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The Portuguese post-2008 period: A narrative from an estimated DSGE model

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Abstract
We present a medium scale small-open DSGE model for an euro-area economy that encompasses a financial accelerator mechanism and a well-developed fiscal block coupled to an overlapping generations scheme. This setup endogenously triggers myopia in households' decisions, breaking the traditional Ricardian equivalence in asset holders. We use Bayesian methods to estimate the model for the Portuguese economy and compute several byproducts of interest—namely historical and variance decompositions and key Bayesian impulse response functions. Finally, we carry out parameter stability tests.

JEL: C11, C13, E20, E32

Keywords: Fiscal policy, Fiscal consolidation, Debt ratio, crisis, DSGE model, Euro Area, Small open economy.

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1. Introduction

We present and estimate a medium scale small-open Dynamic Stochastic General Equilibrium (DSGE) model for the Portuguese economy for the 1999-2015 period, henceforth named PESSOA. The estimated model embodies imperfect market competition and frictions, as most influential references in the field do (*e.g.* Smets and Wouters 2003; Christiano *et al.* 2005; Adolfson *et al.* 2007), and financial frictions *à la* Bernanke *et al.* (1999)—which are explored for instance in Christiano *et al.* 2011. It differs from the mainstream literature by encompassing powerful non-Ricardian features. The lack of access to asset markets by hand-to-mouth households (*à la* Galí *et al.* 2007) strengthens the relationship between current consumption and current disposable income. The overlapping generations scheme, along the lines of Blanchard (1985) and Yaari (1965), together with a magnified life-cycle income profile, endogenously trigger some degree of myopia among otherwise fully Ricardian agents. These features are of particular interest in countries where fiscal policies have triggered important business cycle fluctuations, as it is the case of Portugal. Furthermore, the stochastic finite lifetime framework enables the endogenous determination of the net foreign asset position of the economy in the steady state, by limiting the amount of assets/debt that households can accumulate (Harrison *et al.* 2005) and triggering a positive correlation between public debt and the net foreign debt position.[1]

We take advantage of the highly non-Ricardian setup and estimate, amongst other parameters, the average planning horizon, the average working life, and the share of hand-to-mouth households. Fluctuations in private consumption are to a large extent mimicked by fluctuations in asset holders' consumption—whose estimated share in total population is above 90 percent—rather than by the combination of stable consumption from asset holders with highly volatile consumption from hand-to-mouth households. The overall non-Ricardian behavior of the model is achieved through an estimated average planning horizon of roughly 10 years and an average working life of around 20 years.

Between 2008 and 2013, the Portuguese economy depicted a double dip recession, followed by an economic recovery in the 2014–2015 period. During this time span, Portugal faced a vast set of shocks of distinct origins, from the worldwide financial crisis to the collapse in world trade, from the sovereign debt crisis to the highly volatile import prices and the worldwide GDP growth slowdown. *Ad interim*, fiscal policy played a very active role, first by mitigating the effects triggered by the adverse external environment, and thereafter by

1. The estimated model is a slightly simplified version of *PESSOA*—the DSGE model used at the *Banco de Portugal* for policy analysis and simulation. *PESSOA*'s technical details can be found in Almeida *et al.* 2013a. For examples of applications in a calibrated framework, see Almeida *et al.* (2009, 2010, 2013b) or Castro *et al.* (2013, 2015).

fueling the downturn sparked by the sovereign debt crisis. On top of that, Portugal implemented an economic and financial assistance programme that came into force in mid-2011, aimed at correcting large fiscal imbalances and carrying out structural reforms to increase competitiveness and boost economic growth. We take advantage of several estimation byproducts—namely historical and variance decompositions and key Bayesian impulse response functions—to shed some light on Portuguese business cycle fluctuations, emphasizing the post-2008 period.

Results highlight the vulnerability of the domestic economy to external and financial factors. Shocks impacting the trade balance and risk exhibit persistent macroeconomic effects and are essential to explain GDP fluctuations. Worldwide technology and fiscal shocks play also key roles, the former reflecting a common stochastic trend to Portugal and the remaining euro area and the latter echoing discretionary fiscal policies grounded on several instruments. The 2008–2009 recession was mostly driven by foreign factors, reflecting the collapse in world trade. Fiscal policy performed as a business cycle stabilizer. The 2011-2013 recession was in a first stage triggered by elements of fiscal and financial nature, and in a second stage supported by worldwide technology developments. Fluctuations in private consumption and inflation echo more important contributions from cost-push and fiscal shocks, the former emerging on consumer goods and the latter mirroring changes in indirect taxation. Cost-push shocks offset the effects of the demand-side shocks towards the later part of the horizon, unlinking inflation from the usual co-variability with output.

We perform several model evaluation exercises, and show that the estimated smoothed default probability and smoothed fiscal balance-to-GDP ratio are able to track very closely their data counterparts. The stability evaluation suggests that most parameters remained fairly stable over the 2008–2015 horizon, with the exception of a few highly related with major macroeconomic developments over this period. In the estimated model, the national economy is assumed sufficiently small to have any effect on euro-area macroeconomic aggregates. Monetary policy is exogenously set by the European Central Bank, though we allow for an exogenous nationwide risk premium to create a wedge between domestic and foreign interest rates. The nominal exchange rate is irrevocably set to unity, and trade and financial flows are restricted to euro area countries. The relative version of the law of one price implies that any domestic inflationary process *vis-à-vis* the euro area must be fully canceled out later through a desinflationary process and *vice-versa* in order to keep relative prices unchanged in the long run. The external sector is represented by a Bayesian VAR model encompassing foreign output, interest rates, and inflation.

New Keynesian DSGE models are widely used in macroeconomic analysis due to their strong micro-founded theoretical foundation, emerging as a powerful story-telling device. Until early 2000s, DSGE models were mostly calibrated, due to the lack of well-developed and sufficiently powerful econometric tools and to the computationally intensive burden associated with their estimation. With recent advances in computation, alongside with theoretical developments (*e.g.* Schorfheide 2000), Bayesian methods promptly emerged as a powerful and well-suited method to estimate and quantitatively evaluate medium and large scale DSGE models, triggering a vast literature on the field. Many studies, of which the most well-know is probably the highly influential article of Smets and Wouters (2003), have documented the empirical possibilities of estimated DSGE models, even when compared with more traditional econometric tools. Since then important advances were carried out in the field, both on the methodological ground (*e.g.* Ireland 2004; Fernández-Villaverde and Rubio-Ramírez 2004; Del Negro *et al.* 2007; Ríos-Rull *et al.* 2012) and on the empirical side (*e.g.* Rabanal and Rubio-Ramírez 2005; Lubik and Schorfheide 2006; Smets and Wouters 2005, 2007; Lubik and Schorfheide 2007; Adolfson *et al.* 2007; Fernández-Villaverde and Rubio-Ramírez 2007; Schorfheide 2008). Some articles provide a comprehensive overview, combining methodological synopses in addition to empirical applications (An and Schorfheide 2007). The studies of Christiano *et al.* (2011, 2014) and Christiano *et al.* (2015)—concluding that financial shocks have been a key source of business cycle fluctuations, particularly in the later period—constitute recent influential work on the field. The implementation and estimation of DSGE models has also assumed an important role amongst a number of policy-making institutions, such as the *Riksbank* (Adolfson *et al.* 2008), the *Suomen Pankki* (Kilponen *et al.* 2016), the *Bundesbank* (Gadatsch *et al.* 2015), the European Central Bank (Christoffel *et al.* 2008), the *Banco Central do Brasil* (de Castro *et al.* 2011), or the European Commission (Ratto *et al.* 2009), just to name a few.

The remainder of the article is organized as follows. Section 2 provides a short description of the model. Section 3 discloses the estimation details and main results. Section 4 presents and discusses several byproducts from estimation. Section 5 concludes.

2. The model

PESSOA is a New-Keynesian DSGE model for a monetarily-integrated small open economy. It features a multi-sectoral production structure, non-Ricardian characteristics, imperfect market competition, and a number of nominal and real rigidities that allow for realistic short-run dynamics and create room for welfare-improving stabilization policies. In addition, the model embodies financial frictions *à la* Bernanke *et al.* (1999), whereby financial shocks are transmitted and propagated to the real economy.

Let the monetary union be termed euro area and the monetary authority be named the European Central Bank (ECB). For tractability, trade and financial flows are restricted to euro area countries. The euro area is immune to domestic shocks, a consequence of the small-open economy framework, and domestic interest rates can only deviate from the ECB's reference rate by an exogenous risk premium. The law of one price implies that domestic prices are tied down by the euro-area price level in the long run.

The domestic economy is composed of nine types of agents: households, labor unions, capital goods producers, entrepreneurs, banks, intermediate goods producers (manufacturers), final goods producers (distributors), the government, and foreign agents (the remaining euro area). There are twenty-one structural shocks—either iid or following first-order autoregressive processes—affecting directly the domestic economy. The rest of the euro area is pinned down by a Bayesian VAR *à la* Christiano *et al.* (2011), estimated jointly with the DSGE model and embodying three foreign shocks.

The rest of the section briefly describes the key features of the model.[2]

2.1. Households

Households evolve according to the overlapping generations scheme first proposed in Blanchard (1985). They are subject to stochastic finite lifetimes and face an identical and constant probability of death, independent of age, a (see Frenkel and Razin 1996; Harrison *et al.* 2005; Bayoumi and Sgherri 2006). Population is constant, implying that in each period the number of newborn households equals the number of households that perish. The overlapping generations framework is linked to a life insurance scheme along the lines in Yaari (1965), which ensures net wealth transfers from succumbing households to those that live through the period. Households rent labor services to a labor union, receiving in return an age dependent productivity adjusted wage rate $W_t\Phi_a$, over which they pay a labor income tax $\tau_t^{\mathcal{L}}$. Labor productivity Φ_a is assumed to decay over lifetime at a constant rate χ, allowing aggregation across generations.

Two household types coexist in the model: asset holders or type-$\mathcal{A}$ households, who are able to smooth consumption over lifetime by trading assets; and hand-to-mouth or type-$\mathcal{B}$ households, who have no access to asset markets and therefore consume all their income in each and every period. Let ψ denote the time-invariant share of hand-to-mouth households in a population of unitary measure, and $\mathcal{H} \in \{\mathcal{A}, \mathcal{B}\}$ denote the household type. Both household types derive utility from consumption $C_{a,t}^{\mathcal{H}}$ and leisure $1 - L_{a,t}^{\mathcal{H}}$ according to a constant relative risk aversion utility function. Households discount future events at a higher rate *vis-à-vis* the market, as they face a positive probability of death, $1 - \theta$. Specifically, a representative type-$\mathcal{H}$ household of cohort a maximizes expected lifetime utility

2. We estimate a slightly simplified version of the original *PESSOA* model presented in Almeida *et al.* (2013a) in order to circumvent identifiability issues. Some applications of the original model can be found in Almeida *et al.* (2010) or Almeida *et al.* (2013b).

$$\mathrm{E}_t \sum_{s=0}^{\infty} (\beta\theta)^s U^{\mathcal{H}}_{a+s,t+s}, \quad U^{\mathcal{H}}_{a,t} = \frac{1}{1-\gamma}\left[\left(\frac{C^{\mathcal{H}}_{a,t}}{Hab^{\mathcal{H}}_t}\right)^{\eta_t}(1-L^{\mathcal{H}}_{a,t})^{1-\eta_t}\right]^{1-\gamma}$$

where E_t is the expectation operator, $0 \leq \beta \leq 1$ stands for the standard discount factor, $\gamma > 0$ is the risk aversion coefficient, $\eta_t \in [0,1]$ is a distribution parameter, $Hab^{\mathcal{H}}_t$ stands for type-$\mathcal{H}$ household external habits, $Hab^{\mathcal{A}}_t = \left(C^{\mathcal{A}}_{t-1}/(1-\psi)\right)^{\nu}$ and $Hab^{\mathcal{B}}_t = \left(C^{\mathcal{B}}_{t-1}/\psi\right)^{\nu}$, and $\nu \in [0,1]$ parameterizes the degree of habit persistence. Preference shocks are captured by a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}^{\eta}_t$ in the distribution parameter, *i.e.*

$$\eta_t = \eta + \varepsilon^{\eta}_t,\ \varepsilon^{\eta}_t = \rho^{\eta}(\eta_{t-1} - \eta) + \tilde{\varepsilon}^{\eta}_t$$

where $0 \leq \rho^{\eta} < 1$ and η is a steady-state constant.

Asset holders have four sources of income. First, they are remunerated for labor services rented to labor unions. The after tax labor income is $(1-\tau^{\mathcal{L}}_t)W_t\Phi_a L^{\mathcal{A}}_{a,t}$. Second, they receive dividends totaling $DIV_{a,t}$ from firms and $DU^{\mathcal{A}}_{a,t}$ from labor unions, and transfers $TRG^{\mathcal{A}}_{a,t}$ from the government and $TRX^{\mathcal{A}}_a$ from abroad. Third, they earn interest on bond holdings, in addition to net wealth transfers from succumbing households. Besides foreign bonds $B^*_{a,t}$, there are two types of domestic bonds: those issued by the national government, $B_{a,t}$, and those issued by banks, $B^{\mathcal{BK}}_{a,t}$. Let $\widehat{B}_{a,t} = B_{a,t} + B^{\mathcal{BK}}_{a,t}$. Finally, asset holders receive a remuneration $RBR_{a,t}$ for financial services in the bankruptcy monitoring of firms. On the expenditure side, asset holders buy consumption goods $C^{\mathcal{A}}_{a,t}$ at the price P_t. The domestic interest rate i_t may differ from the euro area's interest rate i^*_t due to a nationwide exogenous risk premium, Ψ_t, assumed to follow a zero-mean first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}^{\Psi}_t$,

$$\Psi_t = \varepsilon^{\Psi}_t,\ \varepsilon^{\Psi}_t = \rho^{\Psi}\Psi_{t-1} + \tilde{\varepsilon}^{\Psi}_t$$

where $0 \leq \rho^{\Psi} < 1$.

The gap between expenditures and income is reflected in changes in their net asset position. Their nominal budget constraint is

$$\begin{aligned} P_t C^{\mathcal{A}}_{a,t} + \widehat{B}_{a,t} + B^*_{a,t} \leq\ & \frac{1}{\theta}\left[i_{t-1}\widehat{B}_{a-1,t-1} + i^*_{t-1}(1+\Psi_{t-1})B^*_{a-1,t-1}\right] \\ &+\ (1-\tau^{\mathcal{L}}_t)W_t\Phi_a L^{\mathcal{A}}_{a,t} + RBR_{a,t} + DIV_{a,t} + DU^{\mathcal{A}}_{a,t} \\ &+\ TRG^{\mathcal{A}}_{a,t} + TRX^{\mathcal{A}}_a \end{aligned}$$

Hand-to-mouth households consume in each and every period their current income, given by the after-tax wage income $(1-\tau_t^{\mathcal{L}})W_t\Phi_a L_{a,t}^{\mathcal{B}}$ plus transfers $TRG_{a,t}^{\mathcal{B}}$ from the government and $TRX_a^{\mathcal{B}}$ from abroad. They receive $DU_{a,t}^{\mathcal{B}}$ from labor unions, but no dividend payments from firms. Their budget constraint is

$$P_t C_{a,t}^{\mathcal{B}} \leq (1-\tau_t^{\mathcal{L}})W_t\Phi_a L_{a,t}^{\mathcal{B}} + DU_{a,t}^{\mathcal{B}} + TRG_{a,t}^{\mathcal{B}} + TRX_a^{\mathcal{B}}$$

After some tedious computations that we do not replicate here (see Almeida *et al.* 2013a for details), it can be shown that aggregate consumption of type-$\mathcal{A}$ cohorts, $C_t^{\mathcal{A}}$, can be expressed as a function of aggregate human and financial wealth,

$$P_t C_t^{\mathcal{A}} = \Theta_t^{-1}(HW_t^{\mathcal{K}} + HW_t^{\mathcal{L}} + FW_t)$$

where Θ_t^{-1}, the marginal propensity to consume out of wealth, is a complicated function of model parameters. Aggregate human wealth stemming from capital is

$$HW_t^{\mathcal{K}} = DIV_t + RBR_t + (1-\psi)\big[DU_t + TRG_t + TRX\big] + \frac{\theta}{i_t}\mathrm{E}_t HW_{t+1}^{\mathcal{K}}$$

and from labor is

$$HW_t^{\mathcal{L}} = (1-\psi)(1-\tau_t^{\mathcal{L}})W_t + \frac{\theta\cdot\chi}{i_t}\mathrm{E}_t HW_{t+1}^{\mathcal{L}}$$

where we assumed that transfers from the government and from abroad and dividends from unions are distributed uniformly across households. Aggregate financial wealth is

$$FW_t = i_{t-1}\widehat{B}_{t-1} + i_{t-1}^*(1+\Psi_{t-1})\widehat{B}_{t-1}^*$$

The optimality condition for bond holdings yields the uncovered interest rate parity, $i_t = (1+\Psi_t)i_t^*$. Finally, the consumption/labor supply choice for type-$\mathcal{B}$ cohorts is

$$\frac{P_t C_t^{\mathcal{B}}}{\psi - L_t^{\mathcal{B}}} = \frac{\eta_t}{1-\eta_t}(1-\tau_t^{\mathcal{L}})W_t$$

which, jointly with the budget constraint

$$P_t C_t^{\mathcal{B}} = (1-\tau_t^{\mathcal{L}})W_t L_t^{\mathcal{B}} + \psi\big[DU_t + TRG_t + TRX\big]$$

pins down the equilibrium pair $\{C_t^{\mathcal{B}}, L_t^{\mathcal{B}}\}$.

Contrary to most general equilibrium models, *PESSOA* has intrinsic non-Ricardian features. Asset holders are not indifferent as to financing government expenditure with tax levies or debt issuance (*i.e.* future taxes); in fact, they strongly prefer debt financing, since future taxes will be largely charged on yet-to-be born generations (Buiter 1988). Part of the debt held by current generations can therefore be used to finance private consumption during their lifetime, instead of being used to face future tax liabilities. Non-Ricardian effects are magnified by the life-cycle income profile, which shifts the proneness of agents towards paying taxes later, when labor income is lower, rather than sooner. Lower values for θ and χ imply respectively a shorter planning horizon and a shorter life-cycle income profile, and therefore stronger responses of households' consumption to fiscal shocks in the short run (see Kumhof and Laxton 2013).[3] The lack of access to asset markets by hand-to-mouth households strengthens the link between households' consumption and disposable income, thus affecting short-run dynamics and triggering larger consumption volatility. Finally, the stochastic finite lifetime framework enables the endogenous determination of the net foreign asset position, limiting the amount of assets/debt that households can accumulate (Harrison *et al.* 2005) and triggering a positive correlation between public debt and the net foreign debt position.

2.2. Labor unions

Labor unions hire labor services from households and rent them to manufacturers operating in the intermediate goods sector. They are perfectly competitive in the input market and monopolistically competitive in the output market, charging a markup to manufacturers and therefore creating a wedge between the wage paid by these firms, V_t, and the wage received by households, W_t. This wedge will henceforth be termed labor wedge. Unions' profits are distributed to households in the form of dividends.

More specifically, there exists a continuum $h \in [0,1]$ of labor unions supplying labor to a continuum $j \in [0,1]$ of manufacturers. Each manufacturer j demands some quantity of each labor variety from union h, $U_t(h,j)$, and aggregate varieties to form an homogeneous labor input $U_t(j)$ according to the following CES specification

$$U_t(j) = \left(\int_0^1 U_t(h,j)^{\frac{1}{1+\sigma_t^{\mathcal{U}}}} \, \mathrm{d}h \right)^{1+\sigma_t^{\mathcal{U}}}$$

3. The prevalence of distortionary taxation on households' consumption, labor, and capital income implies a preference for tax smoothing so as to minimize the intertemporal value of the deadweight loss, something that is achieved by managing the time path of debt, thus also implying a deviation from the Ricardian Equivalence.

where $\sigma_t^{\mathcal{U}} \geq 0$ is a stochastic parameter governing the time-varying wage markup and following a stationary autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{\sigma\mathcal{U}}$

$$\sigma_t^{\mathcal{U}} = \sigma^{\mathcal{U}} + \varepsilon_t^{\sigma\mathcal{U}},\ \varepsilon_t^{\sigma\mathcal{U}} = \rho^{\sigma\mathcal{U}}(\sigma_{t-1}^{\mathcal{U}} - \sigma^{\mathcal{U}}) + \tilde{\varepsilon}_t^{\sigma\mathcal{U}}$$

where $0 \leq \rho^{\sigma\mathcal{U}} < 1$ and $\sigma^{\mathcal{U}}$ is a steady-state constant. The cost minimization problem solved by manufacturers delivers the demand faced by labor union h

$$U_t(h) = \left(\frac{V_t(h)}{V_t}\right)^{-\frac{1+\sigma_t^{\mathcal{U}}}{\sigma_t^{\mathcal{U}}}} U_t \tag{1}$$

where U_t is aggregate labor demand. We obtain sluggish wage adjustment capturing the short-run dynamics present in data by imposing quadratic adjustment costs with the form

$$\Gamma_t^{\mathcal{V}}(h) = \frac{\varphi_{\mathcal{V}}}{2} T_t U_t \left(\frac{V_t(h)}{V_{t-1}(h)} - \pi_{ss}^{\mathcal{V}}\right)^2 \tag{2}$$

where $\pi_{ss}^{\mathcal{V}}$ denotes the steady-state (gross) wage inflation rate, $\varphi_{\mathcal{V}}$ is a sector specific scaling factor and T_t is the technology level. Each labor union selects the wage profile $\{V_{t+s}(h)\}_{s=0}^{\infty}$ that maximizes the expected present discounted value of the dividends stream,

$$\mathrm{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left[(1 - \tau_{t+s}^{\mathcal{L}})\big(V_{t+s}(h) - W_{t+s}\big)U_{t+s}(h) - P_{t+s}\Gamma_{t+s}^{\mathcal{V}}(h)\right]$$

where $\Lambda_{t,t+s} = \Pi_{k=0}^{s} \theta \cdot (i_{t+k})^{-1}$ is the subjective discount factor, subject to the constraints imposed by demand in (1) and adjustment costs in (2). Letting $\pi_t^V = V_t/V_{t-1}$ denote the time t (gross) wage inflation rate and $g_t = T_t/T_{t-1}$ the technology growth rate, the optimal pricing rule mapping wages paid to households W_t to wages charged by unions V_t can be expressed as

$$\frac{V_t}{T_t} = \frac{(1 + \sigma_t^{\mathcal{U}})W_t}{T_t} - P_t \Omega_t^{\mathcal{V}}$$

where

$$\Omega_t^{\mathcal{V}} = \sigma_t^{\mathcal{U}} \varphi_{\mathcal{V}} \left[\left(\pi_t^{\mathcal{V}} - \pi_{ss}^{\mathcal{V}}\right)\pi_t^{\mathcal{V}} - \mathrm{E}_t \frac{1 - \tau_{t+1}^{\mathcal{L}}}{1 - \tau_t^{\mathcal{L}}} \frac{\theta \cdot g_t}{r_t} \frac{U_{t+1}}{U_t} \left(\pi_{t+1}^{\mathcal{V}} - \pi_{ss}^{\mathcal{V}}\right)\pi_{t+1}^{\mathcal{V}}\right]$$

is a sluggish-adjustment factor. The element $r_t = i_t/\mathrm{E}_t \pi_{t+1}$ denotes the *ex-ante* real interest rate.

2.3. The non-financial block

This subsection describes capital goods producers, manufacturers and distributors. Capital goods producers are perfectly competitive in both input and output markets, whilst manufacturers and distributors operate in a monopolistically competition environment in the output market.

In what follows we use the convention that K_t represents the stock of capital that is actually used by manufacturers in period t. This quantity is decided one period in advance, *i.e.*, the manufacturers' demand for K_t is decided at $t-1$. The quantity $\bar{K}_t$ represents the total physical capital stock of the economy at t, fabricated by capital goods producers and owned by entrepreneurs during the production cycle. This may differ from the capital stock that is actually used in production since entrepreneurs adjust capital utilization, u_t. Hence, $K_t = u_t \bar{K}_t$.

2.3.1. Capital goods producers. There is a continuum of capital goods producers indexed by $i \in [0,1]$. At the end of each period t, capital goods producer i purchases the undepreciated fraction of previously installed capital from entrepreneurs $(1-\delta)\bar{K}_t(i)$ and combine it with investment goods bought from investment goods producers $I_t(i)$ to produce new installed capital to be used at $t+1$, $\bar{K}_{t+1}(i)$, according to the following law of motion

$$\bar{K}_{t+1}(i) = (1-\delta)\bar{K}_t(i) + (1+\zeta_t)I_t(i) \tag{3}$$

where δ is the depreciation rate and ζ_t is a zero-mean investment efficiency shock following a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{\zeta}$,

$$\zeta_t = \varepsilon_t^{\zeta}, \varepsilon_t^{\zeta} = \rho^{\zeta}\zeta_{t-1} + \tilde{\varepsilon}_t^{\zeta}$$

with $0 \leq \rho^{\zeta} < 1$. We impose a sluggish pattern for investment, consistent with data, by assuming quadratic adjustment costs with the form

$$\Gamma_t^{\mathcal{I}}(i) = \frac{\varphi_{\mathcal{I}}}{2} I_t \left(\frac{I_t(i)/g_t}{I_{t-1}(i)} - 1 \right)^2 \tag{4}$$

where I_t denotes period t aggregate investment and $\varphi_{\mathcal{I}}$ is a scaling factor. Capital goods producer i select the intertemporal profile $\{I_{t+s}(i)\}_{s=0}^{\infty}$ that maximizes the expected net present value of the dividends stream,

$$\mathrm{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left[Q_{t+s}^{\mathcal{K}} \zeta_{t+s}^{\mathcal{I}} I_{t+s}(i) - \left(I_{t+s}(i) + \Gamma_{t+s}^{\mathcal{I}}(i) \right) \right]$$

where $Q_t^{\mathcal{K}}$ stands for Tobin's Q, subject to the law of motion in (3) and to adjustment costs in (4), and taking all prices as given. Taxes on capital are paid by entrepreneurs, since they are the capital holders in this economy. The inverse demand for investment goods, identical for all capital goods producers, is, after rearrangements,

$$Q_t^{\mathcal{K}}\zeta_t = 1 + \Omega_t^{\mathcal{I}}$$

where

$$\Omega_t^{\mathcal{I}} = \varphi_{\mathcal{I}}\left[\left(\frac{I_t}{g_t \cdot I_{t-1}} - 1\right)\frac{I_t}{g_t \cdot I_{t-1}} - \mathrm{E}_t \frac{\theta}{g_t \cdot r_t}\frac{\pi_{t+1}^{\mathcal{I}}}{\pi_{t+1}}\left(\frac{I_{t+1}}{g_t \cdot I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right]$$

is a sluggish-adjustment factor and $\pi_t^{\mathcal{I}}/\pi_t$ stands for ratio between period's t investment goods inflation, $\pi_t^{\mathcal{I}} = P_t^{\mathcal{I}}/P_{t-1}^{\mathcal{I}}$, and after-tax consumer goods inflation, $\pi_t = P_t/P_{t-1}$.

2.3.2. Intermediate goods producers. There is a continuum of manufacturing firms $j \in [0,1]$, each producing a specific variety of the intermediate good, which is bought by a continuum of distributor firms $f \in [0,1]$ operating in sectors $\mathcal{F} \in \{\mathcal{C}, \mathcal{G}, \mathcal{I}, \mathcal{X}\}$. Let $Z_t^{\mathcal{F}}(j,f)$ stand for the time t quantity of variety j produced by firm j and purchased by distributor f operating in sector $\mathcal{F}$. Distributors buy intermediate goods from many manufacturers, bundling them together in a homogeneous intermediate good, $Z_t^{\mathcal{F}}(f)$, according to

$$Z_t^{\mathcal{F}}(f) = \left(\int_0^1 Z_t^{\mathcal{F}}(j,f)^{\frac{1}{1+\sigma^{\mathcal{Z}}}}\,\mathrm{d}j\right)^{1+\sigma^{\mathcal{Z}}}$$

where $\sigma^{\mathcal{Z}} \geq 0$ is the time-invariant intermediate goods price markup. The solution for the cost minimization problem yields the familiar demand function, after aggregation

$$Z_t(j) = \left(\frac{P_t^{\mathcal{Z}}(j)}{P_t^{\mathcal{Z}}}\right)^{-\frac{1+\sigma^{\mathcal{Z}}}{\sigma^{\mathcal{Z}}}} Z_t \qquad (5)$$

where Z_t is the aggregate demand for the intermediate good and $P_t^{\mathcal{Z}}(j)/P_t^{\mathcal{Z}}$ is the relative price level of manufacturer j *vis-à-vis* the aggregate price. Each manufacturing firm j combines labor services $U_t(j)$ with capital $K_t(j)$ according to the following labor-augmenting technology

$$Z_t(j) = \left(K_t(j)\right)^{1-\alpha^{\mathcal{U}}}\left(T_t A_t U_t(j)\right)^{\alpha^{\mathcal{U}}} \qquad (6)$$

where $0 \leq \alpha^{\mathcal{U}} \leq 1$ is a distribution parameter. The model encompasses a stochastic unit root labor-augmenting technology component with a drift

$$\log T_t = \log T_{t-1} + g_t,\ g_t = g + \varepsilon_t^g,\ \varepsilon_t^g = \rho^g(g_{t-1} - g) + \tilde{\varepsilon}_t^g$$

where $0 \leq \rho^g < 1$, g is the steady-state technology growth rate and $\tilde{\varepsilon}_t^T$ is an iid-normal error term; and a stationary labor-augmenting technology shock following an autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^A$,

$$A_t = A + \varepsilon_t^A,\ \varepsilon_t^A = \rho^A (A_{t-1} - A) + \tilde{\varepsilon}_t^A$$

where $0 \leq \rho^A < 1$ and A is a steady-state constant. The unit root technology shock will also be termed worldwide technology shock hereinafter, since it impacts foreign output (see Section 2.6). Price changes are subject to quadratic adjustment costs of the type

$$\Gamma_t^{P\mathcal{Z}}(j) = \frac{\varphi_{P\mathcal{Z}}}{2} Z_t \left(\frac{P_t^{\mathcal{Z}}(j)}{P_{t-1}^{\mathcal{Z}}(j)} - \pi_{ss}^{\mathcal{Z}} \right)^2 \tag{7}$$

where $\pi_{ss}^{\mathcal{Z}}$ stands for the steady-state (gross) intermediate goods price inflation. On the real side, a sluggish adjustment of hours worked is ensured through the following quadratic adjustment cost function

$$\Gamma_t^{\mathcal{U}}(j) = \frac{\varphi_{\mathcal{U}}}{2} U_t \left(\frac{U_t(j)}{U_{t-1}(j)} - 1 \right)^2 \tag{8}$$

where U_t denotes time t aggregate labor demand. The parameters $\varphi_{P\mathcal{Z}}$ and $\varphi_{\mathcal{U}}$ are sector specific scaling factor determining the magnitude of adjustment costs.

