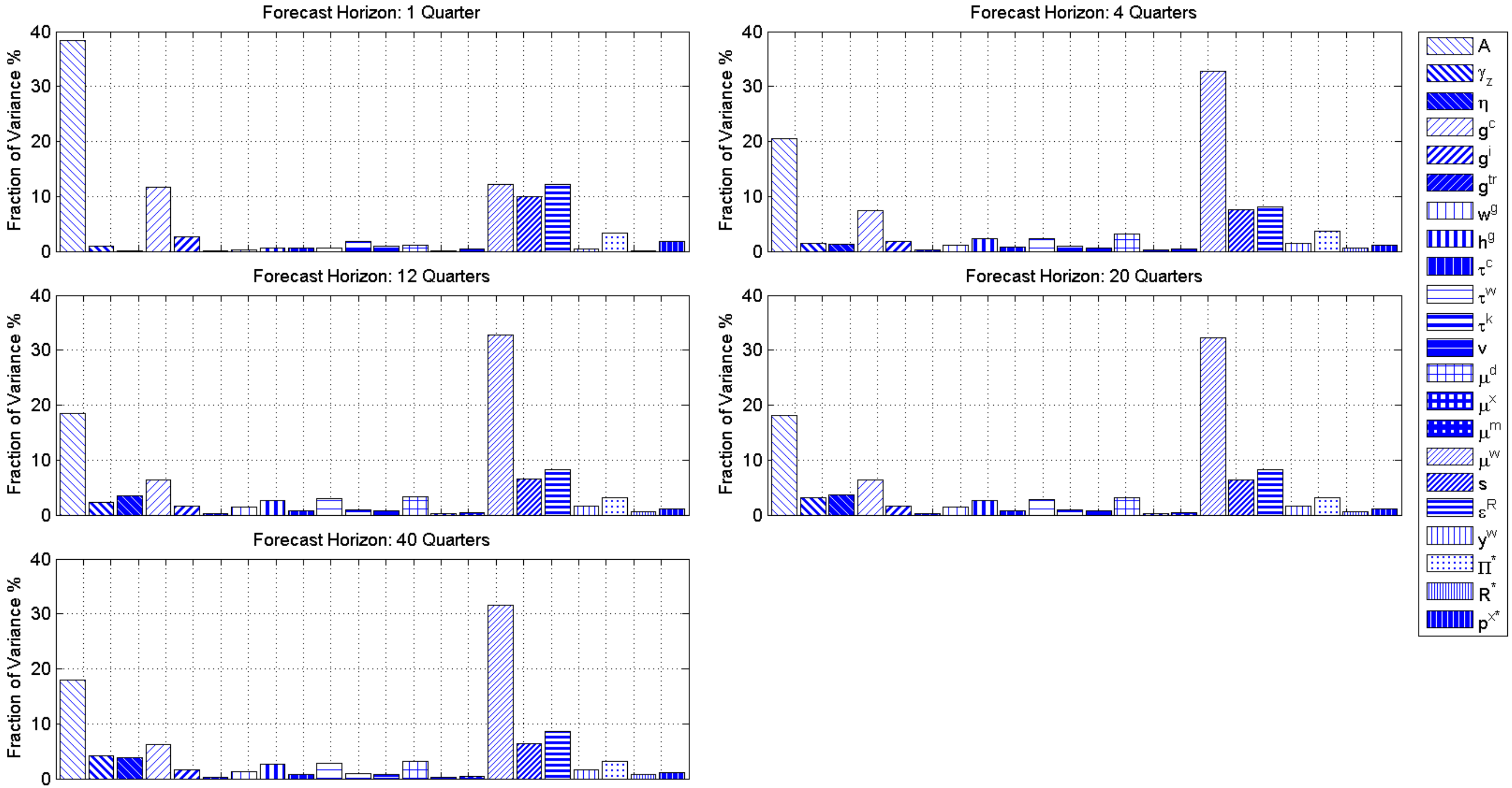


Figure 18: Forecast error variance decomposition – Real private consumption

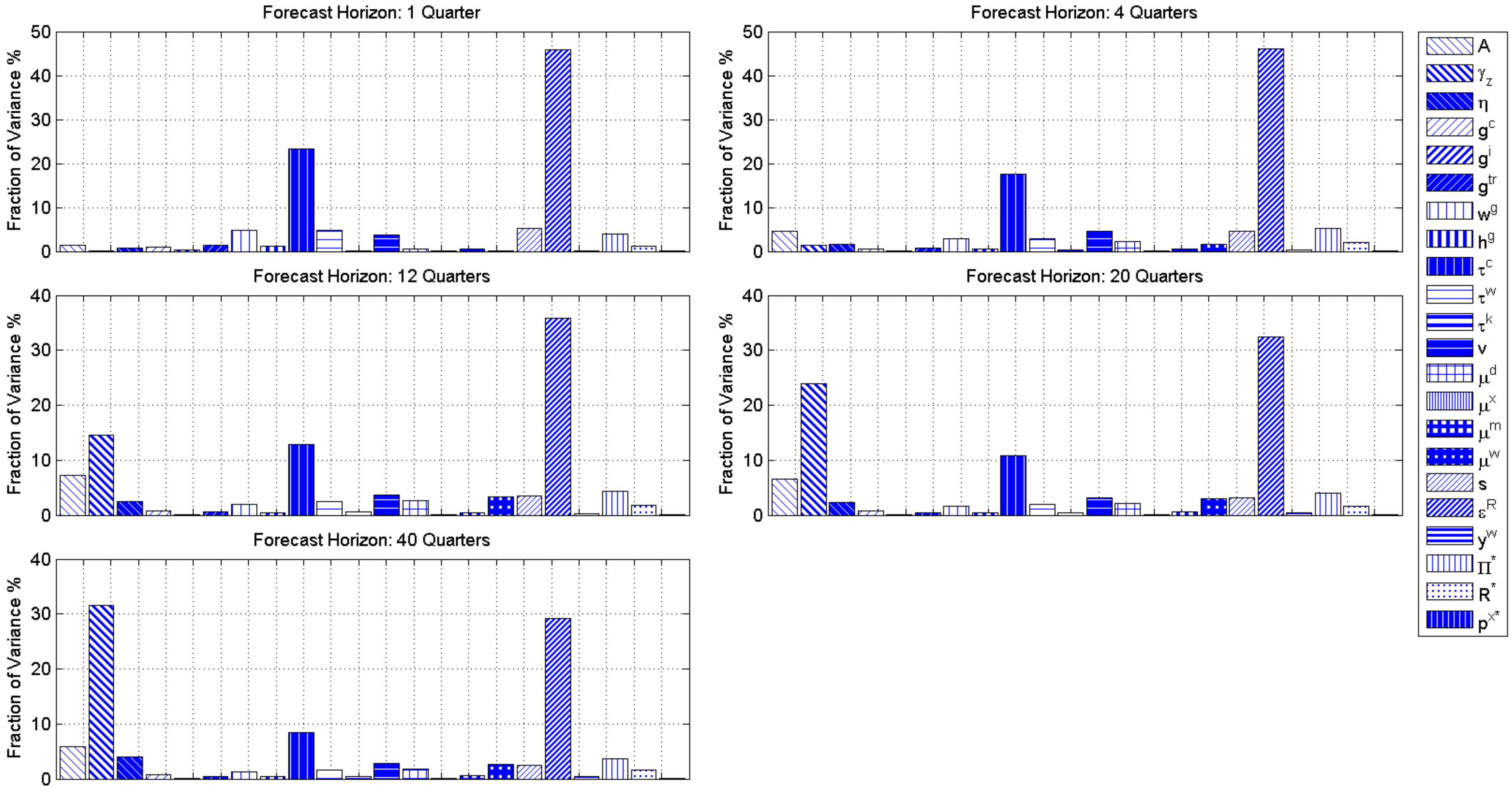


Figure 19: Forecast error variance decomposition – Real private investment

