CENTER OF PLANNING AND ECONOMIC RESEARCH

DISCUSSION PAPERS

No. 128

A Dynamic Stochastic General Equilibrium Model for a Small Open Economy: Greece

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February 2013

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Athens 2/2013

A Dynamic Stochastic General Equilibrium Model for a Small Open Economy: Greece

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Abstract

This paper provides an introduction to the dynamic properties of a dynamic stochastic general equilibrium (DSGE) model for a small open economy developed for quantitative policy analysis. The model is calibrated to the Greek economy. Our approach in examining the model's dynamic properties involves using impulse response functions to a number of domestic and external shocks and analyzing the main transmission mechanisms through which the shocks influence the macroeconomy. The results suggest that reductions in public spending are associated with improvements in fiscal and external imbalances. In terms of output losses, the most desirable way to reduce fiscal and external imbalances is through cuts in public sector wages, government transfers and public sector employment. In contrast, the most harmful option for reducing fiscal and external imbalances seems to be an increase in labour income taxes.

JEL classification: E32, E62, F41, O52

Acknowledgments: We have benefited from discussions with Apostolis Philippopoulos, Elias Tzavalis and Vanghelis Vassilatos. We are grateful to Panagiotis Korliras for his support and hospitality. Any errors are ours. Any views expressed herein are those of the authors and not necessarily those of the Centre of Planning and Economic Research.

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Contents

1. Introduction

The objective of this paper is to provide an introduction to the dynamic properties and implications of a dynamic stochastic general equilibrium (DSGE) model for the Greek economy developed at the Centre of Planning and Economic Research as a quantitative tool for policy analysis.

In light of the recent sovereign debt crisis and the ongoing strong fiscal consolidation effort in Greece, the need for quantitative answers to questions related to the effectiveness of different policy instruments and the extra benefits-costs 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 employing a DSGE model of the Greek economy for quantitative policy analysis. DSGE models integrate both growth and fluctuations and are established as the laboratory in which modern macroeconomic theory and policy are conducted (for reviews, see e.g. Cooley and Prescott (1995), King and Rebelo (1999), Rebelo (2005), McGrattan (2006), and Kydland (2006)). Important work from Smets and and Wouters (2003, 2007) showed that DSGE models can also provide a suitable and credible tool for forecasting.

The model we employ is built in the tradition of Real Business Cycle models with real rigidities and market imperfections and aims at describing the main features of the Greek economy. The baseline version of the DSGE model shares main characteristics of the models used by most central banks and international institutions, but also includes some features that are important for the study of the Geek economy. We would like to highlight the following features of the model:

First, it 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 fiscal

[1] DSGE models for Greece include Kollintzas and Vassilatos (2000), Angelopoulos et al. (2009), Papageorgiou (2009), Papageorgiou et al. (2011) and Papageorgiou (2012). Differences from these papers are made clear below. By contrast, there is a large literature on the effects of policy reforms in other countries (see e.g. Christiano and Eichenbaum (1992), Baxter and King (1993), McGrattan (1994), Braun (1994), Chari et al. (1994), Jonsson and Klein (1996), Malley et al. (2007, 2009), Forni et al. (2009, 2010) and many others). Recent papers by e.g. Ratto et al. (2009), Cogan et al. (2010) and Uhlig (2009) use DSGE models to quantify fiscal policy multipliers and evaluate the stimulus plans used to counter the 2008-2009 crisis.

measures that have been implemented recently in Greece, such as cuts in public sector wages and increases in income taxes. Second, the model incorporates a small open economy structure by allowing households and the government to participate in international financial markets. The open economy framework makes the model suitable for analyzing the impact of fiscal and foreign demand shocks on key macroeconomic variables related to the external sector, such as the current account balance and the real exchange rate. This is of particular importance for the Greek economy, where external imbalances have risen steadily during the last two decades (see e.g. Kollintzas et al. (2012) for a discussion). Third, the model features financial market imperfections in the form of financially constraint households and risk premium on public debt. The presence of liquidity constraint households has been found to be an important determinant for the impact of fiscal policy shocks, particularly in periods of tight financial conditions (see e.g. Coenen et al. (2012, 2013)). In addition, the introduction of risk premia on both domestic and foreign public debt is motivated by the fact that the reaction of sovereign yields to a fiscal consolidation effort has recently identified as a key driving force for the impact on the dynamics of public debt and output (see e.g. European Commission (2012)). Fourthly, the model includes a number of real frictions, such as habit formation in consumption, investment adjustment costs and variable capital utilization, that have been empirically and theoretically identified as playing an important role for the transmission of fiscal shocks (see e.g. Burnside et al. (2004), Cristiano et al. (2005) and Mertens and Ravn (2011)). Finally, the model features a number of market imperfections that have been found to characterize the Greek economy, such as real wage rigidities in the labour market and imperfect competition in the product market.[2] Hence, the model is well suited for examining the macroeconomic effects of structural reforms.

We calibrate the model to the Greek economy at a quarterly frequency over the 2000q1-2011q4 period. Our approach in examining the dynamic properties of the model involves using impulse response functions to a number of domestic and external shocks and analyzing the main transmission mechanisms through which the shocks influence the macroeconomy. In particular, we consider the effects from shocks in government purchases in goods and services, government investment, public sector wages, public sector employment, government transfers, total factor productivity and foreign demand.

The results of our analysis suggest that reductions in public spending are associated with improvements in fiscal and external imbalances. For instance, a decrease in government

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[2] See e.g. European Commission (2010) and Lapatinas (2009) for a discussion regarding market imperfections in Greece.

purchases on goods and services by one percent of GDP leads to an improvement in the trade and current account balance ratios by about 0.13 and 0.11 percentage points, respectively. In terms of output losses, the most desirable way to reduce fiscal and external imbalances is through cuts in public sector wages, government transfers and public sector employment. In contrast, the most harmful option for reducing fiscal and external imbalances seems to be an increase in labour income taxes.

The rest of this paper is as follows: Section 2 presents the model. Section 3 discusses calibration and the long run solution. Section 4 presents impulse response analysis for a number of exogenous shocks and Section 5 concludes.

2. The theoretical model

The economy is populated by 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 invest in the form of physical capital, government bonds and foreign assets. The second type of households is assumed to be liquidity constrained as in Gali et al. (2007); these households are not able to lend or borrow and they just consume their disposable income in each period. Regarding the labour market, real private wages respond only sluggishly to current conditions in the labour market as in Blanchard and Gali (2007) and Malley et al. (2009). Public sector wages are set exogenously by the government.

Concerning the production side of the economy, there are two sectors of production; the intermediate goods sector and the final goods sector. The intermediate goods sector is composed by a large number of monopolistically competitive firms that produce differentiated goods using as inputs private capital, private labour, public capital and intermediate inputs imported from abroad. The final goods sector consists of two types of final goods producers. The first type packs domestic and imported final goods to produce a final non-tradable consumption good, while the second type produces a final domestic good that can be used for investment and consumption by aggregating intermediate domestic goods.

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 (public consumption, public investment, government wages, public employment and government transfers). The government hires labour and combines public consumption and public employment to produce public goods (such as justice, hospitals, education, etc) that provide direct utility to households.

The interest rate at which the country borrows from the world capital market, increases with government's total debt. This is consistent with empirical evidence (see e.g. European Commission (2012)) as well as with previous theoretical modelling (see e.g. Christiano et al., 2011)). The real exchange rate (the price of foreign goods in terms of domestic goods) is determined endogenously in this economy. By this, we implicitly assume that the economy has some degree of monopoly power for its own good in foreign markets. Foreign demand for domestically produced goods is determined by the exogenous foreign income level and the real exchange rate.

2.1. Households

The economy is populated by a continuum of households indexed by $h \in [0,1]$, of which a fraction $i \in \left[0,1-\lambda\right]$ are optimizing (or Ricardian) households and a fraction $j \in (1-\lambda,1]$ are liquidity constraint (or rule-of-thump) households. Optimizing households have access to the bond and capital markets and can invest in the form of physical capital, government bonds and internationally traded bonds. Liquidity constraints households are not able to lend or borrow and they just consume their after-tax disposable income in each period.

2.1.1. Optimizing Households

Each optimizing household i has preferences over consumption and leisure that are represented by the intertemporal utility function:

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

where E_0 is the expectations operator conditional on time t information, $\beta^* \in \left(0,1\right)$ is the discount factor, $\xi^c \in [0,1)$ is a parameter that measures the degree of external habit formation in consumption, C_t^i is the consumption of optimizing households at t, which is a composite of domestically produced and imported consumption goods (explained below), L_t^i is leisure time at

t, $\overline{C}_{t-1}^{i}$ is average (per household i) lagged-once consumption (taking as given by each household) and Y_t^g is per capita public goods and services produced by the government that influence private utility (see also Forni et al. (2010) and Economides et al. (2011, 2012) for a similar formulation).

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

$$u\left(C_t^i - \xi^c \overline{C}_{t-1}^i, L_t^i, Y_t^g\right) = \frac{\left[(C_t^i - \xi^c \overline{C}_{t-1}^i)^{\gamma_1} (L_t^i)^{\gamma_2} \left(Y_t^g\right)^{1-\gamma_1-\gamma_2}\right]^{1-\sigma} - 1}{1-\sigma} \quad (2)$$

where $0 < \gamma_1, \gamma_2, \left(1-\gamma_1-\gamma_2\right) < 1$ are the weights given to consumption, leisure and public goods, respectively, and $\sigma \geq 0$ is a measure of risk aversion.

Each household i is endowed with one unit of time in each period and can either work in the private or the public sector. Thus, the time constraint in each period is:

$$L_t^i = 1 - H_t^i = 1 - H_t^{i,p} - H_t^{i,g} \quad (3)$$

where H_t^i are total hours worked and $H_t^{i,p}$ and $H_t^{i,g}$ are the hours of work supplied to the private and public sector, respectively.

The household can save in the form of physical capital, I_t^i, domestic government bonds, B_t^i, and foreign bonds, F_t^i. It receives labour income from working in the private sector, $w_t^p Z_t H_t^{i,p}$, and the public sector, $w_t^g Z_t H_t^{i,g}$, where w_t^p is the real wage rate per efficient unit of labour hours in the private sector, $Z_t H_t^{i,p}$, and w_t^g is the real wage rate per efficient unit of labour hours in the public sector, $Z_t H_t^{i,g}$. The variable Z_t is labour augmenting technology that grows according to $Z_{t+1} = \gamma_z Z_t$ where $\gamma_z \geq 1$ and $Z_0 > 0$ is given. The households also receive capital income, $r_t^k u_t^i K_t^{i,p}$, where r_t^k is the return to the effective amount of private capital services, $u_t^i K_t^{i,p}$, $K_t^{i,p}$ is the physical private capital stock and $u_t > 0$ is the intensity of use of capital. The households also receive interest income from domestic government and internationally traded bonds that pay a gross interest R_t^b and R_t at time $t+1$, respectively. Two additional sources of income are the firm’s profits that are distributed in the form of dividends,

Π_t^i, and average (per household i) lump-sum government transfers, $\bar{G}_t^{i,tr}$. The household pays taxes on consumption, $0 \le \tau_t^c < 1$, on income from labour, $0 \le \tau_t^l < 1$, and capital earnings and dividends, $0 \le \tau_t^k < 1$. Thus, the budget constraint of each household i is:

$$\begin{aligned}&\left(1+\tau_t^c\right) P_t^c C_t^i + I_t^i + B_{t+1}^i + Q_t F_{t+1}^i = \\ &\qquad = \left(1-\tau_t^l\right)\left(w_t^p Z_t H_t^{i,p} + w_t^g Z_t H_t^{i,g}\right) + \left(1-\tau_t^k\right)\left(r_t^k u_t^i K_t^{i,p} + \Pi_t^i\right) + R_{t-1}^b B_t^i + R_{t-1} Q_t F_t^i + \bar{G}_t^{i,tr}\end{aligned} \tag{4}$$

where Q_t is the real exchange rate, defined as the price of the foreign final good in units of the domestic final good, and P_t^c is the price of the composite consumption final good (i.e. the consumers price index) expressed in units of the final domestic good.

