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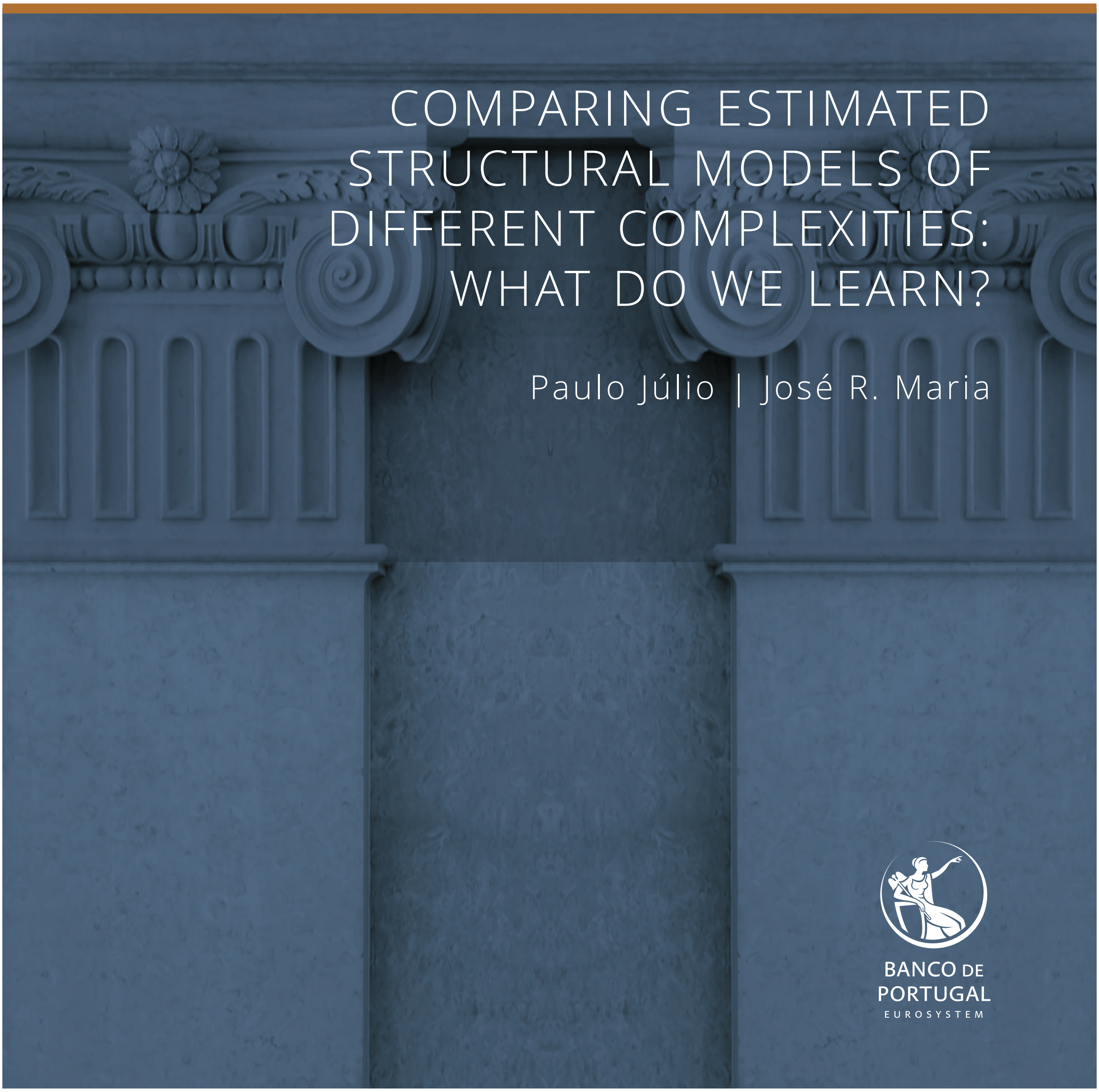

COMPARING ESTIMATED STRUCTURAL MODELS OF DIFFERENT COMPLEXITIES: WHAT DO WE LEARN?

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Comparing estimated structural models of different complexities: What do we learn?

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Abstract
We estimate various models of different complexities for the Portuguese economy. These differ along three key dimensions: the disaggregation of the final goods structure, the existence of a financial sector, and the complexity of the fiscal environment. Simpler models do get the key bullet points of storytelling right, but exacerbate the role of existing mechanisms. More complex models adress this problem, at the cost of greater potential mispecification. A more complex fiscal environment introduces a rule that adjusts labor taxes according to deviations in the fiscal balance from a target level. This mechanism may cushion or enhance the effects of other disturbances. The financial sector originates important differences in impulse responses, driven by inflationary domestic pressures that trigger a reduction in the real cost of credit. Many estimation outcomes are largely indistinguishable across models, such as smoothed shocks, standard deviations, and correlations with output growth.