Capital is accumulated by entrepreneurs and rented to manufacturers at a unitary nominal rental rate of $R_t^{\mathcal{K}}$. Manufacturers are perfectly competitive in the input market and monopolistically competitive in the output market, charging a markup over the marginal cost. They pay a capital income tax $\tau_t^{\mathcal{K}}$, and a social security tax on their payroll, $\tau_t^{\mathcal{SP}}$. Each manufacturer j sets labor demand $U_t(j)$, capital demand $K_{t+1}(j)$, and the price $P_t^{\mathcal{Z}}(j)$ in each period in order to maximize the present discounted value of the dividends stream,

$$\begin{aligned} \mathrm{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} (1 - \tau_{t+s}^{\mathcal{K}}) \Big[P_{t+s}^{\mathcal{Z}}(j) Z_{t+s}(j) - R_{t+s}^{\mathcal{K}} K_{t+s}(j) \\ - (1 + \tau_{t+s}^{\mathcal{SP}}) V_{t+s} \left(U_{t+s}(j) + \Gamma_{t+s}^{\mathcal{U}}(j) \right) - P_{t+s}^{\mathcal{Z}} \left(\Gamma_{t+s}^{P\mathcal{Z}}(j) + T_{t+s} \varpi^{\mathcal{Z}} \right) \Big] \end{aligned}$$

where $P_t^{\mathcal{Z}} T_t \varpi^{\mathcal{Z}}$ is a quasi-fixed cost, subject to variety j demand in (5), to the production technology in (6), and to adjustment costs in (7) and (8). The price equation, identical for all j, collapses to

$$P_t^{\mathcal{Z}} = (1 + \sigma^{\mathcal{Z}}) \frac{P_t \lambda_t^{\mathcal{Z}}}{1 + \Omega_t^{P\mathcal{Z}}}$$

where

$$\Omega_t^{P\mathcal{Z}} = \sigma^{\mathcal{Z}} \varphi_{P\mathcal{Z}} \left[\left(\pi_t^{\mathcal{Z}} - \pi_{ss}^{\mathcal{Z}} \right) \pi_t^{\mathcal{Z}} - \mathrm{E}_t \frac{\theta}{r_t} \frac{1 - \tau_{t+1}^{\mathcal{K}}}{1 - \tau_t^{\mathcal{K}}} \frac{Z_{t+1}}{Z_t} \left(\pi_{t+1}^{\mathcal{Z}} - \pi_{ss}^{\mathcal{Z}} \right) \left(\pi_{t+1}^{\mathcal{Z}} \right)^2 \right]$$

is a sluggish-adjustment factor, $\lambda_t^{\mathcal{Z}}$ is the real marginal cost of producing one additional unit of the intermediate good and $\pi_t^{\mathcal{Z}} = P_t^{\mathcal{Z}}/P_{t-1}^{\mathcal{Z}}$ denotes the (gross) intermediate goods inflation rate. Inverse labor demand can be expressed as

$$(1+\tau_t^{\mathcal{SP}})V_t = \frac{P_t\lambda_t^{\mathcal{Z}}}{1+\Omega_t^{\mathcal{U}}}\left(\frac{\alpha^{\mathcal{U}}Z_t}{U_t}\right)$$

where

$$\Omega_t^{\mathcal{U}} = \varphi_{\mathcal{U}}\left[\left(\frac{U_t}{U_{t-1}}-1\right)\frac{U_t}{U_{t-1}} - \mathrm{E}_t\frac{\theta}{r_t}\frac{1-\tau_{t+1}^{\mathcal{K}}}{1-\tau_t^{\mathcal{K}}}\frac{1+\tau_{t+1}^{\mathcal{SP}}}{1+\tau_t^{\mathcal{SP}}}\frac{\pi_{t+1}^{\mathcal{Z}}}{\pi_{t+1}}\left(\frac{U_{t+1}}{U_t}-1\right)\left(\frac{U_{t+1}}{U_t}\right)^2\right]$$

is a sluggish-adjustment factor. Finally, capital demand is defined implicitly by

$$\mathrm{E}_t\frac{\theta}{r_t}\left(R_{t+1}^{\mathcal{K}} - P_t\lambda_{t+1}^{\mathcal{Z}}\frac{(1-\alpha_{\mathcal{U}})Z_{t+1}}{K_{t+1}}\right) = 0$$

2.3.3. Final goods producers. Distributors produce four types of final goods, each acquired by a unique type of costumer. Consumption goods ($\mathcal{C}$) are acquired by households, investment goods ($\mathcal{I}$) by capital goods producers, government consumption goods ($\mathcal{G}$) by the government, and export goods ($\mathcal{X}$) by foreign distributors.

For each type of final good $\mathcal{F} \in \{\mathcal{C},\mathcal{G},\mathcal{I},\mathcal{X}\}$ there is a continuum of distributors $f \in [0,1]$, each producing a specific variety of the good. For each costumer type $\mathcal{E} \in \{\mathcal{C},\mathcal{G},\mathcal{I},\mathcal{X}\}$ there is a continuum of agents $e \in [0,1]$, demanding many varieties of the good. Let $Y_t^{\mathcal{F}}(f,e)$ stand for the time t quantity of variety f from the final good $\mathcal{F}$ purchased by costumer e. Each agent bundles the different varieties of the final good together to form an homogeneous consumption good $Y_t^{\mathcal{F}}(e)$ according to the CES specification

$$Y_t^{\mathcal{F}}(e) = \left(\int_0^1 Y_t^{\mathcal{F}}(f,e)^{\frac{1}{1+\sigma_t^{\mathcal{F}}}}\,\mathrm{d}f\right)^{1+\sigma_t^{\mathcal{F}}}$$

where the time-varying final goods price markup $\sigma_t^{\mathcal{F}} \geq 0$ is a stochastic parameter with an iid-normal error term, $\sigma_t^{\mathcal{F}} = \sigma^{\mathcal{F}} + \varepsilon_t^{\sigma\mathcal{F}}$, with $\sigma^{\mathcal{F}}$ denoting a steady-state constant. The demand for variety f faced by a distributor operating in sector $\mathcal{F}$ is therefore

$$Y_t^{\mathcal{F}}(f) = \left(\frac{P_t^{\mathcal{F}}(f)}{P_t^{\mathcal{F}}}\right)^{-\frac{1+\sigma_t^{\mathcal{F}}}{\sigma_t^{\mathcal{F}}}} Y_t^{\mathcal{F}} \tag{9}$$

where $Y_t^{\mathcal{F}}$ is the aggregate demand for sector $\mathcal{F}$ final good and $P_t^{\mathcal{F}}(f)/P_t^{\mathcal{F}}$ the relative price level of distributor f *vis-à-vis* the aggregate price level. Each distributor f operating in sector $\mathcal{F}$ combines domestic intermediate goods $Z_t^{\mathcal{F}}(f)$ with imported goods $M_t^{\mathcal{F}}(f)$ according to the following technology

$$Y_t^{\mathcal{F}}(f) = \left((\alpha^{\mathcal{F}})^{\frac{1}{\xi_{\mathcal{F}}}} \left(Z_t^{\mathcal{F}}(f)\right)^{\frac{\xi_{\mathcal{F}}-1}{\xi_{\mathcal{F}}}} + (1-\alpha^{\mathcal{F}})^{\frac{1}{\xi_{\mathcal{F}}}} \left[A_t^{\mathcal{M}} M_t^{\mathcal{F}}(f)(1-\Gamma_t^{\mathcal{F}}(f)) \right]^{\frac{\xi_{\mathcal{F}}-1}{\xi_{\mathcal{F}}}} \right)^{\frac{\xi_{\mathcal{F}}}{\xi_{\mathcal{F}}-1}} \quad (10)$$

where $\xi_{\mathcal{F}} \geq 0$ is the elasticity of substitution between domestic intermediate goods and imported goods for a distributor operating in sector $\mathcal{F}$, and $0 \leq \alpha^{\mathcal{F}} \leq 1$ is the home bias parameter. We impose the following quadratic adjustment cost function on changes in the import content

$$\Gamma_t^{\mathcal{F}}(f) = \frac{\varphi_{\mathcal{F}}}{2} \frac{\left(\mathcal{A}_t^{\mathcal{F}}(f) - 1\right)^2}{1 + \left(\mathcal{A}_t^{\mathcal{F}}(f) - 1\right)^2}, \quad \mathcal{A}_t^{\mathcal{F}}(f) = \frac{M_t^{\mathcal{F}}(f)/Y_t^{\mathcal{F}}(f)}{M_{t-1}^{\mathcal{F}}/Y_{t-1}^{\mathcal{F}}} \quad (11)$$

where $\varphi_{\mathcal{F}}$ is a sector specific scaling factor. The element $A_t^{\mathcal{M}}$ in Equation (10) is a stationary imports efficiency technology shock that follows a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{A\mathcal{M}}$

$$A_t^{\mathcal{M}} = A^{\mathcal{M}} + \varepsilon_t^{A\mathcal{M}}, \ \varepsilon_t^{A\mathcal{M}} = \rho^{A\mathcal{M}}(A_{t-1}^{\mathcal{M}} - A^{\mathcal{M}}) + \tilde{\varepsilon}_t^{A\mathcal{M}}$$

where $0 \leq \rho^{A\mathcal{M}} < 1$ and $A^{\mathcal{M}}$ denotes a steady-state constant. Distributors pay also adjustment costs when updating prices, according to the following quadratic specification

$$\Gamma_t^{P\mathcal{F}}(f) = \frac{\varphi_{P\mathcal{F}}}{2} Y_t^{\mathcal{F}} \left(\frac{P_t^{\mathcal{F}}(f)}{P_{t-1}^{\mathcal{F}}(f)} - \pi_{ss}^{\mathcal{F}} \right)^2 \quad (12)$$

where $\pi_{ss}^{\mathcal{F}}$ stands for sector $\mathcal{F}$ steady-state price inflation and $\varphi_{P\mathcal{F}}$ determines the magnitude of price adjustment costs for firms operating in sector $\mathcal{F}$.

Distributors are perfectly competitive in the input market and monopolistically competitive in the output market. They pay capital income taxes on profits, $\tau_t^{\mathcal{D}}$ and distribute dividends to asset holders. Each distributor selects intermediate goods demand $Z_t^{\mathcal{F}}(f)$, imported goods demand $M_t^{\mathcal{F}}(f)$, and the price $P_t^{\mathcal{F}}(f)$ in each period in order to maximize the present discounted value of the dividends stream,

$$\begin{aligned} \mathrm{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s}(1 - \tau_{t+s}^{\mathcal{D}}) \Big[& P_{t+s}^{\mathcal{F}}(f) Y_{t+s}^{\mathcal{F}}(f) - P_{t+s}^{\mathcal{Z}} Z_{t+s}^{\mathcal{F}}(f) \\ & -(1 + \tilde{\varepsilon}_{t+s}^{\mathcal{M}}) P_{t+s}^{*} M_{t+s}^{\mathcal{F}}(f) - P_{t+s}^{\mathcal{F}} \big(\Gamma_{t+s}^{P\mathcal{F}}(f) + T_{t+s} \varpi^{\mathcal{F}}\big) \Big] \end{aligned}$$

subject to variety f demand in (9), to technology in (10), and to adjustment costs in (11) and (12). The element $P_t^{\mathcal{F}} T_t \varpi^{\mathcal{F}}$ is a quasi-fixed cost, P_t^* is the foreign price level, and $\tilde{\varepsilon}_t^{\mathcal{M}}$ is a tax-like iid-normal markup shock on the price of imported goods. The price equation, identical for all f, collapses to

$$P_t^{\mathcal{F}} = (1+\sigma_t^{\mathcal{F}})\frac{P_t\lambda_t^{\mathcal{F}}}{1+\Omega_t^{P\mathcal{F}}}$$

where

$$\Omega_t^{P\mathcal{F}} = \sigma_t^{\mathcal{F}}\varphi_{P\mathcal{F}}\left[\left(\pi_t^{\mathcal{F}}-\pi_{ss}^{\mathcal{F}}\right)\pi_t^{\mathcal{F}} - \mathrm{E}_t\frac{\theta}{r_t}\frac{1-\tau_{t+1}^{\mathcal{D}}}{1-\tau_t^{\mathcal{D}}}\frac{Y_{t+1}^{\mathcal{F}}}{Y_t^{\mathcal{F}}}\left(\pi_{t+1}^{\mathcal{F}}-\pi_{ss}^{\mathcal{F}}\right)\left(\pi_{t+1}^{\mathcal{F}}\right)^2\right]$$

is a sluggish-adjustment factor, $\lambda_t^{\mathcal{F}}$ is the real marginal cost of producing one additional unit of the final good and $\pi_t^{\mathcal{F}} = P_t^{\mathcal{F}}/P_{t-1}^{\mathcal{F}}$ denotes sector F's (gross) inflation rate. The demand for manufactured goods is

$$Z_t^{\mathcal{F}} = \alpha^{\mathcal{F}}\left(\frac{p_t^{\mathcal{Z}}}{\lambda_t^{\mathcal{F}}}\right)^{-\xi_{\mathcal{F}}} Y_t^{\mathcal{F}}$$

while the demand for imported goods can be expressed as

$$M_t^{\mathcal{F}}(1-\Gamma_t^{\mathcal{F}}) = (1-\alpha^{\mathcal{F}})\left(\frac{(1+\tilde{\varepsilon}_t^{\mathcal{M}})\vartheta_t}{\lambda_t^{\mathcal{F}}\cdot\iota_t^{\mathcal{F}}}\right)^{-\xi_{\mathcal{F}}} Y_t^{\mathcal{F}}$$

where $\vartheta_t = P_t^*/P_t$ is the real exchange rate and

$$\iota_t^{\mathcal{F}} = 1-\Gamma_t^{\mathcal{F}} - M_t^{\mathcal{F}}\left(\frac{\varphi_{\mathcal{F}}}{M_t^{\mathcal{F}}}\frac{(\mathcal{A}_t^{\mathcal{F}}-1)\mathcal{A}_t^{\mathcal{F}}}{[1+(\mathcal{A}_t^{\mathcal{F}}-1)^2]^2}\right)$$

is a sluggish adjustment factor.

2.4. The entrepreneurial and financial sectors

There is a continuum of infinitely lived entrepreneurial firms $l \in [0,1]$. At the end of each period, entrepreneurs buy the new capital stock from capital goods producers and rent it, partially or entirely, to manufacturers, for usage in the production process. The entrepreneurial firm l selects the capital utilization rate, $u_t(l)$ in each period to maximize the net return per unit of capital, $(1-\tau_t^{\mathcal{K}})\big[R_t^{\mathcal{K}}u_t(l) - P_t a\big(u_t(l)\big)\big]$, where $\tau_t^{\mathcal{K}}$ is the capital income tax rate. The cost of capital utilization $a\big(u_t(l)\big)$ takes the following functional form

$$a\big(u_t(l)\big) = \frac{1}{2}\varphi_a\sigma_a\big(u_t(l)\big)^2 + \varphi_a(1-\sigma_a)u_t(l) + \varphi_a\left(\frac{\sigma_a}{2}-1\right)$$

where $\varphi_a > 0$ is calibrated to ensure a unitary capital utilization in the steady state and $\sigma_a > 0$ is a parameter that controls the curvature. The first-order condition, identical for all l, yields the equilibrium real rental rate of capital

$$R_t^{\mathcal{K}} = P_t\left[\varphi_a\sigma_a u_t + \varphi_a(1-\sigma_a)\right]$$

The resource cost associated with variable capital utilization is $RCU_t = P_t a(u_t)\bar{K}_t$. Entrepreneurs do not have access to sufficient internal funds, $N_t(l)$, to finance desired capital purchases, but can cover the funding gap by borrowing $B_t(l)$ from banks at the gross interest rate i_t^B. They face the following balance sheet constraint

$$P_t^{\mathcal{K}}\bar{K}_{t+1}(l) = B_t(l) + N_t(l)$$

where $P_t^{\mathcal{K}}$ is the market price of capital. After purchasing new capital from capital goods producers (but before selecting the utilization rate), entrepreneurs experience an idiosyncratic shock ω_{t+1}^l,

$$\ln \omega_{t+1}^l \sim \mathcal{N}\left(-\frac{1}{2}(\sigma_{t+1}^{\mathcal{E}})^2, (\sigma_{t+1}^{\mathcal{E}})^2\right)$$

distributed independently over time and across entrepreneurs, that changes the capital stock from $\bar{K}_{t+1}(l)$ to $\omega_{t+1}^l\bar{K}_{t+1}(l)$, creating a risky environment. The standard deviation $\sigma_{t+1}^{\mathcal{E}}$ follows itself a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_{t+1}^{\sigma\mathcal{E}}$

$$\sigma_{t+1}^{\mathcal{E}} = \sigma^{\mathcal{E}} + \varepsilon_{t+1}^{\sigma\mathcal{E}},\ \varepsilon_{t+1}^{\sigma\mathcal{E}} = \rho^{\sigma\mathcal{E}}(\sigma_{t+1}^{\mathcal{E}} - \sigma^{\mathcal{E}}) + \tilde{\varepsilon}_{t+1}^{\sigma\mathcal{E}}$$

with $0 \le \rho^{\sigma\mathcal{E}} < 1$ and $\sigma^{\mathcal{E}}$ denotes a steady-state constant. Let $\mathfrak{F}_t(x) = \Pr[\omega_{t+1} < x]$ denote the cumulative distribution function and $\mathfrak{f}_t(x)$ the corresponding probability density function of ω_{t+1}. There exists an endogenous threshold level $\bar{\omega}_{t+1}^l$ for the idiosyncratic shock

$$\bar{\omega}_{t+1}^l Ret_t^{\mathcal{K}} P_t^{\mathcal{K}}\bar{K}_{t+1}(l) = i_t^B(l)B_t(l)$$

below which the expected value of the capital stock does not suffice to meet all debt obligations and the entrepreneur declares bankruptcy. Entrepreneurs *ex-ante* after-tax return on capital is

$$Ret_t^{\mathcal{K}} = \mathrm{E}_t \frac{(1-\tau_{t+1}^{\mathcal{K}})\left[R_{t+1}^{\mathcal{K}}u_{t+1} - P_{t+1}a(u_{t+1})\right] + (1-\delta)P_{t+1}^{\mathcal{K}} + \tau_{t+1}^{\mathcal{K}}\delta P_{t+1}^{\mathcal{K}}}{P_t^{\mathcal{K}}}$$

which reflects the expected income from the rental activity net of tax deductions in addition to changes in the market value of capital. Maximizing the value of the firm is equivalent to maximize the expected value of assets over the non-default region

$$\int_{\bar{\omega}_{t+1}^l}^{\infty} (\omega_{t+1}^l - \bar{\omega}_{t+1}^l) Ret_t^{\mathcal{K}} P_t^{\mathcal{K}}\bar{K}_{t+1}(l)\mathfrak{f}(\omega_{t+1}^l)\mathrm{d}\omega_{t+1}^l$$

Each entrepreneur l signs a standard one-period debt contract with the bank in each period t, defining the total amount borrowed $B_t(l)$ and the state-contingent gross interest rate $i_t^B(l)$, to be paid at period $t+1$. Banks operate in a perfectly competitive environment, making zero *ex-ante* and *ex-post* profits at all times. Since capital acquisitions are risky, so are the loans of banks, who therefore charge a spread over the risk free rate to cover for bankruptcy losses from non-performing entrepreneurs. The existence of identical *a priori* expectations on the idiosyncratic shock implies that the credit spread is identical for all entrepreneurs. Even though individual loans are risky, the aggregate portfolio of banks is risk free, since each bank is assumed to lend to many entrepreneurs, thus recovering through the credit spread what is lost to bankrupt entrepreneurs. Households loans are therefore risk free at all times, and thus they lend to banks at the risk free rate. The banks' participation constraint in the debt contract corresponds therefore to the *ex-ante* zero-profit condition, given by

$$[1-\mathfrak{F}(\bar{\omega}_{t+1}^l)]i_t^B(l)B_t(l)+(1-\mu)\int_0^{\bar{\omega}_{t+1}^l}\omega_{t+1}^l Ret_t^{\mathcal{K}}P_t^{\mathcal{K}}\bar{K}_{t+1}(l)\mathfrak{f}(\omega_{t+1}^l)\mathrm{d}\omega_{t+1}^l = i_t B_t(l)$$

where $1-\mu$ is the recovery rate in case of default. The left-hand side corresponds to the expected banks' income, and is composed of the gross interest paid by performing firms plus the recovered value of non-performing firms. The right-hand side corresponds to banks' outstanding debt, which are exclusively held by asset holders. The entrepreneurs' problem can be restated as the maximization of

$$\left[1-\Gamma(\bar{\omega}_{t+1}^l)\right]Ret_t^{\mathcal{K}}P_t^{\mathcal{K}}\bar{K}_{t+1}(l)$$

subject to

$$\left[\Gamma(\bar{\omega}_{t+1}^l)-\mu G(\bar{\omega}_{t+1}^l)\right]Ret_t^{\mathcal{K}}P_t^{\mathcal{K}}\bar{K}_{t+1}(l)=i_t\left[P_t^{\mathcal{K}}\bar{K}_{t+1}(l)-N_t(l)\right]$$

where

$$\Gamma_{t+1}\equiv\Gamma(\bar{\omega}_{t+1}^l)\equiv\int_0^{\bar{\omega}_{t+1}^l}\omega_{t+1}^l\mathfrak{f}(\omega_{t+1}^l)\mathrm{d}\omega_{t+1}^l+\bar{\omega}_{t+1}^l\int_{\bar{\omega}_{t+1}^l}^{\infty}\mathfrak{f}(\omega_{t+1}^l)\mathrm{d}\omega_{t+1}^l$$

and

$$G_{t+1}\equiv G(\bar{\omega}_{t+1}^l)\equiv\int_0^{\bar{\omega}_{t+1}^l}\omega_{t+1}^l\mathfrak{f}(\omega_{t+1}^l)\mathrm{d}\omega_{t+1}^l$$

The first-order condition with respect to optimal capital purchases, identical to all entrepreneurs, defines the link between the threshold level $\bar{\omega}_{t+1}$ and the after-tax return on capital $Ret_t^{\mathcal{K}}$

$$\left(1-\Gamma_{t+1}\right)\frac{Ret_t^{\mathcal{K}}}{i_t}+\left(\frac{\left(\Gamma_{t+1}\right)'}{\left(\Gamma_{t+1}\right)'-\mu\left(G_{t+1}\right)'}\right)\left[\left(\Gamma_{t+1}-\mu G_{t+1}\right)\frac{Ret_t^{\mathcal{K}}}{i_t}-1\right]=0$$

where $(\Gamma_{t+1})' = \partial\Gamma_{t+1}/\partial\bar{\omega}_{t+1}$ and $(G_{t+1})' = \partial G_{t+1}/\partial\bar{\omega}_{t+1}$. This condition, jointly with the retail branches participation constraint

$$[\Gamma_{t+1} - \mu G_{t+1}] \frac{Ret_t^{\mathcal{K}}}{i_t} \frac{P_t^{\mathcal{K}} \bar{K}_{t+1}}{N_t} = \frac{P_t^{\mathcal{K}} \bar{K}_{t+1}}{N_t} - 1$$

defines the demand for loans from the entrepreneurial sector and the associated threshold $\bar{\omega}_{t+1}$ separating bankruptcy from solvency.

Aggregate net worth can be decomposed as $N_t = (1 - S_t^d)\widetilde{N}_t$, where $\widetilde{N}_t$ is pre-dividend net worth

$$\widetilde{N}_t = i_{t-1}N_{t-1} + P_{t-1}^{\mathcal{K}}\bar{K}_t\big(Ret_{t-1}^{\mathcal{K}}(1 - \mu G_t) - i_{t-1}\big)$$

The stochastic parameter S_t^d—denoting the share of distributed dividends and henceforth termed net worth destroying shock—follows a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{Sd}$,

$$S_t^d = S^d + \varepsilon_t^{Sd},\ \varepsilon_t^{Sd} = \rho^{Sd}(S_{t-1}^d - S^d) + \tilde{\varepsilon}_t^{Sd}$$

with $0 \leq \rho^{Sd} < 1$ and where S^d is a steady-state constant. In each period t, a fraction $\mathfrak{F}(\bar{\omega}_t)$ of entrepreneurs declares bankruptcy and goes out of business. To ensure that entrepreneurial firms have a mass of one at all times, we assume that the same fraction of new businesses starts in every period. Finally, real bankruptcy monitoring costs paid by banks to asset holders are $RBR_t = \bar{K}_t Ret_{t-1}^{\mathcal{K}} P_{t-1}^{\mathcal{K}} \mu G(\bar{\omega}_t)$.

2.5. Fiscal authorities

The government buys from distributors a particular consumption good, G_t, and performs lump-sum transfers to households, TRG_t. Both public consumption and lump-sum transfers follow a first-order autoregressive process with an iid-normal error term, respectively $\tilde{\varepsilon}_t^{\mathcal{G}}$ and $\tilde{\varepsilon}_t^{TRG}$,

$$G_t = G + \varepsilon_t^{\mathcal{G}},\ \varepsilon_t^{\mathcal{G}} = \rho^{\mathcal{G}}(G_{t-1} - G) + \tilde{\varepsilon}_t^{\mathcal{G}}$$

and

$$TRG_t = TRG + \varepsilon_t^{TRG},\ \varepsilon_t^{TRG} = \rho^{TRG}(TRG_{t-1} - TRG) + \tilde{\varepsilon}_t^{TRG}$$

with $\{\rho^{\mathcal{G}}, \rho^{TRG}\} \in [0, 1)$, and where G and TRG are steady-state constants. To finance expenditures, the government levies taxes $\tau_t^{\mathcal{L}}$ on households' labor income and $\tau_t^{\mathcal{SP}}$ on manufacturers' payroll, $\tau_t^{\mathcal{C}}$ on households' consumption, $\tau_t^{\mathcal{K}}$ and $\tau_t^{\mathcal{D}}$ respectively on manufacturers' and distributors' profits, and receives transfers from abroad totaling TRE. The households' labor income tax is selected as the endogenous fiscal instrument, while taxes on manufacturers' payroll, manufacturers' profits, and households' consumption follow first-order autoregressive processes with iid-normal innovations

$$\tau_t^x = \tau^x + \varepsilon_t^{\tau x},\ \varepsilon_t^{\tau x} = \rho^{\tau x}(\tau_{t-1}^x - \tau^x) + \tilde{\varepsilon}_t^{\tau x},\ x \in \{\mathcal{SP}, \mathcal{C}, \mathcal{K}\}$$

with $0 \leq \rho^{\tau x} < 1$, and where τ^x is a steady-state constant. Taxes on distributors' profits are assumed constant. The government may also issue one-period bonds B_t to finance expenditure, paying an interest rate on public debt, which is not necessarily equal to the monetary union's interest rate due to the time-varying country risk premium Ψ_t on government bonds. Government consumption operates as a pure inefficient good that does not affect agent decisions or welfare. The government's budget constraint is

$$B_t = i_{t-1}B_{t-1} + P_t^{\mathcal{G}} G_t + TRG_t - RV_t - TRE$$

where RV_t denotes overall tax revenues. Government debt is held by domestic asset holders, *i.e.* there is full home bias. Households can nevertheless borrow from international debt markets to buy domestic government bonds. Public debt allows the government to postpone tax levies required to finance current public expenditure. This has a nontrivial impact on households' decisions, since part of the public debt is taken as net wealth by asset holders, as they have intrinsic non-Ricardian features. A fiscal rule, ensuring that debt follows a nonexplosive path, links the fiscal balance-to-GDP ratio, SG_t/GDP_t to a pre-determined target level

$$\frac{SG_t}{GDP_t} = \left(\frac{SG_t}{GDP_t}\right)^{\text{target}} + d\ln\left(\frac{GDP_t}{GDP_t^{\text{ss}}}\right) + \varepsilon_t^{SG}$$

where $\ln(GDP_t/GDP_t^{\text{ss}})$ is the gap relative to steady-state output and

$$\varepsilon_t^{SG} = \rho^{SG}\varepsilon_{t-1}^{SG} + \tilde{\varepsilon}_t^{SG}$$

is a first-order autoregressive process with iid-normal innovations $\tilde{\varepsilon}_t^{SG}$, with $0 \leq \rho^{SG} < 1$. The fiscal balance is allowed to deviate from the pre-determined target level due to automatic stabilization policies—captured by the output gap term—and due to discretionary policies—captured by the shock process ε_t^{SG}. A positive innovation to ε_t^{SG} implies a contrationary fiscal policy pursued by setting labor taxes at a level above the one posited by the fiscal rule.

2.6. Rest of the world

We follow closely Adolfson *et al.* (2007) and assume that in the rest of the world there exists a continuum of distributors $m \in [0, 1]$, who demand $Y_t^{\mathcal{X}}(m)$ units of the final good from domestic exporters. This good is thereafter combined with foreign intermediate goods $Z_t^*(m)$ according to the technology

$$Y_t^*(m) = \left((\alpha_t^*)^{\frac{1}{\xi_*}} \left(Y_t^{\mathcal{X}}(m)\right)^{\frac{\xi_*-1}{\xi_*}} + (1-\alpha_t^*)^{\frac{1}{\xi_*}} \left(Z_t^*(m)\right)^{\frac{\xi_*-1}{\xi_*}} \right)^{\frac{\xi_*}{\xi_*-1}}$$

where ξ_* is the elasticity of substitution between intermediate foreign goods and domestic exports. The home bias parameter α_t^* follows a first-order autoregressive process with an iid-normal innovation $\tilde{\varepsilon}_t^{\alpha*}$

$$\alpha_t^* = \alpha^* + \varepsilon_t^{\alpha*},\ \varepsilon_t^{\alpha*} = \rho^{\alpha*}(\alpha_{t-1}^* - \alpha^*) + \tilde{\varepsilon}_t^{\alpha*}$$

where $0 \le \rho^{\alpha*} < 1$ and α^* is a steady-state constant. Changes in α_t^* will be interpreted as export market share shocks. The standard cost minimization problem yields the familiar demand for domestic goods

$$Y_t^{\mathcal{X}} = \alpha_t^* \cdot (\vartheta_t)^{\xi_*} Y_t^*$$

Finally, the net foreign asset position is

$$B_t^* = i_{t-1}^* \Psi_{t-1} B_{t-1}^* + P_t^{\mathcal{X}} X_t - P_t^* M_t + \mathit{TRE} + \mathit{TRX}$$

The foreign economy is represented by a Bayesian VAR model encompassing foreign price inflation π_t^*, foreign output Y_t^*, and the foreign interest rate i_t^*, along the lines in Christiano *et al.* (2011). Let

$$\log y_t^* = \log Y_t^* - \log T_t$$

denote the stationary part of foreign GDP and assume the following VAR representation

$$\begin{pmatrix} \log(y_t^*/y^*) \\ \pi_t^* - \pi^* \\ i_t^* - i^* \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \log(y_{t-1}^*/y^*) \\ \pi_{t-1}^* - \pi^* \\ i_{t-1}^* - i^* \end{pmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix} \begin{pmatrix} \tilde{\varepsilon}_t^{y*} \\ \tilde{\varepsilon}_t^{\pi*} \\ \tilde{\varepsilon}_t^{i*} \end{pmatrix}$$

where the $\tilde{\varepsilon}_t$'s are zero-mean Gaussian i.i.d. innovations. The identification strategy implicit in the VAR representation assumes that innovations do not contemporaneously affect foreign variables. This is a necessary requirement to flush out parameter instability triggered by non-zero correlations between innovations and foreign variables.