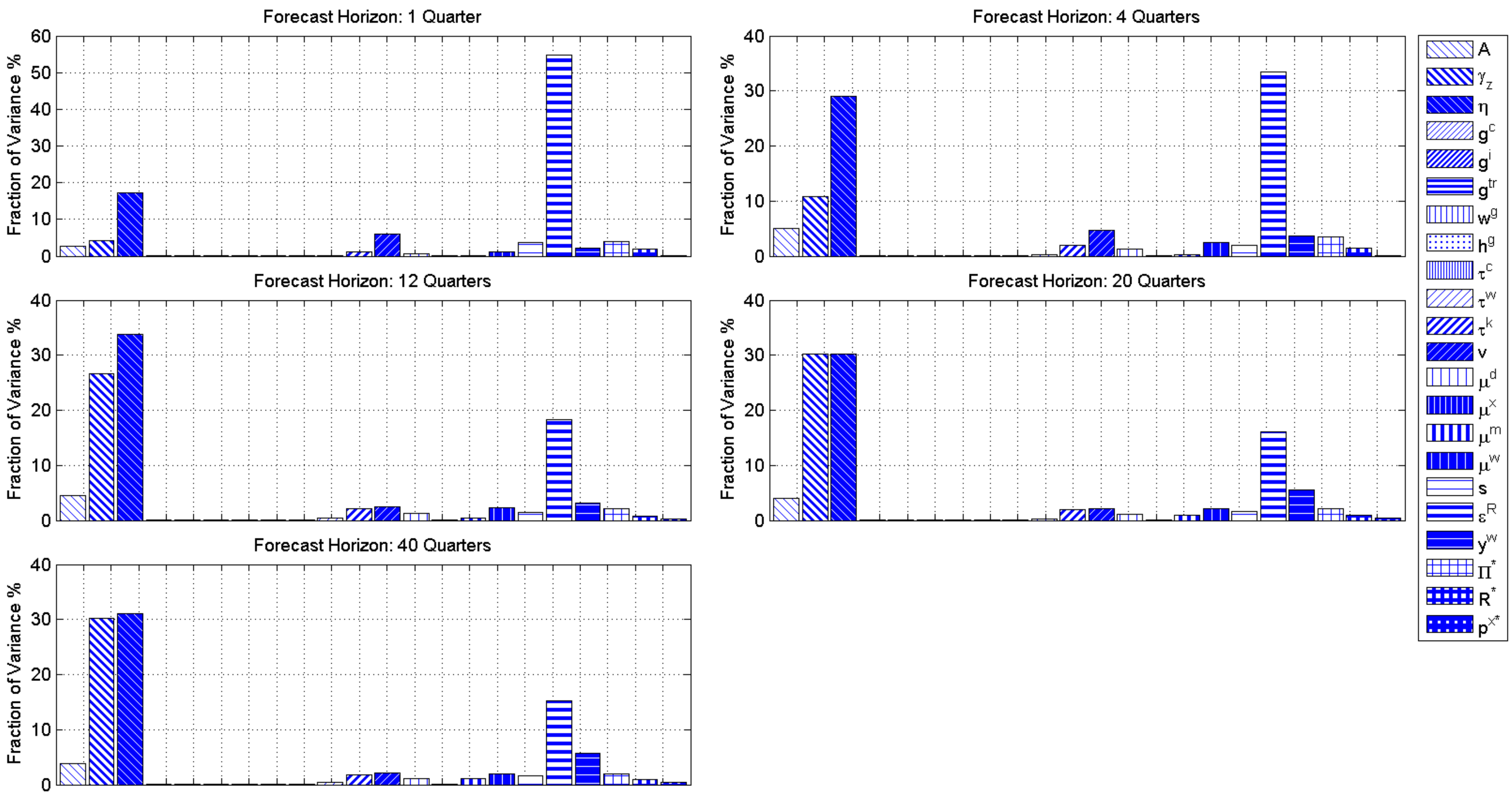


Figure 20: Forecast error variance decomposition – Real exports

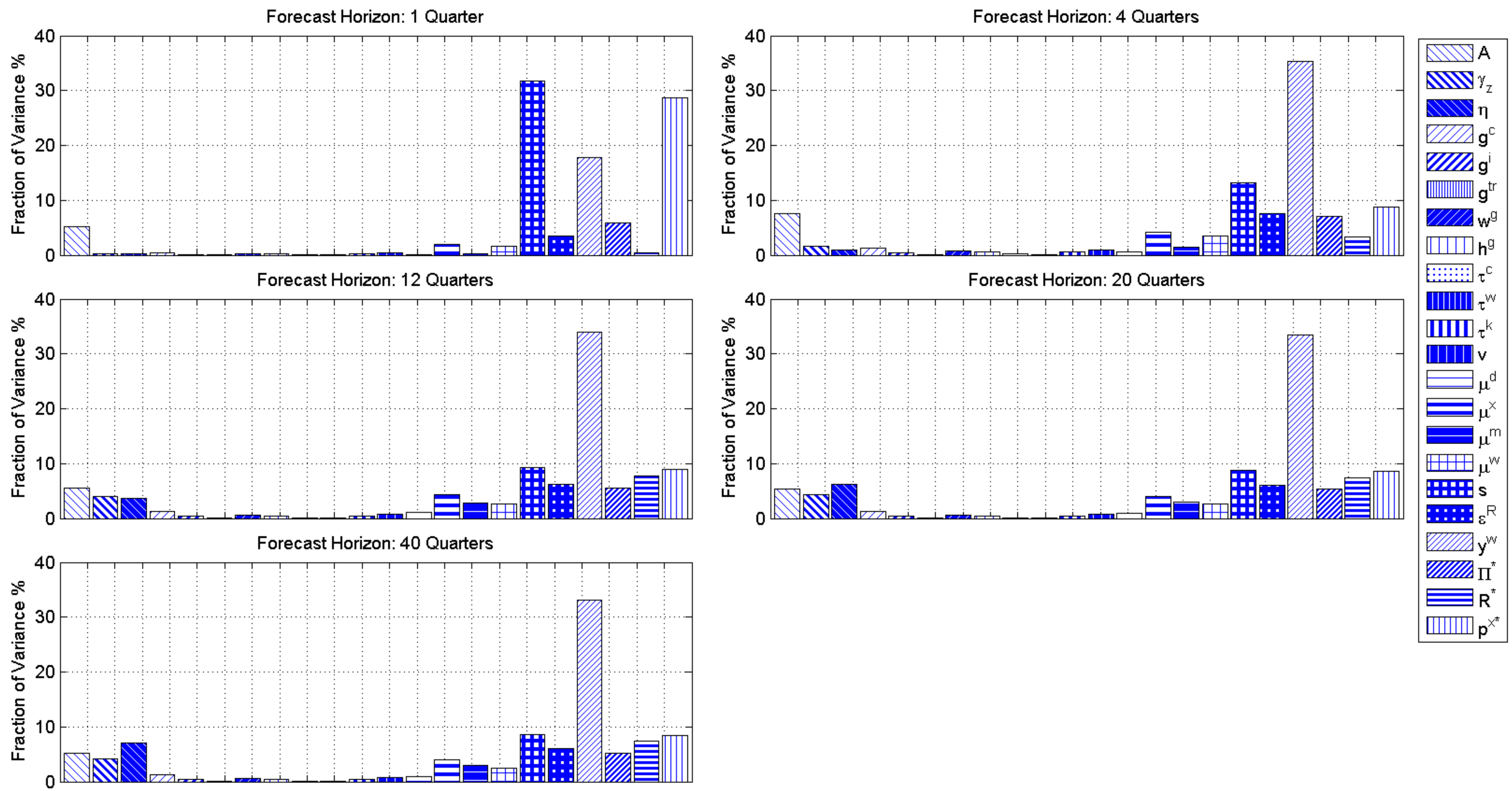
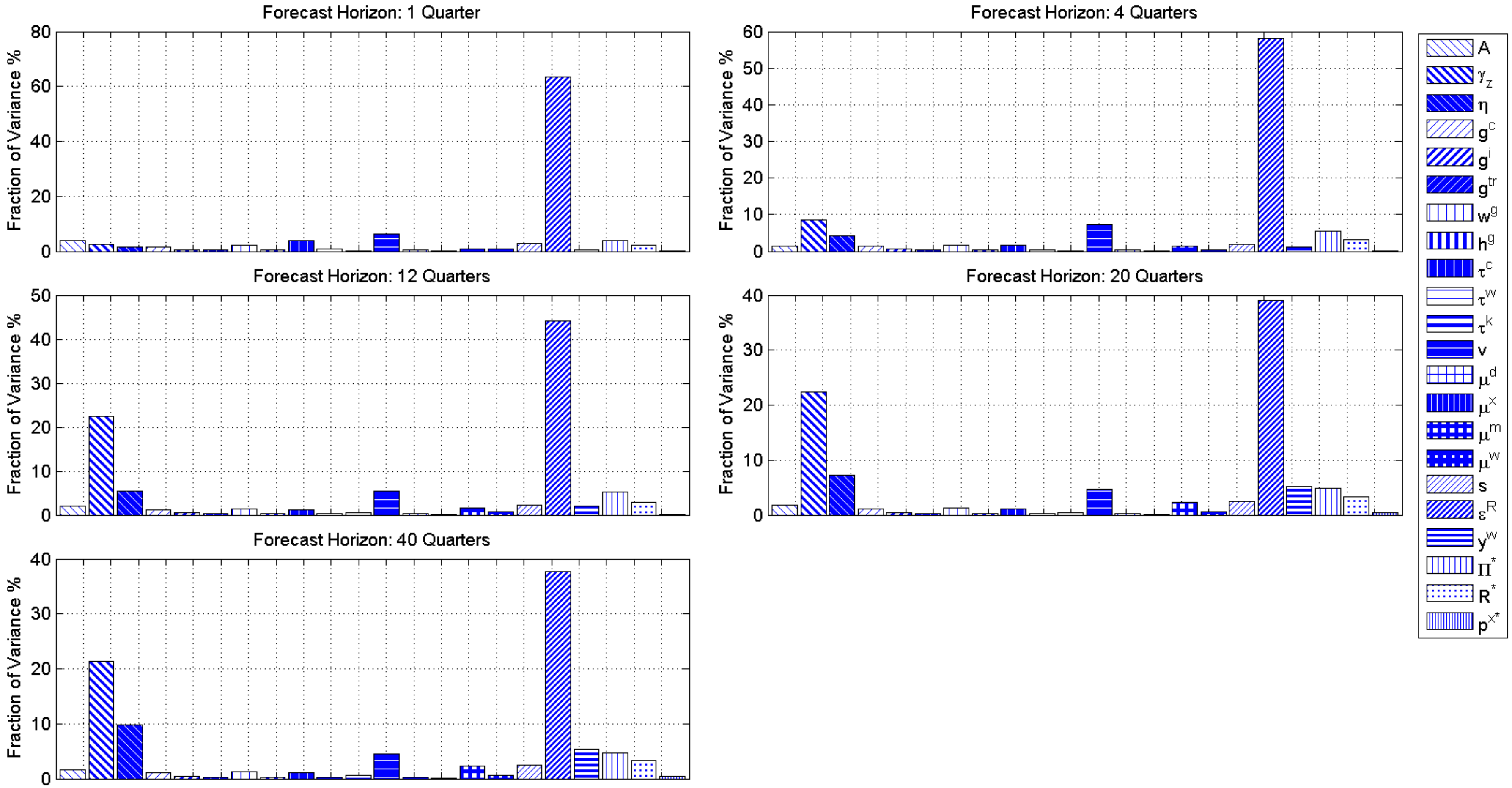