JEL: C11, C13, E20, E32

Keywords: DSGE models, euro area, small-open economy, Bayesian estimation.

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1. Introduction

Dynamic Stochastic General Equilibrium (DSGE) models are standard tools in macroeconomic analysis. They are powerful story-telling devices that can successfully convey clear messages about the state of the economy, the role played by real or financial factors, or the cyclical impacts born out from specific economic policies. They are widely used to effectively identify the sources of business cycle fluctuations.

This article investigates the extent to which key business cycle drivers and main messages change as we add additional features to the model. To address this issue, we estimate eight model versions for a small-open euro area economy, and focus our discussion on selected crisis periods. Our versions differ along three dimensions: the disaggregation of the final goods structure, the existence of a financial sector, and the complexity of the fiscal environment. The most complex version embodies a financial sector and a detailed fiscal structure, and disagregates final goods' production into four sectors. On the opposite direction, the simplest version is endowed with no financial or fiscal structures, and there is solely one type of final good being produced. The remaining versions result from different combinations of these dimensions. Specifically, we consider separately a financial sector and a disagregated final goods structure. We then take the latter version and add separately the financial sector and the detailed fiscal structure. Simpler versions are estimated with and without demand components as observable time series. All estimated models embody imperfect market competition and frictions, as most influential references in the field do (*e.g.* Smets and Wouters 2007; Christiano *et al.* 2005; Adolfson *et al.* 2007a). The financial sector is built on frictions *à la* Bernanke *et al.* (1999a), which are explored for instance in Christiano *et al.* (2014a). All models are estimated through Bayesian techniques, conditioned by priors on parameters that in general follow the literature. Convergence of the Metropolis-Hastings draws is assessed through the diagnostics in Brooks and Gelman (1998). All models are conditioned by an "endogenous prior" procedure that takes into account data-driven standard deviations, as in Christiano *et al.* (2011). Without this restriction, financial factors could emerge as the most important driving force of business cycle fluctuations (Júlio and Maria 2017).[1]

All versions share several identical characteristics. The national economy is always assumed sufficiently small to have any effect on euro-area macroeconomic aggregates. Monetary policy is exogenously set by the monetary union's central bank, and an endogenous nationwide risk premium creates a wedge between domestic and foreign interest rates. A unit root trend component is shared by both the euro-area and the domestic economy. All versions are exactly identified apart from measurement errors, and are estimated with Portuguese data for the

1. Without endogenous priors net worth and borrowers' risk shocks create offsetting effects that propagate to the forecast error variance decomposition.

1999–2019 period, though always including euro area inflation, output and the interest rate.

The most complex model—henceforth full-fledged model—identifies disturbances in the household sector, union-wide technology ("growth shocks") and external environment as pivotal to explain business cycles fluctuations since 1999. Financial disturbances share this identifying mark, although with milder contributions to output growth. The remaining shock categories—markup, technology and government—do not systematically aggravate or stabilize crisis periods. For instance, fiscal policy stands out as counter-cyclical during the global financial crisis and pro-cyclical during the European sovereign debt crises—a period that includes the international financial assistance of 2011-2014.

Our main focus lies on the three crisis periods that have impacted the Portuguese economy over the last twenty years (Figure 1). When included, household demand shocks are key determinants behind output developments. Their negative contribution to output growth was particularly severe over the 2010Q3-2013Q1 period, and systematically more negative in model-versions embodying a financial sector. Growth shocks depict the largest contributions to output growth, but their importance is exacerbated in simpler models due to the lack of additional explanatory mechanisms. Shocks that we link to fiscal policy decisions have systematically the same effect across models, but the importance grows in magnitude with the model's complexity and the existence of a financial sector. In contrast, the contribution of external factors and markup disturbances to output growth is model dependent and time-varying. Simpler models are often dominated by large contributions of interest rate shocks, which dissipate in more complex versions due to the larger influence of real, nominal, and fiscal developments. The contribution of markup disturbances to GDP growth varies substantially, depending on the domestic price data content (the GDP deflator in simpler models and the export deflator in more complex versions) and thus on the definition of the real exchange rate.

The largest impact of financial frictions in crisis times takes place over the 2010Q3-2013Q1 period in the simplest model. More complex model-versions reduce the ability of risk and net worth disturbances in explaining output dynamics, because financial developments become "more endogenously driven" by the state of the economy. Financial frictions did not play an important role during the 2008Q1-2009Q1 downturn as the external finance premium remained relatively flat while corporate credit increased. A Bayesian model comparison strongly favors the inclusion of a financial sector in all cases.