2.7. Market clearing

The model is closed by a set of market clearing conditions. Aggregate consumption is $C_t = C_t^{\mathcal{A}} + C_t^{\mathcal{B}}$, whereas aggregate labor supply is $L_t = L_t^{\mathcal{A}} + L_t^{\mathcal{B}}$. Equilibrium in the labor market requires $L_t = U_t + \Gamma_t^{\mathcal{U}} + \Gamma_t^{\mathcal{V}}$. In the intermediate goods' market, the output produced by manufacturers net of adjustment and fixed costs must equal the demand from distributors,

$$Z_t - \Gamma_t^{P\mathcal{Z}} - RCU_t - T_t\varpi^{\mathcal{Z}} = Z_t^{\mathcal{C}} + Z_t^{\mathcal{I}} + Z_t^{\mathcal{G}} + Z_t^{\mathcal{X}}$$

In the final goods sector, the output produced by distributors net of adjustment costs must equal costumers' demand

$$Y_t^{\mathcal{F}} - \Gamma_t^{P\mathcal{F}} - \mathbf{1}_{\mathcal{I}}(\mathcal{F})\Gamma_t^{\mathcal{I}} - T_t\varpi^{\mathcal{F}} = \mathbf{1}_{\mathcal{C}}(\mathcal{F})C_t + \mathbf{1}_{\mathcal{I}}(\mathcal{F})I_t + \mathbf{1}_{\mathcal{G}}(\mathcal{F})G_t + \mathbf{1}_{\mathcal{X}}(\mathcal{F})X_t,$$

where $\mathbf{1}_x(\mathcal{F})$ is an indicator function which takes the value of 1 if $\mathcal{F} \in x$ and 0 otherwise, $\forall \mathcal{F} \in \{\mathcal{C}, \mathcal{I}, \mathcal{G}, \mathcal{X}\}$. Nominal GDP is

$$GDP_t = P_tC_t + P_t^{\mathcal{G}}G_t + P_t^{\mathcal{I}}I_t + P_t^{\mathcal{X}}X_t - P_t^*M_t$$

Real GDP is given by a similar expression, with steady-state price levels replacing actual price levels.

3. Estimation

3.1. Shocks and data

The stochastic behavior of the model is driven by twenty four structural shocks, categorized into five branches. There are five preference/technology shocks, on the households' consumption/labor supply choice ε_t^{η}, on the efficiency of imports $\varepsilon_t^{A\mathcal{M}}$, on the stationary labor-augmenting technology ε_t^{A}, on the unit root (worldwide) labor-augmenting technology ε_t^{g}, and on private investment efficiency ε_t^{ζ}; five domestic markup shocks, on wages $\varepsilon_t^{\sigma\mathcal{U}}$ and domestic prices $\tilde{\varepsilon}_t^{\sigma\mathcal{F}}$, $\mathcal{F} \in \{\mathcal{C}, \mathcal{I}, \mathcal{G}, \mathcal{X}\}$; six fiscal shocks, on public consumption and investment $\varepsilon_t^{\mathcal{G}}$, on lumpsum transfers ε_t^{TRG}, on tax rates $\varepsilon_t^{\tau x}$, $x \in \{\mathcal{SP}, \mathcal{C}, \mathcal{K}\}$, and on the fiscal rule ε_t^{SG}; three financial shocks, on nationwide risk ε_t^{Ψ}, on borrowers' riskiness $\varepsilon_t^{\sigma\mathcal{E}}$, and on entrepreneurial net worth ε_t^{Sd}; and five external/foreign shocks, on import prices $\tilde{\varepsilon}_t^{\mathcal{M}}$, on the export market share $\varepsilon_t^{\alpha *}$, and on euro-area inflation π_t^*, output y_t^* and interest rate i_t^*. Price markup shocks are assumed to be serially uncorrelated to allow a better identification of adjustment cost parameters.

We estimate the model for the Portuguese economy, using quarterly observations for the 1999Q1–2015Q4 period (after the euro area came into existence) for twenty four observable time series. On the real side, we take the logs and first differences of *per capita* GDP, private consumption, public consumption and investment, private investment, exports, imports, real wages (deflated by the private consumption deflator), and hours worked. On the nominal side we consider inflation levels for GDP, private consumption, public consumption and investment, private investment, and exports. Fiscal policy is brought into estimation through the seasonally adjusted revenue-to-GDP ratios from indirect taxes, household income taxes, corporate taxes, and social security taxes, and through the social benefits-to-GDP ratio. Two of these series—the revenue-to-GDP ratio from social security taxes and the social benefits-to-GDP ratio—exhibit in-sample trends, to a great extent related with a protracted increase in social protection and with aging. The model is not designed to capture these features, which assume a structural nature. To properly take into account high frequency movements in data and avoid trending exogenous processes, we consider the first difference of these two series and levels for the remaining. The nationwide risk premium is measured by the spread on the implicit interest rate on Portuguese government bonds *vis-à-vis* German government bonds. On the financial side we take the log and first difference of loans to non-financial corporations, and consider the level for the corporate interest rate spread—computed as the difference between the interest rate paid by non-financial corporations and the 3-month Euribor. We adjust the spread series by the nationwide risk premium to avoid double accounting the effects of sovereign risk on the financial sector. Finally, the BVAR includes euro area *per capita* GDP, euro area GDP inflation, and the 3-month Euribor interest rate. We follow common practice in the literature (*e.g.* Ratto *et al.* 2009; Christiano *et al.* 2011) and demean all resulting series—thus suppressing trend growth differences or level differences present in the data—to avoid trending exogenous processes or capture structural changes. That is, we remove specific deterministic trends from real variables and specific deterministic means from nominal variables to guarantee that all observable series are consistent with the model's balanced growth path.[4]

With the exception of foreign variables, we allow for measurement errors to take into account measurement noise in macro data. The variance of measurement errors is calibrated at 5 percent of the variance of each data series, except for financial data, where a higher noise justifies a larger value, of 25 percent.[5]

4. Most series were collected from Statistics Portugal. The exceptions are the interest rate on Portuguese and German government bonds and the variables for the euro area, collected from the Eurostat, and loans to non-financial corporations and interest rates, collected from *Banco de Portugal*. Seasonal adjustments were performed through the X12 ARIMA.

5. Measurement errors allow for the inclusion of data for all GDP components in addition to GDP itself, while avoiding stochastic singularity in the resource constraint.

3.2. Methodology

We calibrate several non-identifiable or weakly identified parameters according to related empirical studies or micro evidence, or by matching "great ratios" or any other quantifiable steady-state measure. The remaining parameters are estimated using Bayesian techniques. Prior information is combined with the likelihood to obtain the posterior kernel, which is maximized through a numerical optimization routine to obtain an estimate for the posterior mode and the corresponding variance-covariance matrix. This information is used as an input to initialize the Random-Walk Metropolis-Hastings algorithm, yielding a sample from the posterior density of model parameters. We compute 4 parallel chains of 5 million draws each, and discard the first 2,5 million as the burn-in phase. The acceptance rate is around 37 percent. Convergence of the simulation is assessed through the diagnostics in Brooks and Gelman (1998), presented in the computational appendix. The time unit is a quarter.

3.3. Calibration

Table 1 provides a summary of the calibrated parameters of the model, whereas Table 2 reports the steady state evaluated at the posterior mean. We set the interest rate target at 3.2 percent per year, matching the pre-crisis average for the 3-month Euribor. The nationwide risk premium is nil in the steady state and the domestic interest rate therefore equals the target rate. Steady-state inflation is set at 2 percent and the technology growth rate at 1.2 percent per year; the former in line with the ECB's price stability target and latter in line with both the pre-crisis average value for Portugal and the in-sample average value for the euro area.

The households quarterly discount rate is set to 0.998. Steady-state markups are not identified and thus we calibrate the wage markup at 25 percent, the intermediate goods price markup at around 12 percent, and the final goods price markup at 5 percent, except in the case of exporters where fiercer competition justifies a markup of 2.5 percent. The intermediate goods price adjustment cost is adjusted to ensure a model dynamics similar to that of an implicit average price duration between 3 and 4 quarters.

The quasi-labor income share and the home bias parameters in domestic distributors' technology are endogenously calibrated at the prior mean to match long-run averages for the labor income share and import shares, respectively. The steady-state export market share is calibrated according to the exports-to-GDP ratio. Steady-state tax rates and transfers are calibrated to respectively match data on tax revenue-to-GDP ratios and on the households transfers-to-GDP ratio. The target public debt-to-GDP ratio is set to 60 percent in an annual basis, in line with fiscal targets in place in the euro area. This implies a steady-state fiscal balance-to-GDP ratio of -1.9 percent.

	parameter	value
Nominal adjustment costs		
Intermediate goods' price adjustment cost	$\varphi_{P\mathcal{Z}}$	125
Wage and price markups		
Wage markup	$\sigma^{\mathcal{U}}$	0.25
Manufacturers' price markup	$\sigma^{\mathcal{Z}}$	0.12
Distributors' price markup		
Private consumption	$\sigma^{\mathcal{C}}$	0.05
Private investment	$\sigma^{\mathcal{I}}$	0.05
Gov consumption & investment	$\sigma^{\mathcal{G}}$	0.05
Exports	$\sigma^{\mathcal{X}}$	0.025
Households parameters		
Discount rate	β	0.998
Technology		
Technology growth rate	g	1.003
Quasi-labor income share	$\alpha^{\mathcal{U}}$	0.54
Home bias in domestic distributors		
Private consumption	$\alpha^{\mathcal{C}}$	0.63
Private investment	$\alpha^{\mathcal{I}}$	0.51
Gov consumption & investment	$\alpha^{\mathcal{G}}$	0.86
Exports	$\alpha^{\mathcal{X}}$	0.52
Government parameters		
Consumption tax rate	$\tau^{\mathcal{C}}$	0.28
Capital income tax rate	$\tau^{\mathcal{K}}$	0.23
Dividends tax rate	$\tau^{\mathcal{D}}$	0.15
Employers' payroll tax rate	$\tau^{\mathcal{SP}}$	0.24
Target debt to GDP ratio	B/GDP	0.60
Financial frictions		
Monitoring cost	μ	0.46
Borrowers Riskiness	$\sigma^{\mathcal{E}}$	0.26
Dividend distribution	S^d	0.05
Sensibility of dividends to SS deviations	θ_{nw}	0.00
Miscellaneous		
Export market share	α^*	0.030
ECB interest rate target	i^*	1.008
Inflation	π^*	1.005
Risk Premium	Ψ	0.000

TABLE 1. Calibrated parameters.

Notes: The model is quarterly and parameters are not annualized.

In the financial sector we endogenously calibrate the steady-state borrowers' riskiness $\sigma^{\mathcal{E}}$, monitoring cost μ, and share of distributed dividends S^d, to match historical averages for the probability of default, the leverage ratio, and the credit spread.

Some parameters, particularly those determining the elasticity of substitution between domestic and imported goods in the final goods distributors technology, may alter the non-stochastic steady state when estimated, leading to implausible great ratios at the posterior mean. We follow the approach in Christiano *et al.* (2011) and overcome this issue by constantly re-calibrating two parameters during estimation. Specifically, we set

	model	data
Expenditure (GDP ratio)		
Private consumption	0.63	0.65
Private investment	0.19	0.18
Public consumption & investment	0.23	0.24
Exports	0.36	0.31
Imports	0.41	0.38
Import shares (output ratio)		
Private consumption	0.29	0.29
Private investment	0.45	0.39
Public consumption & investment	0.10	0.10
Exports	0.45	0.38
Labor income share	0.65	0.67
Frish elasticities		
Type-$\mathcal{A}$ households	1.0	n.a.
Type-$\mathcal{B}$ households	0.8	n.a.
Government (GDP ratio, in %)		
Public debt	60.0	83.2
Fiscal surplus	-1.9	-5.4
Total revenues	36.0	34.4
Consumption tax	14.0	13.9
Capital income tax	3.1	3.2
Labor income tax	7.9	5.9
Employers' payroll tax	11.0	11.4
Household transfers	14.7	14.7
External account (GDP ratio, in %)		
Net foreign assets (annualized)	-78.9	-81.9
Current and capital accounts	-2.5	-5.7
Trade balance	-5.2	-5.9
Financial sector		
Leverage ratio	1.2	1.3
Probability of default (in %)	4.0	4.1
Credit spread (in %)	2.0	2.1

TABLE 2. Implied steady-state relationships.

Notes: The steady state is evaluated at the posterior mean. The values in the column data are averages for the 1999–2015 period, except for import contents, which were taken from Cardoso *et al.* (2013). The values for public debt, net foreign assets, default probability and credit spread are annualized.

the depreciation rate δ and the level of public consumption G as endogenous to match the target ratios for private investment and public consumption and investment, respectively. The imports-to-GDP ratio results from a steady-state compatible trade balance. The net foreign asset position is roughly 80 percent of GDP.

3.4. Prior selection and posterior analysis

Our priors represent a compromise between looseness and convergence, and in some cases we chose to tight the prior to ensure convergence in Metropolis-Hastings draws. We use the gamma distribution for parameters that are theoretically constrained to a positive domain, the beta distribution for parameters that are bounded to the unit interval, and the inverse gamma distribution for the standard deviation of innovations. Parameters pertaining the Bayesian VAR follow a beta distribution with informative priors. Distributions for parameters measuring the elasticities of substitution in distributors' technology are truncated at one to impose some degree of substitutability between domestic and foreign goods.

Tables 3 and 4 document the prior-posterior analysis. These results, jointly with the posterior plots presented in the computational appendix, suggest that data is informative about estimated parameters, with a few exceptions. Posteriors are in general tighter then priors or centered at different points of the support.[6]

On the household side prior means largely reflect the values in Fagan *et al.* (2004), Harrison *et al.* (2005), Kumhof and Laxton (2007) and Kumhof *et al.* (2010). The share of hand-to-mouth households is set at 40 percent, reflecting the implicit assumption that private consumption is a weighted average of smoothed asset holders' consumption with volatile hand-to-mouth households' consumption. The average planning horizon is set at 10 years and the average working life at 20 years, implying $1 - \theta = 0.025$ and $1 - \chi = 0.0125$, and the consumption quasi-share η is pinned down by imposing a labor supply Frisch elasticity of 1/2 for asset holders. Results at the posterior mean suggest a smaller consumption quasi-share coefficient, entailing a larger labor supply Frisch elasticity, of around 1 (see Table 2). Overall private consumption is driven by asset holders consumption, who represent nearly 95 percent of total population. Posterior distributions regarding the average planning horizon and the average working life are not far away from their prior counterparts. The parameter d in the fiscal policy rule is set to 0.5 at the prior mean, though the lower value at the posterior mean suggests that fiscal policy is weakly pro-cyclical at best.

Prior distributions for nominal adjustment costs reflect dynamics roughly similar to those implied by implicit average price durations of around 1 to 2 quarters, alongside with an implicit average contract duration of around 5 quarters. Posterior distributions pinpoint harsher wage adjustment costs and higher price adjustment costs in public consumption and export goods, but milder adjustment costs in investment goods. Prior means concerning real adjustment costs were selected to ensure plausible *ex-ante* labor, investment, and utilization rate dynamics. The posterior mean for the labor stickiness coefficient is higher than the prior mean and data is informative in the sense that it shrinks the support distribution. Investment and capital utilization sluggishness are associated with tighter posterior distributions centered at lower values of the support *vis-à-vis* the prior. Adjustment costs in import contents

6. The computational appendix presents additional outputs and estimation byproducts that are not mentioned in the main text.

	param.	prior			posterior		
		dist.	mean	s.d.	mean	5%	95%
Nominal adjustment costs							
Wage	$\varphi_{\mathcal{V}}$	Γ	125	25	194	144	243
Private consumption	$\varphi_{\mathcal{PC}}$	Γ	125	25	116	78	152
Private investment	$\varphi_{\mathcal{PI}}$	Γ	125	25	87	53	120
Public consumption & investment	$\varphi_{\mathcal{PG}}$	Γ	125	25	146	102	188
Exports	$\varphi_{\mathcal{PX}}$	Γ	125	25	142	101	182
Real adjustment costs							
Investment	$\varphi_{\mathcal{I}}$	Γ	5.00	1.50	2.43	1.58	3.25
Labor	$\varphi_{\mathcal{U}}$	Γ	15.00	5.00	20.20	14.80	25.52
Capital utilization rate	σ_a	Γ	1.00	0.30	0.25	0.13	0.36
Import content adjustment costs							
Private consumption	$\varphi_{\mathcal{C}}$	Γ	2.00	0.50	1.52	0.82	2.18
Private investment	$\varphi_{\mathcal{I}}$	Γ	2.00	0.50	1.64	0.91	2.36
Gov consumption & investment	$\varphi_{\mathcal{G}}$	Γ	2.00	0.50	2.02	1.18	2.83
Exports	$\varphi_{\mathcal{X}}$	Γ	2.00	0.50	1.15	0.62	1.66
Technology							
EoS, consumer goods	$\xi_{\mathcal{C}}$	$\Gamma_{>1}$	1.50	0.15	1.67	1.40	1.93
EoS, investment goods	$\xi_{\mathcal{I}}$	$\Gamma_{>1}$	1.50	0.15	1.30	1.07	1.53
EoS, government goods	$\xi_{\mathcal{G}}$	$\Gamma_{>1}$	1.50	0.15	1.60	1.34	1.86
EoS, export goods	$\xi_{\mathcal{X}}$	$\Gamma_{>1}$	1.50	0.15	1.23	1.02	1.41
EoS, foreign distributors	ξ_*	$\Gamma_{>1}$	2.50	0.25	1.62	1.35	1.89
Households parameters							
Instant probability of death	$1-\theta$	β	0.025	0.003	0.023	0.019	0.028
Productivity decay rate	$1-\chi$	β	0.013	0.003	0.012	0.008	0.017
Consumption quasi-share	η	β	0.81	0.1	0.65	0.58	0.73
Share of type-$\mathcal{B}$ households	ψ	β	0.40	0.2	0.07	0.02	0.11
Government parameters							
Surplus sensibility to output gap	d	Γ	0.50	0.3	0.13	0.01	0.24
Persistence, Technology & preferences							
Consumption/labor choice	ρ^{η}	β	0.50	0.15	0.80	0.72	0.89
Unit root tech	ρ^{g}	β	0.50	0.15	0.57	0.40	0.74
Stationary tech	ρ^{A}	β	0.50	0.15	0.44	0.26	0.62
Investment efficiency	ρ^{ς}	β	0.50	0.15	0.14	0.05	0.23
Imports efficiency	$\rho^{A\mathcal{M}}$	β	0.50	0.15	0.31	0.15	0.46
Persistence, Markups							
Wage markup	$\rho^{\sigma\mathcal{U}}$	β	0.50	0.15	0.75	0.65	0.85
Persistence, Fiscal authorities							
Public consumption & investment	$\rho^{\mathcal{G}}$	β	0.50	0.15	0.89	0.84	0.94
Household transfers	ρ^{TRG}	β	0.50	0.15	0.48	0.30	0.66
Taxes on consumption	$\rho^{\tau\mathcal{C}}$	β	0.50	0.15	0.57	0.41	0.72
Taxes on payroll	$\rho^{\tau\mathcal{SP}}$	β	0.50	0.15	0.26	0.10	0.41
Taxes on profits	$\rho^{\tau\mathcal{K}}$	β	0.50	0.15	0.28	0.13	0.43
Fiscal rule	ρ^{SG}	β	0.50	0.15	0.62	0.49	0.75
Persistence, Financial							
Nationwide risk	ρ^{Ψ}	β	0.50	0.15	0.96	0.94	0.98
Borrowers' riskiness	$\rho^{\sigma\mathcal{E}}$	β	0.50	0.15	0.97	0.95	0.99
Entrepreneurial net worth destruction	ρ^{Sd}	β	0.50	0.15	0.38	0.19	0.56
Persistence, External							
Export market share	$\rho^{\alpha*}$	β	0.50	0.15	0.92	0.84	0.99
Foreign VAR							
Foreign VAR parameter	a_{11}	β	0.50	0.25	0.88	0.82	0.93
Foreign VAR parameter	a_{12}	β	0.10	0.05	0.09	0.02	0.16
Foreign VAR parameter	a_{13}	$-\beta$	-0.10	0.05	-0.15	-0.25	-0.04
Foreign VAR parameter	a_{21}	β	0.10	0.05	0.12	0.08	0.15
Foreign VAR parameter	a_{22}	β	0.10	0.05	0.10	0.03	0.18
Foreign VAR parameter	a_{23}	$-\beta$	-0.10	0.05	-0.08	-0.14	-0.02
Foreign VAR parameter	a_{31}	β	0.10	0.05	0.22	0.16	0.27
Foreign VAR parameter	a_{32}	β	0.10	0.05	0.05	0.01	0.09
Foreign VAR parameter	a_{33}	β	0.10	0.05	0.20	0.07	0.33

TABLE 3. Estimated parameters.

Notes: Based on 4 parallel chains of 5 million draws each, after a burn-in of 2,5 million draws. Γ stands for the gamma distribution, $\Gamma_{>1}$ for the truncated gamma distribution and β for the beta distribution. In the table, EoS stands for elasticity of substitution.

	param.	prior			posterior		
		dist.	mean	d.f.	mean	5%	95%
Technology & preferences							
Consumption/labor choice	$100\text{sd}(\varepsilon_t^{\eta})$	Inv-Γ	1.0	2	0.80	0.61	0.99
Unit root technology	$1000\text{sd}(\varepsilon_t^{T})$	Inv-Γ	1.0	2	3.20	2.24	4.14
Stationary technology	$100\text{sd}(\varepsilon_t^{A})$	Inv-Γ	1.0	2	3.76	2.94	4.55
Investment efficiency	$10\text{sd}(\varepsilon_t^{\zeta})$	Inv-Γ	1.0	2	1.00	0.64	1.35
Imports efficiency	$100\text{sd}(\varepsilon_t^{A\mathcal{M}})$	Inv-Γ	1.0	2	3.34	2.66	3.99
Domestic markups							
Wage	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{U}})$	Inv-Γ	1.0	2	1.05	0.78	1.31
Private consumption	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{C}})$	Inv-Γ	1.0	2	1.02	0.71	1.32
Private investment	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{I}})$	Inv-Γ	1.0	2	1.34	0.87	1.80
Gov consumption & investment	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{G}})$	Inv-Γ	1.0	2	1.16	0.81	1.49
Exports	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{X}})$	Inv-Γ	1.0	2	0.60	0.44	0.76
Fiscal authorities							
Gov consumption & investment	$100\text{sd}(\varepsilon_t^{\mathcal{G}})$	Inv-Γ	1.0	2	1.44	1.22	1.66
Household transfers	$100\text{sd}(\varepsilon_t^{TRG})$	Inv-Γ	1.0	2	3.04	2.55	3.51
Taxes on consumption	$100\text{sd}(\varepsilon_t^{\tau\mathcal{C}})$	Inv-Γ	1.0	2	1.37	1.15	1.60
Taxes on payroll	$100\text{sd}(\varepsilon_t^{\tau\mathcal{SP}})$	Inv-Γ	1.0	2	0.51	0.42	0.60
Taxes on profits	$100\text{sd}(\varepsilon_t^{\tau\mathcal{K}})$	Inv-Γ	1.0	2	4.15	3.49	4.80
Fiscal rule	$100\text{sd}(\varepsilon_t^{SG})$	Inv-Γ	1.0	2	1.53	1.28	1.76
Financial sector							
Nationwide risk premium	$1000\text{sd}(\varepsilon_t^{\Psi})$	Inv-Γ	1.0	2	0.32	0.26	0.37
Borrowers' riskiness	$100\text{sd}(\varepsilon_t^{\sigma\mathcal{E}})$	Inv-Γ	1.0	2	0.57	0.43	0.70
Entrepreneurial net worth	$100\text{sd}(\varepsilon_t^{Sd})$	Inv-Γ	1.0	2	0.95	0.62	1.28
External/foreign							
Export market share	$100\text{sd}(\varepsilon_t^{\alpha *})$	Inv-Γ	1.0	2	2.75	2.29	3.19
Import prices	$10\text{sd}(\varepsilon_t^{\sigma\mathcal{M}})$	Inv-Γ	1.0	2	0.29	0.24	0.34
Foreign GDP	$100\text{sd}(\varepsilon_t^{Y*})$	Inv-Γ	1.0	2	0.43	0.31	0.54
Foreign inflation	$1000\text{sd}(\varepsilon_t^{\pi *})$	Inv-Γ	1.0	2	1.69	1.43	1.94
Foreign interest rate	$1000\text{sd}(\varepsilon_t^{i*})$	Inv-Γ	1.0	2	0.52	0.38	0.65

TABLE 4. Estimated standard error of innovations.

Notes: Based on 4 parallel chains of 5 million draws each, after a burn-in of 2,5 million draws. Inv-Γ stands for the inverse gamma distribution; d.f. is the number of degrees of freedom.

were tuned to deliver plausible real exchange rate fluctuations at the prior mean, though the posterior distribution advocates slightly lower values (except for the case of public consumption goods where the prior and posterior means nearly coincide). Posteriors means concerning technology parameters suggest a lower degree of substitubility between inputs than the prior mean (set at 1.5 based in the macro-literature) for investment and exports, and a larger degree for private and public consumption. The posterior mean for the elasticity of substitution in foreign distributors technology is also below the prior value of 2.5, suggesting a more confined response of exports to real exchange rate fluctuations.

Priors for persistence parameters and for the standard deviation of innovations are harmonized as much as possible. Prior means of autoregressive parameters are 0.5 and standard deviations are set at 0.15. Innovations have infinitely loose priors, and the mean depends on the measurement unit. Risk shocks—both at nationwide and firm level—are estimated to be highly persistent, with autoregressive coefficients standing above 0.9 at the posterior mean. This outcome possibly reflects long-lasting effects triggered by the financial and the sovereign debt crises in the Portuguese economy. Public consumption shocks and export market share shocks are also highly persistent.[7] On the opposite direction, some technology shocks and fiscal shocks are largely transitory.

Finally, the foreign VAR embodies a mild persistency level at the prior mean for the euro area output shock, while inflation and monetary policy shocks are assumed to be largely transitory. The latter reflects a tight prior on the behavior of monetary policy shocks, a necessary condition to avoid a near random walk behavior in the interest rate and ensure stable impulse response functions. We impose also *a priori* sign restrictions on parameters a_{13} and a_{23}, in accordance with economic theory. The posterior mean implies a substantially larger persistence level regarding the euro area output shock, but asserts the transitory nature of inflation and monetary policy shocks.

4. Model properties

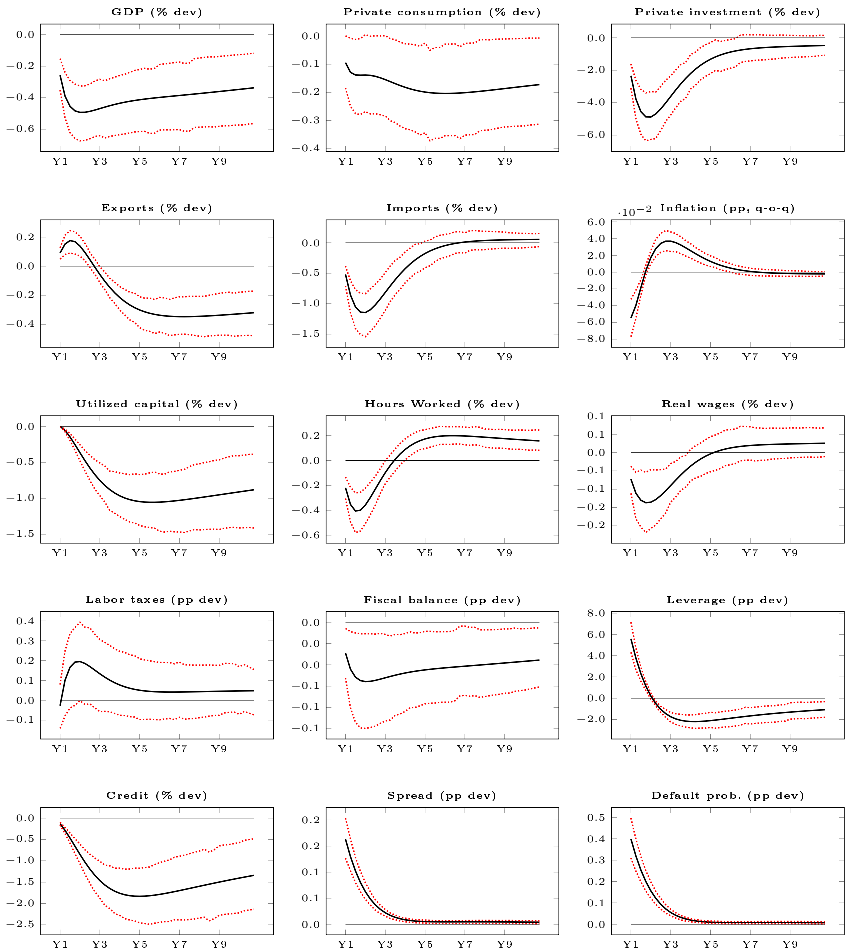
This section presents several estimation byprodults, namely impulse response functions, smoothed shock processes, historical and variance decompositions, model evaluation and stability tests. Estimation byproducts are evaluated at the posterior mean except indicated otherwise. The plots in the appendix show that observed data series used in estimation and smoothed variables without measurement error are virtually identical, with the exception of credit growth where the larger measurement error drives a wedge between the two.

4.1. Impulse response functions

We first discuss selected impulse responses, plotted in Figure 1, for five key shocks, *viz* entrepreneur's risk, nationwide risk, labor taxes (the fiscal rule), export market share, and stationary labor-augmenting technology. A common feature to all impulse responses is the law of one price, which produces effects on the medium term and triggers an external adjustment so as to keep the relative domestic price constant *vis-à-vis* the foreign price level. The ensuing discussion is therefore mostly targeted at the short-run dynamics.

The entrepreneurs' risk shock—which produces long lasting effects on some key variables due to its high persistence—raises the probability of default and therefore the credit spread. Firms reduce the demand for (more expensive) credit, halting investment projects. Lower aggregate demand triggers a slack in

7. Persistent fiscal policy shocks can be related with the traditional view in the political economy literature, that expenditure cuts may face severe societal blockages and thus expenditure hikes will most likely have persistent effects. For instance, Alesina and Drazen (1991) and Spolaore (2004) develop models that can be easily extended to embody an increasing profile of government expenditure, and where a war of attrition is waged until a majority agrees on how to share the burden of the adjustment.



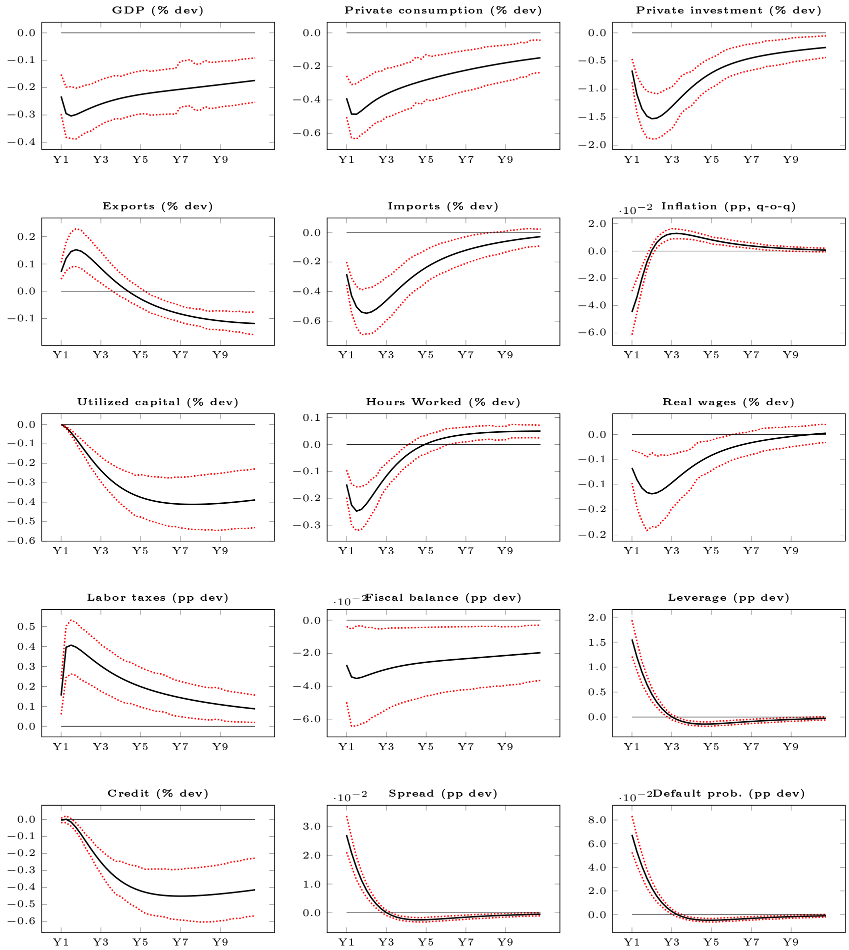
(A) Entrepreneurs' risk shock, $\sigma^{\mathcal{E}}_{t+1}$.