Figure 21: Forecast error variance decomposition – Real imports



Appendix A: Stationary decentralized competitive equilibrium

Note that all real variables, with the exception of hours worked, in a balance growth path grow by the factor $z_t^+ = z_t^{\frac{1-a}{1-a-a_g}}$. To solve for a stationary decentralized competitive equilibrium (DCE), we have to make all the relevant real variables stationary by scaling them with z_t^+. Thus, for any per-capita variable X_t, we define its stationary level as $x_t \equiv X_t / z_t^+$. Note that the endogenous state variables that are predetermined in period t, as e.g. the private capital stock, are scaled by z_{t-1}^+, that is, $k_t^p \equiv K_t^p / z_{t-1}^+$. Accordingly, the end of period t private capital stock, real net private foreign assets, the total real public debt, the foreign real public debt and the domestic real public debt are scaled by z_t^+, that is, $k_{t+1}^p \equiv K_{t+1}^p / z_t^+$, $f_{t+1}^p = \frac{S_t F_{t+1}^p}{z_t^+ P_t^c}$, $d_{t+1} = \frac{D_{t+1}}{z_t^+ P_t^c}$, $f_{t+1}^g = \frac{S_t F_{t+1}^g}{z_t^+ P_t^c}$ and $b_{t+1}^g = \frac{B_{t+1}^g}{z_t^+ P_t^c}$, respectively. In addition, we divide all price indices with the price index of the consumption good, P_t^c, in order to make them stationary. For instance, the relative price of domestically produced and sold goods is defined as $p_t^d = P_t^d / P_t^c$. We also scale up the marginal utilities of consumption of Ricardian and non-Ricardian households, Λ_t^R, Λ_t^{NR} with z_t^+, and we define $\lambda_t^R = z_t^+ \Lambda_t^R$ and $\lambda_t^{NR} = z_t^+ \Lambda_t^{NR}$. Note that foreign GDP is assumed to grow at the same rate as the domestic economy, z_t^+, while the price of foreign competitors in the export markets, $P_t^{x^*}$, is stationarized by dividing it with the foreign GDP deflator P_t^{y*}. The stationary DCE is summarized by the following equations:

Ricardian Households

$$\lambda_t^R = \frac{\left[c_t^R - \xi^c \gamma_{z^+,t}^{-1} c_{t-1}^R\right]^{-1}}{\left(1+\tau_t^c\right)} \tag{A1}$$

$$\lambda_t^R = \beta E_t \left[\lambda_{t+1}^R \frac{R_t}{\Pi_{t+1}^c} \gamma_{z^+,t}^{-1}\right] \tag{A2}$$

$$\lambda_t^R = \beta E_t \left[\lambda_{t+1}^R \frac{R_t^H}{\Pi_{t+1}^c} \gamma_{z^+,t}^{-1} s_{t+1}\right] \tag{A3}$$

$$\left(1-\tau_t^k\right)r_t^k = q_t\,\phi\delta^p u_t^{\phi-1} \tag{A4}$$

$$p_t^I = \eta_t^I q_t\left[1-\frac{\xi^k}{2}\left(\frac{\gamma_{z^+,t}i_t}{i_{t-1}}-\gamma_{z^+}\right)^2-\xi^k\left(\frac{\gamma_{z^+,t}i_t}{i_{t-1}}-\gamma_{z^+}\right)\frac{\gamma_{z^+,t}i_t}{i_{t-1}}\right]+ \beta E_t\left[q_{t+1}\eta_{t+1}^I\frac{\lambda_{t+1}^R}{\lambda_t^R}\xi^k\left(\frac{\gamma_{z^+,t+1}i_{t+1}}{i_t}-\gamma_{z^+}\right)\gamma_{z^+,t+1}\left(\frac{i_{t+1}}{i_t}\right)^2\right] \tag{A5}$$

$$q_t = \beta E_t\frac{\lambda_{t+1}^R}{\lambda_t^R}\gamma_{z^+,t}^{-1}\left[\left(1-\tau_{t+1}^k\right)r_{t+1}^k u_{t+1}+q_{t+1}\left(1-\delta^\rho u_{t+1}^\phi\right)\right] \tag{A6}$$

$$k_{t+1}^p = \left(1-\delta^\rho u_t^\phi\right)\gamma_{z^+,t}^{-1}k_t^p+\eta_t^I\left[1-\frac{\xi^k}{2}\left(\frac{\gamma_{z^+,t}i_t}{i_{t-1}}-\gamma_{z^+}\right)^2\right]i_t \tag{A7}$$

$$c_t^R = c_t^{p,R}+\vartheta y_t^g \tag{A8}$$

Non-Ricardian households

$$\left(1+\tau_t^c\right)c_t^{p,NR} = \left(1-\tau_t^l\right)\left(w_t^p h_t^p + w_t^g h_t^g\right)+\bar{\lambda}g_t^{tr} \tag{A9}$$

$$\lambda_t^{NR} = \frac{\left[c_t^{NR}-\xi^c\gamma_{z^+,t}^{-1}c_{t-1}^{NR}\right]^{-1}}{\left(1+\tau_t^c\right)} \tag{A10}$$

$$c_t^{NR} = c_t^{p,NR}+\vartheta y_t^g \tag{A11}$$

Aggregate private consumption

$$c_t^p = \lambda c_t^{p,NR}+\left(1-\lambda\right)c_t^{p,R} \tag{A12}$$

Optimal labour supply

$$w_t^{*p}\frac{\left(1-\tau^l\right)}{\kappa h_t^\gamma}\left[\lambda\lambda_t^{NR}+\left(1-\lambda\right)\lambda_t^R\right] = \mu_t^w \tag{A13}$$