The GDP forecast error variance decomposition suggests a balance of contributions across categories in more complex models, with household-driven demand shocks and external factors playing the most important roles at short-term horizons and markup and technology disturbances at longer terms. As the model complexity increases and we include more real, nominal and fiscal data, we observe an increasing role played by household, technology, external, and government

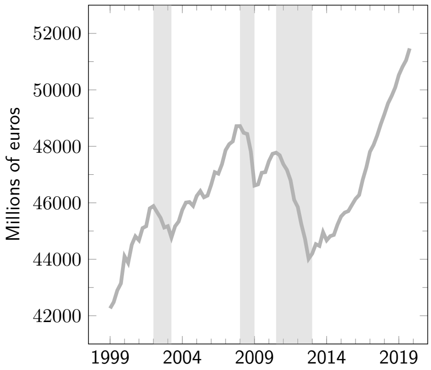


Figure 1: Portuguese Gross Domestic Product.

Source: Statistic Portugal.

Notes: Quarterly data (base = 2016). Vertical shaded bars coincide with the business cycle dating suggested by an expert committee of the Fundação Francisco Manuel dos Santos, namely a downturn over 2002Q1-2003Q2 (henceforth the "first crisis"), 2008Q1-2009Q1 (the second crisis, coinciding with the "global financial crisis"), and 2010Q3-2013Q1 (the third crisis, coinciding with the "sovereign debt crisis"). More information is available at *www.ffms.pt*.

shocks in business cycle fluctuations. This occurs at the expense of markup and financial perturbations, in models that include a financial sector.

Impulse response functions of most shocks are remarkably similar across model versions, particular when the financial sector is included. Domestic inflationary processes, which trigger no response from the euro area monetary authority, reduce real borrowing costs of non-financial corporations and create expansionary effects that counteract the deterioration of the trade balance driven by the price-competitiveness loss—an idiosyncratic structural characteristic of the small-open economy. Models without financial intermediaries are only endowed with the price-competitiveness effect. The final impact on output and inflation is conditioned by the presence of a fiscal authority empowered with stabilization objectives, that characterizes the more complex model versions.

Many estimation outcomes are largely indistinguishable across our estimated model versions. Smoothed shock processes are to a great extent similar, including those affecting investment efficiency, wage markup, preferences, net worth or borrowers' riskiness. The most noteworthy exception is stationary technology, whose disturbances are shifted towards the financial sector once this is included in the model. Standard deviations and GDP growth correlations generated by all models are relatively close to their data counterparts. Some noteworthy exceptions are the correlation of between GDP growth and corporate credit growth, which is marginally positive in the data and negative in the model, and between GDP growth and imports growth, which is slightly positive in the data and marginally negative in models embodying the financial sector.

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

We organize the exposition as follows. First, we present the richest form of our model, encapsulating a final goods structure and a detailed fiscal environment. Next, we deal specifically with the financial sector and present the market clearing conditions that close the model. Finally, we provide a description of the parsimonious features associated with the remaining model forms.

The domestic economy is composed of eight types of agents: households, intermediate goods producers (manufacturers), final goods producers (distributors), importers, government, capital goods producers, entrepreneurs, and banks. The model is closed with the foreign economy—the remaining euro area composed of foreign agents and the central bank—with whom domestic agents interact in the goods and financial markets. The exposition omits some details which can be widely found in related literature.

The rest of the euro area is pinned down by a system of three unknowns (output, interest rates and inflation disturbances) and three equations—namely an IS curve, an AS curve and a Taylor rule (henceforth IS-AS-TR framework)—jointly estimated with the DSGE model. We assume that the demand for domestic exports depends on foreign demand, which in turn depends on euro area output via an ADL equation—also jointly estimated with the rest of the model.

2.1. Non-financial block

2.1.1. Households. Two household types coexist in the model, asset holders or type-$\mathcal{A}$ households, and hand-to-mouth or type-$\mathcal{B}$ households. Type-$\mathcal{A}$ households are composed of workers and entrepreneurs, and there is perfect consumption insurance within the family. For simplicity, we assume that the percentage of entrepreneurs is infinitesimally small to avoid keeping track of their mass. Let ψ denote the time-invariant share of hand-to-mouth in a population of unitary measure, and $\mathcal{H} \in \{\mathcal{A}, \mathcal{B}\}$ denote the household type.

A representative household derives utility from consumption $C_t^{\mathcal{H}}(h)$ and disutility from working $U_t^{\mathcal{H}}(h)$. The term $U_t^{\mathcal{H}}$ stands for hours worked as a fraction of total time endowment. Expected lifetime utility is $\mathrm{E}_t \sum_{s=0}^{\infty} (\beta)^s \mathrm{UTIL}_{t+s}^{\mathcal{H}}(h)$, where E_t is the expectation operator (dropped hereinafter) and $0 \leq \beta \leq 1$ stands for the discount factor. Flow utility is separable in all arguments

$$\mathrm{UTIL}_t^{\mathcal{H}}(h) = (1-\nu)\eta_t \log(C_t^{\mathcal{H}}(h) - Hab_t^{\mathcal{H}}) - \frac{(U_t^{\mathcal{H}}(h))^{1+\sigma_L}}{1+\sigma_L}$$

where $\eta_t > 0$ is a time-varying distribution parameter and σ_L is the inverse Frisch elasticity of labor supply. The element $Hab_t^{\mathcal{H}} = \nu C_{t-1}^{\mathcal{H}}$ stands for external habits, where ν is a scale parameter. Preference shocks are captured by a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{\eta}$, *i.e.*