FIGURE 1: Selected impulse response functions.
(deviations from steady state)

Note: Red dotted lines represent the 90 percent confidence band.

input markets—on both the intermediate and the final goods sectors—driving wages, hours worked and imports downwards. Inflation declines on impact, boosting exports, though the effects reverse on the medium run as the law of one price kicks in. Private consumption faces a protracted decline, since households use savings to smooth out the short-run decline in disposable income over time.

The nationwide risk shock—which is also highly persistent and endowed with enduring effects on some macroeconomic variables—has a direct negative impact on households' consumption, raising the interest rate premium paid by

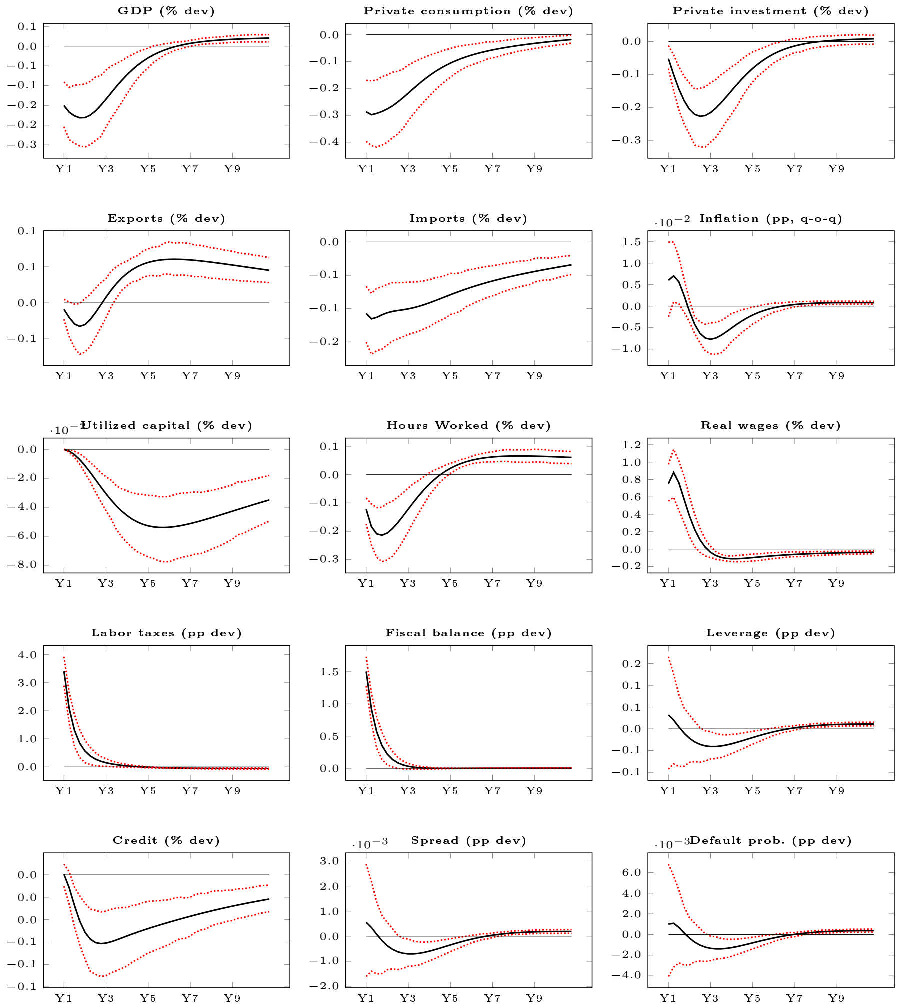


(B) Nationwide risk shock, Ψ_t.

FIGURE 1: Selected impulse response functions.
(deviations from steady state)

Note: Red dotted lines represent the 90 percent confidence band.

indebted asset holders. The demand for inputs concomitantly declines, pushing wages, hours worked and utilized capital downwards. Labor taxes increase to cope with larger interest outlays. On the financial side, a higher nationwide interest rate raises the cost of credit, and thus leverage and the spread. External finance declines as a result. On the nominal side, the downfall in inflation boosts competitiveness and thus exports in the short run, though the effects reverse on the medium term due to domestic inflationary pressures triggered by the law of one price. Households smooth out the short-run decline in disposable income, triggering protracted effects on GDP and private consumption.

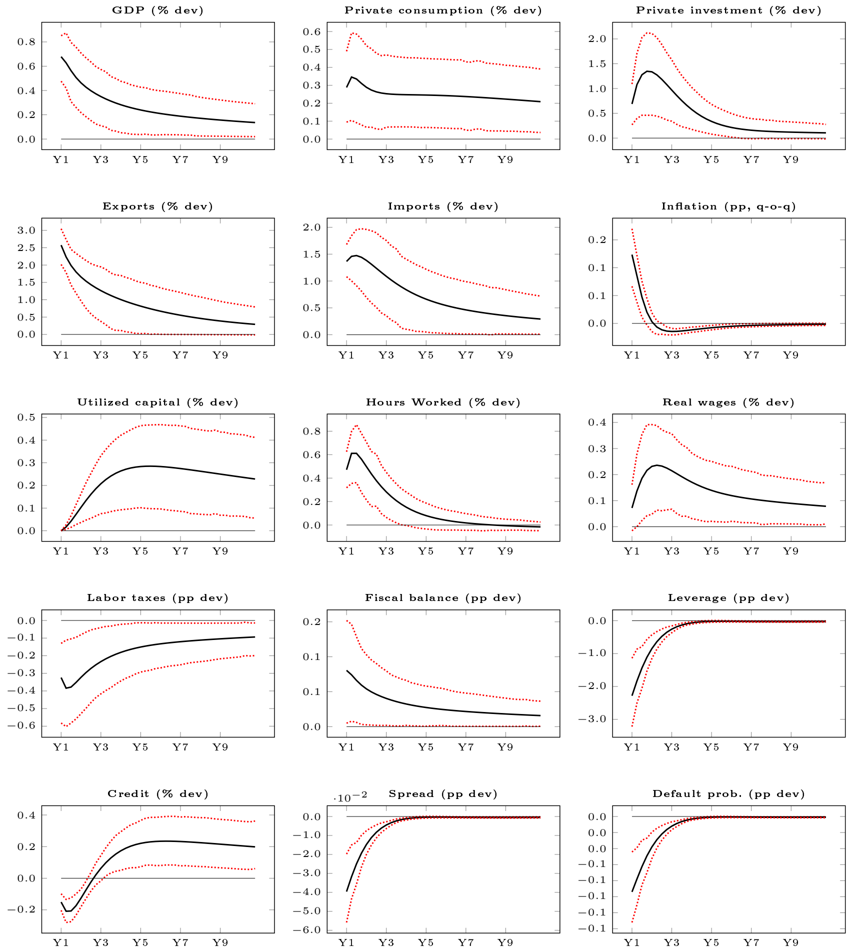


(c) Fiscal rule shock, ε_t^{SG}.

Figure 1: Selected impulse response functions.
(deviations from steady state)

Note: Red dotted lines represent the 90 percent confidence band.

The fiscal rule shock—corresponding to an increase in labor taxes *vis-à-vis* the fiscal rule implied rate—shrinks disposable income and drives households' consumption downwards. Factor demands—in particular hours worked—and imports decrease, but real wages are pushed upwards due to the contraction in labor supply. Capital also faces a demand downfall, though the effects are mitigated by the higher relative price of labor, which leads manufacturers to substitute away towards capital. Higher labor costs prevent a downturn in



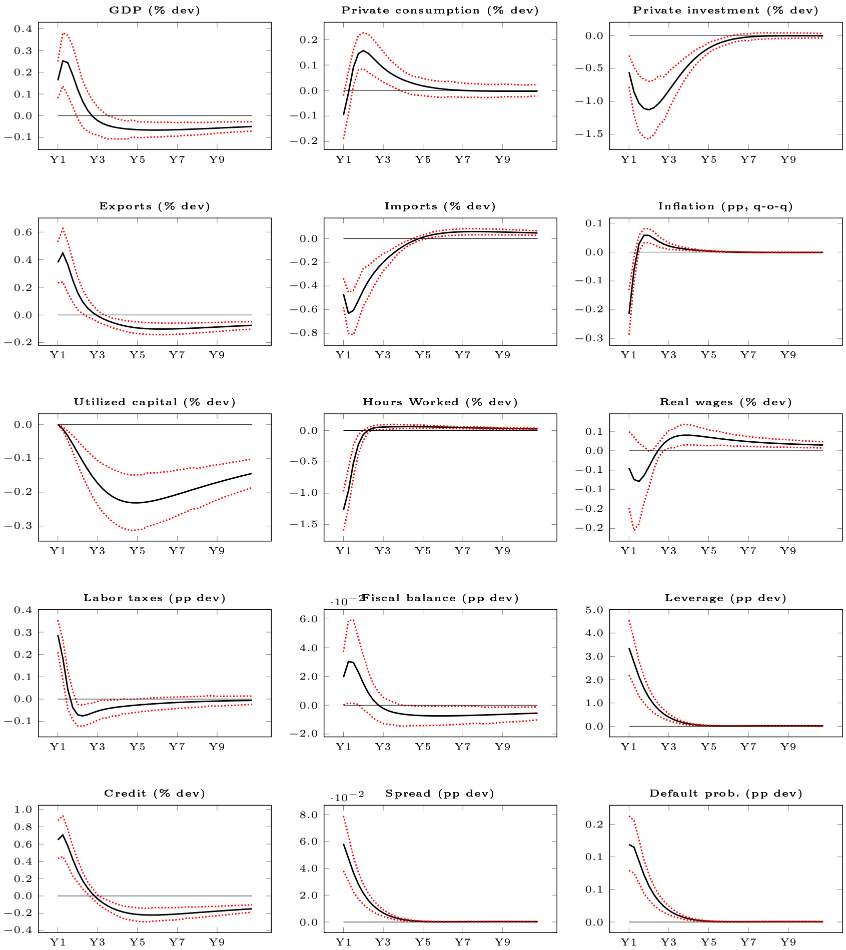
(D) Export market share shock, α_t^*.

FIGURE 1: Selected impulse response functions.
(deviations from steady state)

Note: Red dotted lines represent the 90 percent confidence band.

inflation and contribute to keep exports close to the steady-state level, and financial variables barely move due to the reduced effects on the demand for investment goods. As in previous shocks, households use savings to smooth out the impacts on private consumption over time.

The export market share shock boosts exports, to which firms respond by increasing the demand all factor inputs—capital, labor, and import goods. Factor prices and thus inflation are pressured upwards as the economy overheats, and households' consumption increases nurtured by higher disposable income. On the financial side, the entrepreneurial sector benefits



(E) Stationary labor-augmenting technology shock, A_t.

FIGURE 1: Selected impulse response functions.
(deviations from steady state)

Note: Red dotted lines represent the 90 percent confidence band.

from lower real interest rates, which boost net worth and pressure down the default probability and the spread. Credit nevertheless remains close to steady state levels, since higher net worth and greater capital demand have opposing and offsetting effects in the need for external finance.

Finally, the stationary labor-augmenting technology shock fosters the production of intermediate goods and thus GDP. The more efficient use of technology reduces factor demands, resulting in fewer hours worked, less utilized capital, and a decline in the corresponding equilibrium factor prices. Lower costs push inflation downwards, triggering a competitiveness gain that is reversed on the medium term due to the law of one price. On the household side the decline in wage income is progressively outweighed by larger rents in the intermediate goods sector and by the medium-term decline in the real interest rate, which are translated into an upsurge in wealth and thus into greater households' consumption. On the financial side, the short-run increase in the real interest rate raises the cost of credit and pressures down net worth. Leverage, the probability of default and the spread concomitantly increase. Credit also increases preventing a larger capital downfall, grounded on the medium-term real interest rate decline. The effects are short-lived as the labor-augmenting technology shock is largely transitory.

4.2. Smoothed shock processes and historical decompositions

Figure 2 depicts the values for smoothed shock processes, which we complement with the historical decomposition in Figure 3. Our description is mostly focused on the recent period, from the 2008 worldwide financial turmoil onwards.[8]

Financial shocks suggest that Portugal was not severely hit by the 2008 worldwide financial turbulence. The 2008-2010 increase in risk was moderately confined and there were no important net worth effect. On the opposite direction, the 2009 collapse in world trade and the concomitant decline in worldwide GDP resulted in powerful negative export market share and worldwide technology shocks. GDP tumbled as a result, despite outweighing contributions from the fiscal side—mostly driven by larger public consumption, lower indirect taxes, and lower labor income taxes (relative to the value implicit in the fiscal rule). The tumble in consumer goods inflation during this period echoes to a great extent lower indirect taxes and the demand downshift triggered by the negative export market share shock.

The dissipation and reversal of the most important shocks driving the 2009 downturn placed GDP growth and inflation back to near steady-state values in early 2010. However, the worldwide growth shock, the imports efficiency technology shock, the harsh fiscal adjustment (implemented during the economic and financial assistence programme) and the adverse increment in sovereign risk plummeted GDP from early 2011 to late 2013. Public consumption plunged and taxes hiked (especially those on consumption and labor income) during 2011, while technology shocks under-performed throughout the 2012-2013 period. The concomitant increase in the wage markup suggests that real wages faced a downward stickiness, preventing a swifter adjustment on the real side and negatively impacting GDP growth.

8. The charts in the appendix present more detailed historical decompositions.

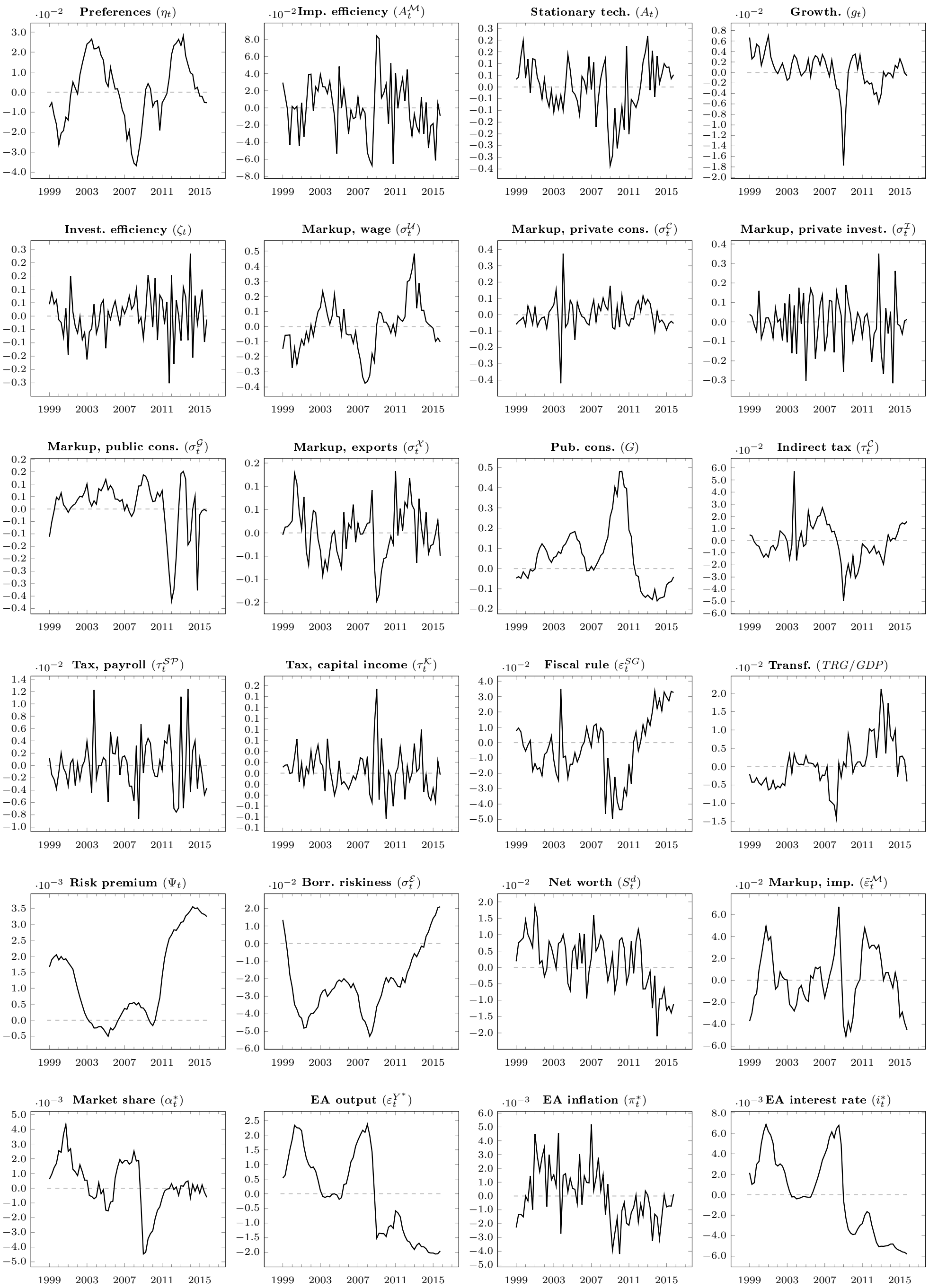
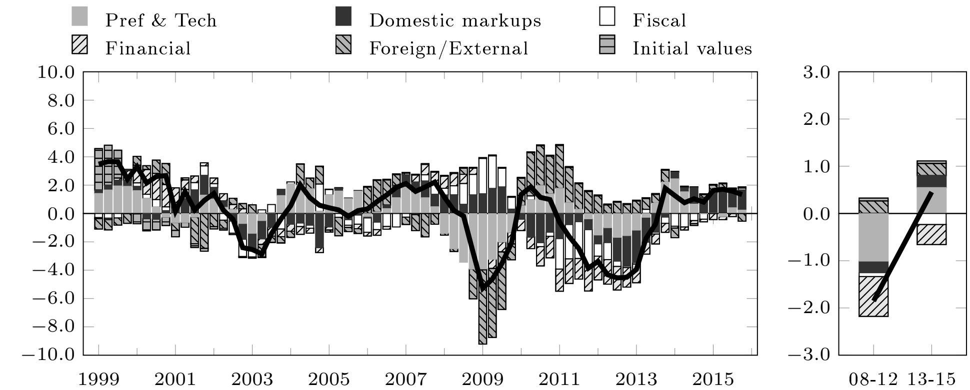
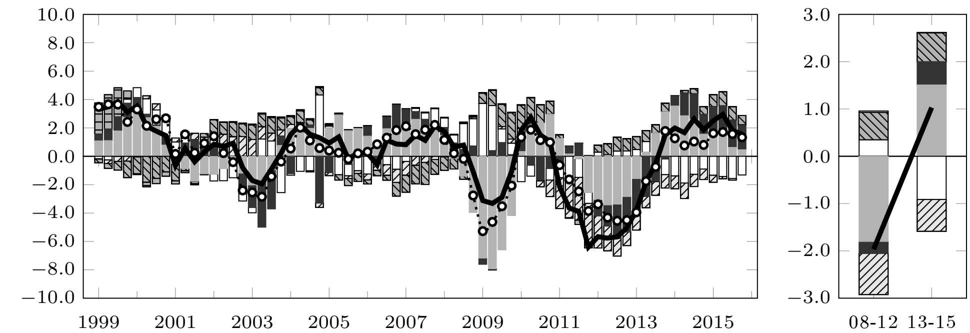


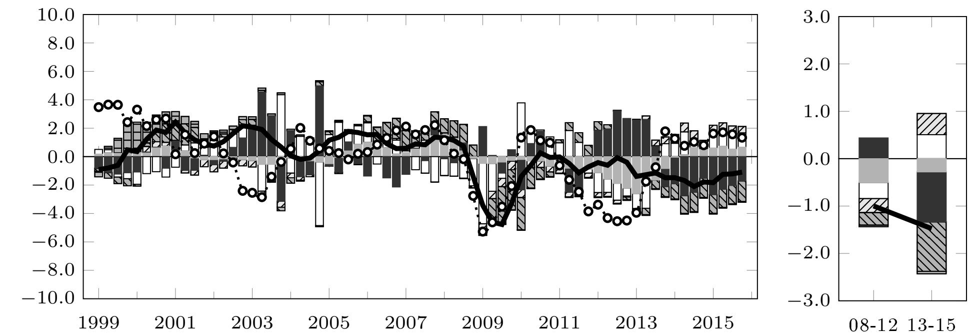
FIGURE 2: Smoothed shock processes (deviations from steady state).



(A) GDP growth (year-on-year).



(B) Private consumption growth (year-on-year). The solid black line is private consumption growth, the dotted line with markers denotes GDP growth.



(C) Private consumption goods inflation (year-on-year). The solid black line is private consumption goods inflation, the dotted line with markers denotes GDP growth.

Figure 3: Historical decompositions: GDP growth, private consumption growth, and private consumption goods inflation (deviations from steady state).

As for consumer goods inflation, the negative contributions from fiscal and technology shocks were to some extent outweighed by a sequence of positive cost-push shocks on private consumption goods and import goods.[9]

GDP growth recovered from the double dip recession in the 2014–2015 period, experiencing a downfall in wage and consumer goods markups and benefiting from low interest rates. The fiscal adjustment in place—grounded on indirect and labor income taxes—continued to contribute negatively to GDP growth during this period. On the financial side the increase in retained earnings (*i.e.* the negative net worth destroying shock) offset the damaging effects on entrepreneurial net worth triggered by the hike in borrowers' riskiness. The negative correlation between GDP growth and consumer goods inflation is explained by the supply-side nature of domestic cost-push shocks and by low external inflation, which is transposed to the domestic economy through the law of one price.

The historical decomposition of private consumption growth is broadly similar to that of GDP growth, with a few noteworthy distinctions. Preference and technology shocks and the nationwide risk shock played more prominent roles during the 2008–12 period. External shocks and cost-push shocks on consumer goods are more important to explain the 2013–15 recovery, though their effects were to some extent offset by adverse fiscal policies, rooted on higher indirect and labor income taxes. Preference shocks are a meaningful source of fluctuations, contributing to an important contraction in private consumption in the post-2008 period.

Figure 4 draws the contribution of selected shocks to GDP growth, private consumption growth, and consumer goods inflation. The selection was based on the correlation with the endogenous variable over the entire sample period. The unit root worldwide technology shock is a key driver of GDP growth, reflecting the common stochastic trend between Portugal and the remaining euro area. It has played a key role in explaining the 2009–10 downturn and subsequent recovery, jointly with the export market share shock. Borrowers' riskiness is also and important contributor to GDP growth, particularly since 2009. Private consumption growth reflects to a great extent preference shocks, though worldwide technology and sovereign risk are also important. Finally, consumer goods inflation depends strongly on cost-push shocks—decisive to explain the recent low inflation dynamics—but also on indirect taxes and on the export market share. The former has a direct impact on inflation, whereas the latter assumes an important role in the 2009–10 negative inflation period

9. The increase in the imports' markup in the 2011–2012 period and the decline in the 2013–2015 period reflects to some extent the path of oil prices in international markets.

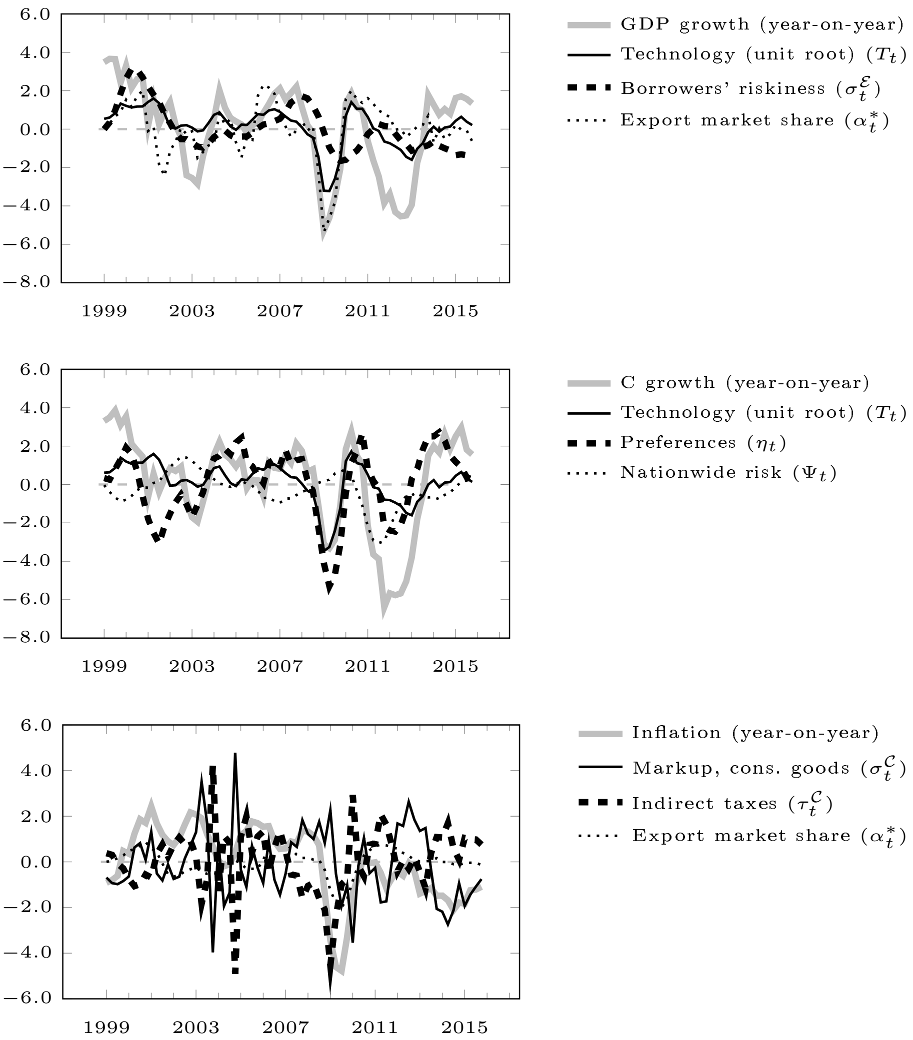


FIGURE 4: Contributions to year-on-year GDP growth, private consumption growth, and consumer goods inflation—selected shocks.

4.3. Variance decomposition

Figure 5 depicts the forecast error variance decomposition for stationary GDP, stationary private consumption, and consumer goods inflation at horizons of 1, 3, and 25 years. Financial factors, and in particular borrowers' riskiness, account for most of the GDP long-run forecast error variance. This result is related with the severe persistence of financial shocks—the borrowers' riskiness shock has an half-life of around 6 years and the nationwide risk premium shock of around 4 years— induced by the long-lasting effects of the financial turmoil

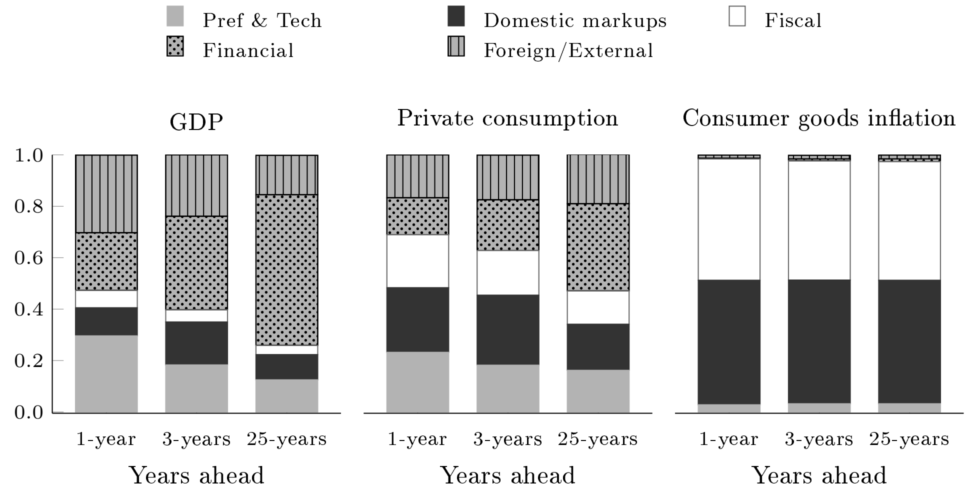


FIGURE 5: Forecast error variance decompositions: GDP, private consumption, and consumer goods inflation.

and the sovereign debt crises experienced in the recent period. At shorter horizons technology—in particular the imports' efficiency shock— and external factors—in particular the export market share shock—play a more important role.[10]

Fluctuations in private consumption and inflation echo more important contributions from cost-push and fiscal shocks. The former reflects above all shifts in the consumer goods price markup, whereas the latter mostly expresses impacts triggered by changes in indirect taxation. An important fraction of private consumption fluctuations is also driven by preference shocks and by shifts in the domestic interest rate—either triggered by monetary policy shocks (external factors) or by sovereign risk shocks (financial factors). This later result simply mirrors the role played by interest rate movements in households' wealth and in intertemporal smoothing. On the opposite direction, borrowers' riskiness and imports efficiency play nearly no role in the private consumption forecast error variance.

4.4. Smoothed default probability and smoothed fiscal balance

The first plot in Figure 6 draws the smoothed default probability, jointly with the credit spread and an observed measure for the frequency of defaults. The smoothed default probability is driven closely by the credit spread, a built-in

10. Notice that the unit root worldwide technology shock plays an important role in GDP growth but is not expected to severely influence the variance decomposition, since the latter is carried out for stationary variables, *i.e.* after extracting the unit root trend component.

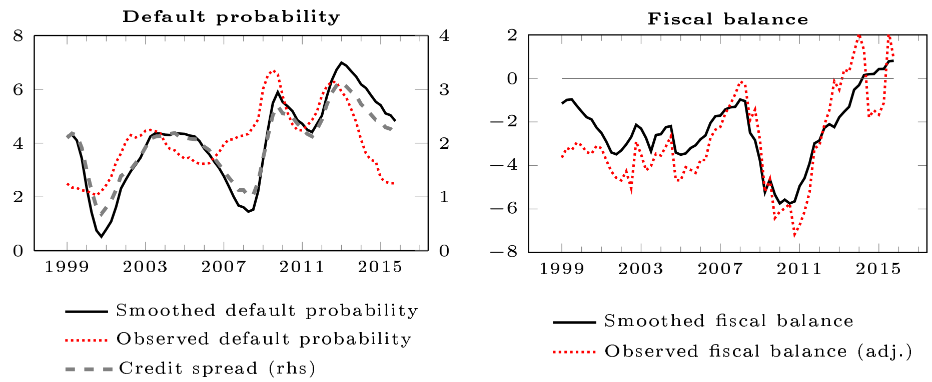


FIGURE 6: Smoothed default probability and smoothed fiscal balance.