Real wage rate in the private sector

$$w_t^p = \left(\gamma_{z^+,t}^{-1}w_{t-1}^p\right)^n\left(w_t^{*p}\right)^{1-n} \tag{A14}$$

Intermediate good firms

$$y_t = A_t\left(\frac{1}{\gamma_{z^+,t}}\right)^{a+a_g}\left(u_t k_t^p\right)^a\left(h_t^p\right)^{1-a}\left(k_t^g\right)^{a_g}-\Phi \tag{A15}$$

$$w_t^p = mc_t\left(1-a\right)\frac{y_t+\Phi}{h_t^p} \tag{A16}$$

$$r_t^k = mc_t \, a \frac{y_t + \Phi}{u_t k_t^p} \tag{A17}$$

$$g_t^{d_1} = mc_t^d \, y_t^d \, \mu_t^d \lambda_t^R p_t^d + \left(\beta \theta_p^d\right) E_t \left[\frac{\left(\Pi_t^d\right)^{x_d}}{\Pi_{t+1}^d} \right]^{-\frac{\mu_t^d}{\mu_t^d - 1}} g_{t+1}^{d_1} \tag{A18}$$

$$g_t^{d_2} = \Pi_t^{*d} y_t^d \lambda_t^R p_t^d + \left(\beta \theta_p^d\right) E_t \left[\frac{\left(\Pi_t^d\right)^{x_d}}{\Pi_{t+1}^d} \right]^{1 - \frac{\mu_t^d}{\mu_t^d - 1}} \frac{\Pi_t^{*d}}{\Pi_{t+1}^{*d}} g_{t+1}^{d_2} \tag{A19}$$

$$g_t^{d_1} = g_t^{d_2} \tag{A20}$$

$$1 = \left(1 - \theta_p^d\right)\left(\Pi_t^{*d}\right)^{\frac{1}{1-\mu_t^d}} + \theta_p^d \left[\frac{\left(\Pi_{t-1}^d\right)^{x_d}}{\Pi_t^d} \right]^{\frac{1}{1-\mu_t^d}} \tag{A21}$$

$$mc_t^d = mc_t \, / \, p_t^d \tag{A22}$$

$$g_t^{x_1} = mc_t^x \, y_t^x \, \mu_t^x \lambda_t^R p_t^x + \left(\beta \theta_p^x\right) E_t \left[\frac{\left(\Pi_t^x\right)^{x_x}}{\Pi_{t+1}^x} \right]^{-\frac{\mu_t^x}{\mu_t^x - 1}} g_{t+1}^{x_1} \tag{A23}$$

$$g_t^{x_2} = \Pi_t^{*x} y_t^x \lambda_t^R p_t^x + \left(\beta \theta_p^x\right) E_t \left[\frac{\left(\Pi_t^x\right)^{x_x}}{\Pi_{t+1}^x} \right]^{1 - \frac{\mu_t^x}{\mu_t^x - 1}} \frac{\Pi_t^{*x}}{\Pi_{t+1}^{*x}} g_{t+1}^{x_2} \tag{A24}$$

$$g_t^{x_1} = g_t^{x_2} \tag{A25}$$

$$1 = \left(1 - \theta_p^x\right)\left(\Pi_t^{*x}\right)^{\frac{1}{1-\mu_t^x}} + \theta_p^x \left[\frac{\left(\Pi_{t-1}^x\right)^{x_x}}{\Pi_t^x} \right]^{\frac{1}{1-\mu_t^x}} \tag{A26}$$

$$mc_t^x = mc_t \, / \, p_t^x \tag{A27}$$

$$g_t^{m_1} = mc_t^m \, y_t^m \, \mu_t^m \lambda_t^R p_t^m + \left(\beta \theta_p^m\right) E_t \left[\frac{\left(\Pi_t^m\right)^{x_m}}{\Pi_{t+1}^m} \right]^{-\frac{\mu_t^m}{\mu_t^m - 1}} g_{t+1}^{m_1} \tag{A28}$$

$$g_t^{m_2} = \Pi_t^{*m} y_t^m \lambda_t^R p_t^m + \left(\beta \theta_p^m\right) E_t \left[\frac{\left(\Pi_t^m\right)^{x_m}}{\Pi_{t+1}^m} \right]^{1 - \frac{\mu_t^m}{\mu_t^m - 1}} \frac{\Pi_t^{*m}}{\Pi_{t+1}^{*m}} g_{t+1}^{m_2} \tag{A29}$$

$$g_t^{m_1} = g_t^{m_2} \tag{A30}$$

$$1 = \left(1 - \theta_p^m\right)\left(\Pi_t^{*m}\right)^{\frac{1}{1-\mu_t^m}} + \theta_p^m \left[\frac{\left(\Pi_{t-1}^m\right)^{x_m}}{\Pi_t^m} \right]^{\frac{1}{1-\mu_t^m}} \tag{A31}$$

$$mc_t^m = q_t^{ex} p_t^y \, / \, p_t^m \tag{A32}$$

Domestic final good firms

$$c_t^p = \left[\omega_c^{\frac{1}{\varepsilon_c}} \left(c_t^d \right)^{\frac{\varepsilon_c - 1}{\varepsilon_c}} + (1-\omega_c)^{\frac{1}{\varepsilon_c}} \left(c_t^m \right)^{\frac{\varepsilon_c - 1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c - 1}} \tag{A33}$$

$$\frac{c_t^m}{c_t^d} = \frac{\left(1-\omega_c\right)}{\omega_c} \left(\frac{p_t^m}{p_t^d} \right)^{-\varepsilon_C} \tag{A34}$$

$$1 = \left[\omega_c \left(p_t^d \right)^{1-\varepsilon_c} + \left(1-\omega_c\right) \left(p_t^m \right)^{1-\varepsilon_c} \right]^{\frac{1}{1-\varepsilon_c}} \tag{A35}$$

$$i_t^p = \left[\omega_i^{\frac{1}{\varepsilon_i}} \left(i_t^d \right)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} + (1-\omega_i)^{\frac{1}{\varepsilon_i}} \left(i_t^m \right)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right]^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \tag{A36}$$

$$\frac{i_t^m}{i_t^d} = \frac{\left(1-\omega_i\right)}{\omega_i} \left(\frac{p_t^m}{p_t^d} \right)^{-\varepsilon_i} \tag{A37}$$

$$p_t^i = \left[\omega_i \left(p_t^d \right)^{1-\varepsilon_i} + \left(1-\omega_i\right) \left(p_t^m \right)^{1-\varepsilon_i} \right]^{\frac{1}{1-\varepsilon_i}} \tag{A38}$$

Real exports

$$y_t^x = \left(\frac{p_t^x / p_t^y}{q_t^{ex} p_t^{x^*}} \right)^{-\varepsilon_x} y_t^* \tag{A39}$$

Real imports

$$m_t = u_t^m y_t^m \tag{A40}$$

$$y_t^m = c_t^m + i_t^m \tag{A41}$$

Government

$$\begin{aligned} d_{t+1} + \tau_t^c c_t^p + \tau_t^l \left(w_t^p h_t^p + w_t^g h_t^g \right) + \tau_t^k \left(r_t^k u_t \gamma_{z^+,t}^{-1} k_t^p + div_t \right) + \tau_t \, p_t^y y_t^{GDP} = \\ = p_t^d g_t^c + p_t^d g_t^i + g_t^{tr} + w_t^g h^g + \left(R_{t-1} \frac{v_t d_t}{\Pi_t^c} \gamma_{z^+,t}^{-1} + R_{t-1}^H \frac{\left(1-v_t\right) s_t d_t}{\Pi_t^c} \gamma_{z^+,t}^{-1} \right) \end{aligned} \tag{A42}$$

$$\tau_t = \varphi^T \left(\frac{d_t}{p_{t-1}^y y_{t-1}^{GDP}} \right) \tag{A43}$$

$$y_t^g = \left(g_t^c \right)^{\chi} \left(h_t^g \right)^{1-\chi} \tag{A44}$$

$$k_{t+1}^g = \left(1-\delta^g\right) \gamma_{z^+,t}^{-1} k_t^g + g_t^i \tag{A45}$$