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

where $0 \leq \rho^{\eta} < 1$ and η is a steady-state constant. The type$-\mathcal{A}$ household supplies labor services to manufacturers, receiving an after-tax wage rate $(1 - \tau_t^{\mathcal{L}})V_t(h)$. She receives government transfers worth TRG_t, and dividends D_t^x, $x \in \{\mathcal{M}, \mathcal{D}, \mathcal{KP}, \mathcal{IM}, \mathcal{E}\}$ originating from manufacturers ($\mathcal{M}$), distributors ($\mathcal{D}$), capital goods producers ($\mathcal{KP}$), importers ($\mathcal{IM}$), and entrepreneurs ($\mathcal{E}$). Over time, an entrepreneur in period t stays an entrepreneur in the next period with probability $1 - \iota_t^{\mathcal{E}}$. The remaining fractions become workers and transfer accumulated earnings to their respective household, and are replaced by a similar measure of entrepreneurs. The household provides these elements with small amount of startup funds. Let $D_t^{\mathcal{E}}$ denote transferred earnings net of startup funds. The household can also invest on foreign bond holdings B_t^*, on domestic government bonds $B_t^{\mathcal{G}}$, and on domestic corporate bonds $B_t^{\mathcal{E}}$ issued by banks. Domestic bonds earn interest rates of i_t and $i_t^{\mathcal{E}}$ respectively, which the arbitrage condition will match in equilibrium. These may differ from the euro area's interest rate i_t^* due to a nationwide endogenous risk premium

$$\Psi_t = \exp\left[-\varphi_{BF} \cdot \left(\frac{B_t^*}{4 \cdot P_t \cdot GDP_t} - \left(B_{GDP}^*\right)^{target}\right) + \Upsilon_t\right]$$

where $\varphi_{BF} > 0$ represents a scale parameter, $\left(B_{GDP}^*\right)^{target}$ is the target foreign assets-to-GDP ratio, and Υ_t is an exogenous shock, captured by a first-order autoregressive process with an iid-normal error term ε_t^{Υ}

$$\log((1 + \Upsilon_t)/(1 + \Upsilon)) = \rho^{\Upsilon}\log((1 + \Upsilon_{t-1})/(1 + \Upsilon)) + \tilde{\varepsilon}_t^{\Upsilon}$$

where $0 \leq \rho^{\Upsilon} < 1$ and Υ is a steady-state constant.[2] On the expenditure side, asset holders buy consumption goods $C_t^{\mathcal{A}}$ at the price P_t, taken as *numéraire*. The gap between expenditures and income is reflected in changes in their net asset position. Their nominal budget constraint is

$$\begin{aligned} P_t C_t^{\mathcal{A}}(h) + B_t^*(h) + B_t^{\mathcal{G}}(h) + B_t^{\mathcal{E}}(h) &\leq i_{t-1}^*(1 + \Psi_{t-1})B_{t-1}^*(h) + i_{t-1}B_t^{\mathcal{G}}(h) \\ &+ i_{t-1}^{\mathcal{E}}B_t^{\mathcal{E}}(h) + (1 - \tau_t^{\mathcal{L}})V_t(h)U_t^{\mathcal{A}}(h) + (1 - \psi)TRG_t + DIV_t \end{aligned}$$

2. GDP is adjusted by a factor of 4, since the model is quarterly and the net foreign assets ratio is annualized.

where $DIV_t = \sum_x \int_0^1 D_t^x(i)\mathrm{d}i$. The type$-\mathcal{B}$ household also supplies labor services to manufacturers and receives government transfers, but has no access to financial markets. Her budget constraint is

$$P_t C_t^{\mathcal{B}}(h) \leq (1-\tau_t^{\mathcal{L}}) V_t(h) U_t^{\mathcal{B}}(h) + \psi TRG_t$$