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

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

where S is an adjustment cost function of the form proposed by Christiano et al. (2005) that satisfies $S\left(\gamma_z\right) = S'\left(\gamma_z\right) = 0, S''\left(\cdot\right) > 0$. We adopt the following specification for S:

$$S\left(\frac{I_t^i}{I_{t-1}^i}\right) = \frac{\xi^k}{2}\left(\frac{I_t^i}{I_{t-1}^i} - \gamma_z\right) \tag{5a}$$

where $\xi^k \ge 0$ is a parameter. We assume that the depreciation rate of private capital, $\delta^p\left(u_t\right)$, is an increasing and convex function of the rate of capacity utilization. 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:

$$\delta^p\left(u_t\right) = \delta^p u_t^{\phi} \tag{5b}$$

where $\delta^{p} \in (0,1), \phi > 0$ are respectively the average rate of depreciation of private capital and the elasticity of marginal depreciation costs.

Taking prices $\left\{r_t^k, R_t^b, R_t, Q_t, P_t^c, w_t^p\right\}_{t=0}^{\infty}$ and fiscal policy $\left\{\tau_t^c, \tau_t^l, \tau_t^k, w_t^g, H_t^{i,g}, \overline{G}_t^{i,tr},\right\}_{t=0}^{\infty}$ as given, each household i chooses a sequence $\left\{C_t^i, L_t^i, H_t^{i,p}, I_t^i, u_t^i, K_{t+1}^{i,p}, B_{t+1}^i, F_{t+1}^i\right\}_{t=0}^{\infty}$ in order to maximize (1)-(2) subject to the constraints (3)-(5), the initial conditions for $K_0^{i,p}, B_0^i, F_0^i$ plus the non-negatively constraints for $C_t^i, H_t^{i,p}, L_t^i, K_{t+1}^{i,p}, B_{t+1}^i, F_{t+1}^i$. The first-order conditions for an interior solution include the constraints and the following conditions:

$$\frac{\partial u_t(.)}{\partial C_t^i} = \lambda_t P_t^c \left(1+\tau_t^c\right) \tag{6a}$$

$$w_t^p = \frac{\left(\partial u_t(.)/\partial L_t^i\right)}{\left(\partial u_t(.)/\partial C_t^i\right)} \frac{P_t^c\left(1+\tau_t^c\right)}{\left(1-\tau_t^l\right)Z_t} \equiv MRS_t \tag{6b}$$

$$\left(1-\tau_t^k\right) r_t^k = q_t \delta^{p\prime}(u_t) \tag{6c}$$

$$\lambda_t = \beta^* E_t \lambda_{t+1} R_t^b \tag{6d}$$

$$\lambda_t Q_t = \beta^* E_t \lambda_{t+1} R_t Q_{t+1} \tag{6e}$$

$$1 = q_t \left(1 - S\left[\frac{I_t^i}{I_{t-1}^i}\right] - S'\left[\frac{I_t^i}{I_{t-1}^i}\right]\frac{I_t^i}{I_{t-1}^i}\right) + \beta^* E_t q_{t+1} \frac{\lambda_{t+1}}{\lambda_t} S'\left[\frac{I_{t+1}^i}{I_t^i}\right]\left(\frac{I_{t+1}^i}{I_t^i}\right)^2 \tag{6f}$$

$$q_t = \beta^* E_t \frac{\lambda_{t+1}}{\lambda_t}\left[\left(1-\tau_{t+1}^k\right) r_{t+1}^k u_{t+1}^i + q_{t+1}\left(1-\delta^p\left(u_{t+1}\right)\right)\right] \tag{6g}$$

where λ_t is the Langrange multiplier associated with the household's budget constraint, and $q_t = \frac{\mu_t}{\lambda_t}$ the Tobin's Q, where μ_t is the Langrange multiplier associated with the private capital accumulation equation. The optimality conditions are completed with the transversality conditions for the three assets, $\lim_{t\to\infty} \beta^{*t} \frac{\partial u_t(.)}{\partial C_t^i} K_{t+1}^{i,p} = 0$, $\lim_{t\to\infty} \beta^{*t} \frac{\partial u_t(.)}{\partial C_t^i} B_{t+1}^i = 0$ and $\lim_{t\to\infty} \beta^{*t} \frac{\partial u_t(.)}{\partial C_t^i} F_{t+1}^i = 0$.

Condition (6a) states that the Lagrange multiplier equals the marginal utility of consumption adjusted by the term $P_t^c\left(1+\tau_t^c\right)$. Equation (6b) is the intratemporal condition for the hours worked and states that the marginal rate of substitution between leisure and consumption at the same period should equal to the after-tax wage. Condition (6c) states that the marginal benefit of raising utilization must equal the associated marginal cost. Conditions (6d), (6e) and (6f) are the standard Euler equations for B_{t+1}^i, F_{t+1}^i, and I_t^i, respectively. Finally, condition (6g) states that the relative price of capital is equal to the expected return of capital. Note that by combining conditions (6d) and (6e) we get the uncovered interest parity condition (UIP) in real terms:

$$R_t^b = R_t E_t\left(\frac{Q_{t+1}}{Q_t}\right) \tag{6h}$$

2.1.2. Liquidity constraint households

Liquidity constraint households have the same preferences as optimizing households that are represented by equation (2). They receive labour income from working in the private and public sector, but they have no access to the capital and 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:

$$\left(1+\tau_t^c\right)P_t^c C_t^j = \left(1-\tau_t^l\right)\left(w_t^p Z_t H_t^{j,p} + w_t^g Z_t H_t^{j,g}\right) + \bar{G}_t^{j,tr} \tag{7}$$

where $H_t^{j,p}$ and $H_t^{j,g}$ are respectively hours worked in the private and public sector and $\bar{G}_t^{j,tr}$ are average (per household j) lump-sum government transfers. Following the usual approach in the literature (see e.g. Erceg et al. (2005)), it is assumed that liquidity constraint households supply the same amount of private labour as intertemporal optimizing households. Consequently, the private wage rate across the two types of households will be the same. Similarly, we assume that hours worked in the public sector are the same both for liquidity constraint and optimizing households. Thus, $H_t^{j,p} = H_t^{i,p}$ and $H_t^{j,g} = H_t^{i,g}$.

2.2. Firms

There are two sectors of production in this economy: (i) The intermediate goods sector, which consists of a continuum of monopolistically competitive intermediate goods firms indexed by $f \in [0,1]$, each of which produces a single differentiated domestic intermediate good, Y_t^f, and (ii) The final-goods sector that consists of two types of perfectly competitive firms; a final domestic good producer that aggregates all domestic intermediate goods to produce the final domestic good, Y_t^d, and a final consumption good producer that combines purchases of the final domestic good, C_t^d, with the final imported good, C_t^m, to produce a final non-tradable private consumption good, C_t^c.

2.2.1. Final good producer

There is a representative perfectly competitive final good producer that produces the final domestic good by aggregating intermediate domestic goods, Y_t^f, with the following constant returns to scale production function:

$$Y_t^d = \left(\int_0^1 \left(Y_t^f\right)^{\frac{\varepsilon-1}{\varepsilon}} df \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{8}$$

where $\varepsilon > 1$ is the elasticity of substitution across domestic intermediate goods and Y_t^d is the per capita final domestic good. The firm acts competitively by choosing Y_t^f to maximize its profits, taking the price of each intermediate good as given. Thus, the firm maximizes profits:

$$\Pi_t = Y_t^d - \int_0^1 p_t^f Y_t^f df \tag{9}$$

subject to equation (8), where p_t^f is the price of the intermediate good f relative to the price of the final domestic good, Y_t^d. From the solution of the firm's problem we get the inverse demand function for the intermediate good f :

$$p_t^f = \left(\frac{Y_t^f}{Y_t^d}\right)^{-\frac{1}{\varepsilon}} \tag{10}$$

2.2.2. Final consumption good producer

There is a representative perfectly competitive consumption good producer that aggregates consumption of the domestically produced final good, C_t^d, with consumption of the imported final good, C_t^m, to generate a composite non-tradable consumption good, C_t^c, by using a constant elasticity of substitution production function of the form:

$$C_t^c = \left[\omega^{\frac{1}{\mu}}\left(C_t^d\right)^{\frac{\mu-1}{\mu}} + (1-\omega)^{\frac{1}{\mu}}\left(C_t^m\right)^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}} \tag{11}$$

where ω is the share of domestically produced goods in consumption (i.e. the home bias that determines the degree of openness in the long run) and μ is the elasticity of substitution between domestic and imported consumption goods. The consumption good producer chooses output, C_t^c, and inputs, C_t^d, C_t^m, to maximize profits:

$$\Pi_t^c = P_t^c C_t^c - C_t^d - Q_t C_t^m \tag{12}$$

subject to equation (11). The first-order conditions are:

$$\frac{C_t^d}{C_t^c} = \omega\left(P_t^c\right)^{\mu} \tag{13a}$$

$$\frac{C_t^m}{C_t^c} = \left(1-\omega\right)\left(P_t^c\right)^{\mu}\left(Q_t\right)^{-\mu} \tag{13b}$$

which give the demand functions for domestic and imported consumption goods, respectively. From the zero profit condition we get the consumer’s price index, which is a weighted sum of the price of the domestic final good and the imported final good:

$$P_t^c = \left[\omega + (1-\omega)(Q_t)^{1-\mu}\right]^{\frac{1}{1-\mu}} \tag{14}$$

2.2.3. Intermediate goods producers

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 differentiated domestic intermediate good, Y_t^f, by using as inputs private labour, H_t^f, private capital services, K_t^f, imported intermediate inputs, IM_t^f, and by making use of average (per firm f) public capital $\bar{K}_t^g$. The production function of each firm is:

$$Y_t^f = A_t\left[\left(K_t^f\right)^{1-\theta}\left(IM_t^f\right)^{\theta}\right]^{a_1}\left(Z_t H_t^f\right)^{a_2}\left(\bar{K}_t^g\right)^{a_3} - Z_t\Phi \tag{15}$$

where $a_i \in (0,1)$, $i = 1,2,3$ is respectively the output elasticity of gross capital services, private labour and public capital, θ is the share of intermediate imported inputs in the production function and Φ corresponds to the fixed cost of production. The production function exhibits constant returns to all three inputs, that is, $a_1 + a_2 + a_3 = 1$. A_t characterizes the stochastic total factor productivity, which is common across intermediate goods firms, and whose evolution will be specified in the next section. Each firm takes as given the factor prices and aggregate variables, and chooses K_t^f, H_t^f, IM_t^f, in order to maximize profits:

$$\Pi_t^f = p_t^f Y_t^f - r_t^k K_t^f - w_t^p Z_t H_t^f - Q_t IM_t^f \tag{16}$$

subject to (10) and (15). The first-order conditions for K_t^f, H_t^f, IM_t^f are respectively:

$$r_t^k = \frac{\varepsilon-1}{\varepsilon} p_t^f a_1 (1-\theta)\left(\frac{Y_t^f + Z_t\Phi}{K_t^f}\right) \tag{17a}$$

$$w_t^p = \frac{\varepsilon-1}{\varepsilon} p_t^f a_2 \left(\frac{Y_t^f + Z_t\Phi}{Z_t H_t^f}\right) \tag{17b}$$

$$Q_t = \frac{\varepsilon - 1}{\varepsilon} p_t^f a_1 \theta \left(\frac{Y_t^f + Z_t \Phi}{IM_t^f} \right) \tag{17c}$$