World capital markets

$$R_t^H = R_t^* + \psi_t + \rho_\psi \psi_{t-1} \tag{A46}$$

$$\psi_t = \psi^d\left(\exp\left(\frac{d_{t+1}}{p_t^y y_t^{GDP}} - \bar{d}\right) - 1\right) + \psi^f\left(-\exp\left(\frac{f_{t+1}^p}{p_t^y y_t^{GDP}} - \bar{f}\right) + 1\right) + \left(\exp\left(\varepsilon_t^R\right) - 1\right) \quad \text{(A47)}$$

Market clearing conditions

$$h_t = h_t^p + h_t^g \quad \text{(A48)}$$

$$k_t^f = u_t k_t^p \quad \text{(A49)}$$

$$y_t = u_t^d y_t^d + u_t^x y_t^x \quad \text{(A50)}$$

$$y_t^d = c_t^d + i_t^d + g_t^c + g_t^i \quad \text{(A51)}$$

$$div_t = div_t^f + div_t^m \quad \text{(A52)}$$

$$div_t^f = p_t^d y_t^d + p_t^x y_t^x - mc_t\left(y_t + \Phi\right) \quad \text{(A53)}$$

$$div_t^m = p_t^m y_t^m - q_t p_t^y u_t^m y_t^m \quad \text{(A54)}$$

GDP deflator

$$p_t^y y_t = p_t^d y_t^d + p_t^x y_t^x \quad \text{(A55)}$$

Definition of real GDP

$$y_t^{GDP} = y_t + \left(p_t^y\right)^{-1} w_t^g h_t^g \quad \text{(A56)}$$

Evolution of net foreign assets

$$f_{t+1}^p - \left(1 - v_t\right) d_{t+1} = R_{t-1}^H\left(\frac{s_t f_t^p}{\Pi_t^c}\gamma_{z^+,t}^{-1} - \frac{s_t\left(1 - v_t\right) d_t}{\Pi_t^c}\gamma_{z^+,t}^{-1}\right) + p_t^x y_t^x - q_t^{ex} p_t^y u_t^m y_t^m \quad \text{(A57)}$$

Trade balance-to-GDP ratio

The trade balance is defined as the value of exports minus the value of imports. We express the trade balance as a share of GDP:

$$tby_t = \frac{p_t^x y_t^x - q_t^{ex} p_t^y u_t^m y_t^m}{p_t^y y_t^{GDP}} \quad \text{(A58)}$$

Current account balance-to-GDP ratio

The current account balance is defined as the change in net total foreign assets. We express the current account as share of GDP:

$$cay_t = tby_t + \frac{\left(R_{t-1}^H - 1\right)\gamma_{z^+,t}^{-1}}{p_t^y y_t^{GDP}}\left(\frac{s_t f_t^p}{\Pi_t^c} - \frac{s_t\left(1 - v_t\right) d_t}{\Pi_t^c}\right) \quad \text{(A59)}$$

Real effective exchange rate

$$q_t^{ex} = q_{t-1}^{ex} \frac{s_t \Pi_t^{*y}}{\Pi_t^y} \tag{A60}$$

Price dispersion

$$u_t^d = \left(1-\theta_p^d\right)\left(\Pi_t^{*d}\right)^{-\frac{\mu_t^d}{\mu_t^d-1}} + \theta_p^d \left(\frac{\left(\Pi_{t-1}^d\right)^{x_d}}{\Pi_t^d}\right)^{-\frac{\mu_t^d}{\mu_t^d-1}} u_{t-1}^d \tag{A61}$$

$$u_t^x = \left(1-\theta_p^x\right)\left(\Pi_t^{*x}\right)^{-\frac{\mu_t^x}{\mu_t^x-1}} + \theta_p^x \left(\frac{\left(\Pi_{t-1}^x\right)^{x_d}}{\Pi_t^x}\right)^{-\frac{\mu_t^x}{\mu_t^x-1}} u_{t-1}^x \tag{A62}$$

$$u_t^m = \left(1-\theta_p^m\right)\left(\Pi_t^{*m}\right)^{-\frac{\mu_t^m}{\mu_t^m-1}} + \theta_p^m \left(\frac{\left(\Pi_{t-1}^m\right)^{x_m}}{\Pi_t^m}\right)^{-\frac{\mu_t^m}{\mu_t^m-1}} u_{t-1}^m \tag{A63}$$

Definition of inflation rates

$$\Pi_t^d = \frac{p_t^d}{p_{t-1}^d}\Pi_t^c \tag{A64}$$

$$\Pi_t^x = \frac{p_t^x}{p_{t-1}^x}\Pi_t^c \tag{A65}$$

$$\Pi_t^m = \frac{p_t^m}{p_{t-1}^m}\Pi_t^c \tag{A66}$$

$$\Pi_t^y = \frac{p_t^y}{p_{t-1}^y}\Pi_t^c \tag{A67}$$

$$\Pi_t^i = \frac{p_t^i}{p_{t-1}^i}\Pi_t^c \tag{A68}$$

Appendix B: Data Appendix

We use quarterly data that cover a maximum time span from 2000:1-2011:4. Our main data source is Eurostat. Other data sources are the Bank of Greece, OECD.Extacts and the European Central Bank, Statistical Data Warehouse. All macroeconomic variables that are in real terms are expressed in 2005 prices. All variables have been seasonally adjusted with the TRAMO-SEATS method. Table B provides information for the macroeconomic variables used and the data sources.

Table B: List of macroeconomic and other variables

Variable	Description	Source
V1	Nominal gross domestic product	Eurostat
V2	Real gross domestic product	Eurostat
V3	Population (15-64 years)	Eurostat
V4	GDP deflator	Eurostat
V5	GDP deflator inflation	= V4(t)/V4(t-1)
V6	CPI deflator	OECD
V7	CPI inflation	= V6(t)/V6(t-1)
V8	Gross fixed capital formation deflator	Eurostat
V9	Compensation of employees – Total economy	Eurostat
V10	Real compensation of employees – Total economy	= V10/V6
V11	Household and NPISH final consumption expenditure	Eurostat
V12	Real household and NPISH final consumption expenditure	= V11/V6
V13	Gross fixed capital formation – Total economy	Eurostat
V14	Gross fixed capital formation – Private sector	= V13-V23
V15	Real gross fixed capital formation – Private sector	= V15/V8
V16	Gross operating surplus and gross mixed income – Total economy	Eurostat
V17	Consumption of fixed capital – Total economy	Eurostat
V18	Final consumption expenditure - Government	Eurostat
V19	Compensation of employees – Government	Eurostat
V20	Real compensation of employees – Government	= V19/V6
V21	Intermediate consumption - Government	Eurostat
V22	Real intermediate consumption - Government	= V21/V4
V23	Gross fixed capital formation – Government	Eurostat
V24	Real gross fixed capital formation – Government	= V24/V4
V25	Consumption of fixed capital - Government	Eurostat
V26	Gross total public debt	Eurostat
V27	Gross foreign public debt	Bank of Greece
V28	Net foreign investment position – Total economy	Eurostat
V29	Net foreign investment position – Private sector	= V28-V27
V30	Real exports of goods and services	Eurostat
V31	Real imports of goods and services	Eurostat
V32	Trade balance	Eurostat
V33	Current account balance	Eurostat
V34	Imported intermediate goods (BEC)	Eurostat
V35	Imported consumption goods (BEC)	Eurostat. We allocate imported intermediate goods to imported consumption goods according to the relative weight of consumption goods in total imported goods
V36	Imported capital goods (BEC)	Eurostat. We allocate imported intermediate goods to imported capital goods according to the relative weight of capital goods in total imported goods
V37	Total imported goods	Eurostat
V38	Employment – Total economy	Eurostat