Asset holders are the wage setters of this economy. Manufacturer j combines specialized labor supply from households into a homogeneous labor service according to a CES aggregator, yielding the usual demand for labor variety h,

$$U_t(h) = (V_t(h)/V_t)^{-\sigma_t^{\mathcal{U}}} U_t \tag{1}$$

where $V_t(h)$ and V_t denote the wage charged by household h and aggregate wage, respectively, and U_t is aggregate labor demand. The element $\sigma_t^{\mathcal{U}} \geq 0$ is a stochastic parameter governing the time-varying wage markup and following a first-order autoregressive process with an iid-normal error term $\hat{\varepsilon}_t^{\sigma\mathcal{U}}$,

$$\log\left((1+\sigma_t^{\mathcal{U}})/(1+\sigma^{\mathcal{U}})\right) = \rho^{\sigma\mathcal{U}} \log\left((1+\sigma_{t-1}^{\mathcal{U}})/(1+\sigma^{\mathcal{U}})\right) + \hat{\varepsilon}_t^{\sigma\mathcal{U}} \tag{2}$$

where $0 \leq \rho^{\sigma\mathcal{U}} < 1$ and $\sigma^{\mathcal{U}}$ is a steady state constant. We consider Rotemberg-type frictions on wage adjustments of the form

$$\Gamma_t^{\mathcal{V}}(h) = \frac{\varphi_{\mathcal{V}}}{2} U_t T_t \left(\frac{V_t(h)}{V_{t-1}(h)} - \pi_{ss}^{\mathcal{V}}\right)^2 \tag{3}$$

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. Asset holders select the wage profile $\{V_{t+s}(h)\}_{s=0}^{\infty}$ that maximizes the present discounted value of working, *i.e.*

$$\max_{V_t(h)} \mathrm{E}_t \sum_{s=0}^{\infty} (\beta)^s \Bigg\{ -\frac{\eta_L}{1+\sigma_L} \left(U_{t+s}(h)\right)^{1+\sigma_L} - \frac{\lambda_{t+s}(h)}{P_{t+s}T_{t+s}} \left[(1-\tau_t^{\mathcal{L}}) V_{t+s}(h) \left(U_{t+s}(h) - P_{t+s}\Gamma_{t+s}^{\mathcal{V}}(h)\right)\right] \Bigg\}$$

subject to (1) and (3), and where $\lambda_{t+s}(h)$ corresponds to the Lagrange multiplier from the household's problem. We ignore irrelevant terms from the objective function. 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 V_t to the marginal disutility from working W_t, $W_t \equiv \left(P_t T_t/(1-\tau_t^{\mathcal{L}})\right)(\eta_L/\lambda_t)[(1-\psi)U_t^{\mathcal{A}}]^{\sigma_t^L}$, 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

$$\Omega_t^{\mathcal{V}} = \sigma_t^{\mathcal{U}} \varphi_{\mathcal{V}} \left[\left(\pi_t^{\mathcal{V}} - \pi_{ss}^{\mathcal{V}}\right) \pi_t^{\mathcal{V}} - \Lambda_{t,t+1} \frac{U_{t+1}}{U_t} \frac{1-\tau_{t+1}^{\mathcal{L}}}{1-\tau_t^{\mathcal{L}}} \left(\pi_{t+1}^{\mathcal{V}} - \pi_{ss}^{\mathcal{V}}\right) \pi_{t+1}^{\mathcal{V}} \right]$$

is a sluggish-adjustment factor term and $\Lambda_{t,t+1}$ is the stochastic discount factor. Hand-to-mouth households simple match their disutility from working to the wage rate V_t, yielding $(1-\tau_t^{\mathcal{L}})V_t = P_t T_t (\eta_L/\lambda_t)(\psi U_t^{\mathcal{B}})^{\sigma_t^L}$. Aggregate labor supply is $U_t = U_t^{\mathcal{A}} + U_t^{\mathcal{B}}$.

2.1.2. Capital goods producers. There exists a continuum of capital goods producers indexed by $i \in [0,1]$. In each period, capital goods producers combine the undepreciated installed productive capital stock $(1-\delta^{\mathcal{K}})\bar{K}_t(i)$ bought from entrepreneurs with investment goods $I_t(i)$, bought from distributors, to produce new installed productive capital $\bar{K}_{t+1}(i)$, according to the law of motion

$$\bar{K}_{t+1}(i) = (1-\delta^{\mathcal{K}})\bar{K}_t(i) + (1 - S(\zeta_t \cdot I_t/I_{t-1}))I_t(i) \tag{4}$$

The element $\delta^{\mathcal{K}}$ is the depreciation rate, $\bar{K}_t(i)$ represents the available physical capital stock, $S(\zeta_t \cdot I_t/I_{t-1})$ is a cost function and ζ_t is a unit-mean investment efficiency shock following an autoregressive process

$$\log(\zeta_t) = \rho^{\zeta} \log(\zeta_{t-1}) + \tilde{\varepsilon}_t^{\zeta} \tag{5}$$

where $0 \leq \rho^{\zeta} < 1$ and $\tilde{\varepsilon}_t^{\zeta}$ is an iid-normal error term. We set

$$S_t = S(x_t) = 1/2 \left\{ \mathsf{exp}[(S'')^{(1/2)}(x_t - x)] + \mathsf{exp}[(S'')^{(1/2)}(x_t - x) - 2] \right\} \tag{6}$$