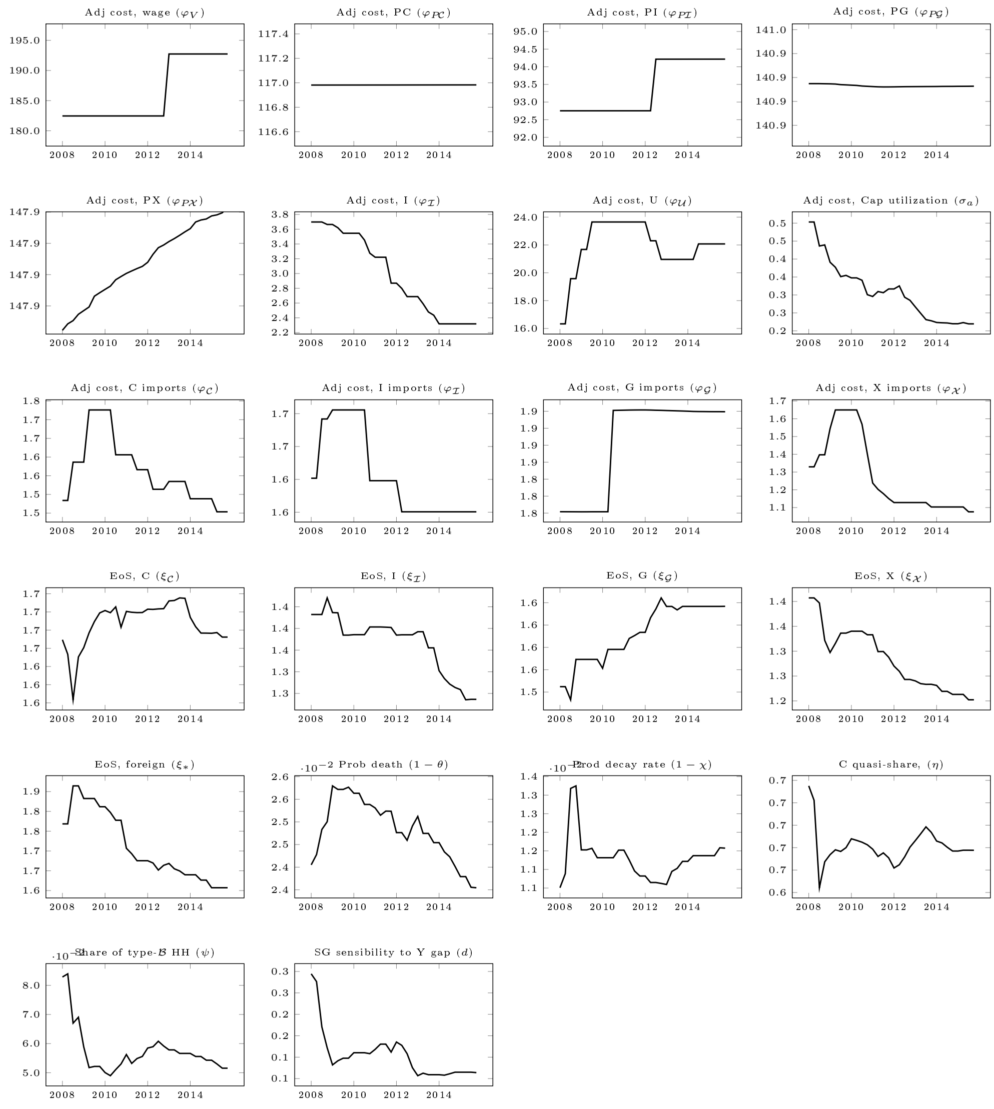
Notes: The default probability, measuring new defaults in each quarter, was computed with data from the Central Credit Registry of Banco de Portugal. It corresponds to the percentage of performing firms in which at least 2.5 percent of the total amount of credit is due for 3 or more consecutive months. For comparability purposes, the observed fiscal balance was computed by applying the transformation that was carried out prior to estimation for the data series concerning household transfers and the payroll tax-to-revenue ratio (see Section 3.1).

mechanism in the financial frictions setup. It is able to track closely the main movements in its data counterpart, and in particular the hikes in the 2009–2010 and in the 2012–2013 periods, though it is not able to capture the dynamics prior to the financial crisis. This period was characterized by a strong decline in the credit spread, and the model associates this to a decline in the default probability that did not occur according to the observed data series.

The second plot presents a similar exercise for the fiscal balance. In this case, we adjusted the data counterpart by applying the same transformation that was carried out for the data series (See Section 3.1). The estimated model encloses information on tax revenue ratios and on household transfers, but does not embody information on observed dynamics for interest outlays or other types of (current and capital) transfers. Hence, the smoothed series for the fiscal balance does not exactly match the data counterpart, but co-moves well with it. In particular, the model is able to track the observed medium term movements in the fiscal balance, including the large increase in deficit that followed the 2009 turmoil and the subsequent fiscal adjustment.

4.5. Parameter stability

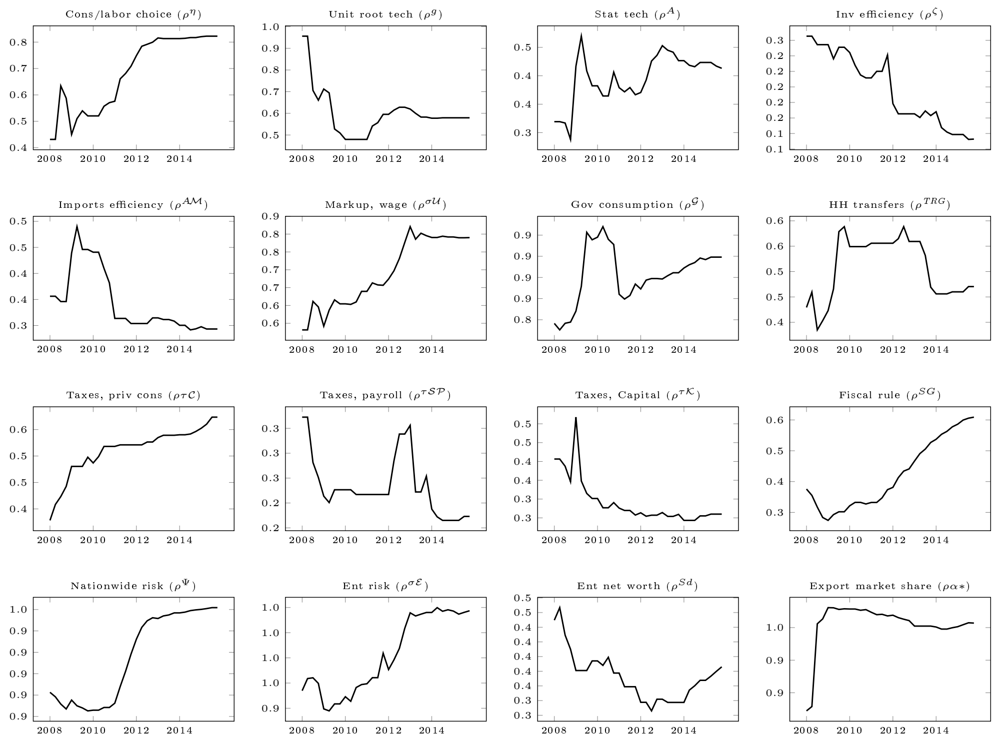
We access the stability of estimated parameters by re-estimating the model recursively for the 2008Q1–2015Q4 period. The exercise—whose results are reported in Figure 7—is performed at the posterior mode.



(A) Structural parameters.

FIGURE 7: Parameter stability.

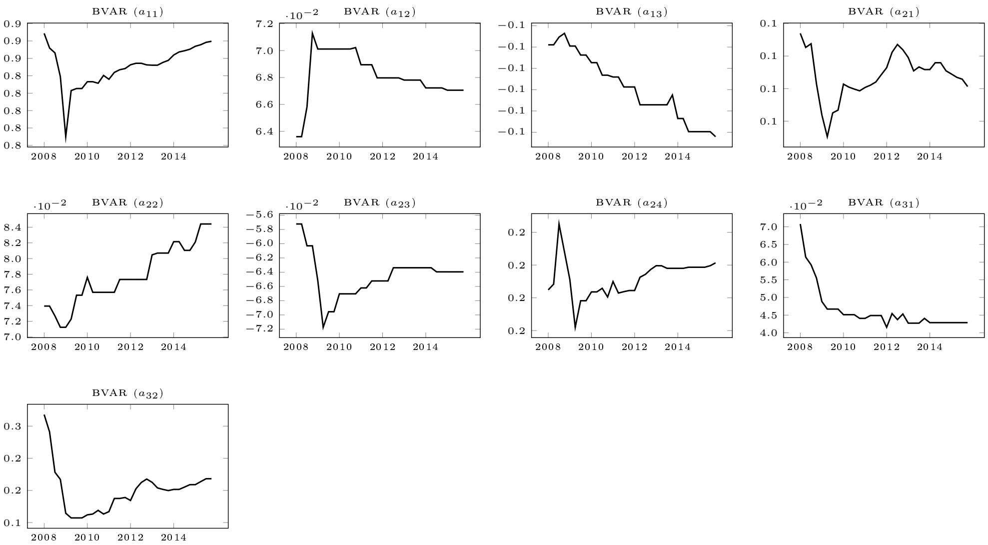
Investment and capital utilization adjustment costs declined from 2008 till 2015. Likewise for the sensibility of the fiscal balance to the output gap, possibly due to the fiscal retrenchment carried out during the sovereign debt crisis. Other structural parameters remained relatively stable over the evaluation horizon, and the same also holds for most persistence and BVAR parameters, with a few exceptions.



(b) Persistence parameters.

Figure 7: Parameter stability.

The persistence of the wage markup shock has increased, suggesting a greater wage stickiness over the crisis period. Likewise for private consumption taxes and labor taxes (the fiscal rule), hinting that fiscal measures associated with the recent fiscal retrenchment have a more resilient nature as opposed to fiscal policies carried out in the past. Preference shocks have also become more persistent, as opposed to some technology which have experienced an increase in their transitory nature.



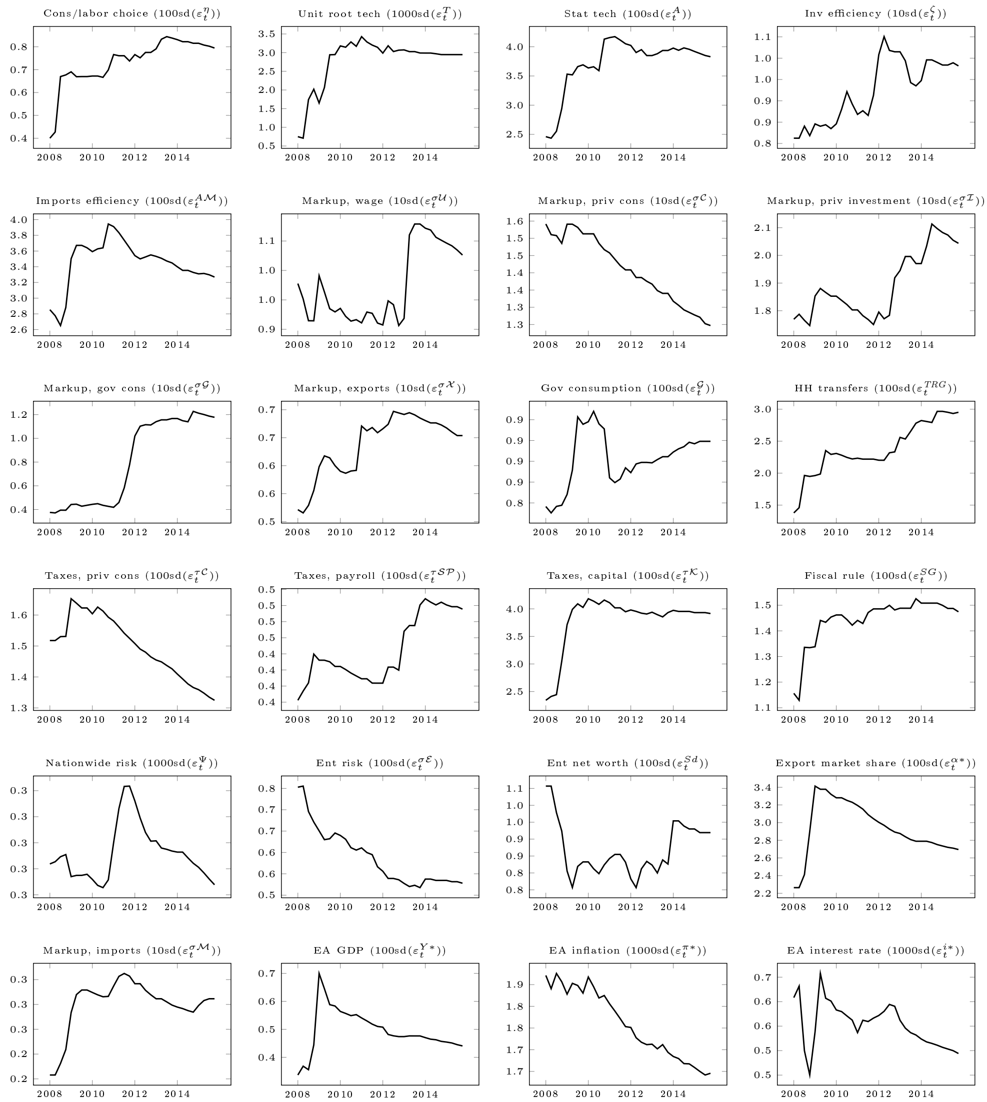
(c) BVAR parameters.

Figure 7: Parameter stability.

Note: The figure reports estimated parameters at the posterior mode.

The BVAR parameter assessing the impact of inflation on the interest rate declined over the horizon, which may reflect a disconnection between the monetary policy rate and inflation most probably triggered by the zero-lower bound.

Finally, several shocks experienced slight increases in volatility over the recent period, particularly preferences and some technology components, as well as the price markup on government goods and household transfers. On the opposite direction, risk shocks became less volatile.



(D) Standard errors.

FIGURE 7: Parameter stability.

Note: The figure reports estimated parameters at the posterior mode.

5. Concluding remarks

We present a medium-scale small-open Dynamic Stochastic General Equilibrium model encompassing a financial accelerator mechanism and an overlapping generations scheme that is able to deliver a highly non-Ricardian behavior. We then employ Bayesian methods and estimate the model for the Portuguese economy for the period after the euro area inception until 2015.

Our findings suggest that a few shocks are able to explain major macroeconomic developments over 2008–2015 period. External factors, in particular the export market share decline and subsequent recovery, and worldwide technology developments, are key to explain the 2008–2010 cycle. The 2011-2013 recession was precipitated by financial and fiscal factors, the former mimicking an increase in both nationwide and investment riskiness and the latter echoing the fiscal retrenchment carried out on the aftermath of the sovereign debt crisis. Both recessions were exacerbated by negative worldwide technological developments, reflecting an unobserved trend component common to both Portugal and the euro area.

GDP fluctuations have been mostly driven by the export market share and some technology components in the short term and by financial factors at longer horizons, particularly borrowers' riskiness. Fluctuations in private consumption and inflation, on the other hand, echo more important contributions from cost-push and fiscal shocks, the former emerging on consumer goods prices and the latter mirroring changes in indirect taxation. An important fraction of private consumption fluctuations is also driven by preference shocks and by sovereign risk shocks.

We carry out several evaluation exercises and conclude that the estimated model performs satisfactorily well. The smoothed default probability and smoothed fiscal balance-to-GDP ratio are able to track very closely their data counterparts. Parameters tended to remain relatively stable over the 2008–2015 horizon, with a few noteworthy exceptions that can be related with key macroeconomic developments over this period.

Appendix A: Brooks and Gelman (1998) convergence diagnostic

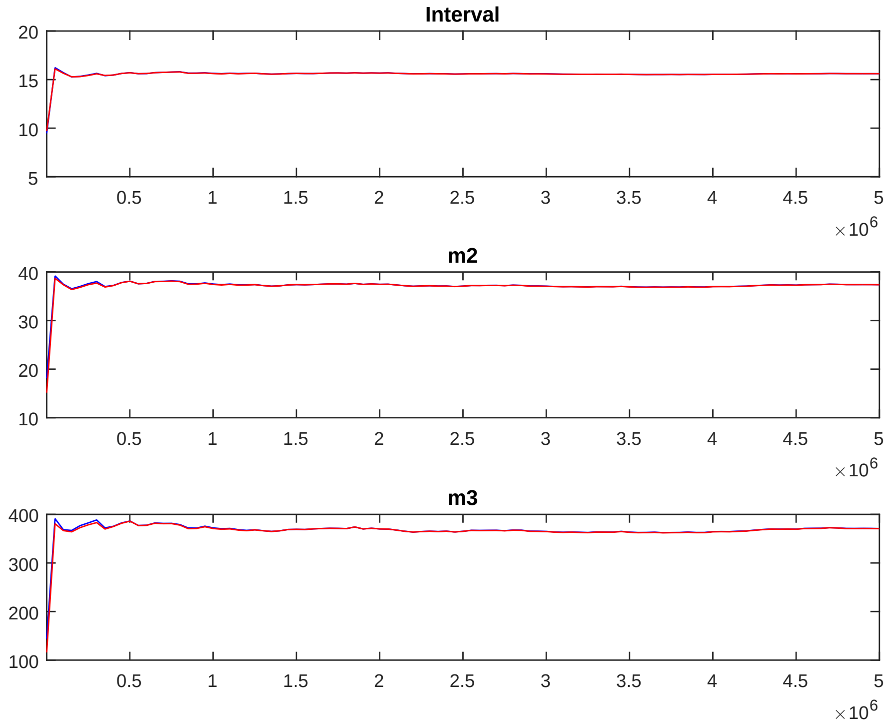


FIGURE A.1: Multivariate convergence diagnostics for the Metropolis-Hastings. The first, second and third rows are respectively the criteria based on the eighty percent interval, the second and third moments. The different parameters are aggregated using the posterior kernel.

Appendix B: Prior and posterior plots

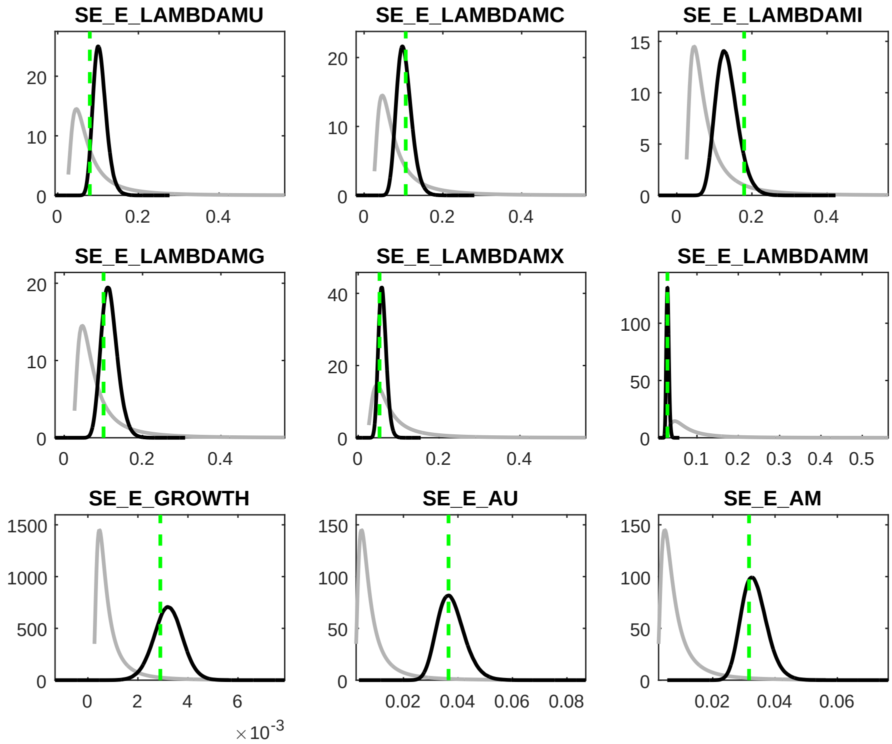


FIGURE B.1: Priors and posteriors. Notes: SE_E_LAMBDAMU = s.e.($\tilde{\varepsilon}_t^{\sigma\mathcal{U}}$); SE_E_LAMBDAMC = s.e.($\tilde{\varepsilon}_t^{\sigma\mathcal{C}}$); SE_E_LAMBDAMI = s.e.($\tilde{\varepsilon}_t^{\sigma\mathcal{I}}$); SE_E_LAMBDAMG = s.e.($\tilde{\varepsilon}_t^{\sigma\mathcal{G}}$); SE_E_LAMBDAMX = s.e.($\tilde{\varepsilon}_t^{\sigma\mathcal{X}}$); SE_E_LAMBDAMM = s.e.($\tilde{\varepsilon}_t^{\mathcal{M}}$); SE_E_GROWTH = s.e.($\tilde{\varepsilon}_t^{T}$); SE_E_AU = s.e.($\tilde{\varepsilon}_t^{A}$); SE_E_AM = s.e.($\tilde{\varepsilon}_t^{A\mathcal{M}}$).

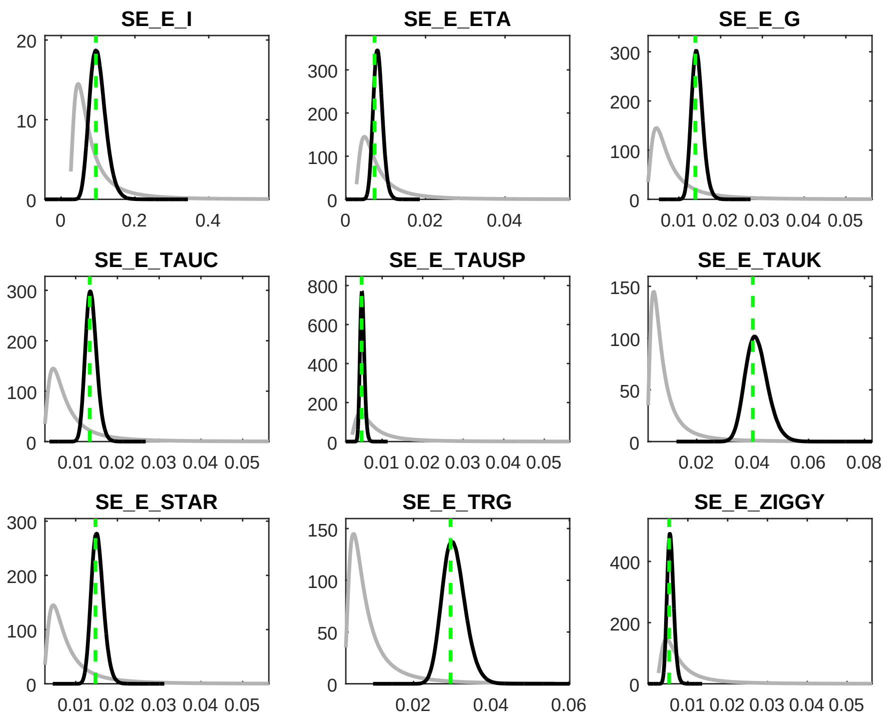


FIGURE B.2: Priors and posteriors. Notes: SE_E_I = s.e.($\tilde{\varepsilon}_t^{\zeta}$); SE_E_ETA = s.e.($\tilde{\varepsilon}_t^{\eta}$); SE_E_G = s.e.($\tilde{\varepsilon}_t^{\mathcal{G}}$); SE_E_TAUC = s.e.($\tilde{\varepsilon}_t^{\tau C}$); SE_E_TAUSP = s.e.($\tilde{\varepsilon}_t^{\tau SP}$); SE_E_TAUK = s.e.($\tilde{\varepsilon}_t^{\tau K}$); SE_E_STAR = s.e.($\tilde{\varepsilon}_t^{SG}$); SE_E_TRG = s.e.($\tilde{\varepsilon}_t^{TRG}$); SE_E_ZIGGY = s.e.($\tilde{\varepsilon}_t^{\sigma \mathcal{E}}$).

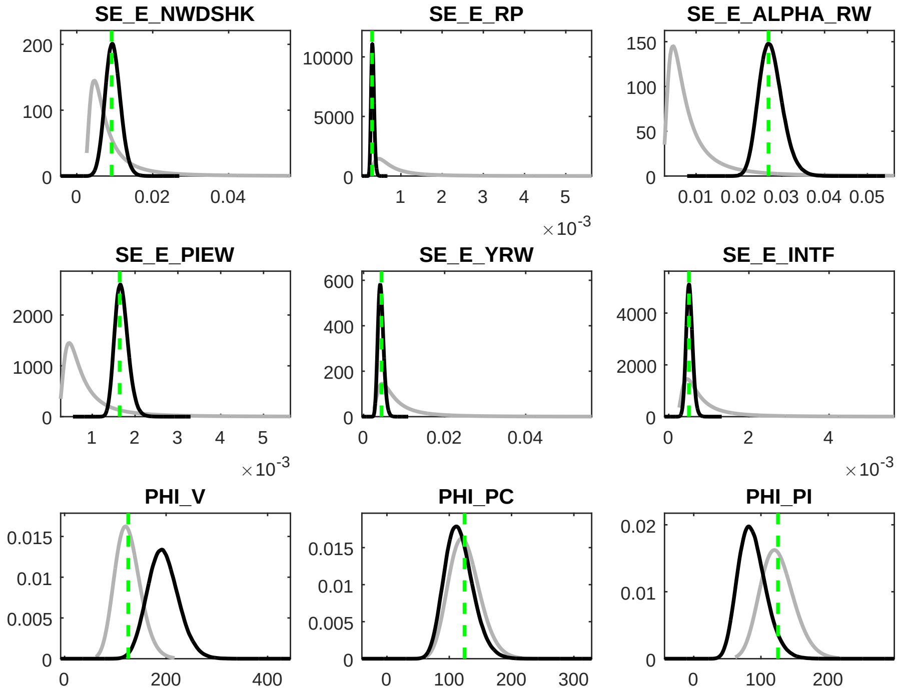


FIGURE B.3: Priors and posteriors. Notes: SE_E_NWDSHK = s.e.($\tilde{\varepsilon}_t^{Sd}$); SE_E_RP = s.e.($\tilde{\varepsilon}_t^{\Psi}$); SE_E_ALPHA_RW = s.e.($\tilde{\varepsilon}_t^{\alpha*}$); SE_E_PIEW = s.e.($\tilde{\varepsilon}_t^{\pi*}$); SE_E_YRW = s.e.($\tilde{\varepsilon}_t^{y*}$); SE_E_INTF = s.e.($\tilde{\varepsilon}_t^{i*}$); PHI_V = $\varphi_{\mathcal{V}}$; PHI_PC = $\varphi_{\mathcal{PC}}$; PHI_PI = $\varphi_{\mathcal{PI}}$.

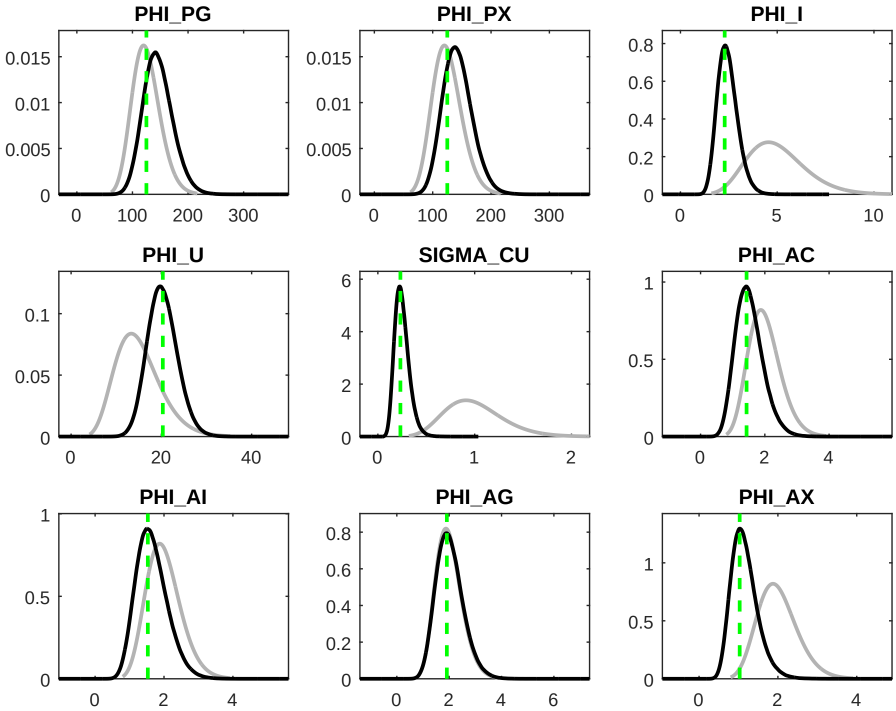


FIGURE B.4: Priors and posteriors. Notes: PHI_PG = $\varphi_{P\mathcal{G}}$; PHI_PX = $\varphi_{P\mathcal{X}}$; PHI_I = $\varphi_{\mathcal{I}}$; PHI_U = $\varphi_{\mathcal{U}}$; SIGMA_CU = σ_a; PHI_AC = $\varphi_{\mathcal{C}}$; PHI_AI = $\varphi_{\mathcal{I}}$; PHI_AG = $\varphi_{\mathcal{G}}$; PHI_AX = $\varphi_{\mathcal{X}}$.

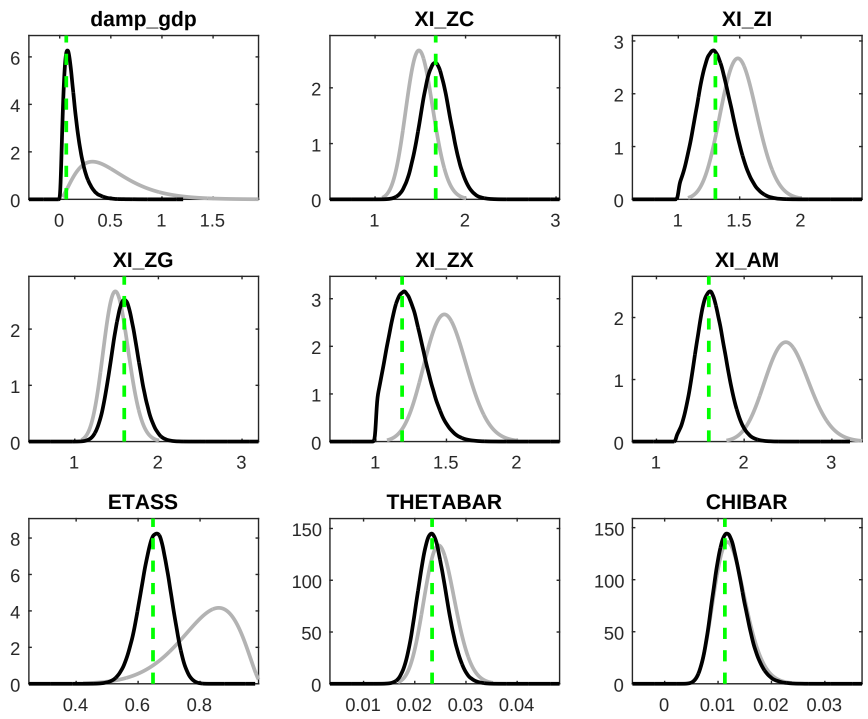


Figure B.5: Priors and posteriors. Notes: damp_gdp $= d$; XI_ZC $= \xi_{\mathcal{C}}$; XI_ZI $= \xi_{\mathcal{I}}$; XI_ZG $= \xi_{\mathcal{G}}$; XI_ZX $= \xi_{\mathcal{X}}$; XI_AM $= \xi_*$; ETASS $= \eta$; THETABAR $= 1-\theta$; CHIBAR $= 1-\chi$.