Table B: continued

V39	Employment – Public administration and defense, compulsory social security contribution	Eurostat
V40	Employment – Education	Eurostat
V41	Employment – Health and social work	Eurostat
V42	Employment – Public sector	= V39+V40+V41
V43	Employment – Private sector	= V38-V42
V44	Average actual weekly hours worked – Total employment	Eurostat
V45	Total actual weekly hours worked – Total employment	= V38*V44
V46	Average actual weekly hours worked – Public administration and defense, compulsory social security contribution	Eurostat
V47	Average actual weekly hours worked – Education	Eurostat
V48	Average actual weekly hours worked – Health and social work	Eurostat
V49	Total actual weekly hours worked – Public sector	= V46+V47+V48
V50	Total actual weekly hours worked – Private sector	= V45-V49
V51	Producer price index in industry – Domestic market	Eurostat
V52	Import price index in industry	Eurostat
V53	Real GDP – EU28 countries	Eurostat
V54	Household and NPISH final consumption expenditure deflator	Eurostat
V55	Measure of investment specific technology	= V54/V8
V56	Price index of exports	Eurostat
V57	Price index of exports - EU28 countries	Eurostat
V58	Consumption of fixed capital – Private sector	= V17-V25
V59	Current level of capacity utilization	European Commission, BSC database
V60	Compensation of employees in the private sector	= V9-V19
V61	Real Compensation in the private sector	= V60/V6
V62	Real compensation rate in the private sector	= V61/V43
V63	Real compensation rate in the public sector	= V20/V42
V64	Gross wages and salaries	Eurostat
V65	Current taxes on income and wealth of households	Eurostat
V66	Gross operating surplus and mixed income – household sector	Eurostat
V67	Consumption of fixed income – household sector	Eurostat
V68	Property income received– household sector	Eurostat
V69	Property income paid– household sector	Eurostat
V70	Employees	Eurostat
V71	Self-employed	Eurostat
V72	Actual social security contributions	Eurostat
V73	Gross wages and salaries	Eurostat
V74	Capital taxes	Eurostat
V75	Taxes on income of non-financial corporations	Eurostat
V76	Taxes on income of financial corporations	Eurostat
V77	Other taxes in production	Eurostat
V78	Taxes on production and imports	Eurostat

Table B: continued

V79	Government intermediate consumption	Eurostat
V80	Real government intermediate consumption	= V79/V4
V81	Social benefits other than social transfers in kind	Eurostat
V82	Social transfers in kind	Eurostat
V83	Subsidies, payable	Eurostat
V84	Other subsidies	Eurostat
V85	Government transfers	= V81+V82+V83+V84
V86	Real government transfers	= V85/V6
V87	Interest rate on ten-year government bonds - Greece	Eurostat
V88	Interest rate on ten-year government bonds – Euro area-17 countries	Eurostat
V89	GDP deflator – EU28 countries	Eurostat
V90	Nominal effective exchange rate -37 partners	Eurostat
V91	Imputed wage of the self-employed	= (V73/V70)*V71
V92	Gross external public debt	= V26-V27

B.1. Construction of capital stock series

We construct series for the private capital stock and calibrate the average quarterly depreciation rate in the private sector, δ^p, and the elasticity of marginal depreciation costs, ϕ, following a modified version of the methodology proposed in Conesa et al. (2007) and Gogos et al. (2014). The main difference is that we allow the depreciation rate to vary with capacity utilization. Series for the private capital stock are constructed by using data on real gross fixed capital formation in the private sector, consumption of fixed capital in the private sector, the current level of capacity utilization, and the law of motion for private capital:

$$K_{t+1}^{p} = \left(1-\delta^{p}u_{t}^{\phi}\right)K_{t}^{p} + I_{t}^{p} \tag{B1}$$

In order to construct the private capital stock series we need an initial value for the capital stock, a value for the average depreciation rate, δ^p, and the elasticity of marginal depreciation costs, ϕ. The value of the depreciation rate is chosen to match the average consumption of fixed capital in the private sector-to-GDP ratio observed over the data period used for calibration. This ratio over the period 2000:1-2011:4 is equal to 0.118. Thus,

$$\frac{1}{48}\sum_{t=2000}^{2011}\frac{\delta^{p}u_{t,j}^{\phi}K_{t,j}^{p}}{Y_{t,j}} = 0.1108 \qquad j = 1,2,3,4 \tag{B2}$$

We choose the initial private capital stock so that the capital-to-GDP ratio in 2000:1 matches its average value over the period 2000:1-2011:4:

$$\frac{K^p_{2001,1}}{Y_{2001,1}} = \frac{1}{48}\sum_{t=2000}^{2011}\frac{K^p_{t,j}}{Y_{t,j}} \qquad j = 1,2,3,4 \tag{B3}$$

Finally, we choose the value of the elasticity of marginal depreciation costs, ϕ, to satisfy the following condition:

$$\phi = \frac{\gamma_{z^+} - \beta\left(1-\delta^p\right)}{\beta\delta^p} \tag{B4}$$

B4 is obtained by combining the steady-state versions of Equations (A4) and (A6). We set the values for γ_{z^+} and β equal to their calibrated values in Table 1. Thus, there are 50 unknowns: δ^p, ϕ, $K^p_{2000,1}, K^p_{2000,2}, ..., K^p_{2011,4}$, in 50 equations: B1 (47 equations), B2, B3 and B4. Solving this system of equations, we obtain the sequence of private capital stocks, a calibrated value for the quarterly average depreciation rate, $\delta^p = 0.0172$ (0.0688 annually), and a calibrated value for $\phi = 1.625$.

The method for the construction of the public capital stock series is similar as above. In particular, we use available data for government consumption of fixed capital, real gross government fixed capital formation and the law of motion of public capital stock. The equivalent equations to (B.1) - (B.3) are:

$$K^g_{t+1} = \left(1-\delta^g\right)K^g_t + G^i_t \tag{B5}$$

$$\frac{1}{48}\sum_{t=2000}^{2011}\frac{\delta^g K^g_{t,j}}{Y_{t,j}} = 0.0204 \qquad j = 1,2,3,4 \tag{B6}$$

$$\frac{K^g_{2001,1}}{Y_{2001,1}} = \frac{1}{48}\sum_{t=2000}^{2011}\frac{K^g_{t,j}}{Y_{t,j}}, \qquad j = 1,2,3,4 \tag{B7}$$

In this case, there are 49 unknowns: δ^g, $K^g_{2000,1}, K^g_{2000,2}, ..., K^g_{2011,4}$, in 49 equations: B5 (47 equations), B6 and B7. The solution of this system gives a quarterly depreciation rate for public capital stock equal to $\delta^g = 0.0107$ (0.0428 annually).

B.2 Computation of the effective tax rates

Our methodology in constructing quarterly effective tax rates on labour income, capital income and consumption is based on the work of Mendoza et al. (1994). Broadly speaking, the effective tax rates are estimated from information provided by the National Accounts as the ratios between the tax revenues from particular taxes and the corresponding tax bases. We follow e.g. Papageorgiou (2012) in treating the income of the self-employed as a combination of labour and capital income.

Personal income tax rate

The personal income tax rate that applies both to labour and capital income of households is:

$$\tau^h = \frac{TYH}{\left(WSS - SSC\right) + \left(GOSH - CFCH\right) + \left(PIR - PIP\right)} \tag{B8}$$

where TYH denotes current taxes on income and wealth of households, WSS denotes compensation of employees, SSC denotes total actual social security contributions, $GOSH$ denotes the gross operating surplus and mixed income of households, $CFCH$ is the consumption of fixed income of households and PIR, PIP denote respectively the property income received and paid by the households.

Effective tax rate on labour income

The effective tax rate on labour income is computed as:

$$\tau^l = \frac{\tau^h\left(W + WSE\right) + SSC}{WSS + WSE} \tag{B9}$$

where W denotes gross wages and salaries of employees, $WSE = \left(W / EE\right) \times SE$ is the imputed wage of the self-employed, EE is the number of employees and SE is the number of the self-employed persons. Note that WSS and W differ in that the former includes the social security contributions paid by the employers.

Effective tax rate on capital income

The effective tax rate on capital income is computed as:

$$\tau^k = \frac{\tau^h\left[\left(GOSH - CFCH\right) + \left(PIR - PIP\right) - WSE\right] + CTAX + TYC + TYF + OTP}{GOS - CFC - WSE} \quad \text{(B10)}$$

where $CTAX$ denotes capital taxes, TYC denotes taxes on income of non-financial corporations, TYF denotes taxes on the income of financial corporations, OTP denotes other taxes in production (for Greece this category mainly includes taxes on capital income), GOS denotes the gross operating surplus and mixed income of the total economy and CFC denotes the consumption of fixed capital of the total economy.