as in Christiano *et al.* (2014b), where $x_t \equiv \zeta_t \cdot I_t/I_{t-1}$ and x denotes the steady-sate value of x_t. Notice that $S''(x) = S''$ is a model parameter affecting the dynamics but not the steady state. Capital goods producers select the intertemporal profile $\{I_{t+s}(i)\}_{s=0}^{\infty}$ that maximize the present discounted value of the dividends stream

$$\mathrm{E}_t \sum_{s=0}^{\infty} \frac{\Lambda_{t,t+s}}{\pi_{t+s} g_{t+s}} P_{t+s}^{\mathcal{I}} \left[Q_{t+s}^{\mathcal{K}} (1 - S(\zeta_{t+s} \cdot I_{t+s}/I_{t+s-1})) I_{t+s}(i) - I_{t+s}(i) \right]$$

where $Q_{t+s}^{\mathcal{K}}$ stands for Tobin's Q, $P_{t+s}^{\mathcal{I}}$ is the price of investment goods, subject to the law of motion in (4) and to adjustment costs in (6), and taking all prices as given. The inverse demand for investment goods, identical for all capital goods producers, is, after rearrangements,

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

where

$$\Omega_t^{\mathcal{I}} = Q_t^{\mathcal{K}}\left(S_t + S_t' x_t\right) - Q_{t+1}^{\mathcal{K}} \Lambda_{t,t+1} \frac{\pi_{t+1}^{\mathcal{I}}}{\pi_{t+1}} S_{t+1}' x_{t+1}^2$$

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, $\pi_t = P_t/P_{t-1}$. The element S_t' is the derivative of $S(x_t)$ with respect to x_t.

2.1.3. Manufacturers. Manufacturers combine capital with labor services to produce intermediate goods, which distributors use as inputs. There is a continuum of manufacturing firms $j \in [0,1]$. Each firm produces a specific variety of the intermediate good, to be bought by a continuum of distributor firms and bundled together in a homogeneous intermediate good. The bundling technology is given by the CES aggregator, yielding the usual demand for intermediate goods

$$Z_t(j) = [P_t^{\mathcal{Z}}(j)/P_t^{\mathcal{Z}}]^{-\sigma^{\mathcal{Z}}} Z_t \tag{7}$$

where $\sigma^{\mathcal{Z}} \geq 0$ is the time-invariant intermediate goods price markup, $P_t^{\mathcal{Z}}(j)$ and $P_t^{\mathcal{Z}}$ denote the price charged by manufacturer j and the aggregate price, and Z_t is the aggregate demand for the intermediate good.

Each manufacturing firm j combines labor services $U_t^{\mathcal{Z}}(j)$ with capital $K_t(j)$ according to the following labor-augmenting technology

$$Z_t(j) = (K_t(j))^{1-\alpha^{\mathcal{U}}} \left(T_t A_t U_t^{\mathcal{Z}}(j)\right)^{\alpha^{\mathcal{U}}} \tag{8}$$

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

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

and a stationary labor-augmenting technology shock following an autoregressive process

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

The elements $0 \leq \{\rho^g, \rho^A\} < 1$ are parameters, $\{g, A\}$ are steady-state constants, and $\{\tilde{\varepsilon}_t^A, \tilde{\varepsilon}_t^T\}$ are iid-normal error terms. The unit root technology shock will also be termed worldwide technology shock hereinafter, since it impacts foreign output. Price changes are subject to quadratic adjustment costs of the type

$$\Gamma_t^{P\mathcal{Z}}(j) = \frac{\varphi_{P\mathcal{Z}}}{2} Z_t \left(\frac{P_t^{\mathcal{Z}}(j)}{P_{t-1}^{\mathcal{Z}}(j)} - \pi_{ss}^{\mathcal{Z}}\right)^2 \tag{9}$$

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

$$\Gamma_t^{\mathcal{U}}(j) = \frac{\varphi_{\mathcal{U}}}{2} U_t^{\mathcal{Z}} \left(\frac{U_t^{\mathcal{Z}}(j)}{U_{t-1}^{\mathcal{Z}}(j)} - 1 \right)^2 \tag{10}$$

The parameters $\varphi_{P\mathcal{Z}}$ and $\varphi_{\mathcal{U}}$ are sector-specific scaling factors determining the magnitude of adjustment costs, and $U_t^{\mathcal{Z}}$ is aggregate labor used in the manufacturing sector. 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, $\tau_t^{\mathcal{SP}}$, and set labor demand $U_t^{\mathcal{Z}}(j)$, 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,

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

where $P_{t+s}^{\mathcal{Z}} T_{t+s} \varpi^{\mathcal{Z}}$ is a quasi-fixed cost, subject to demand in (7), the production technology in (8) and to adjustment costs in (9) and (10). 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