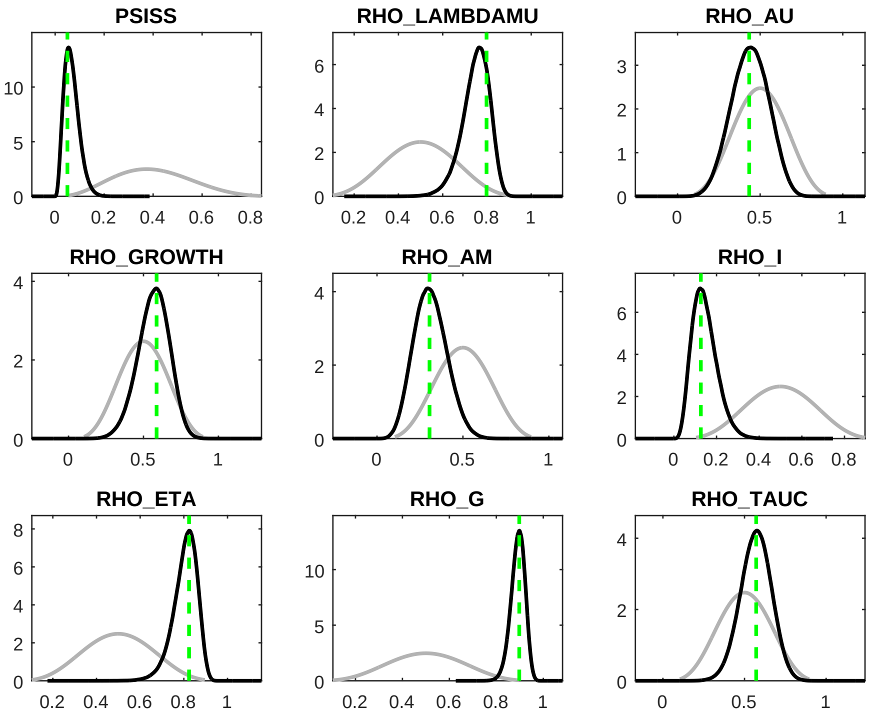


FIGURE B.6: Priors and posteriors. Notes: PSISS = ψ; RHO_LAMBDAMU = $\rho^{\sigma\mathcal{U}}$; RHO_AU = ρ^{A}; RHO_GROWTH = ρ^{g}; RHO_AM = $\rho^{\overline{\mathcal{AM}}}$; RHO_I = ρ^{ζ}; RHO_ETA = ρ^{η}; RHO_G = $\rho^{\mathcal{G}}$; RHO_TAUC = $\rho^{\tau\overline{\mathcal{C}}}$.

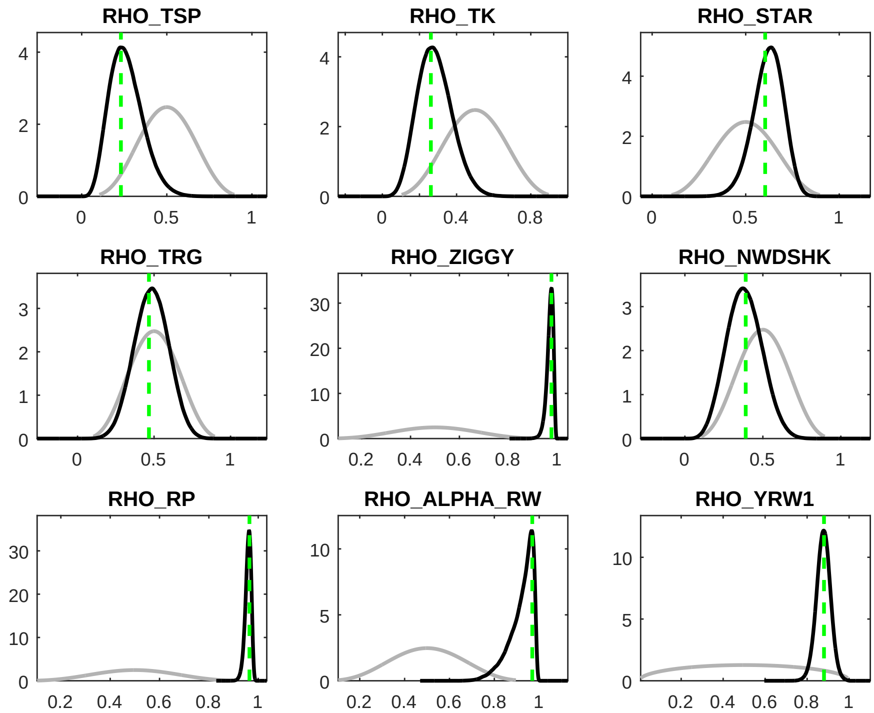


FIGURE B.7: Priors and posteriors. Notes: RHO_TSP $= \rho^{\tau\mathcal{SP}}$; RHO_TK $= \rho^{\tau\mathcal{K}}$; RHO_STAR $= \rho^{SG}$; RHO_TRG $= \rho^{TRG}$; RHO_ZIGGY $= \rho^{\sigma\mathcal{E}}$; RHO_NWDSHK $= \rho^{S\bar{d}}$; RHO_RP $= \rho^{\Psi}$; RHO_ALPHA_RW $= \rho^{\alpha*}$; RHO_YRW1 $= a_{11}$.

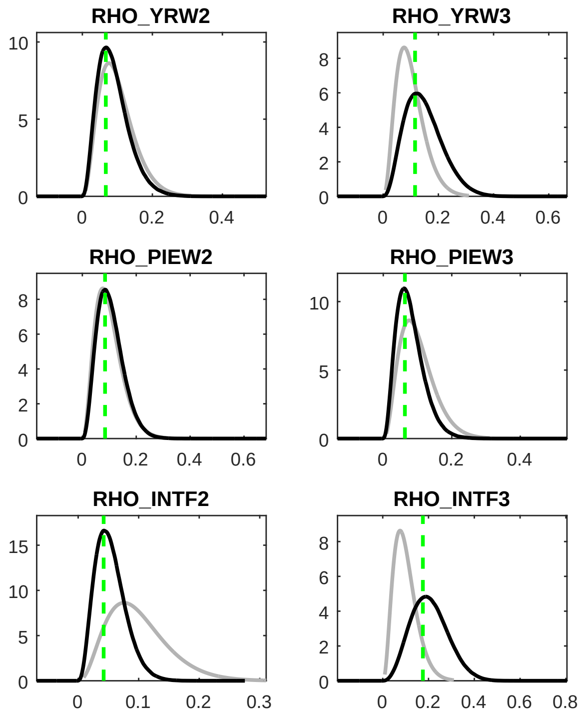


FIGURE B.8: Priors and posteriors. Notes: RHO_YRW2 = a_{12}; RHO_YRW3 = $-a_{13}$; RHO_PIEW1 = a_{21}; RHO_PIEW2 = a_{22}; RHO_PIEW3 = $-a_{23}$; RHO_INTF1 = a_{31}; RHO_INTF2 = a_{32}; RHO_INTF3 = a_{33}.

Appendix C: Smoothed variables

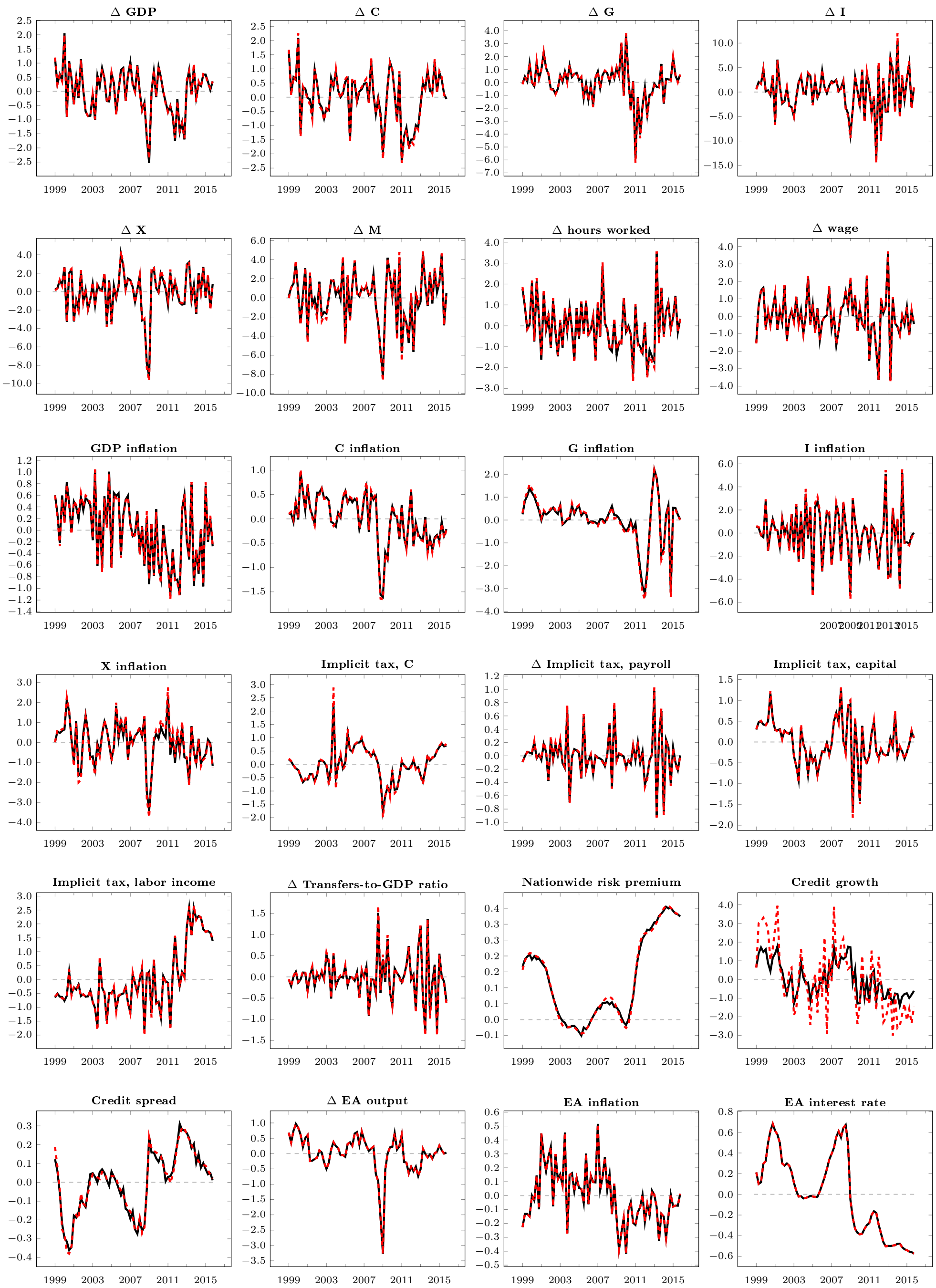


FIGURE C.1: Data series used in estimation (solid black line) and smoothed variables without measurement error (red dashed line), deviations from steady state.

Appendix D: Smoothed innovations

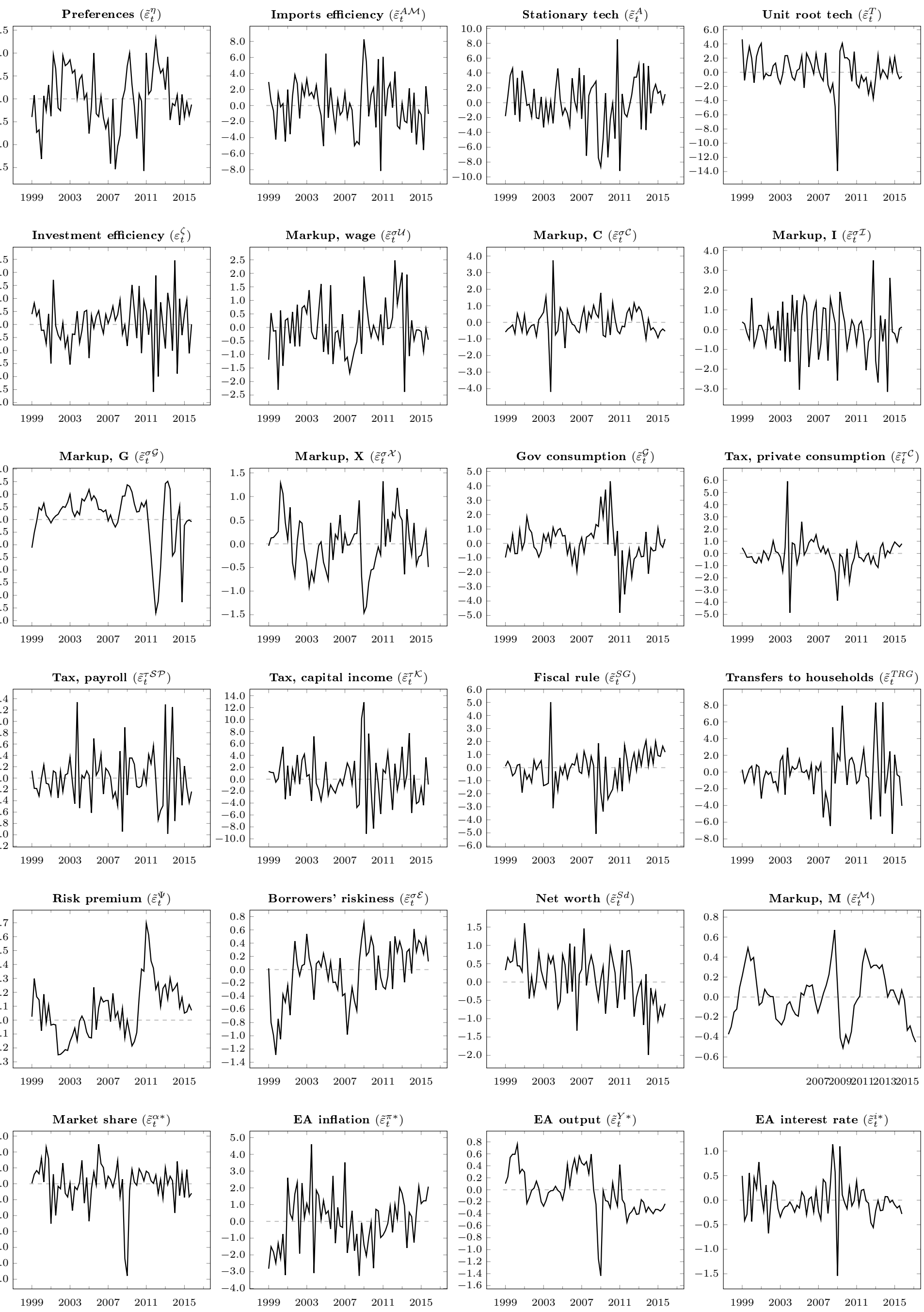


FIGURE D.1: Smoothed innovations.

Appendix E: Detailed historical decomposition

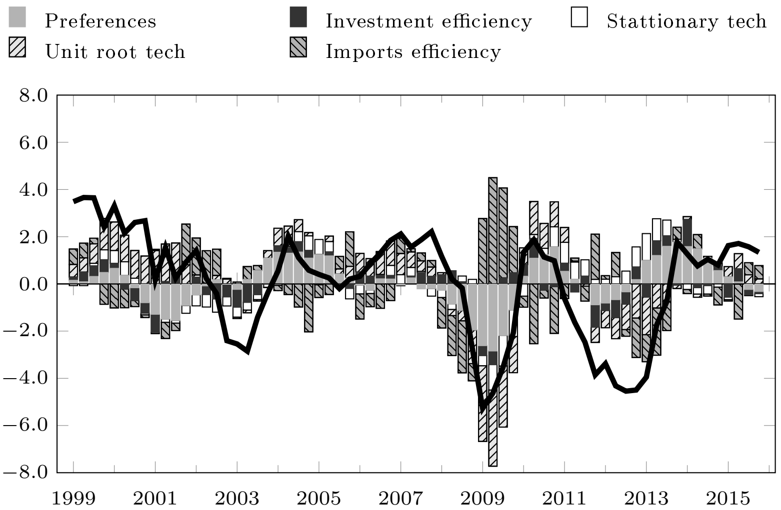


FIGURE E.1: GDP growth (year-on-year), detailed contributions, preference and technology shocks.

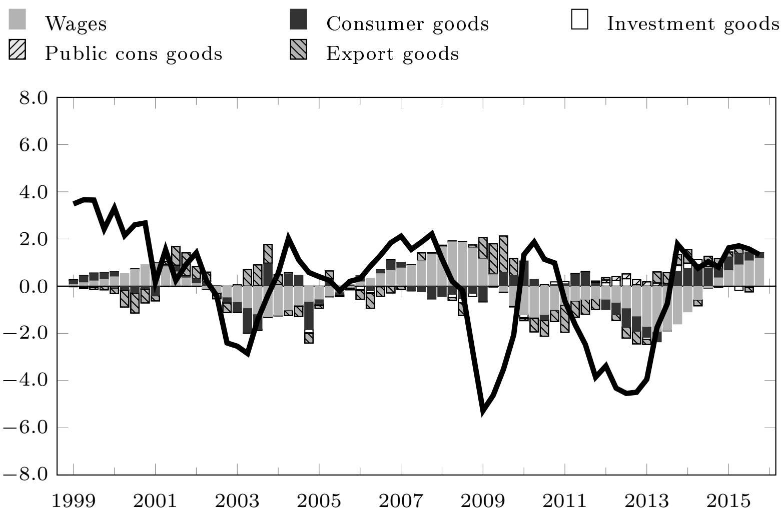


FIGURE E.2: GDP growth (year-on-year), detailed contributions, markup shocks.

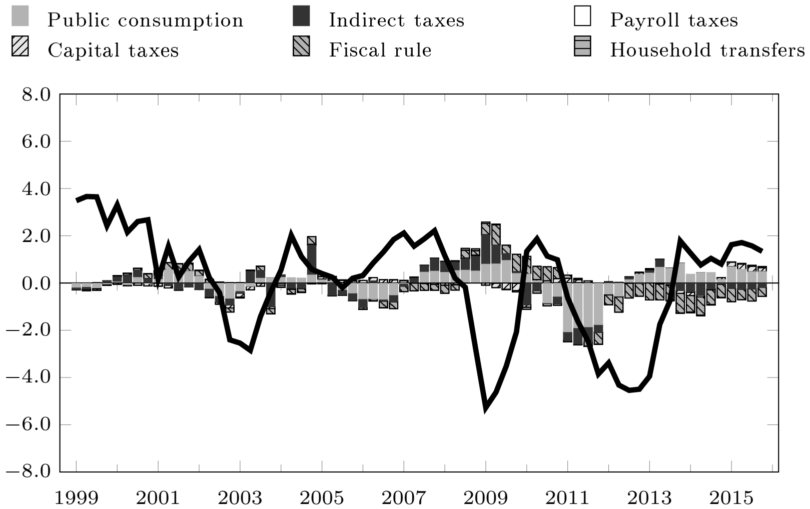


Figure E.3: GDP growth (year-on-year), detailed contributions, fiscal shocks.

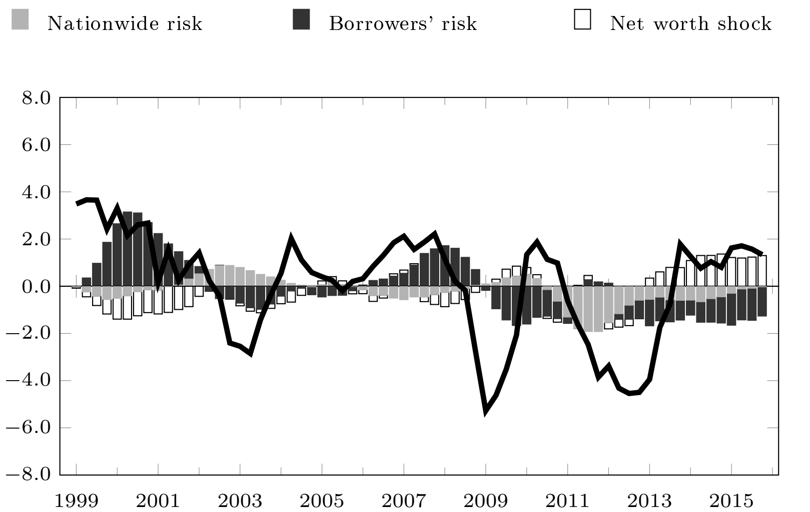


Figure E.4: GDP growth (year-on-year), detailed contributions, financial shocks.

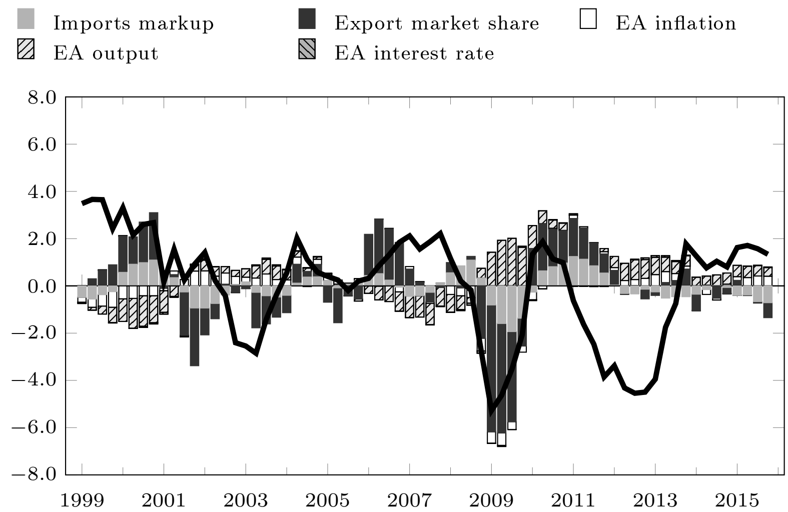


Figure E.5: GDP growth (year-on-year), detailed contributions, external/foreign shocks.

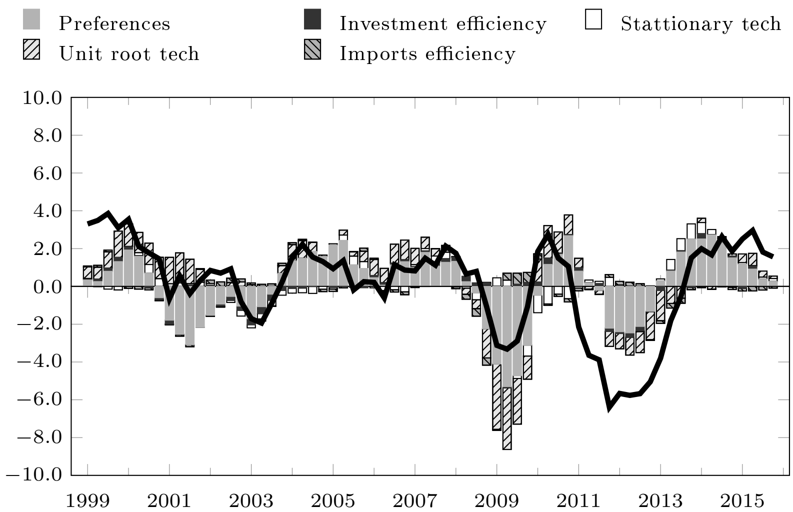


Figure E.6: Private consumption growth (year-on-year), detailed contributions, preference and technology shocks.

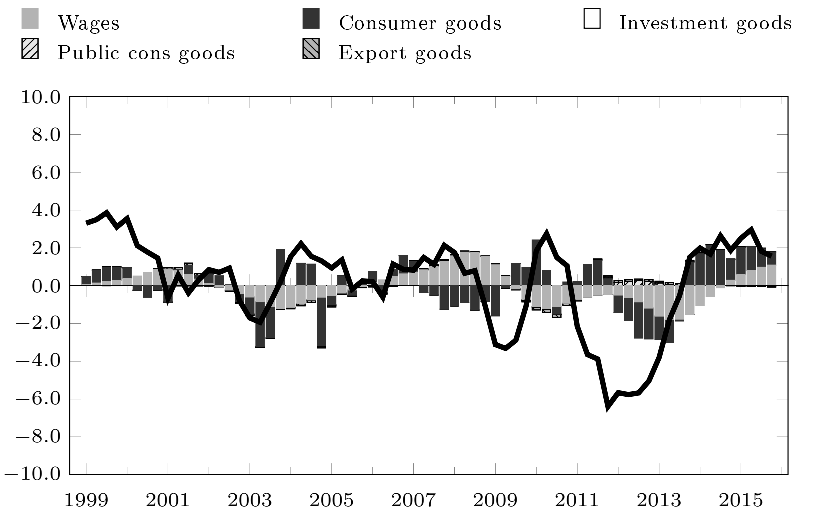


FIGURE E.7: Private consumption growth (year-on-year), detailed contributions, markup shocks.

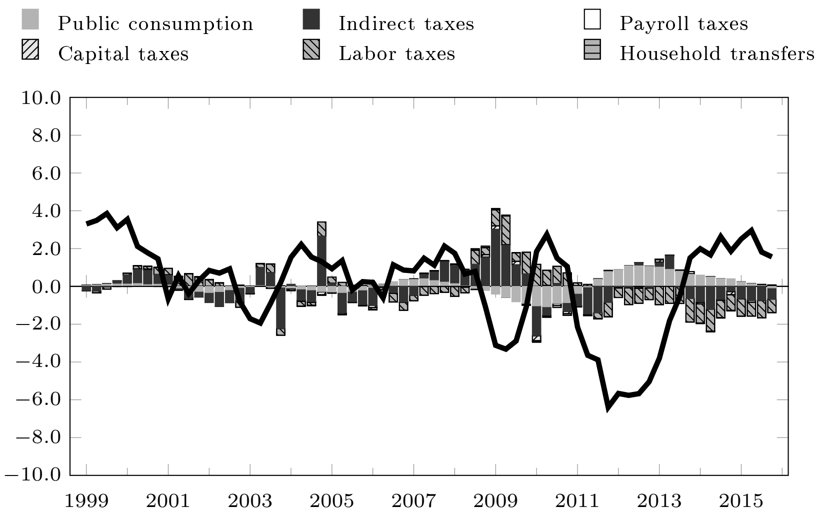


FIGURE E.8: Private consumption growth (year-on-year), detailed contributions, fiscal shocks.

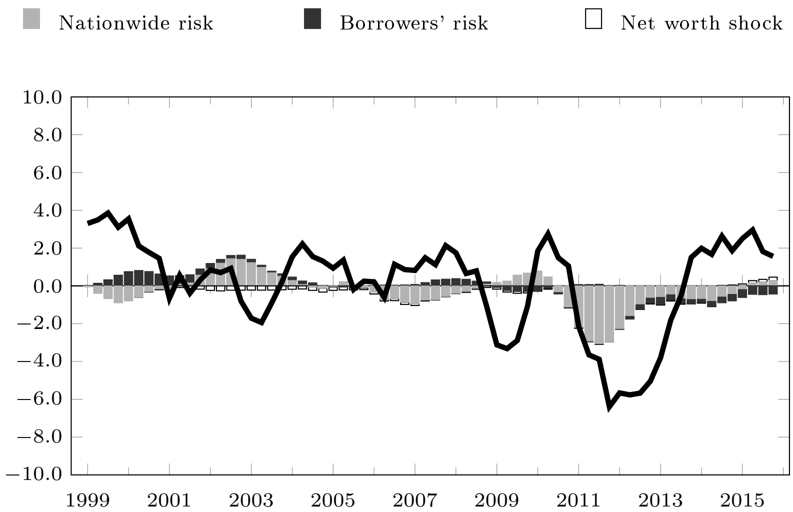


FIGURE E.9: Private consumption growth (year-on-year), detailed contributions, financial shocks.

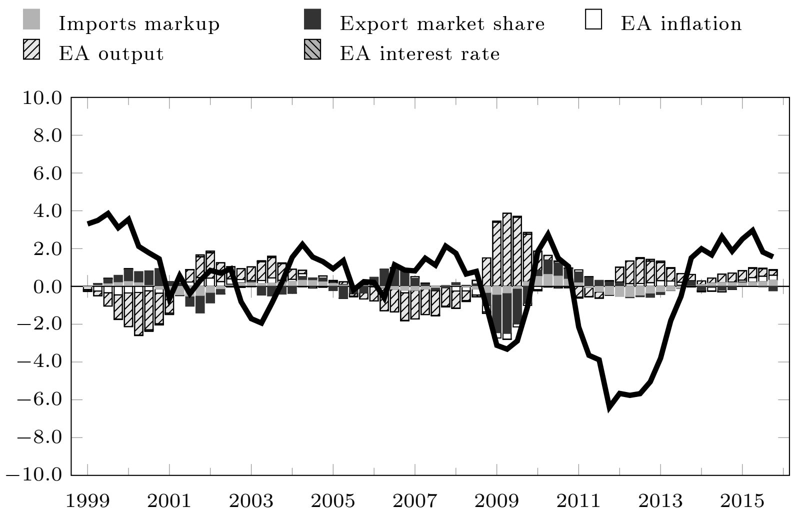


FIGURE E.10: Private consumption growth (year-on-year), detailed contributions, external/foreign shocks.

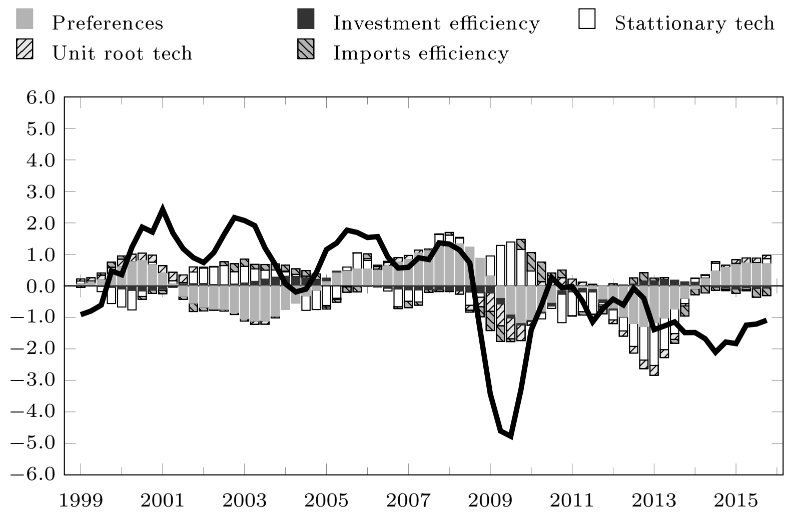


Figure E.11: Consumer goods Inflation (year-on-year), detailed contributions, preference and technology shocks.

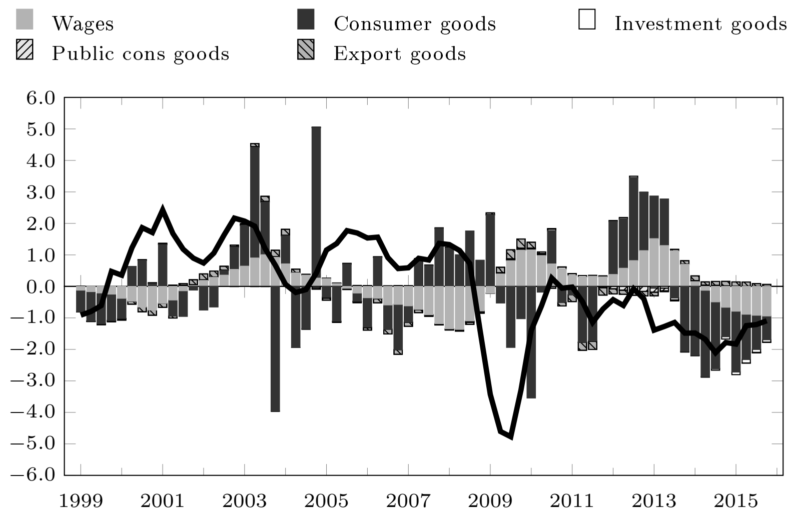


Figure E.12: Consumer goods Inflation (year-on-year), detailed contributions, markup shocks.