We restrict attention to a symmetric equilibrium in which $K_t^f = K_t, H_t^f = H_t, IM_t^f = IM_t, Y_t^f = Y_t$ and $p_t^f = p_t \ \forall f$. Also, note that substituting $Y_t^f = \left(p_t^f\right)^{-\varepsilon} Y_t^D$ from (10) into the zero profit condition of the final goods firm, $Y_t - \int_0^1 p_t^f Y_t^f df = 0$, and imposing symmetry, yields $p_t^f = p_t = 1 \ \forall f$. Thus, equations (17a)-(17c) can be written as:

$$r_t^k = \frac{\varepsilon - 1}{\varepsilon} a_1 (1-\theta) \left(\frac{Y_t^f + Z_t \Phi}{K_t^f} \right) \tag{18a}$$

$$w_t^p = \frac{\varepsilon - 1}{\varepsilon} a_2 \left(\frac{Y_t^f + Z_t \Phi}{Z_t H_t^f} \right) \tag{18b}$$

$$Q_t = \frac{\varepsilon - 1}{\varepsilon} a_1 \theta \left(\frac{Y_t^f + Z_t \Phi}{IM_t^f} \right) \tag{18c}$$

2.3. Wage setting

Following Blanchard and Gali (2007) and Malley et al. (2009), we assume that real wages respond sluggishly to labour market conditions as a result of some unmodeled imperfections or frictions in the labour market. In particular, we adopt the following specification:

$$w_t^p = \left(w_{t-1}^p\right)^n \left(MRS_t\right)^{1-n} \tag{19}$$

where $0 \le n \le 1$ is an index of real wage rigidities and MRS_t is given by (6b). The basic idea behind this specification is to capture 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.

2.4. Government

The government levies taxes on consumption and on income from labour and capital earnings, and issues one-period government bonds in the domestic bond market, B_{t+1}^{g}, and in the international market, F_{t+1}^{g}. Total tax revenues plus the issue of new one-period 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 constraint households, G_t^{tr}, and total compensation of public employees, $w_t^g Z_t H_t^g$. Moreover, the government pays interest payments on past domestic public debt, R_t^b, and foreign public debt, R_t. The within-period government budget constraint in per-capita terms is:

$$\begin{aligned} B_{t+1}^{g} + Q_t F_{t+1}^{g} + \tau_t^c P_t^c C_t + \tau_t^l \left(w_t^p Z_t H_t^p + w_t^g Z_t H_t^g \right) + \tau_t^k \left(r_t^k K_t + \Pi_t \right) = \\ = G_t^c + G_t^i + G_t^{tr} + w_t^g Z_t H_t^g + R_{t-1}^b B_t^g + R_{t-1} Q_t F_t^g \end{aligned} \tag{20}$$

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. For convenience, we assume that $B_{t+1}^g = \gamma_{t+1} D_{t+1}$ and $Q_t F_{t+1}^g = (1-\gamma_{t+1}) D_{t+1}$, where $0 \leq \gamma_{t+1} \leq 1$ is the share of total public debt held by domestic agents at the end of period t, and $D_{t+1} = B_{t+1}^g + Q_t F_{t+1}^g$ is the end-of-period total public debt issued by the government. Following usual practice, the residually determined policy instrument that adjusts to satisfy the period budget constraint is total public debt, D_{t+1}, while the other nine policy instruments, $\tau_t^c, \tau_t^l, \tau_t^k, w_t^g, H_t^g, G_t^c, G_t^i, G_t^{tr}, \gamma_t$, 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. (2011, 2012), 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 (such as education, health, justice etc) by using the following production function:

$$Y_t^g = A_t \left(G_t^c \right)^x \left(Z_t H_t^g \right)^{1-x} \tag{21}$$

where $0 \leq x \leq 1$ is a technology parameter.

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

$$K_{t+1}^{g} = \left(1-\delta^{g}\right)K_{t}^{g} + G_{t}^{i} \tag{22}$$

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

2.5. World capital markets

We assume 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), the interest rate at which the country borrows from the international markets, R_t, is the sum of the exogenously given world interest rate, R_t^{*}, and a risk-premium that is increasing in the ratio of the end-of-period t total holdings of private foreign assets over output, F_{t+1}/Y_t, and the total public debt-to-output ratio, D_{t+1}/Y_t:

$$R_t = R_t^{*} + \psi^{f}\left(e^{-(\frac{Q_t F_{t+1}}{Y_t}-\bar{f})} - 1\right) + \psi^{d}\left(e^{(\frac{D_{t+1}}{Y_t}-\bar{d})} - 1\right) \tag{23}$$

where $\psi^{f}, \psi^{d} \geq 0$ are parameters and $\bar{f} \geq 0$, $\bar{d} \geq 0$ are respectively the target values of the net foreign private asset position-to-output ratio and the public debt-to-output ratio, above which risk-premia are positive.[3] This formulation is consistent with empirical evidence (see e.g. European Commission (2012)) as well as with previous theoretical modelling (see e.g. Christiano et al., 2011)).

2.6. Foreign demand

Foreign demand for the domestically produced good, X_t, is assumed to be determined by foreign income and the real exchange rate:

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

$$X_t = Q_t^{\varepsilon^x} Y_t^*, \tag{24}$$

where $\varepsilon^x > 0$ is the price elasticity of foreign demand with respect to the real exchange rate and Y_t^* denotes the exogenous foreign income level, assumed to grow at the same rate as domestic output in steady state.

2.7. 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.

Aggregation

The aggregate quantity, expressed in per-capita terms, of any household specific variable X_t^h, is given by $X_t = \int_0^1 X_t^h dh = (1-\lambda) X_t^i + \lambda X_t^j$. Thus, per capita private consumption is given by

$$C_t = (1-\lambda) C_t^i + \lambda C_t^j$$

while the per capita quantities for hours worked in the private and the public sector are:

$$H_t^p = (1-\lambda) H_t^{i,p} + \lambda H_t^{j,p} \equiv H_t^{i,p}$$

$$H_t^g = (1-\lambda) H_t^{i,g} + \lambda H_t^{j,g} \equiv H_t^{i,g}$$

Per capita government transfers are:

$$G_t^{tr} = (1-\lambda) G_t^{i,tr} + \lambda G_t^{j,tr}$$

Following Coenen et al. (2012), we allow for a possible uneven distribution of government transfers between optimizing and liquidity constraint households according to the following rules:

$$G_t^{tr,c} = \bar{\lambda} G_t^{tr}$$

$$G_t^{tr,o} = (1-\bar{\lambda}) G_t^{tr}$$

where $G_t^{tr,c}$ and $G_t^{tr,o}$ are total transfers received by liquidity constraint and optimizing households, respectively and $0 \leq \bar{\lambda} \leq 1$.

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:

$$K_t^p = \left(1-\lambda\right) K_t^i$$

$$I_t = \left(1-\lambda\right) I_t^i$$

$$B_t = \left(1-\lambda\right) B_t^i$$

$$F_t = \left(1-\lambda\right) F_t^i$$

$$\Pi_t = \left(1-\lambda\right) \Pi_t^i$$

Market clearing conditions

Market clearing in the labour market

The labour demanded by the intermediate goods firms needs to equal the supply of labour from households in the private labour market,

$$\int_0^1 H_t^f df = H_t^p$$

while, total labour supply must be equal to the amount of labour employed in private firms and the public sector.

$$H_t = H_t^p + H_t^g$$

Market clearing in the capital market

$$\int_0^1 K_t^f df = u_t K_t^p$$

Market clearing in the dividend market:

$$\int_0^1 \Pi_t^f df = \Pi_t$$

Market clearing in the domestic bond market

$$B_t^g = \gamma_t D_t = B_t$$

Also, note that the external public debt is: $Q_t F_t^g = (1-\gamma_t) D_t = D_t - B_t$

Market clearing in the intermediate goods sector

The supply of each differentiated good needs to meet total demand:

$$Y_t = \int_0^1 Y_t^f df = Y_t^d$$

where the production function in per capital terms is:

$$Y_t = A_t \left[\left(u_t K_t^p \right)^{1-\theta} \left(IM_t \right)^{\theta} \right]^{a_1} \left(Z_t H_t^p \right)^{a_2} \left(K_t^g \right)^{a_3} - Z_t \Phi$$

and per capita profits are defined as: $\Pi_t = Y_t - r_t^k u_t K_t^p - w_t^p Z_t H_t^p - Q_t IM_t$

Market clearing in the consumption goods sector

$$C_t^c = C_t$$

Market clearing in the domestic final goods market

$$Y_t^d = C_t^d + I_t + G_t^c + G_t^i + X_t$$

Evolution in net foreign assets

The evolution of the net foreign assets is derived from the optimizing households' budget constraint, after imposing the budget constraint of the liquidity constraint households, the government budget constraint, the definition of firm's profits and by making use of the zero profit conditions of the final consumption good sector:

$$Q_t F_{t+1} - (1-\gamma_{t+1}) D_{t+1} = X_t - Q_t (IM_t + C_t^m) + R_{t-1}\left(Q_t F_t - (1-\gamma_t) D_t\right)$$

where $Q_t F_{t+1} - (1-\gamma_{t+1}) D_{t+1}$ is the net foreign asset position of the total economy.

2.8. Decentralized competitive equilibrium

We solve for a decentralized competitive equilibrium (DCE) in which (i) households maximize welfare (ii) firms maximize profits (iii) all constraints are satisfied and (iv) all markets clear. We first need to transform the components of national income into efficiency units to make them stationary. The stationary DCE is presented in Appendix.