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

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

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

where

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

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

$$\Lambda_{t,t+1}\Big(R^{\mathcal{K}}_{t+1} - P_t\lambda^{\mathcal{Z}}_{t+1}\frac{(1-\alpha_{\mathcal{U}})Z_{t+1}}{K_{t+1}}\Big) = 0$$

2.1.4. Distributors. 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. Each costumer bundles the different varieties of the final good together to form an homogeneous consumption good according to the CES specification, yielding the usual demand for variety f

$$Y^{\mathcal{F}}_t(f) = [P^{\mathcal{F}}_t(f)/P^{\mathcal{F}}_t]^{-\sigma^{\mathcal{F}}_t} Y^{\mathcal{F}}_t \tag{11}$$

The element $P^{\mathcal{F}}_t(f)$ denotes the price charged by distributor f operating in sector $\mathcal{F}$, $P^{\mathcal{F}}_t$ is F's aggregate price level, $Y^{\mathcal{F}}_t$ is F's aggregate demand, and finally $\sigma^{\mathcal{F}}_t$ is the time-varying final goods price markup, which follows an autorregresive structure

$$\log\Big((1+\sigma^{\mathcal{F}}_t)/(1+\sigma^{\mathcal{F}})\Big) = \rho^{\sigma\mathcal{F}}\log\Big((1+\sigma^{\mathcal{F}}_{t-1})/(1+\sigma^{\mathcal{F}})\Big) + \tilde{\varepsilon}^{\sigma\mathcal{F}}_t \tag{12}$$

where $0 \leq \rho^{\sigma\mathcal{F}} < 1$, $\sigma^{\mathcal{F}}$ is a steady-state constant, and $\tilde{\varepsilon}^{\sigma\mathcal{F}}_t$ is iid-normal error term. Each distributor f in sector F combines domestic manufactured goods $Z^{\mathcal{F}}_t(f)$ with imported goods $M^{\mathcal{F}}_t(f)$ to obtain the final good $Y^{F}_t(f)$, according to the technology

$$Y^{\mathcal{F}}_t(f) = \left(\left(\alpha^{\mathcal{F}}\right)^{\frac{1}{\xi_{\mathcal{F}}}}\left(Z^{\mathcal{F}}_t(f)\right)^{\frac{\xi_{\mathcal{F}}-1}{\xi_{\mathcal{F}}}} + \left(1-\alpha^{\mathcal{F}}\right)^{\frac{1}{\xi_{\mathcal{F}}}}\left[M^{\mathcal{F}}_t(f)\left(1-\Gamma^{\mathcal{F}}_t(f)\right)\right]^{\frac{\xi_{\mathcal{F}}-1}{\xi_{\mathcal{F}}}}\right)^{\frac{\xi_{\mathcal{F}}}{\xi_{\mathcal{F}}-1}} \tag{13}$$

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

$$\Gamma^{\mathcal{F}}_t(f) = \frac{\varphi_{\mathcal{AMF}}}{2}\left(\mathcal{A}^{\mathcal{F}}_t(f) - 1\right)^2, \quad \mathcal{A}^{\mathcal{F}}_t(f) = \frac{M^{\mathcal{F}}_t(f)/Y^{\mathcal{F}}_t(f)}{M^{\mathcal{F}}_{t-1}/Y^{\mathcal{F}}_{t-1}}\left(A^{\mathcal{M}}_t\right)^{\frac{-1}{\varphi_{\mathcal{AMF}}}} \tag{14}$$

where $\varphi_{\mathcal{AMF}}$ is $\mathcal{F}$-specific scaling factor and $A^{\mathcal{M}}_t$ is a sectorwide import penetration shock that follows an autoregressive process

$$\log\left(A^{\mathcal{M}}_t/A^{\mathcal{M}}\right) = \rho^{\mathcal{M}}\log\left(A^{\mathcal{M}}_{t-1}/A^{\mathcal{M}}\right) + \tilde{\varepsilon}^{A\mathcal{M}}_t \tag{15}$$

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

$$\Gamma_t^{P\mathcal{F}}(f) = \frac{\varphi_{P\mathcal{F}}}{2} Y_t^{\mathcal{F}} \left(\frac{P_t^{\mathcal{F}}(f)}{P_{t-1}^{\mathcal{F}}(f)} - \pi_{ss}^{\mathcal{F}} \right)^2 \tag{16}$$

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, $\tau_t^{\mathcal{D}}$. 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

$$\mathrm{E}_t \sum_{s=0}^{\infty} \frac{\Lambda_{t,t+s}}{\pi_{t+s} g_{t+s}} (1 - \tau_{t+s}^{\mathcal{D}}) \Big[P_{t+s}^{\mathcal{F}}(f) Y_{t+s}^{\mathcal{F}}(f) - P_{t+s}^{\mathcal{Z}} Z_{t+s}^{\mathcal{F}}(f) - P_{t+s}^{\mathcal{IM}} M_{t+s}^{\mathcal{F}}(f) - P_{t+s}^{\mathcal{F}} \big(\Gamma_{t+s}^{P\mathcal{F}}(f) + T_{t+s} \varpi^{\mathcal{F}} \big) \Big]$$

subject to demand in (11), technology in (13), and adjustment costs in (14) and (16). The element $P_{t+s}^{\mathcal{F}} T_{t+s} \varpi^{\mathcal{F}}$ is a quasi-fixed cost and $P_{t+s}^{\mathcal{IM}}$ is the price level charged by importers. 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