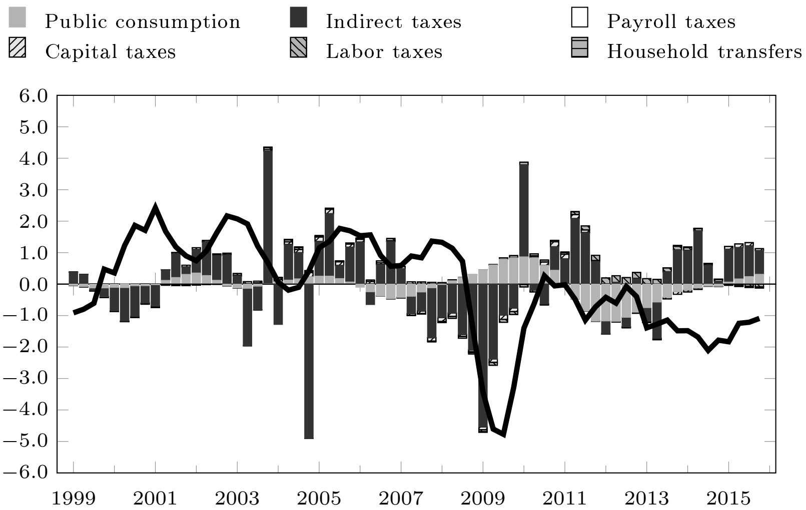


FIGURE E.13: Consumer goods inflation (year-on-year), detailed contributions, fiscal shocks.

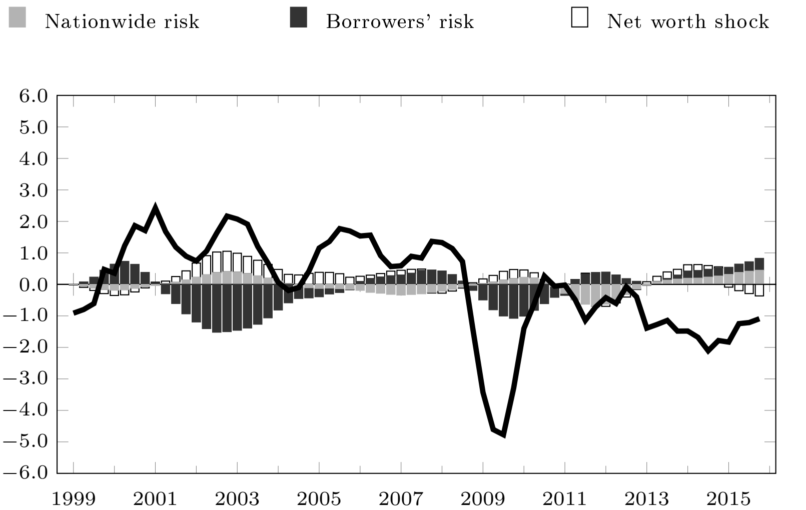


FIGURE E.14: Consumer goods inflation (year-on-year), detailed contributions, financial shocks.

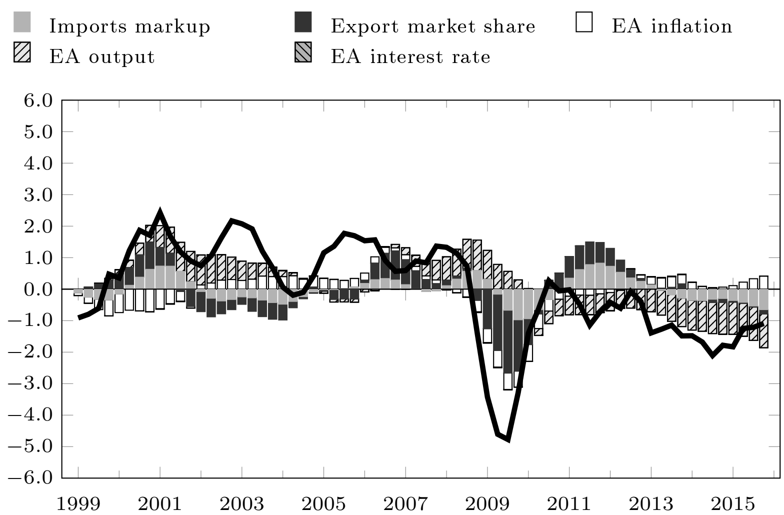


FIGURE E.15: Consumer goods inflation (year-on-year), detailed contributions, external/foreign shocks.

Appendix F: Impulse response functions
(red dotted lines correspond to the 90% confidence band)

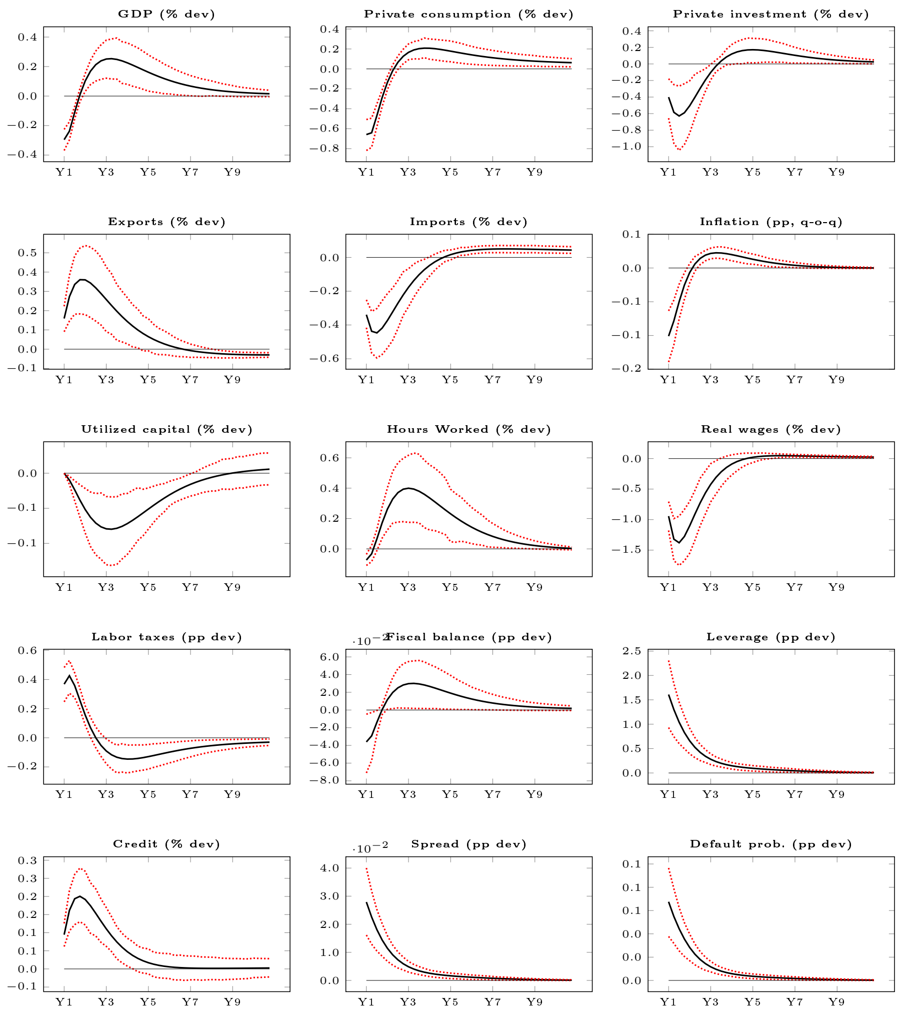


FIGURE F.1: Preference shock, η_t.
(deviations from steady state)

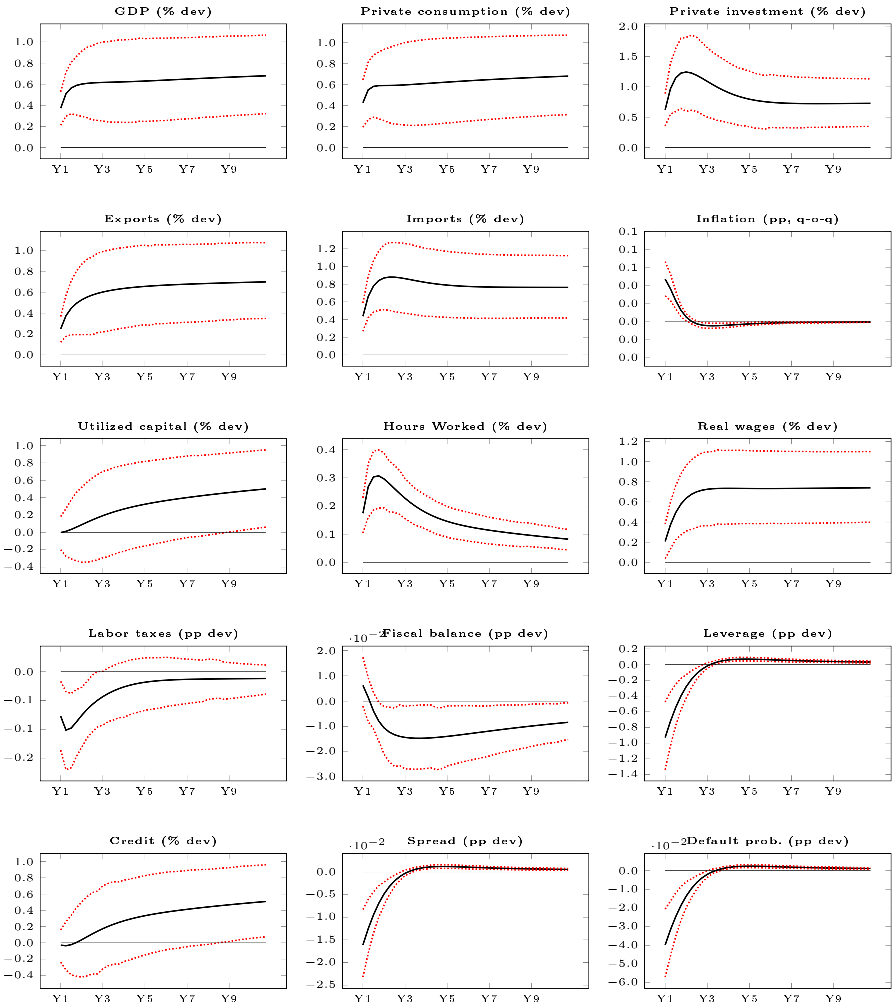


FIGURE F.2: Unit root labor-augmenting technology shock, T_t.
(deviations from steady state)

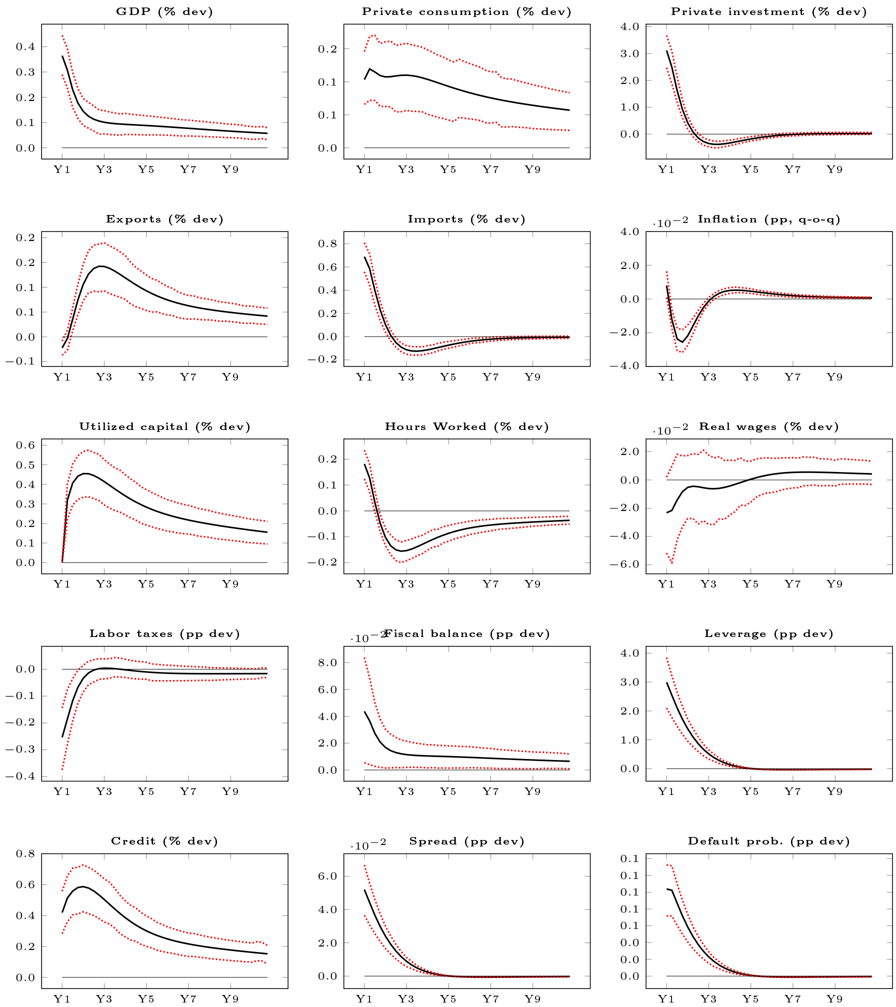


FIGURE F.3: Investment efficiency technology shock, ζ_t.
(deviations from steady state)

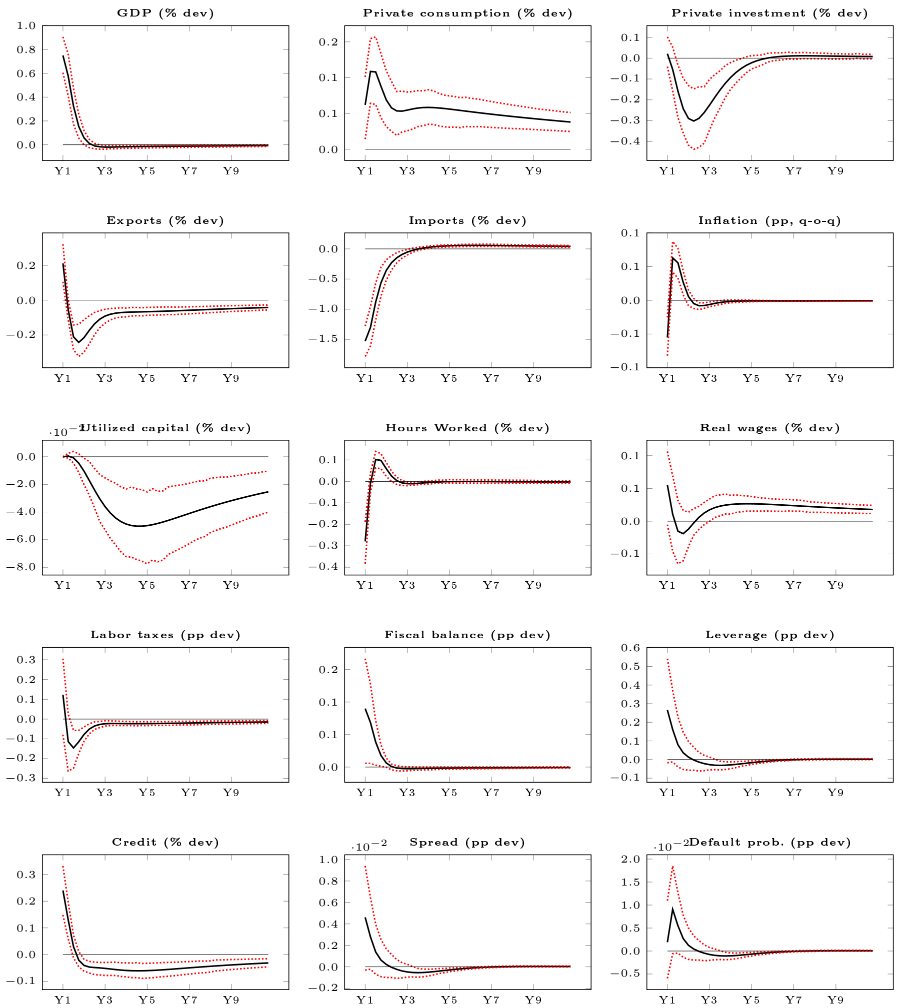


FIGURE F.4: Imports efficiency shock, $A_t^{\mathcal{M}}$.
(deviations from steady state)

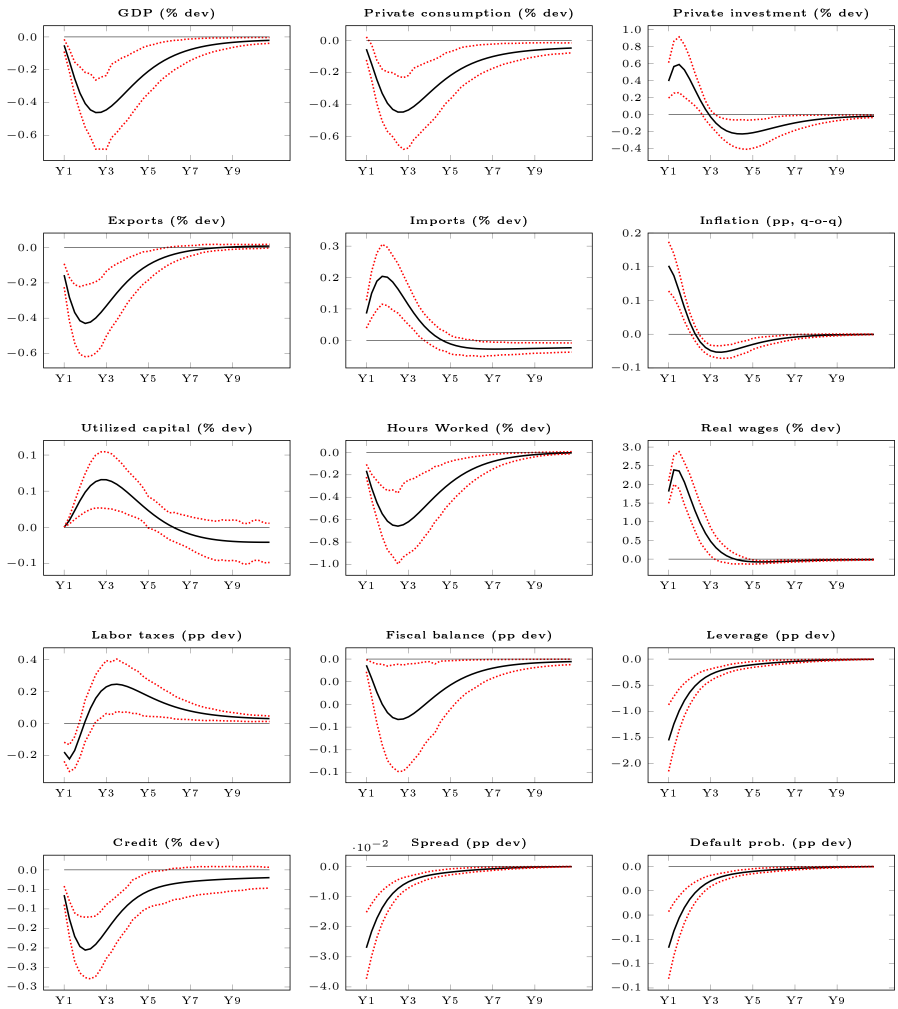


FIGURE F.5: Wage markup shock, $\sigma_t^{\mathcal{U}}$.
(deviations from steady state)

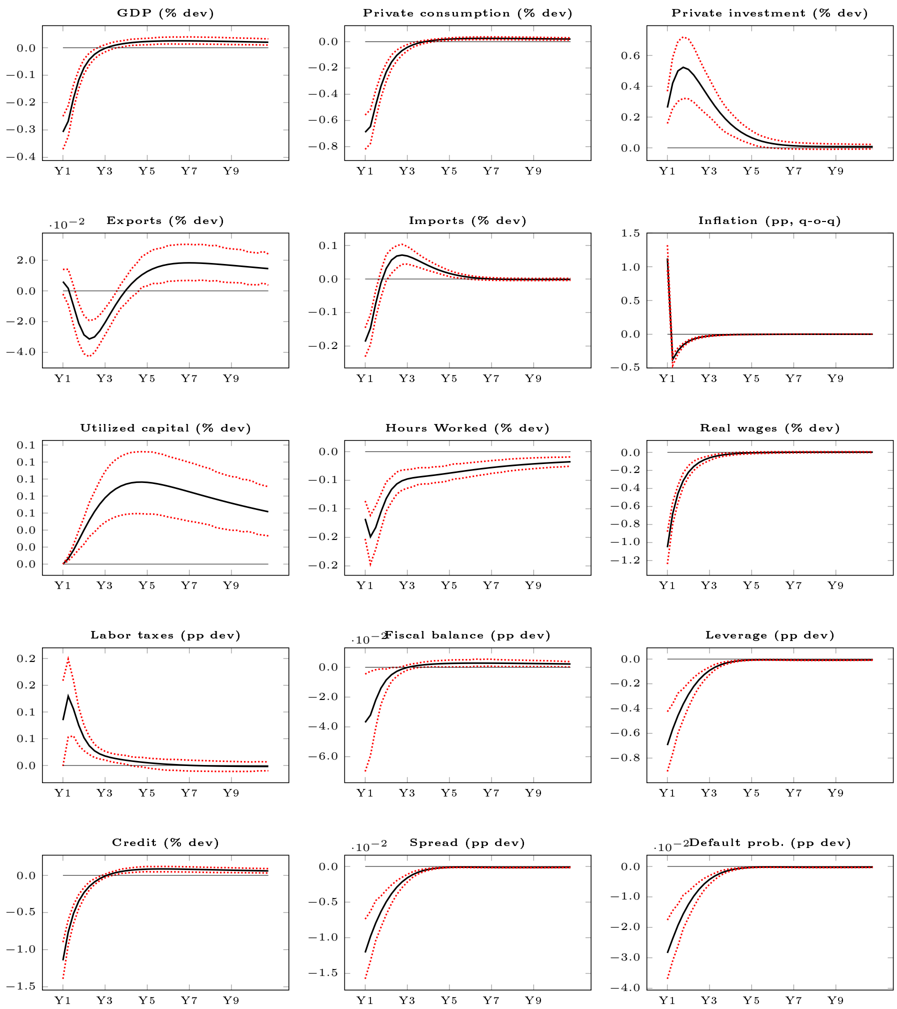


FIGURE F.6: Private consumption goods price markup shock, $\sigma_t^{\mathcal{C}}$.
(deviations from steady state)

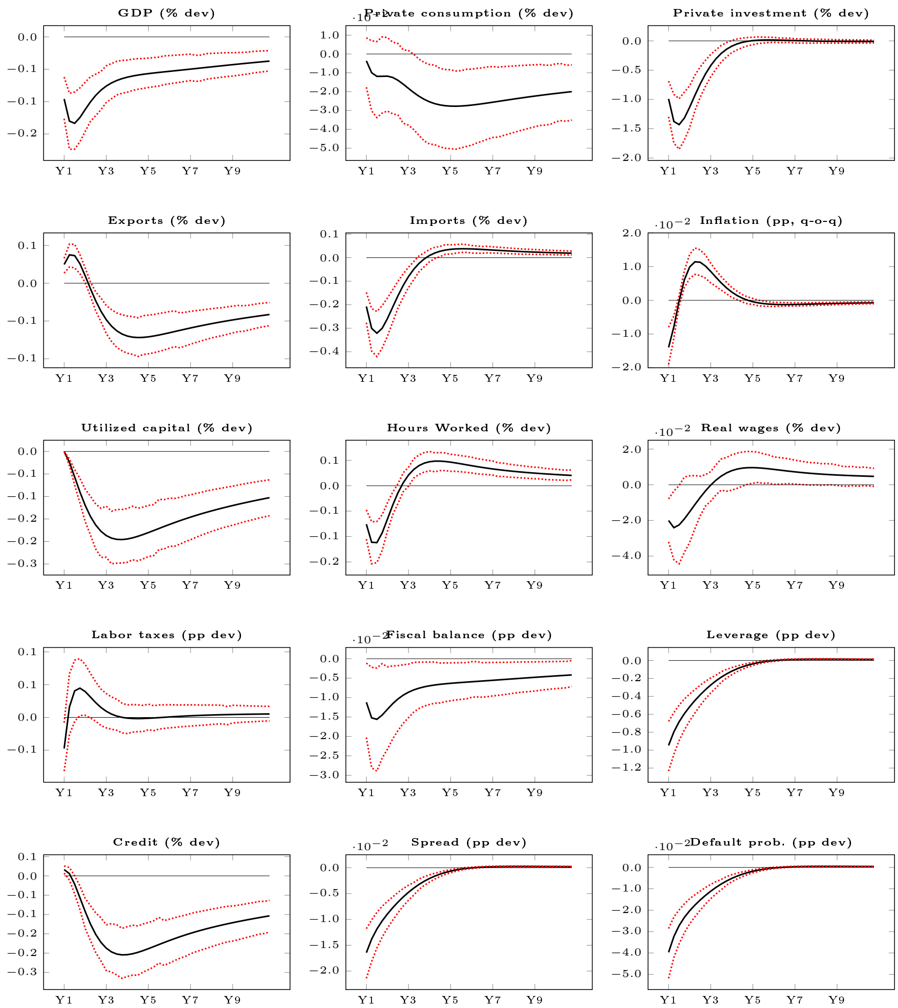


FIGURE F.7: Investment goods price markup shock, $\sigma_t^{\mathcal{I}}$.
(deviations from steady state)

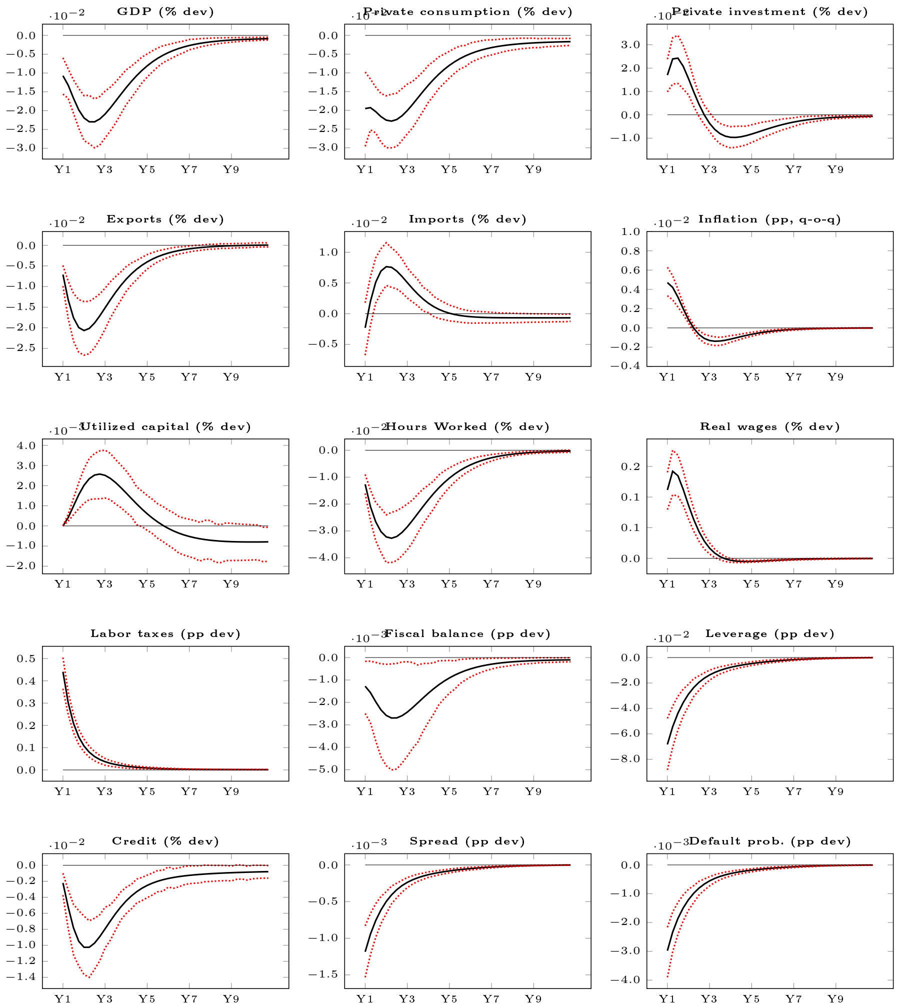


FIGURE F.8: Public consumption goods price markup shock, $\sigma_t^{\mathcal{G}}$.
(deviations from steady state)

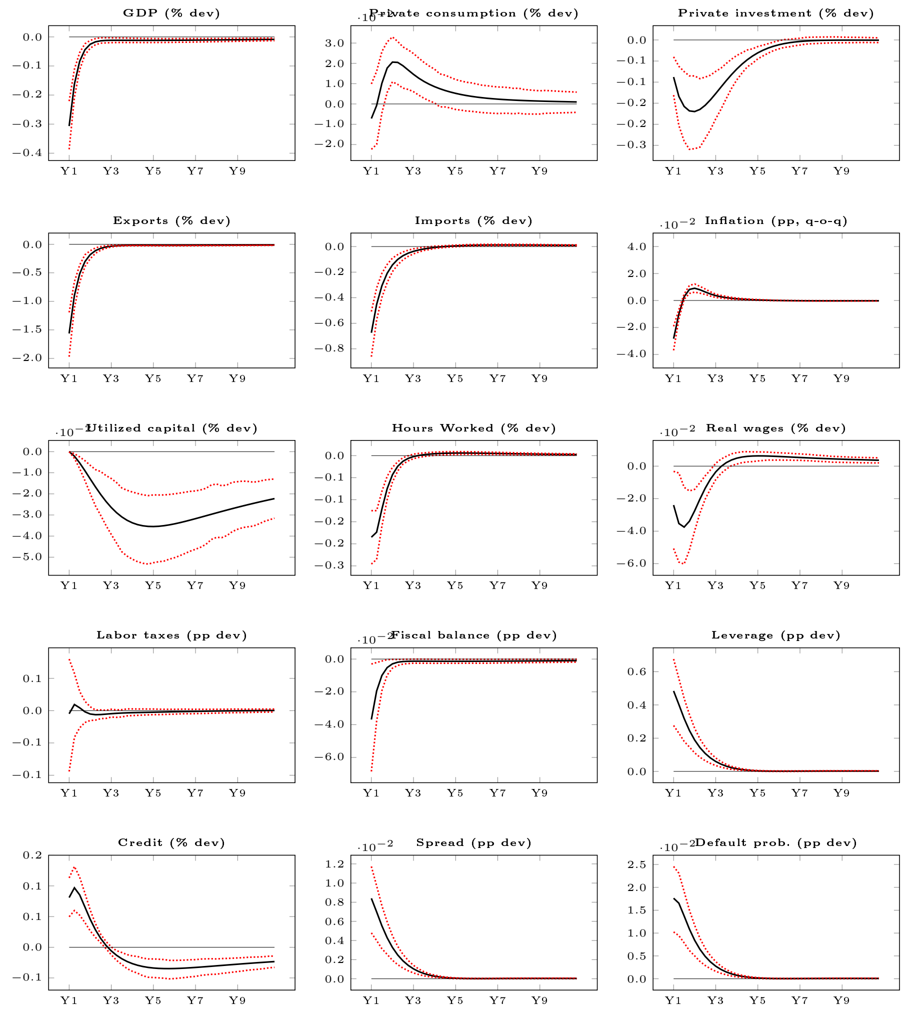


FIGURE F.9: Export goods price markup shock, $\sigma_t^{\mathcal{X}}$.
(deviations from steady state)