2.9. Policy instruments and exogenous stochastic variables

Concerning the fiscal policy instruments, $\{\tau_t^c, \tau_t^l, \tau_t^k, g_t^c, g_t^i, w_t^g, h_t^g, \gamma_t\}_{t=0}^{\infty}$, it is assumed that they follow univariate stochastic $AR(1)$ process of the form:

$$\ln(g_{t+1}^c / g^c) = \rho^{gc} \ln(g_t^c / g^c) + \varepsilon_{t+1}^{gc} \tag{25a}$$

$$\ln(g_{t+1}^i / g^i) = \rho^i \ln(g_t^i / g^i) + \varepsilon_{t+1}^{gi} \tag{25b}$$

$$\ln(w_{t+1}^g / w^g) = \rho^w \ln(w_t^g / w^g) + \varphi^w \ln(w_t^p / w^p) + \varepsilon_{t+1}^w \tag{25c}$$

$$\ln(\tau_{t+1}^c / \tau^c) = \rho^c \ln(\tau_t^c / \tau^c) + \varepsilon_{t+1}^c \tag{25d}$$

$$\ln(\tau_{t+1}^l / \tau^l) = \rho^l \ln(\tau_t^l / \tau^l) + \varepsilon_{t+1}^l \tag{25e}$$

$$\ln(\tau_{t+1}^{k} / \tau^{k}) = \rho^{k} \ln(\tau_{t}^{k} / \tau^{k}) + \varepsilon_{t+1}^{k} \quad (25f)$$

$$\ln(h_{t+1}^{g} / h^{g}) = \rho^{h} \ln(h_{t}^{g} / h^{g}) + \varepsilon_{t+1}^{h} \quad (25g)$$

$$\ln(\gamma_{t+1} / \gamma) = \rho^{\gamma} \ln(\gamma_{t} / \gamma) + \varepsilon_{t+1}^{\gamma} \quad (25h)$$

where $\varepsilon_t^s \sim \ i.i.d.\ N(0,1)$ for $s = \{gc, gi, c, l, k, w, h, \gamma\}$. We follow most of the literature (see e.g. Coenen et al. (2012)), by allowing government transfers to react systematically to the public debt-to-output ratio in order to ensure fiscal solvency:

$$\ln(g_{t+1}^{tr} / g^{tr}) = \rho^{tr} \ln(g_{t}^{tr} / g^{tr}) + \varphi^{tr} \ln(s_{t}^{d} / s^{d}) + \varepsilon_{t+1}^{tr} \quad (25i)$$

where $s_t^d \equiv d_t / y_t$, $\varphi^{tr} < 0$ and $\varepsilon_t^{tr} \sim \ i.i.d.\ N(0,1)$.

Regarding the rest exogenous stochastic variables, we assume that total factor productivity, A_t, the world interest rate, R_t^*, and foreign income, y_t^*, follow independent $AR(1)$ stochastic processes of the form:

$$\ln(A_{t+1} / A) = \rho^{A} \ln(A_{t} / A) + \varepsilon_{t+1}^{A} \quad (25j)$$

$$\ln(R_{t}^{*} / R^{*}) = \rho^{R} \ln(R_{t-1}^{*} / R^{*}) + \varepsilon_{t}^{R} \quad (25k)$$

$$\ln(y_{t+1}^{*} / y^{*}) = \rho^{y^{*}} \ln(y_{t}^{*} / y^{*}) + \varepsilon_{t+1}^{y^{*}} \quad (25l)$$

where $\varepsilon_t^s \sim \ i.i.d.\ N(0,1)$ for $s = \{A, R, y^*\}$

3. Calibration and long run solution

The model is calibrated for the Greek economy. The data source is Eurostat, unless otherwise stated. The data set comprises quarterly data and covers the period 2000:1-2011:4. Quarterly effective tax rates on consumption, labour income and capital income are computed following the methodology of Mendoza et al. (1994), while series for the two capital stocks are constructed following the approach in Conesa et al. (2007).

3.1. Calibration

Table 1 reports the calibrated parameters and the average values of the fiscal policy variables in the data. As in most studies, the curvature parameter in the utility function, σ, is set equal to 2. Following the study of Baier and Glomm (2001), the relative weight of public goods in utility, $1-\gamma_1-\gamma_2$, is set equal to 0.1. The preference parameter γ_2, which is the leisure weight in utility, is calibrated for a given labour allocation equal to 23.5% of time. The preference parameter, γ_1, is then residually calibrated. The habit persistence parameter, ξ^c, is set equal to 0.65, which is in the midpoint of the values reported in Smets and Wouters (2003) and Forni et al. (2009) for the euro area. The annual gross growth rate of technological process, γ_z, is set equal to 1.02 (1.005 quarterly), which is the average annual growth rate of real per capita GDP in the USA (see e.g. Kehoe and Prescott (2002)). The discount factor, β, is calibrated as $\beta=\gamma_z/R^*$, assuming a quarterly world real interest rate, R^*, equal to 0.75% (3% annually). The home bias parameter, ω, is set equal to the share of domestically produced goods in total private consumption expenditures. Following Forni et al. (2009), we choose a value equal to 0.4 for the fraction of liquidity constraint households. The initial level of technological process, Z_0, and the level of long-run aggregate productivity, A, are set equal to one since they are scale parameters, which affect only the scale of the economy; see King and Rebelo (1999).

Following the study of Papageorgiou (2012), the two physical depreciation rates, δ^p and δ^g, are respectively set equal to 0.0098 (0.039 annually) and 0.0064 (0.027 annually), while the labour share in output is set at 0.5715.[4] The value of the adjustment cost parameter in private capital, ξ^k, is set at 8, somewhat lower that the value reported in Papageorgiou et al. (2011), but in the range of values found in the literature. The steady-state value of capital utilization is normalized to unity. The elasticity of marginal depreciation costs, ϕ, is calibrated from the steady-state versions of equations (A3) and (A7). The exponent of public capital in the production function, a_3, is set at 0.0314, which is the average public investment to output ratio in the data (see also Baxter and King (1993)). The gross capital share is then calibrated as $a_1=1-a_2-a_3$. The share of intermediate imported inputs in the production function, θ, is set equal to the ratio of imported intermediate inputs to total intermediate inputs.[5] The fixed cost parameter in production, Φ, is chosen to ensure zero profits in steady state. The price elasticity

[4] Similar results for the labour share in output can also be found in Gogos et al. (2012).

[5] The data source is the OECD STAN database.

of demand for the differentiated outputs, ε, is calibrated such that to imply a 40% steady-state markup of intermediate producers over marginal cost, which is in line with the empirical estimates of Molnár and Bottini (2010) and Rezitis and Kalantzi (2011).[6] Regarding the wage persistent parameter, n, we set it equal to 0.95, which is in the midpoint of the estimates reported in Malley et al. (2009).

The elasticity of substitution between imported and domestically produced consumption goods, μ, and the elasticity of exports, ε^x, are estimated via OLS from the log-linear forms of equations (A9) and (A27), respectively. The estimated values are $\mu = 1.36$ and $\varepsilon^x = 1.29$. The long-run value of the real exchange rate, Q_t, is normalized to unity, as is usual the case in similar studies (see e.g. Adolfson et al. (2007)). The risk premium coefficient on net private foreign assets, ψ^f, is set to guarantee that the equilibrium solution is stationary (see e.g. Schmitt-Grohe and Uribe (2003)). The risk premium coefficient on public debt, ψ^d, is set equal to 0.01 on annual basis, which means that a one percentage point increase in the debt ratio, increases risk premia by 1 basis point (see e.g. Ardagna et al. (2004)). The target level for the debt-to-output ratio, $\bar{d}$, is set equal to 3.6 (90% annually), which is the threshold level found in Rainhart and Rogoff (2009) above which public debt has a negative effect on the macroeconomy. The parameter $\bar{f}$ is set equal the average value of the net private foreign asset position-to-output ratio found in the data.

Regarding fiscal policy instruments, the long-run values of public spending on goods and services and public investment as shares of output are respectively 0.064 and 0.0314, which are the average values in the data. Similarly, the tax rates on consumption, labour income and capital income, as well as the ratio of government to private employment, h_t^g / h_t^p, and the share of domestic public debt to total public debt, γ_t, are set equal to their data averages.[7] The average wage rate in the public sector, w_t^g, is set such that the total wage bill as share of output to match the average data. The productivity of public employment in the public sector's production function, x, is calibrated at 0.3236, which is the data average value of the total wage bill as a share of total government consumption expenditures. We set the share of government

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[6] In particular, the markup is computed as a weighted average of the markups in the service and manufacturing sectors, where the shares of each sector in gross value added were used as weights.

[7] Data for the calculation of the ratio of government to private employment are from OECD Economic Outlook.

transfers that is allocated to liquidity constraint households, $\bar{\lambda}$, equal to their share in total population.

The coefficients $\rho^{gc}, \rho^{i}, \rho^{w}, \rho^{h}, \rho^{tr}, \rho^{c}, \rho^{l}, \rho^{k}, \rho^{R}, \rho^{y^*}, \varphi^{w}, \varphi^{tr}$, were estimated via OLS from their respective stochastic processes. The same applies to the standard deviations $\sigma^{gc}, \sigma^{i}, \sigma^{w}, \sigma^{tr}, \sigma^{h}, \sigma^{c}, \sigma^{l}, \sigma^{k}, \sigma^{R}, \sigma^{y^*}$. We set the persistence and the volatility of the Solow residual, ρ^{A} and σ^{A}, equal to 0.7 and 0.017 respectively, following Papageorgiou et al. (2011). Finally, we treat the share of domestic public debt in total public debt, γ, as constant over time.

Table 1: Calibration

Parameter or Variable	**Description**	**Value**
σ	Curvature parameter in the utility function	2
γ_1	Consumption weight in utility	0.2104
γ_2	Labour weight in utility	0.6896
$1-\gamma_1-\gamma_2$	Weight of public goods in utility	0.1
ξ^c	Habit persistence	0.65
γ_z	Growth rate of labor augmenting technology	1.005
β	Time discount factor	0.9975
ω	Home bias	0.84
λ	Fraction of liquidity constraint households	0.4
A	Long run aggregate productivity	1
Z_0	Initial level of technological process	1
δ^p	Private capital quarterly depreciation rate	0.0098
δ^g	Public capital quarterly depreciation rate	0.0064
ξ^k	Private capital adjustment cost parameter	8
ϕ	Elasticity of marginal depreciation costs	1.7692
a_1	Gross capital elasticity in production	0.3971
a_2	Labour elasticity in production	0.5715
a_3	Public capital elasticity in production	0.0314

θ	Share of intermediate imported inputs in production	0.2670
Φ	Fixed cost parameter	0.0641
ε	Price elasticity of demand	3.5
μ	Degree of real wage rigidity	0.95
ν	Elasticity of substitution between imported and domestic consumption goods	1.36
ε^x	Elasticity of exports	1.29
ψ^f	Risk premium coefficient on net private foreign assets	0.0005
ψ^d	Risk premium coefficient on total public debt	0.01/16
$\bar{d}$	Target level of debt-to-output ratio	3.6
$\bar{f}$	Target level of net private foreign assets	0.0196
$\bar{\lambda}$	Share of total government transfers allocated to liquidity constraint households	0.4
g^c / y	Government purchases of goods and services to output ratio	0.0644
g^i / y	Government investment to output ratio	0.0314
h^g / h^p	Government employment to private employment ratio	0.2145
τ^c	Tax rate on consumption	0.16
τ^l	Tax rate on labor income	0.31
τ^k	Tax rate on capital income	0.21
γ	Share of domestic public debt	0.355
ρ^A	Persistent parameter of A_t	0.70
ρ^{gc}	Persistent parameter of g_t^c	0.89
ρ^i	Persistent parameter of g_t^i	0.94
ρ^w	Persistent parameter of w_t^g	0.65
ρ^h	Persistent parameter of h_t^g	0.94
ρ^{tr}	Persistent parameter of g_t^{tr}	0.59
ρ^c	Persistent parameter of τ_t^c	0.63
ρ^l	Persistent parameter of τ_t^l	0.79
ρ^k	Persistent parameter of τ_t^k	0.83

ρ^R	Persistent parameter of R_t	0.93
ρ^{y^*}	Persistent parameter of y_t^*	0.95
φ^w	Feedback parameter on private wages	0.33
φ^{tr}	Feedback parameter on total public debt	-0.30
σ^A	Standard deviation of innovation ε_t^A	0.017
σ^{gc}	Standard deviation of innovation ε_t^{gc}	0.0664
σ^i	Standard deviation of innovation ε_t^i	0.0641
σ^w	Standard deviation of innovation ε_t^w	0.0291
σ^h	Standard deviation of innovation ε_t^h	0.0036
σ^{tr}	Standard deviation of innovation ε_t^{tr}	0.0338
σ^c	Standard deviation of innovation ε_t^c	0.0525
σ^l	Standard deviation of innovation ε_t^l	0.0146
σ^k	Standard deviation of innovation ε_t^k	0.0337
σ^R	Standard deviation of innovation ε_t^R	0.233
σ^{y^*}	Standard deviation of innovation $\varepsilon_t^{y^*}$	0.0065

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-output ratio equal to the target level $\bar{d}$. 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. 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 output to play that role and we set the rest fiscal instruments equal to their data averages (see Table 1). Notice that, in order to satisfy the government budget constraint, the share of transfers has to fall below its value in the data (from 0.2102 to 0.1213).