Effective tax rate on consumption

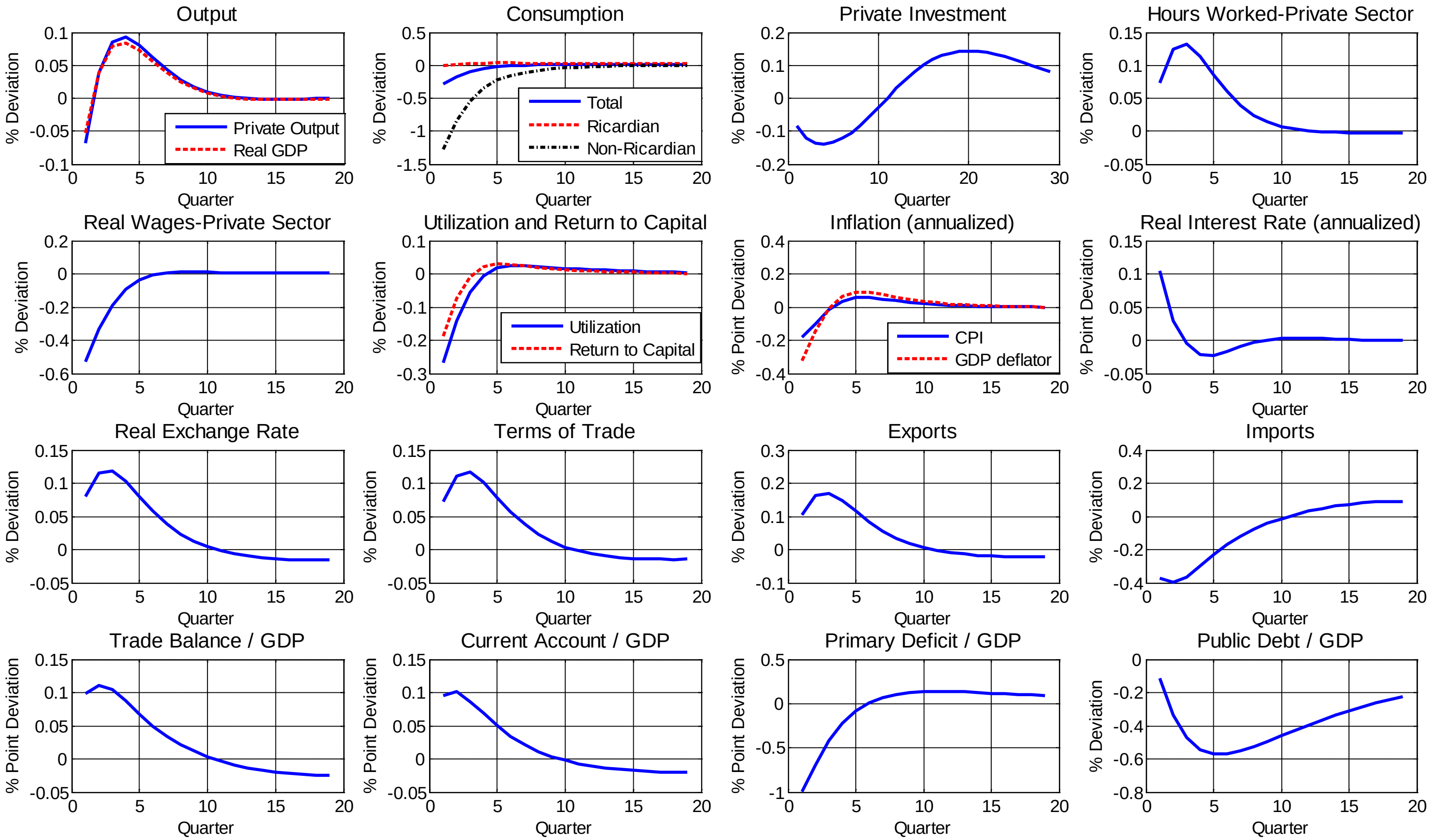
The effective tax rate on consumption is computed as:

$$\tau^c = \frac{TPI - OTP}{HC + GIC - \left(TPI - OTP\right)} \quad \text{(B11)}$$

where TPI denotes taxes on production and imports, HC denotes household and NPISH final consumption expenditures and GIC denotes government intermediate consumption expenditures.

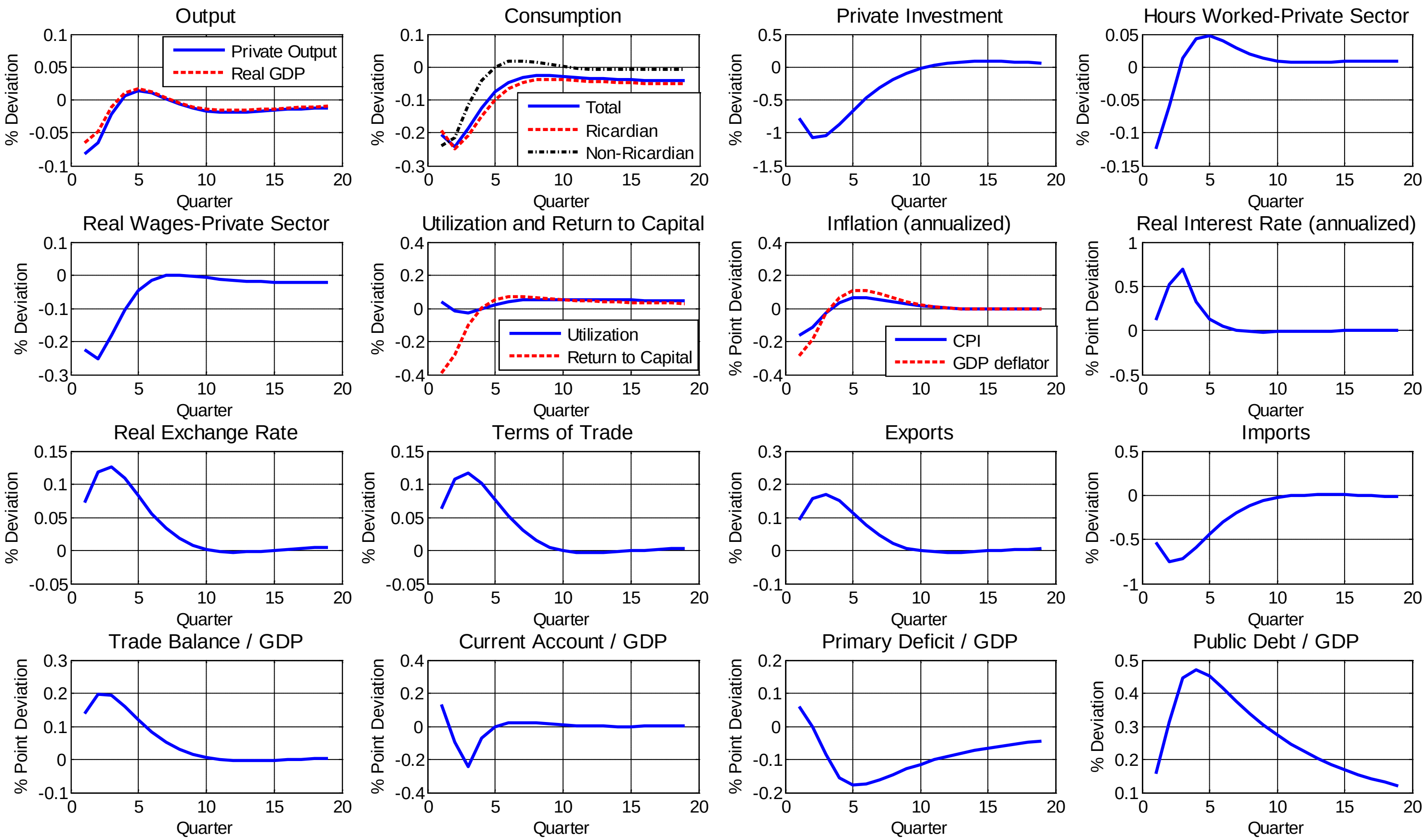
Appendix C: Additional impulse responses