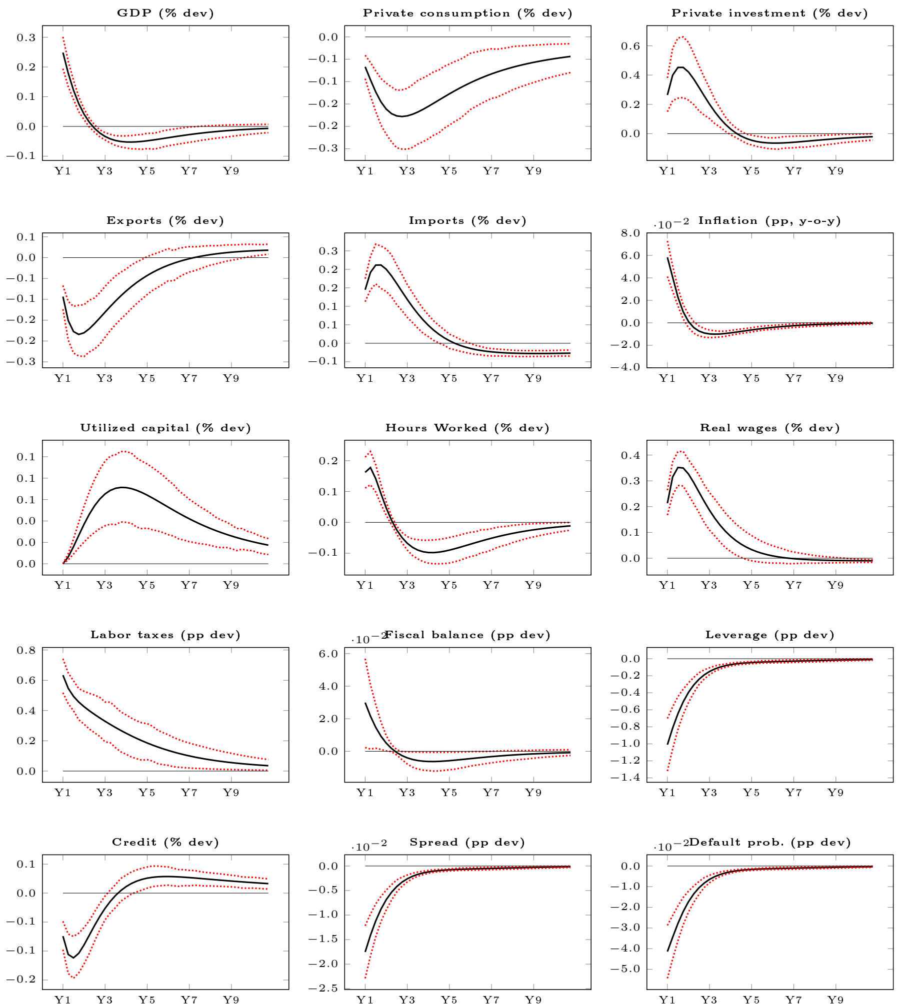


FIGURE F.10: Public consumption shock, G_t.
(deviations from steady state)

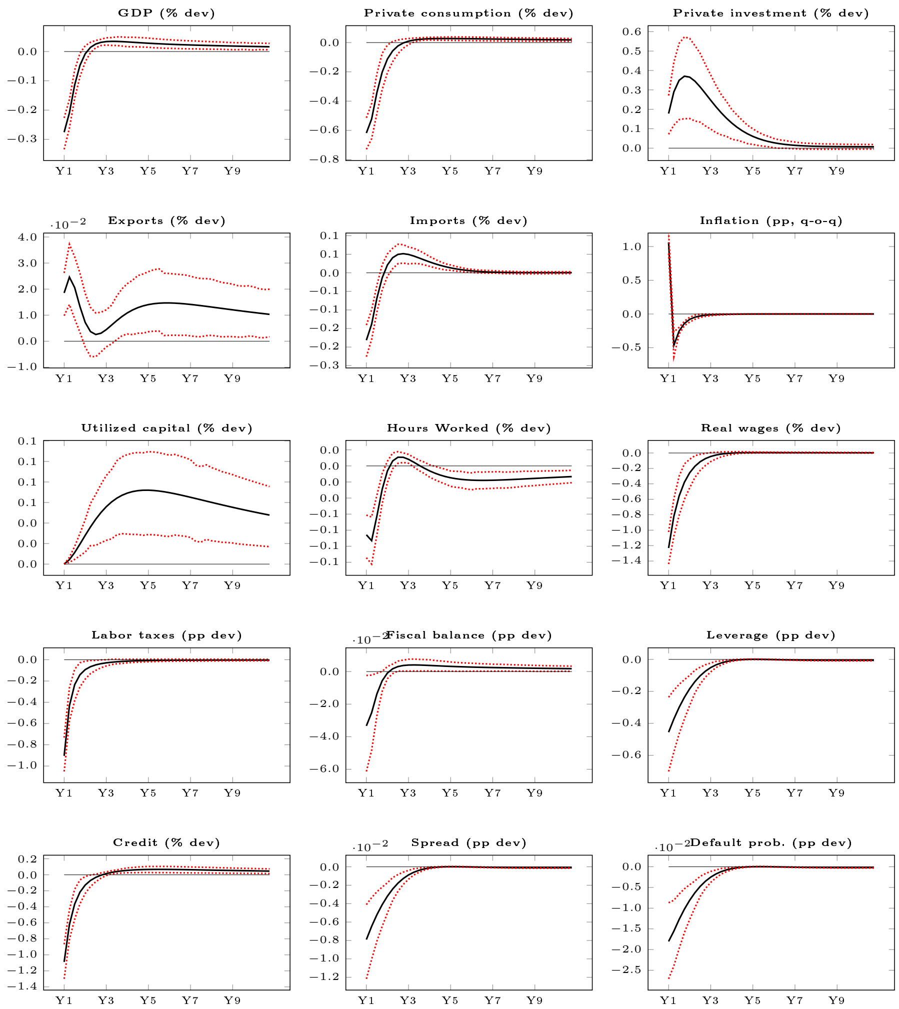


FIGURE F.11: Private consumption tax shock, $\tau_t^{\mathcal{C}}$.
(deviations from steady state)

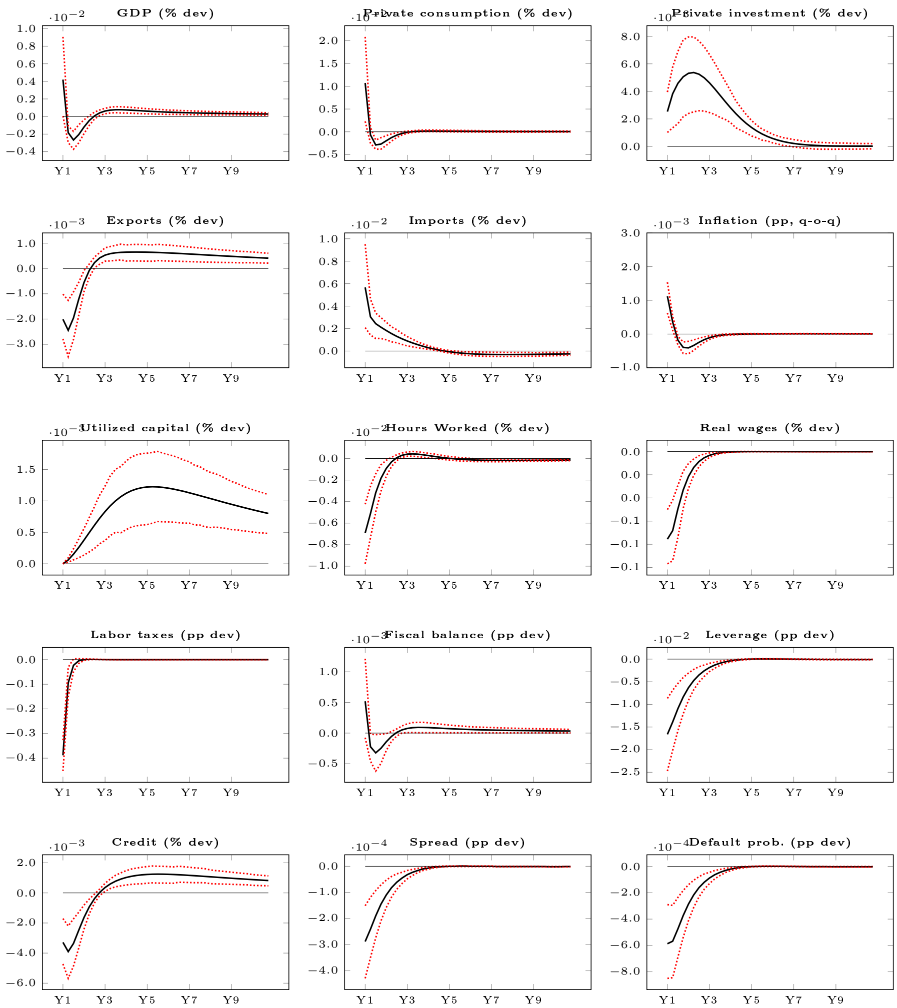


FIGURE F.12: Payroll tax shock, $\tau_t^{\mathcal{SP}}$.
(deviations from steady state)

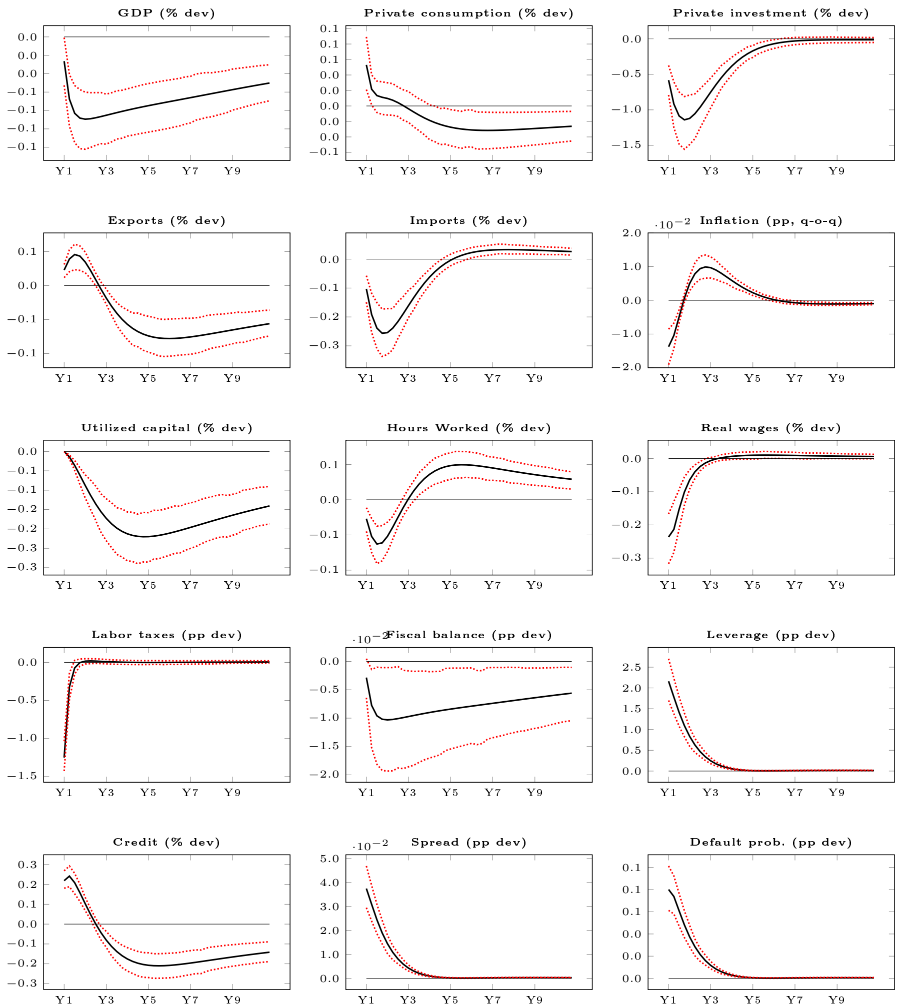


FIGURE F.13: Capital tax shock, $\tau_t^{\mathcal{K}}$.
(deviations from steady state)

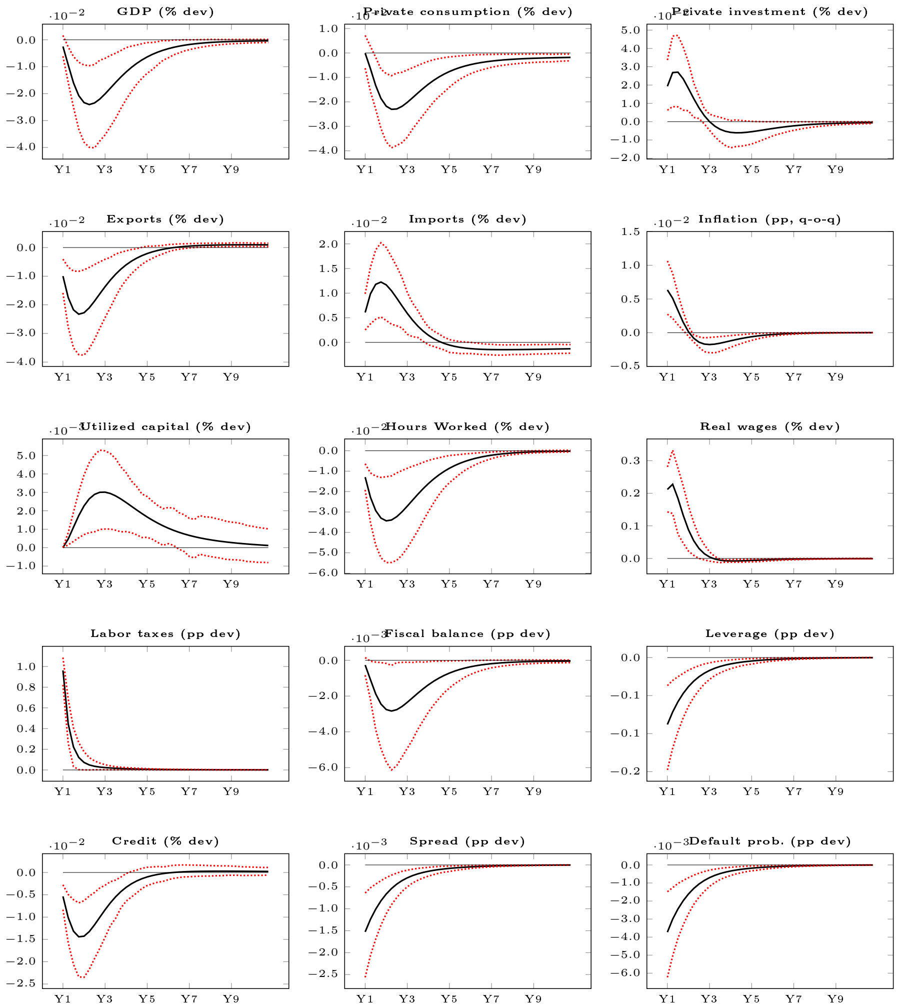


FIGURE F.14: Lumpsum transfers shock, TRG_t.
(deviations from steady state)

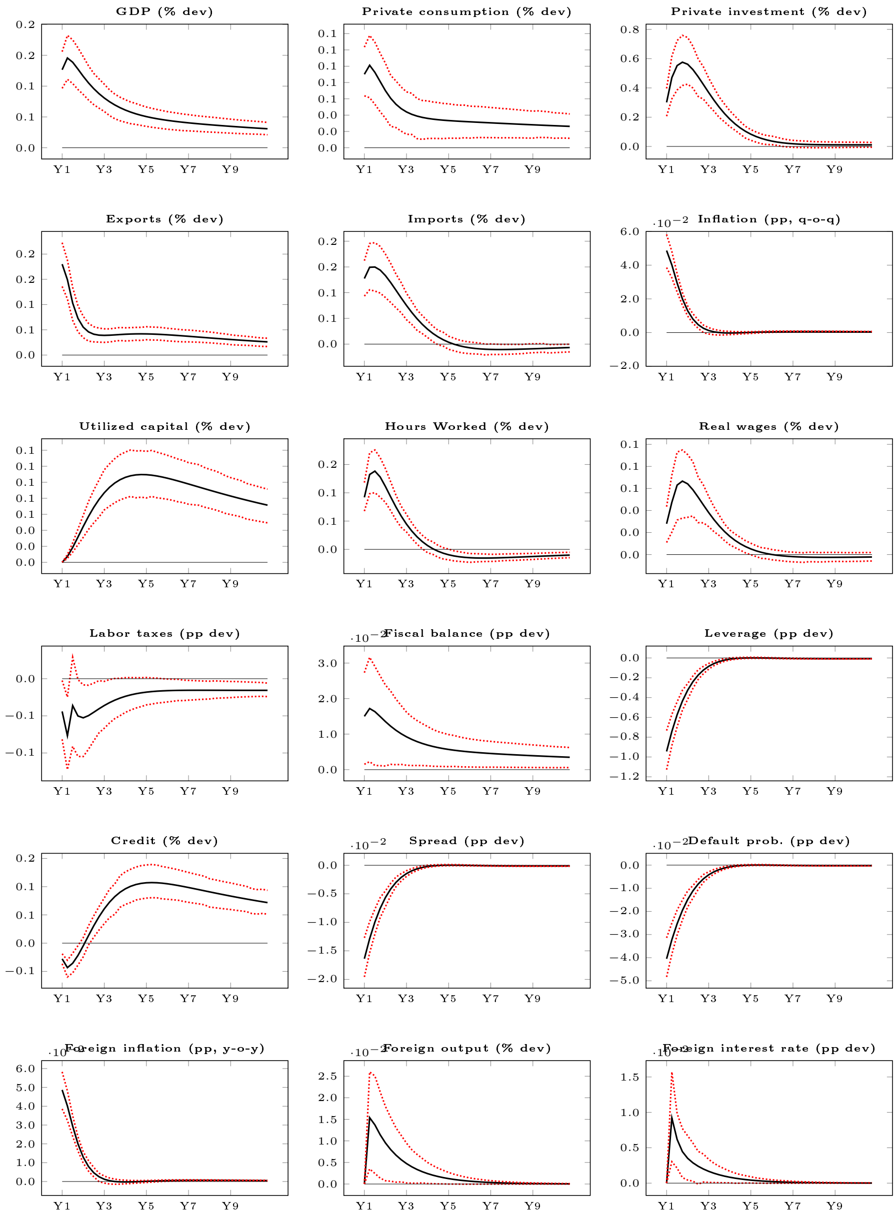


FIGURE F.15: Foreign inflation shock, π_t^*.
(deviations from steady state)

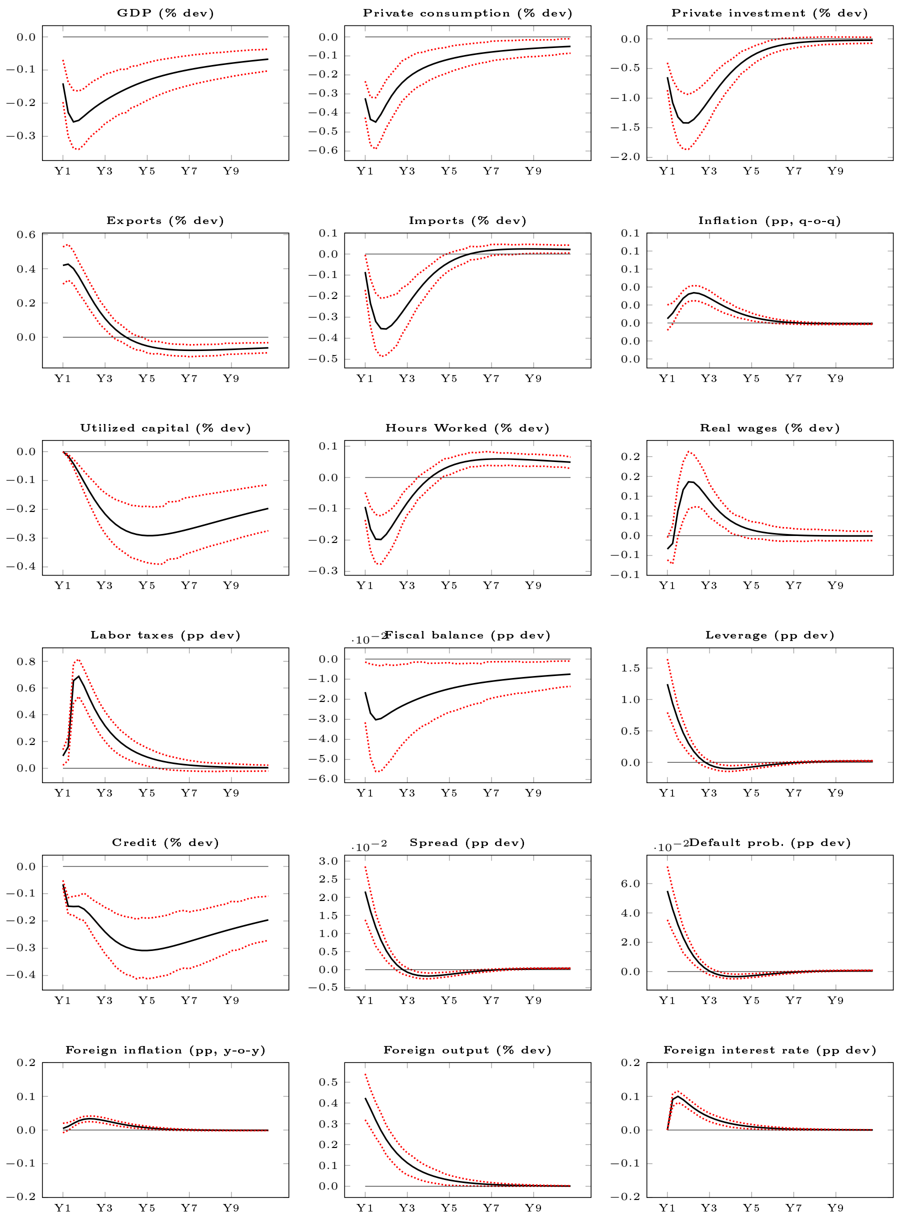


FIGURE F.16: Euro area output shock, y_t^*.
(deviations from steady state)

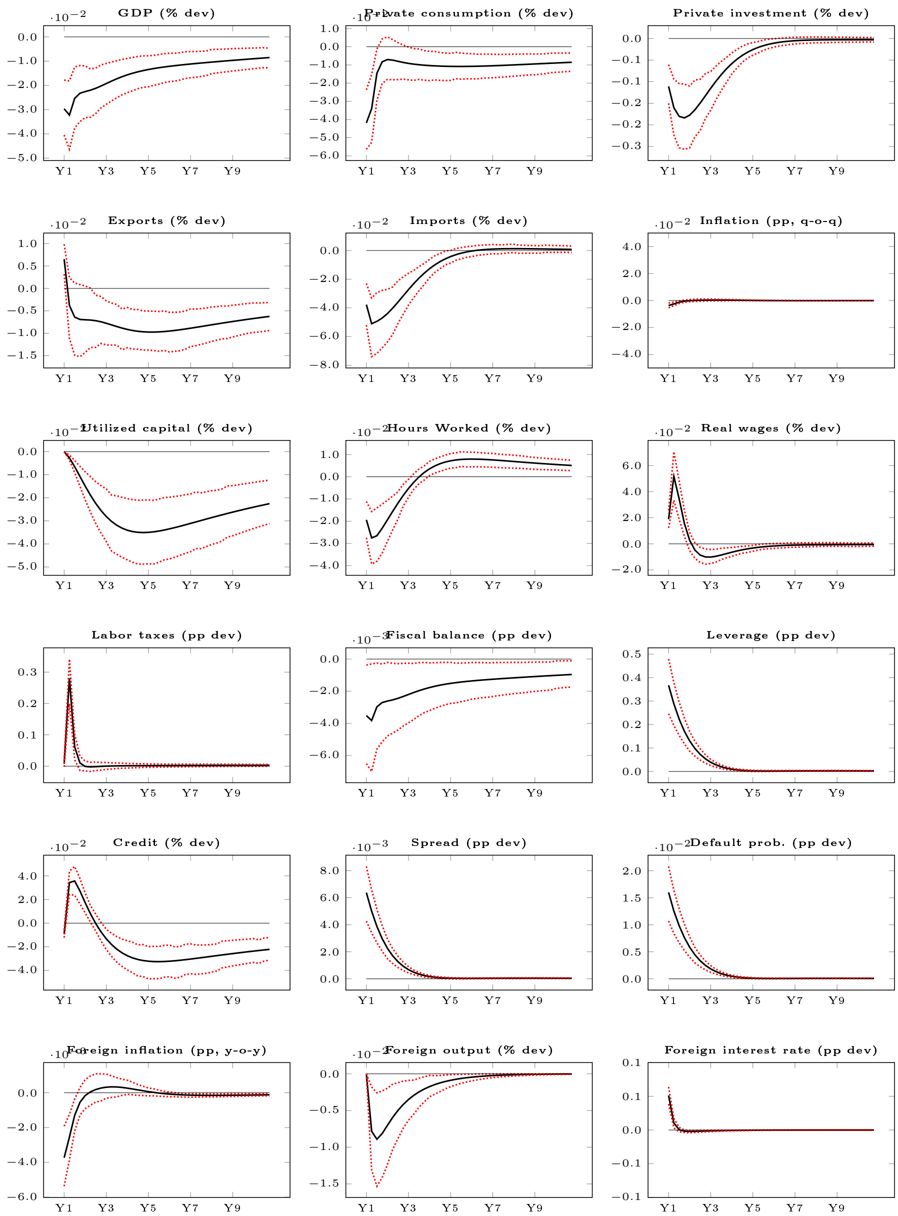


FIGURE F.17: Foreign interest rate shock, i_t^*.
(deviations from steady state)

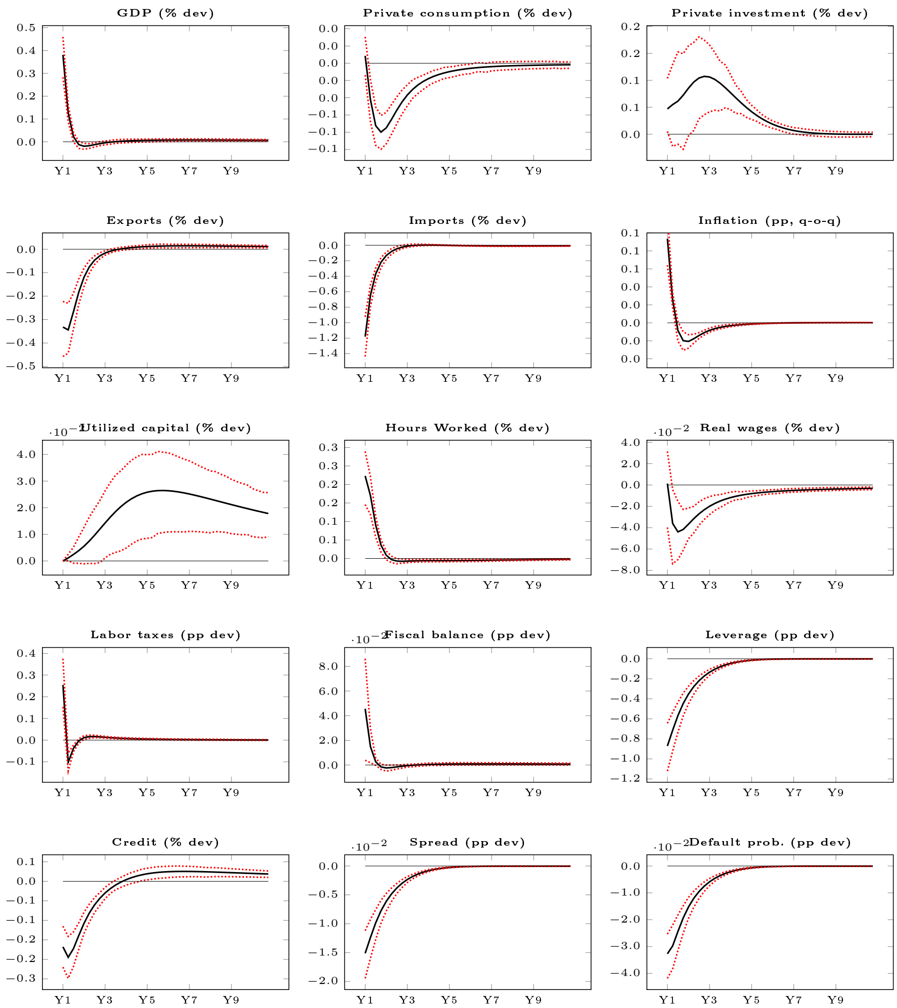


FIGURE F.18: Import price markup shock, $\tilde{\varepsilon}_t^{\mathcal{M}}$.
(deviations from steady state)

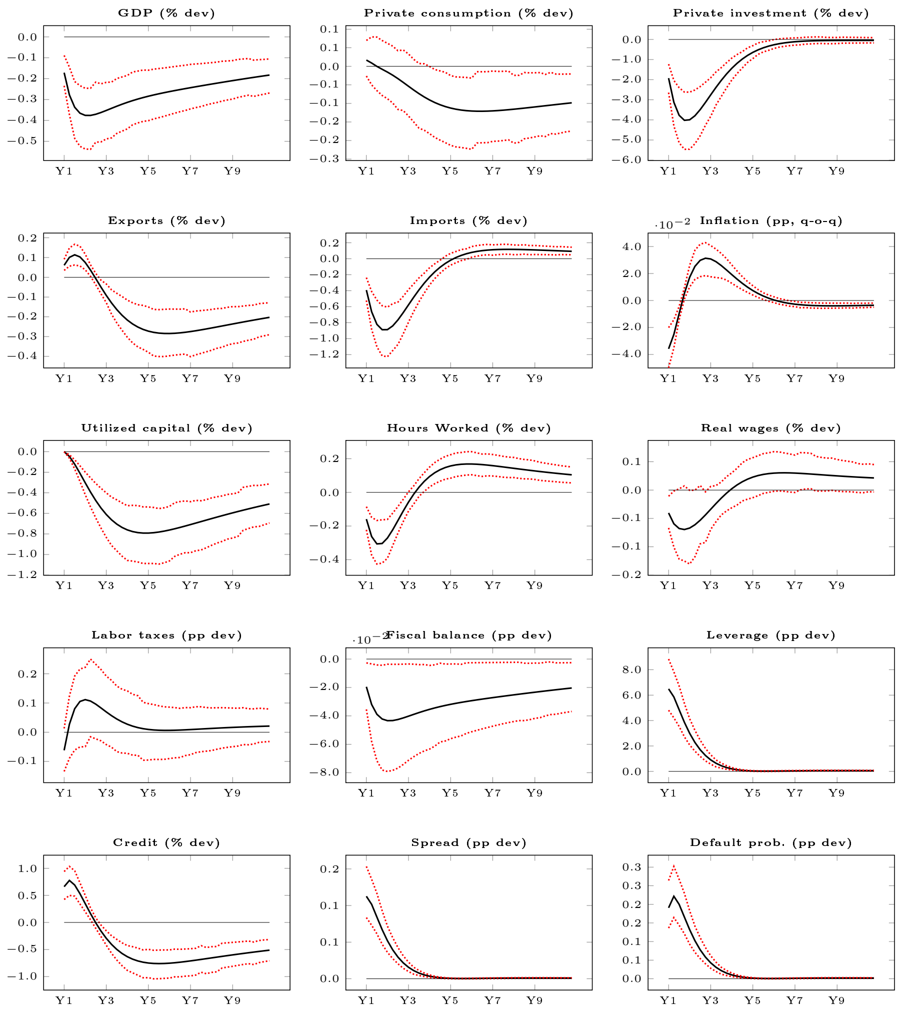


FIGURE F.19: Net worth shock, S_t^d.
(deviations from steady state)

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