Table 2: Data averages and long-run model solution

Variable	Description	Data Averages	Long Run Solution
c/y	Total consumption-to-output ratio	0.7202	0.6432
c^d/y	Domestic consumption goods-to-output ratio	0.6070	0.5403
c^m/y	Imported consumption goods-to-output ratio	0.1143	0.1029
i/y	Private investment-to-output ratio	0.1782	0.1656
h	Total hours at work	0.2350	0.2350
h^p	Hours at work in the private sector	-	0.1935
h^g	Hours at work in the public sector	-	0.0415
k^p/y	Private capital-to-output ratio	11.2755	11.256
k^g/y	Public capital-to-output ratio	3.1604	2.7573
d/y	Total public debt-to-output ratio	4.4672	3.60
f^g/y	Foreign public debt-to-output ratio	2.8812	2.3219
b/y	Domestic public debt-to-output ratio	1.5860	1.2781
g^{tr}/y	Government transfers-to-output ratio	0.2102	0.1213
f/y	Private net foreign asset position-to-output ratio	0.0196	0.0196
f^T/y	Total economy's net foreign asset position-to-output ratio	2.8616	2.3023
x/y	Exports-to-output ratio	0.2245	0.1983
m/y	Total imports-to-output ratio	0.3413	0.1924
im/y	Imported intermediate goods-to-output ratio	0.1157	0.0895
tb/y	Trade balance-to-output ratio	-0.1153	0.0058
ca/y	Current account-to-output ratio	-0.0949	-0.0114

Note: (i) Quarterly data over the period 2000q1-2011q4 (ii) Data averages for f^g/y and b/y are over the period 2003q1-2011q4, (iii) A positive value of f^T/y means that the economy is a net debtor, (iv) f/y has been computed as $f/y=\left(f^g-f^T\right)/y$. A positive values means that households are net lenders.

3.3. Linearization and approximate solution

Equations (A1)-(A37), 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).

4. Model properties

In this Section we consider the dynamic properties of the model by reporting the impulse response functions to some of the stochastic shocks of the model and analyzing the main transmission channels through which the shocks influence the macroeconomy. We are particular interested in investigating the responses of major macroeconomic variables to changes in the innovations of the exogenous fiscal (tax-spending) policy variables to illustrate the contribution that the model can make to policy analysis.

4.1. Effects of shocks to government spending instruments

Figures 1-5 show the dynamic effects of transitory, but persistent shocks to government purchases of goods and services, government investment, public sector wage rates, government transfers and public sector employment. The magnitude of the shocks to government purchases of goods and services, government investment and government transfers is set in order to have a decrease in the various components of public spending at time $t = 0$ equal to 1% of steady-state output. The shock in public wage rates is set in order to have a decrease in the total public wage bill equal to 1% of steady-state output. 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 output. The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes.

4.1.1. Effects of shocks to government purchases of goods and services

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

The first order effect is a positive wealth effect that leads optimizing households to increase current consumption and leisure (or to decrease labour supply in the private sector).[8] In contrast, liquidity constraint households reduce their consumption demand since they suffer income loss from the fall in hours worked, even though real wages increase due to the fall in private employment. The net effect on total private consumption is negative on impact, due to the presence of liquidity constraint households and real rigidities in the labour market (see e.g. Gali et al. (2007) for a discussion). In addition, the open economy set-up allows optimizing households to smooth consumption more effectively than when the economy is closed, 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 (only for one quarter), and its dynamic response in the following years of transition is denominated by the behaviour of optimizing households. The private sector real wage rate increases on impact, while the real return to capital decreases in order for the goods market to clear. The decrease in aggregate demand, coming from the initial reduction in public consumption, along with the decline in the inputs of production, leads to a fall in output both on impact and along the transition to the initial equilibrium. The estimated impact multiplier is found to be 0.96.[9] It is interesting to note that the fiscal contraction results to a rise in the debt-to-output ratio in the first quarters, due to the adverse effects on output.

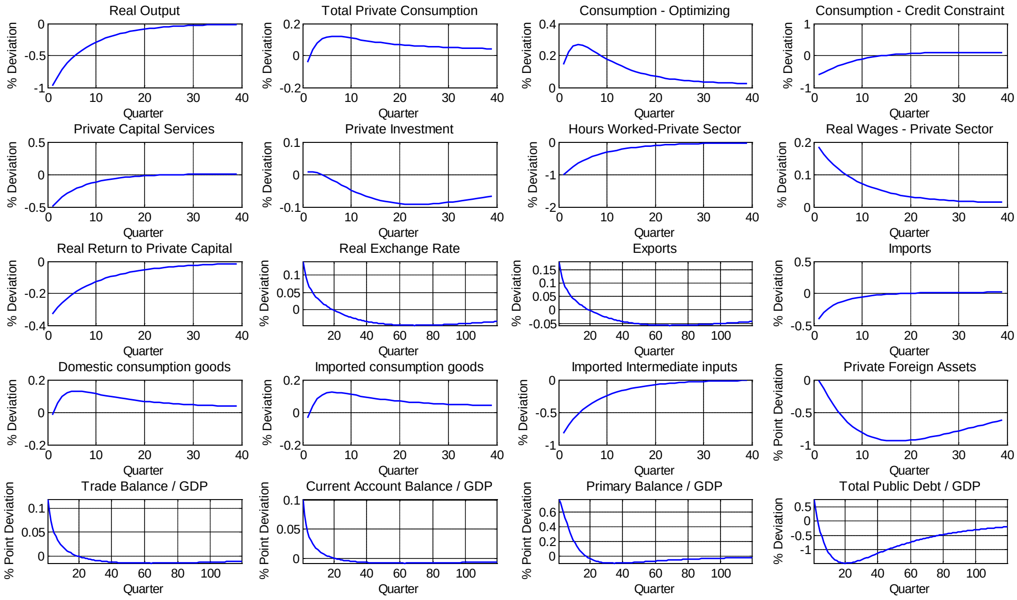
Regarding the variables related to the external sector, there is an increase in the real exchange rate in the short run, that is, a real depreciation. The reason is the violation of the uncovered interest parity, which must be restored by a rise in the real exchange rate relative to its expected future value. In turn, the increase in competitiveness results to a rise in exports in the short run, while there is a decrease in imports that is driven by the reduction in imported intermediate inputs. Consequently, there is an improvement in the trade balance and the current account balance as shares of GDP in the early years of transition. For instance, the trade balance

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

[9] The output multiplier on impact period after a change in government spending or tax policy instruments is defined as: $\varphi_t = \Delta Y_t / \Delta X_t$, where ΔY_t and ΔX_t are respectively level changes in output and the fiscal variable of interest relative to their pre-policy reform values.

and the current account balance as shares of GDP increase by around 0.13 and 0.11 percentage points on impact, in line with the results obtained in Erceg et al. (2005) for the U.S. economy.

Figure 1: Dynamic responses to a government purchases shock



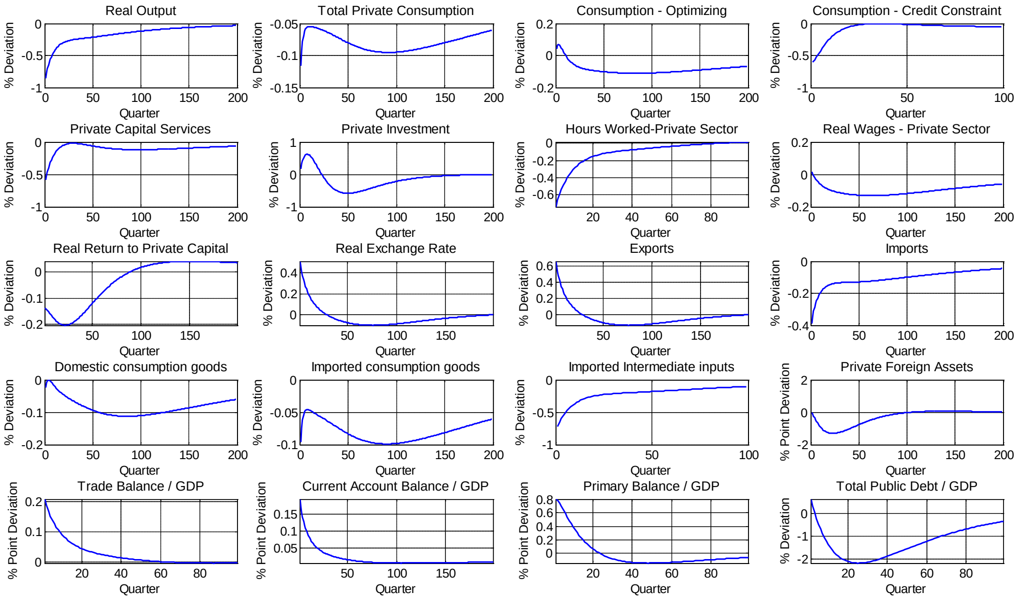
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.1.2. Effects of shocks to government investment

Figure 2 shows selected dynamic responses to a persistent government shock in public investment equal to a 1% decrease in steady-state output. The reduction in public investment implies a decrease in governmental absorption of recourses, 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, while private consumption and investment of optimizing households rise on impact, they both fall in the later years. At the same time, the reduction in hours worked and real wages induces liquidity constraint households to decrease consumption demand. Output is below its initial level all the time, while the contraction of output produces a rise in the debt-to-GDP ratio in the short run. The impact multiplier for output is estimated at 0.89.

Finally, it should be noted that the reduction in public investment causes an increase in the real exchange rate that shifts foreign and domestic demand towards domestic goods, particularly in the short run, and gives rise to an expansion in exports and a decrease in the value of imports. Consequently, the trade balance-to-output ratio increases by around 0.2 percentage points on impact, while the effect on the current account balance is also positive along the dynamic path.