Figure C.1: Dynamic responses to a shock in government transfers



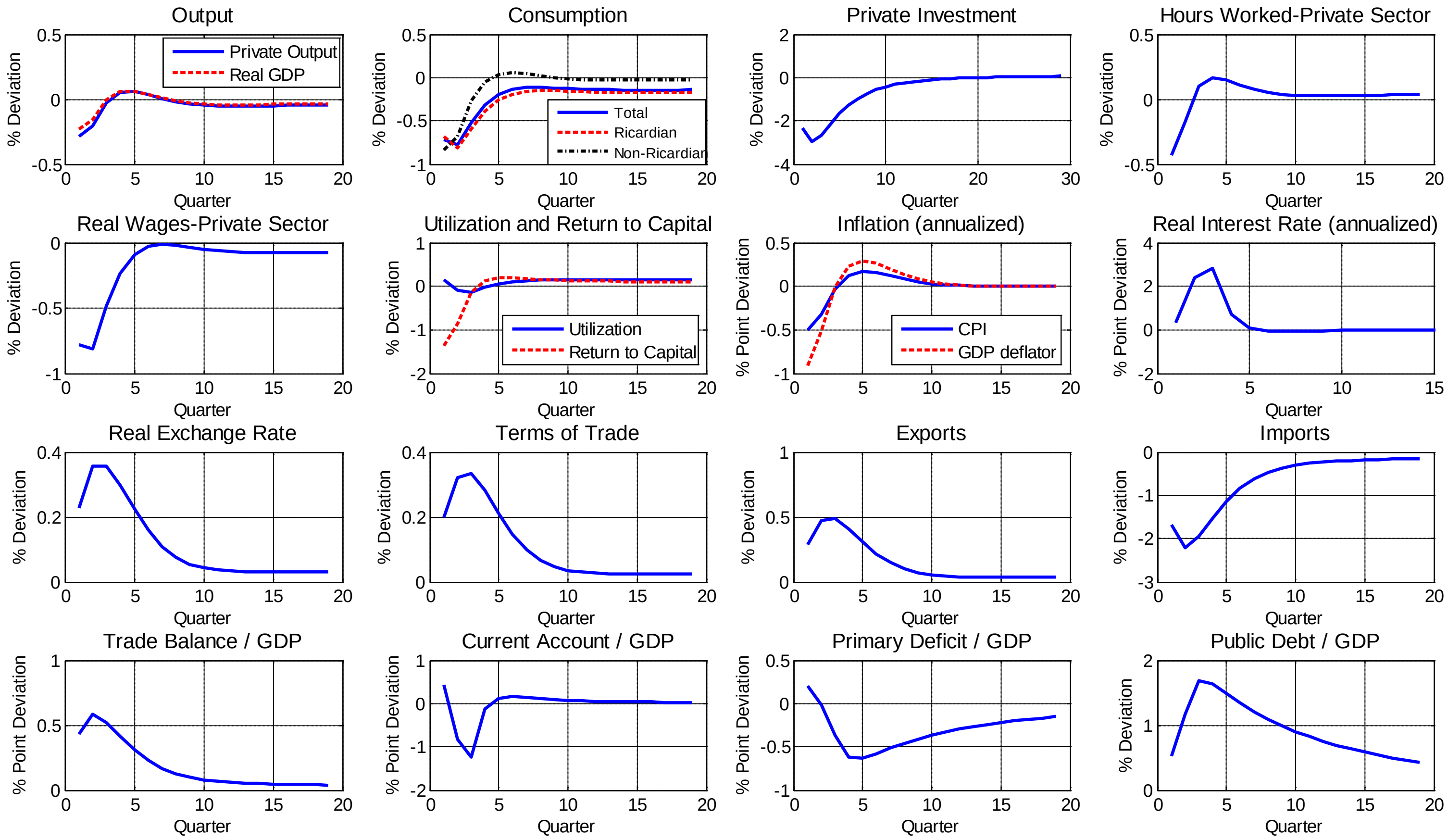
Notes: (i) Government transfers decrease by 1% of initial steady-state GDP, (ii) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure C.2: Dynamic responses to a shock in the share of domestically held public debt



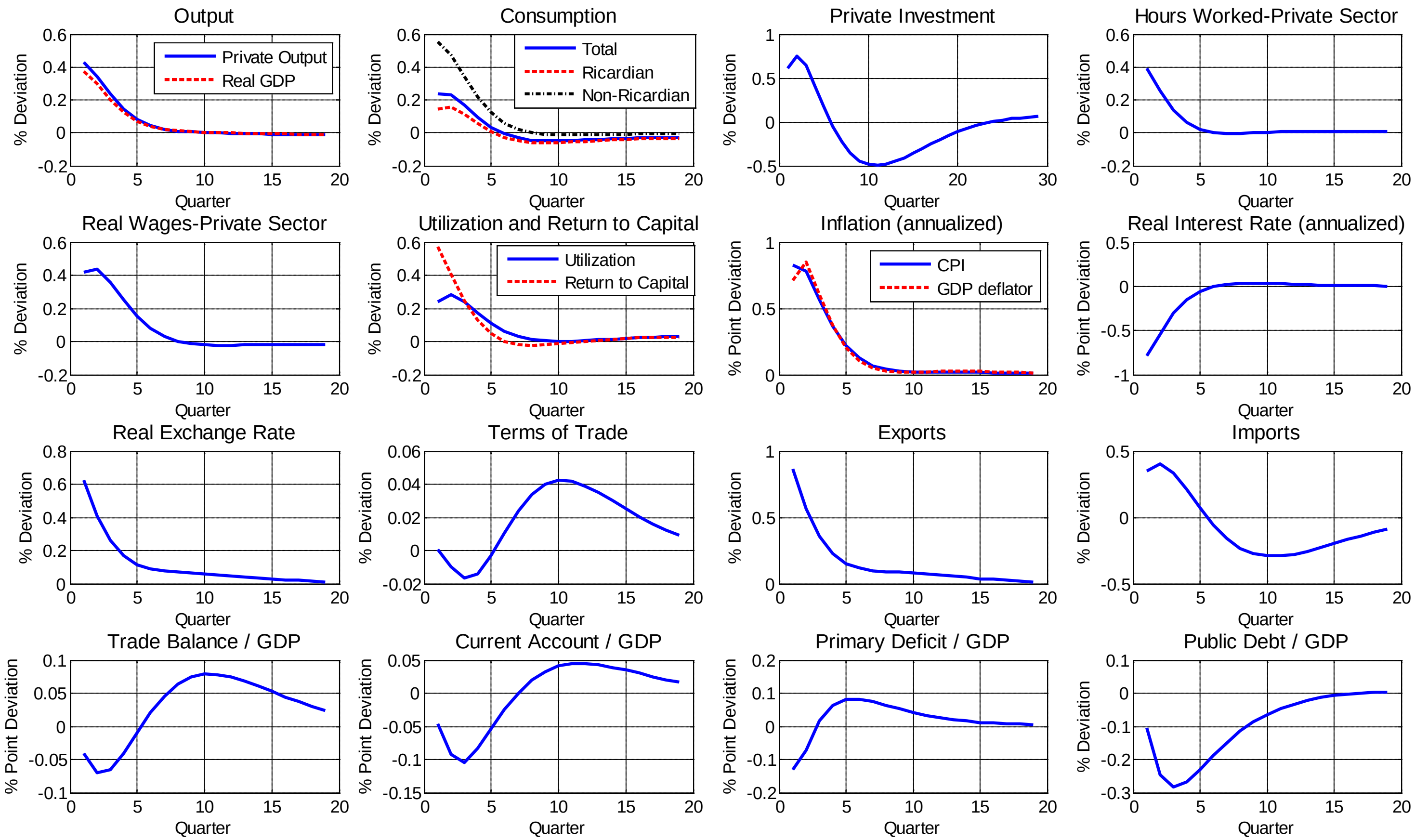
Notes: (i) Increase in the share of domestically held public debt by one standard deviation, (ii) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure C.3: Dynamic responses of a risk-premium shock



Notes: (i) Increase in the risk-premium by one standard deviation, (ii) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

Figure C.4: Dynamic responses of a shock in the growth rate of the nominal exchange rate



Notes: (i) Increase in the growth rate of the nominal exchange rate by one standard deviation, (ii) The series plotted are percentage deviations from the steady-state, except for the trade balance as share of GDP, the current account balance as share of GDP and the primary deficit as share of GDP, which are percentage point changes. The real interest rate and the inflations rates are in annualized percentage point deviations. (ii) a positive change in the trade balance-to-GDP ratio and the current account balance-to-GDP ratio means an improvement in these variables.

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