Figure 2: Dynamic responses to a government investment shock



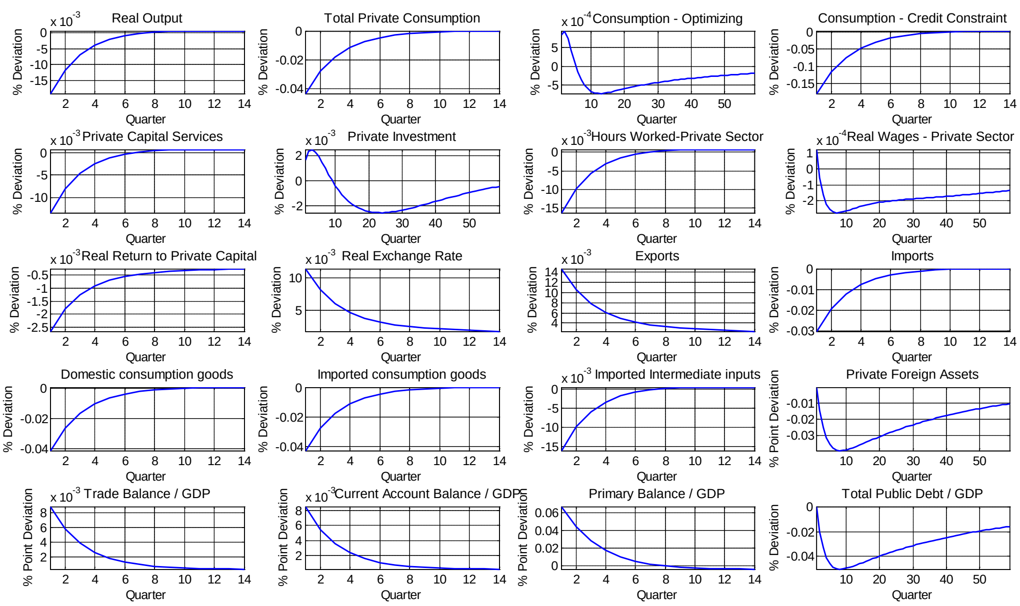
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.1.3. Effects of shocks to public sector wages

Figure 3 summarizes the dynamic responses to a shock in the average wage rate of the public sector. Recall that the shock in the average wage rate is set in order to have a decrease in the total public wage bill equal to 1% of initial output. Cutting public sector wages reduces the disposable income of liquidity constraint households, leading to a reduction in consumption purchases. Regarding the behavior of optimizing households, the decrease in aggregate demand, driven by the lower consumption demand of liquidity constraint households, leads to a fall in the real return to private capital and generates an inter-temporal substitution effect that induces them to increase current consumption and leisure (or decrease labour supply in the private sector). In turn, the fall in labour supply produces a small, albeit negligible increase in private sector wages on impact. However, private sector wages fall in the following years of transition and converge to the initial equilibrium from below. The negative response of both hours of worked and capital services, combined with the reduction in imported intermediate inputs, translate into a fall in output along the dynamic path to the initial steady state. Nevertheless, the negative impact on output is much smaller than in the case of a fiscal contraction in the form of lower government purchases on goods and services or public infrastructures. For instance, the output multiplier on impact period is estimated at 0.18. However, it should be stressed that the value of the multiplier depends on the share of liquidity constrained households. For instance, for a share of liquidity constraint households equal to 0.6, the impact multiplier is about 0.28. The debt ratio decreases on impact and converges to the initial equilibrium from below. Thus, in terms of output losses, reductions in public wages is a more desirable option for reducing public debt than cuts in public consumption and investment.

Concerning the variables associated with the external sector, there is an increase in the real exchange that triggers a rise in exports. At the same time, the decrease in imports, driven mainly by the reduction in imported consumption goods, gives rise to an improvement in the trade and current account balance ratios.

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

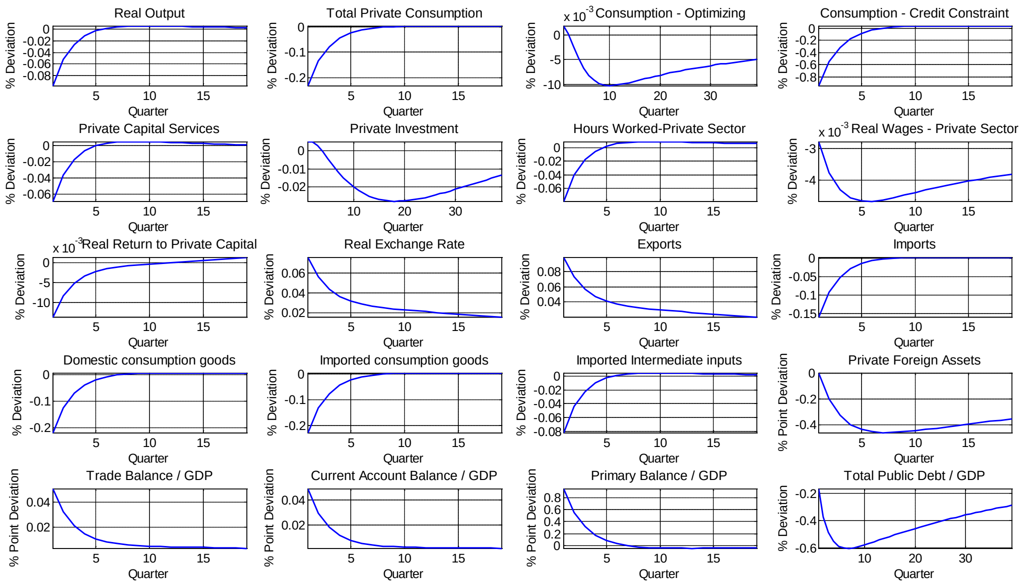


Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.1.4. Effects of shocks to government transfers

Figure 4 shows selected dynamic responses to a shock in public transfers equal to a 1% decrease in steady-state output. The reduction in government transfers induces a decrease in total consumption driven by the fall in the consumption demand of liquidity constraint households, who experience a loss in their disposable income. At the same time, optimizing households decrease both their labour and capital supply, while they also reduce the holdings of foreign assets in an attempt to smooth consumption over time. Since employment and capital services fall, output also falls. In addition, the reduction in domestic interest rates leads to a real depreciation, that is, an increase in competitiveness that gives rise to an expansion in real exports. The reduction in consumption purchases dampens imports, particularly the level of imported consumption goods, and hence produces an improvement in the trade balance and the current account balance as shares of GDP. Finally, the debt-to-output ratio decrease both on impact and during the transition to the initial equilibrium.

Figure 4: Dynamic responses to a government transfer shock



Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

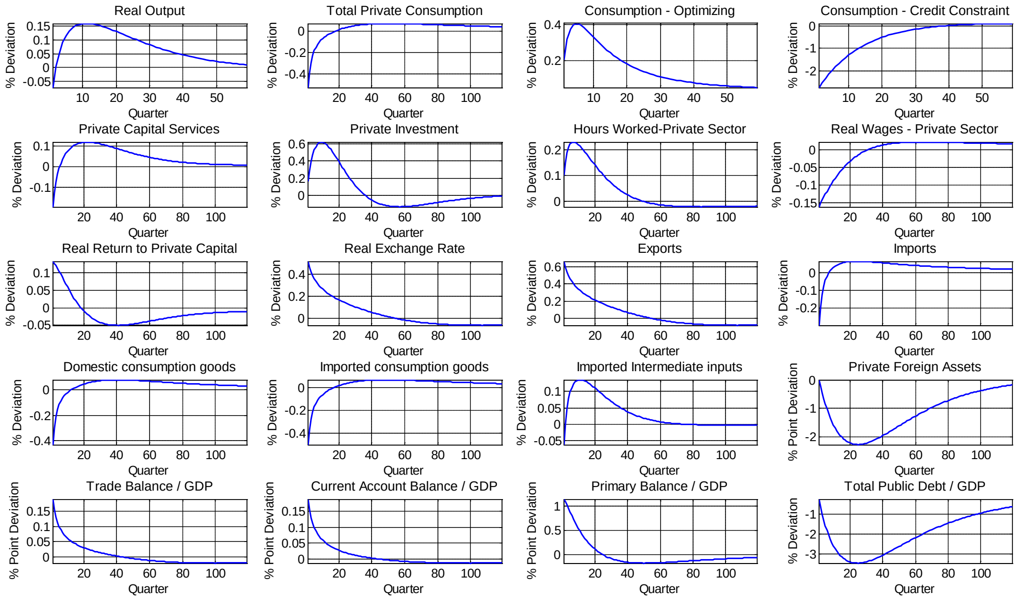
4.1.5. Effects of shocks to public employment

Figure 5 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 output.

The decrease in public employment lowers the labour income of the liquidity constraint households, inducing a sizable reduction in consumption demand. At the same time, the decrease in public employment leads optimizing households to increase labour supply in the private sector, as well as consumption purchases. This behavior is explained by the leisure-consumption intra-temporal condition, which given the fall in total employment, it requires an increase in hours worked (and thus a decrease in the private wage rate) or consumption. Eventually, both labour supply and consumption increases, while the real wage rate in the private sector falls. The net effect on total private consumption is, however, negative. Despite the rise in hours worked, output decreases on impact due to the fall in private capital services and imported intermediate inputs in the short run. However, there is an expansion of output in the following years of transition, triggered by the rise in the inputs of production. At the same time, the public debt-to-output ratio decreases significantly both on impact and along the dynamic path to the initial equilibrium. Thus, in terms of output losses, a reduction in public employment seems to be the most desirable policy in improving public finances.

Finally, note that the reduction in public employment induces a real depreciation in the early years of transition that boosts real exports and hence leads to an improvement in the trade balance and the current account balance ratios. For instance, the trade balance and the current account balance as shares of GDP increase by around 0.19 percentage points on impact.

Figure 5: Dynamic responses to a public sector employment shock



Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.2. Effects of shocks to tax policy instruments

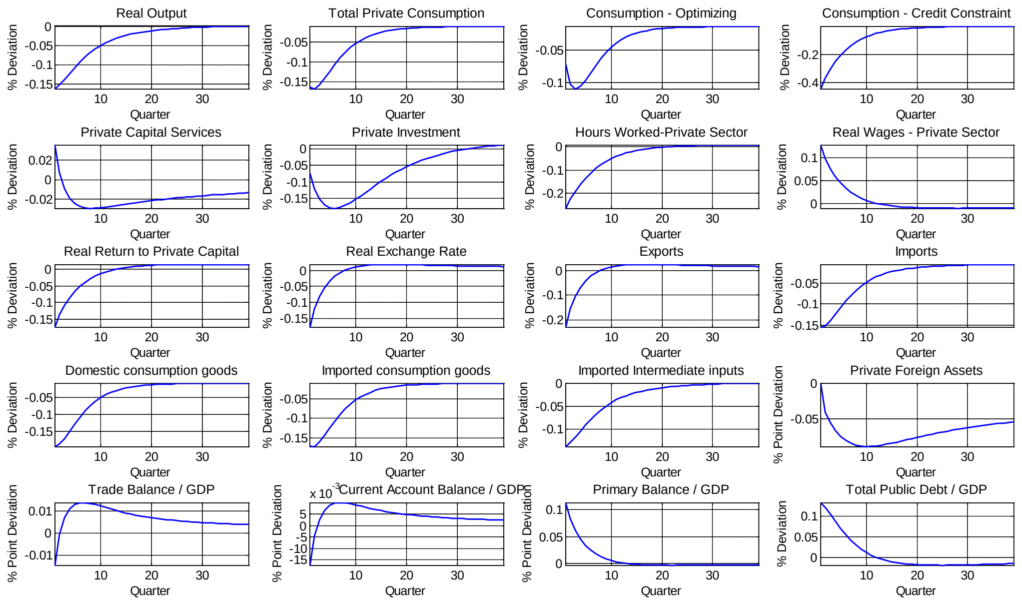
Figures 6-8 show the dynamic effects of transitory, but persistent shocks to the tax rates on consumption, labour income and capital income. The shocks to different tax instruments are set so that to achieve an increase in the different categories of tax revenues by 1% of initial output. The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes.

4.2.1. Effects of shocks to the labour tax rate

Figure 6 depicts the dynamic responses to a persistent shock in the tax rate on labour income. The increase in the labour income tax rate causes a negative wealth effect that induces optimizing households to reduce current consumption and leisure (and thus increase current labour supply). But, at the same time, the higher tax rate reduces the net return to labour inducing an intra-temporal substitution effect that leads households to reduce current labour supply and consumption. As the impulses show, the latter substitution effect dominates, so that labour supply and hours of work fall. Eventually, output decreases and so does private consumption. The impact multiplier for output is estimated at -1.24. At the same time, the decrease in the after-tax labour income forces liquidity constraint households to reduce consumption demand. It is worth noting that the debt-to-output ratio increases during the early years transition (for more than 10 quarters), which reflects the fact that a fiscal consolidation aiming at reducing public debt via increases in labour taxes is not a good idea (see also Forni et al. (2011) and Papageorgiou (2012)).

Regarding the impact of the higher labour tax rate on the variables related to the external sector, we observe a decrease in the real exchange rate in the short run, that is, a real appreciation. The loss in competitiveness causes a sizable reduction in the demand for exports and hence a deterioration in the trade balance in the short run. Nevertheless, the significant fall in imports in the latter years causes an improvement in the trade balance.

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



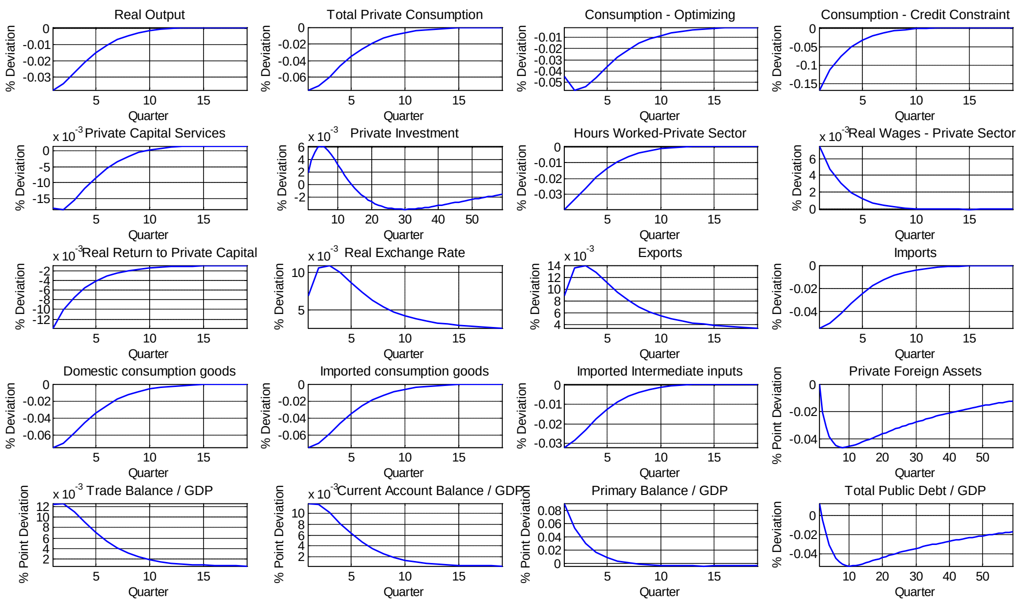
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.2.2. Effects of shocks to the consumption tax rate

Figure 7 illustrates the dynamic responses to a persistent shock in the tax rate on consumption. There is again a negative wealth effect that pushes optimizing households to decrease current consumption and leisure (and thus increase labour supply). At the same time, the higher consumption tax rate induces an intra-temporal substitution effect that leads optimizing households to reduce labour supply and consumption. As the impulses show, the latter substitution effect dominates the former wealth effect, so that labour supply and hours of work fall, together with private consumption. The consumption demand of liquidity constraint households also falls due to the decrease in the disposable income. Consequently, output also falls, while the impact multiplier for output is estimated at -0.49, which is much lower than in the case of an increase in labour taxes.

In contrast to the case of a rise in labour taxes, the increase in the consumption tax rate induces an increase in the real exchange rate, that is, a real depreciation that 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.

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



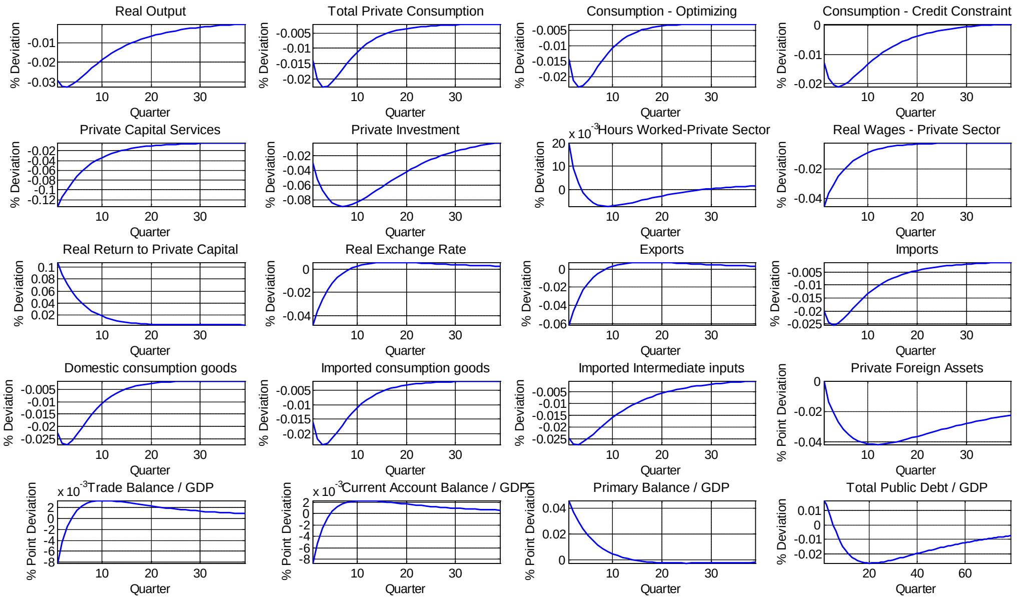
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.2.3. Effects of shocks to the capital income tax rate

Figure 8 summarizes the dynamic responses to a persistent shock in the tax rate on capital income. An increase in the capital income tax rate has a negative wealth effect that pushes optimizing households to decrease current consumption and leisure (and thus increase labour supply). At the same time, the fall in the net return to capital, which reduces private investment and capital over time, produces an inter-temporal substitution effect that leads households to increase current consumption and leisure. As can be seen from Figure 8, the net effect on consumption and leisure is negative so that hours of work rise and consumption falls in the short run. Despite the rise in hours worked, output falls during the transition due to the sizable reduction in capital services. The impact multiplier is estimated at 0.73.

The increase in labour supply reduces the real wage rate, leading to a reduction in the labour of the liquidity constraint households who are forced to reduce consumption demand. The fall in aggregate consumption dampens imports, while at the same time the reduction in the real exchange rate triggers a reduction in exports and hence gives rise to a deterioration in the trade balance in the short run. Finally, it is interesting to point out that, as in the case of higher labour taxes, the debt-to-output rises in the short run due to the contractionary effects that capital taxes have on output.

Figure 8: Dynamic responses to a shock in the tax rate on capital income



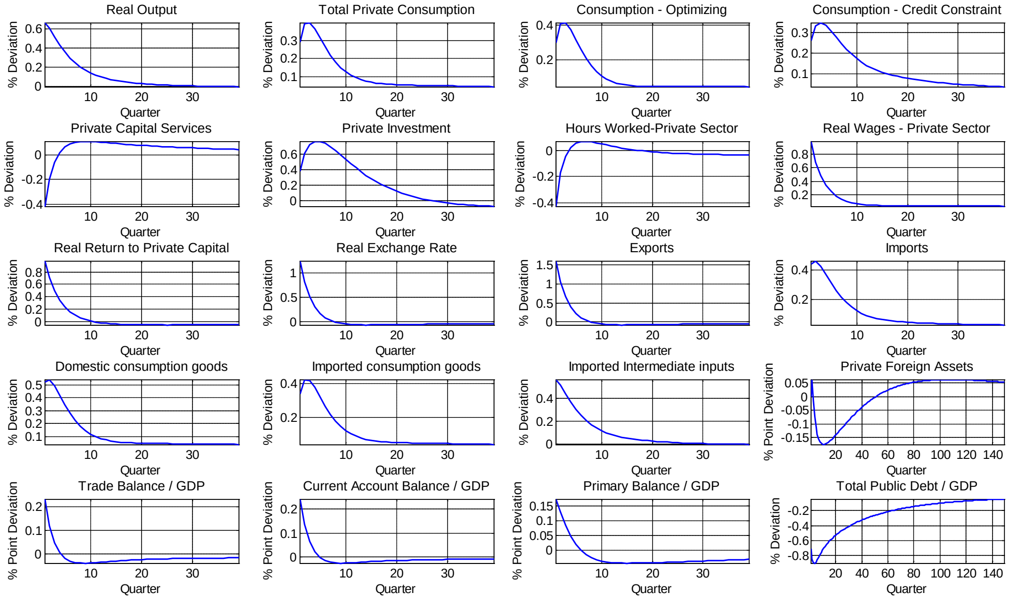
Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

4.3. Effects of shocks to total factor productivity and world output

Figures 9 and 10 depict the dynamic responses to a temporary unitary increase in the innovations of total factor productivity and world output, respectively.

The shock in total factor productivity generates a positive wealth effect that leads optimizing households to increase current consumption and leisure. At the same time, the increase in the marginal productivity of private inputs gives households the incentive to substitute away from leisure and increase consumption. As Figure 9 shows, optimizing households decrease current labour supply, whereas they increase consumption and investment demand. The fall in hours of work triggers a rise in real private sector wages and hence on the disposable income of liquidity constraint households, who in turn, increase consumption purchases. The real interest rate rises in order to restrain the increase in domestic demand and triggers a depreciation of the real exchange rate. In turn, the real depreciation gives rise to an expansion in exports and an improvement in the trade balance, although imports of both consumption goods and intermediate inputs increase. Despite the fall in hours worked and capital services in the short run, the positive technology shock, combined with the higher imported inputs, generate an expansion in output along the dynamic path.

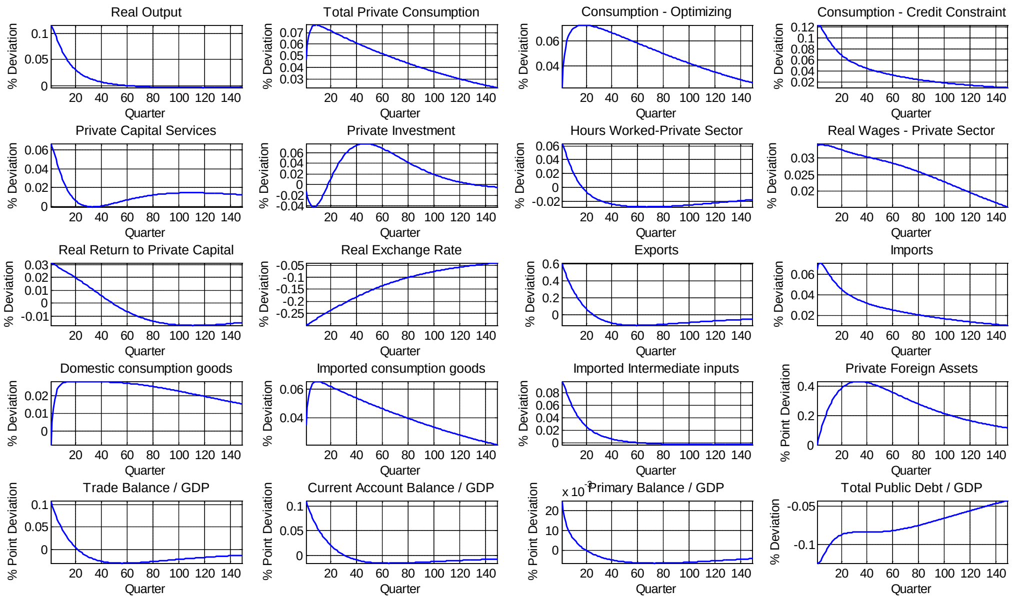
Figure 9: Dynamic responses to a shock in total factor productivity



Notes: (i) The series plotted are percentage deviations from the steady-state, except for the net private foreign assets, the trade balance as share of GDP, the current account balance as share of GDP and the primary balance as share of GDP, which are percentage point changes, (ii) a positive change in the trade balance, the current account balance and the primary balance as shares of GDP means an improvement in these variables.

Figure 10 shows the effects from a rise in world output by 1%. The first order effect is an increase in the demand for exports that induces an expansion in domestic output and a real exchange appreciation. The higher output allows both types of households to increase consumption purchases, whereas the real exchange appreciation shifts the consumption demand towards imported consumption goods. Eventually, there is an improvement in the trade balance and the current account balance ratios in the short run.

Figure 10: Dynamic responses to a shock in world output



5. Concluding remarks

In this paper we have examined the dynamic properties of a DSGE model developed for quantitative policy analysis. The model was calibrated to the Greek economy at a quarterly frequency over the 2000q1-2011q4 period. Our approach in examining the dynamic properties of the model involved using impulse response functions to a number of shocks and analyzing the main transmission channels through which the shocks influence the macroeconomy. The results suggest that reductions in public spending are associated with improvements in fiscal and external imbalances. In terms of output losses, the most desirable way to reduce fiscal and external imbalances is through cuts in public sector wages, government transfers and public sector employment. In contrast, the most harmful option for reducing fiscal and external imbalances seems to be an increase in labour income taxes.

We acknowledge that the model assumes away a number of nominal frictions that have been found important in the data. Adding such features is an interesting extension. Estimating the model and examining its forecasting performance are also important future objectives.

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Appendix: Stationary decentralized competitive equilibrium

All variables (except of hours worked) grow at the constant growth rate γ_z. We thus need to make them stationary. For any per capita variable X_t define $x_t = X_t / Z_t$. Also, define $\tilde{\lambda}_t = \lambda_t / Z_t^{(1-\gamma_2)(1-\sigma)-1}$, while note that q_t does not grow since $q_t = \mu_t / \lambda_t$.

$$\tilde{\lambda}_t = \frac{1}{P_t^c\left(1+\tau_t^c\right)}\gamma_1 \frac{\left[\left(c_t^i - \left(\xi^c/\gamma_z\right)c_{t-1}^i\right)^{\gamma_1}\left(1-h_t\right)^{\gamma_2}\left(y_t^g\right)^{1-\gamma_1-\gamma_2}\right]^{1-\sigma}}{c_t^i - \left(\xi^c/\gamma_z\right)c_{t-1}^i} \tag{A1}$$

$$\frac{\gamma_2}{\gamma_1}\frac{c_t^i - \left(\xi^c/\gamma_z\right)c_{t-1}^i}{1-h_t}\frac{P_t^c\left(1+\tau_t^c\right)}{1-\tau_t^l} = w_t^p \equiv MRS_t \tag{A2}$$

$$\left(1-\tau_t^k\right)r_t^k = q_t\delta^\rho\phi u_t^{\phi-1} \tag{A3}$$

$$\gamma_z\tilde{\lambda}_t = \beta E_t\tilde{\lambda}_{t+1}R_{t+1}^b \tag{A4}$$

$$\gamma_z k_{t+1}^p = \left(1-\delta^\rho u_t^\phi\right)k_t^p + \left[1-\frac{\xi^k}{2}\left(\frac{\gamma_z i_t}{i_{t-1}}-\gamma_z\right)^2\right]i_t \tag{A5}$$

$$R_t^b - R_t = E_t\left(Q_{t+1}/Q_t\right) \tag{A6}$$

$$\gamma_z q_t = \beta\frac{\tilde{\lambda}_{t+1}}{\tilde{\lambda}_t}\left[\left(1-\tau_{t+1}^k\right)\left(r_{t+1}^k u_{t+1}\right) + q_{t+1}\left(1-\delta^\rho u_{t+1}^\phi\right)\right] \tag{A7}$$

$$1 = q_t \left[1 - \frac{\xi^k}{2} \left(\frac{\gamma_z i_t}{i_{t-1}} - \gamma_z \right)^2 - \xi^k \left(\frac{\gamma_z i_t}{i_{t-1}} - \gamma_z \right) \frac{\gamma_z i_t}{i_{t-1}} \right] + \beta \frac{\tilde{\lambda}_{t+1}}{\tilde{\lambda}_t} q_{t+1} \left[\xi^k \left(\frac{\gamma_z i_{t+1}}{i_t} - \gamma_z \right) \gamma_z \left(\frac{i_{t+1}}{i_t} \right)^2 \right] \quad \text{(A8)}$$

where $\beta = \beta^* \gamma_z^{(1-\gamma_2)(1-\sigma)}$

$$\frac{c_t^m}{c_t^d} = \frac{1-\omega}{\omega} Q_t^{-\mu} \left(P_t^c \right)^{\mu} \quad \text{(A9)}$$

$$P_t^c = \left[\omega + (1-\omega) Q_t^{1-\mu} \right]^{\frac{1}{1-\mu}} \quad \text{(A10)}$$

$$c_t = \left[\omega^{\frac{1}{\mu}} \left(c_t^d \right)^{\frac{\mu-1}{\mu}} + (1-\omega)^{\frac{1}{\mu}} \left(c_t^m \right)^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \quad \text{(A11)}$$

$$r_t^k = \frac{\varepsilon - 1}{\varepsilon} \left(a_1 (1-\theta) \frac{y_t + \Phi}{u_t k_t^p} \right) \quad \text{(A12)}$$

$$w_t^p = \frac{\varepsilon - 1}{\varepsilon} \left(a_2 \frac{y_t + \Phi}{h_t^p} \right) \quad \text{(A13)}$$

$$Q_t = \frac{\varepsilon - 1}{\varepsilon} \left(a_1 \theta \frac{y_t + \Phi}{im_t} \right) \quad \text{(A14)}$$

$$w_t^p = \left(w_{t-1}^p \right)^n \left(MRS_t \right)^{1-n} \quad \text{(A15)}$$

$$\begin{aligned} \gamma_z d_{t+1} = g_t^c + g_t^i + w_t^g h_t^g + g_t^{tr} + d_t \left[\gamma_t R_t^b + R_t (1-\gamma_t) \right] - \\ - \tau_t^c p_t^c c_t - \tau_t^l \left(w_t^p h_t^p + w_t^g h_t^g \right) - \tau_t^k \left(r_t^k u_t k_t^p + \Pi_t \right) \end{aligned} \quad \text{(A16)}$$

$$\gamma_z k_{t+1}^g = \left(1 - \delta^g \right) k_t^g + g_t^i \quad \text{(A17)}$$

$$y_t^g = A_t \left(g_t^c \right)^x \left(h_t^g \right)^{1-x} \quad \text{(A18)}$$

$$R_t = R_t^* + \psi^f \left(e^{-\left(\frac{Q_t f_{t+1}}{y_t} - \bar{f} \right)} - 1 \right) + \psi^d \left(e^{\left(\frac{d_{t+1}}{y_t} - \bar{d} \right)} - 1 \right) \quad \text{(A19)}$$

$$y_t = A_t \left[\left(u_t k_t^p \right)^{1-\theta} im_t^{\theta} \right]^{a_1} \left(h_t^p \right)^{a_2} \left(k_t^g \right)^{a_3} - \Phi \quad \text{(A20)}$$

$$\Pi_t = y_t - r_t^k u_t k_t^p - w_t^p h_t^p - Q_t im_t \quad \text{(A21)}$$

$$P_t^c \left(1 + \tau_t^c \right) c_t^j = \left(1 - \tau_t^l \right) \left(w_t^p h_t^p + w_t^g h_t^g \right) + g_t^{tr,j} \quad \text{(A22)}$$

$$c_t = \lambda c_t^j + (1-\lambda) c_t^i \quad \text{(A23)}$$

$$y_t = c_t^d + i_t + g_t^c + g_t^i + x_t \tag{A24}$$

$$h_t = h_t^p + h_t^g \tag{A25}$$

$$Q_t\left(\gamma_z f_{t+1} - R_t f_t\right) = x_t + \left(1-\gamma_{t+1}\right)\gamma_z d_{t+1} - R_t\left(1-\gamma_t\right)d_t - Q_t\left(im_t + c_t^f\right) \tag{A26}$$

$$x_t = Q_t^{\varepsilon^x} y_t^* \tag{A27}$$

$$g_t^{tr,j} = \bar{\lambda} g_t^{tr} \tag{A28}$$

$$g_t^{tr,i} = \left(1-\bar{\lambda}\right) g_t^{tr} \tag{A29}$$

We also define the following equations:

Real imports

$$m_t = Q_t\left(c_t^m + im_t\right) \tag{A30}$$

Trade balance

$$tb_t = x_t - m_t \tag{A31}$$

Current account balance

$$ca_t = tb_t + r_t\left[f_t - \left(1-\gamma_t\right)d_t\right] \tag{A32}$$

where $R_t = 1 + r_t$ (A33)

Primary balance

$$pb_t = \tau_t^c P_t^c c_t + \tau_t^l\left(w_t^p h_t^p + w_t^g h_t^g\right) + \tau_t^k\left(r_t^k u_t k_t + \Pi_t\right) - \left(g_t^c - g_t^i - g_t^{tr} - w_t^g h_t^g\right) \tag{A34}$$

Labour tax revenues

$$ltr_t = \tau_t^l\left(w_t^p h_t^p + w_t^g h_t^g\right) \tag{A35}$$

Consumption tax revenues

$$ctr_t = \tau_t^c P_t^c c_t \tag{A36}$$

Capital tax revenues

$$ktr_t = \tau_t^k\left(r_t^k u_t k_t + \Pi_t\right) \tag{A37}$$

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