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

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

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

while the demand for imported goods can be expressed as

$$M_t^{\mathcal{F}} (1 - \Gamma_t^{\mathcal{F}}) = (1 - \alpha^{\mathcal{F}}) \left(\frac{P_t^{\mathcal{IM}}}{P_t \lambda_t^{\mathcal{F}} \cdot \iota_t^{\mathcal{F}}} \right)^{-\xi_{\mathcal{F}}} Y_t^{\mathcal{F}}$$

with

$$\iota_t^{\mathcal{F}} = 1 - \Gamma_t^{\mathcal{F}} - \varphi_{\mathcal{AMF}} (\mathcal{A}_t^{\mathcal{F}} - 1) \mathcal{A}_t^{\mathcal{F}}$$

2.1.5. Importers. There is a continuum of importers $m \in [0,1]$, each producing a specific variety of imported good, which are bundled together by distributors to form an homogeneous imported good. The bundling technology is given by the CES aggregator, yielding the usual demand for variety m

$$M_t(m) = \left(P_t^{\mathcal{IM}}(m)/P_t^{\mathcal{IM}}\right)^{-\sigma^{\mathcal{IM}}} M_t \tag{17}$$

where $P_t^{\mathcal{IM}}(m)$ denotes the price charged by importer m and $\sigma_t^{\mathcal{IM}}$ is the time-varying import goods price markup following an autoregressive structure

$$\log\left(\sigma_t^{\mathcal{IM}}/\sigma^{\mathcal{IM}}\right) = \rho^{\sigma\mathcal{IM}} \log\left(\sigma_{t-1}^{\mathcal{IM}}/\sigma^{\mathcal{IM}}\right) + \tilde{\varepsilon}_t^{\sigma\mathcal{IM}} \tag{18}$$

where $0 \leq \rho^{\sigma\mathcal{IM}} \leq 1$, $\sigma^{\mathcal{IM}}$ is a steady-state constant, and $\tilde{\varepsilon}_t^{\sigma\mathcal{IM}}$ is an iid-normal error term. Importers are perfectly competitive in the input market and monopolistically competitive in the output market. Each importer m selects $\{M_{t+s}(m)\}_{s=0}^{\infty}$ to maximize the discounted value of the dividend stream

$$\mathrm{E}_t \sum_{s=0}^{\infty} \frac{\Lambda_{t,t+s}}{\pi_{t+s} g_{t+s}} \left[\left(P_{t+s}^{\mathcal{IM}}(m) - P_{t+s}^{*}\right) M_{t+s}(m) - P_{t+s}^{\mathcal{IM}} \Gamma_{t+s}^{\mathcal{PIM}}(m)\right]$$

where P_{t+s}^{*} is the foreign price level, subject to (17) and the price adjustment cost function

$$\Gamma_t^{P\mathcal{IM}}(m) = \frac{\varphi_{P\mathcal{IM}}}{2} M_t \left(\frac{P_t^{\mathcal{IM}}(m)}{P_{t-1}^{\mathcal{IM}}(m)} - \pi_{ss}^{\mathcal{IM}}\right)^2 \tag{19}$$

The element $\pi_{ss}^{\mathcal{IM}}$ stands for sector steady-state foreign inflation and $\varphi_{P\mathcal{IM}}$ determines the magnitude of price adjustment costs. The price equation, identical for all m, collapses to

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

where

$$\Omega_t^{P\mathcal{IM}} = \sigma_t^{\mathcal{IM}} \varphi_{P\mathcal{IM}} \left[\left(\pi_t^{\mathcal{IM}} - \pi_{ss}^{\mathcal{IM}}\right) \pi_t^{\mathcal{IM}} - \Lambda_{t,t+1} \frac{M_{t+1}^{\mathcal{IM}}}{M_t^{\mathcal{IM}}} \left(\pi_{t+1}^{\mathcal{IM}} - \pi_{ss}^{\mathcal{IM}}\right) \left(\pi_{t+1}^{\mathcal{IM}}\right)^2\right]$$

is a sluggish-adjustment factor.

2.1.6. Fiscal authorities. The government buys from distributors a particular consumption good, G_t, and performs lump-sum transfers to households, TRG_t.[3]

3. Government consumption operates as a pure inefficient good that does not affect agent decisions or welfare.

Both public consumption and lump-sum transfers follow a first-order autoregressive process with a iid-normal error terms $\{\tilde{\varepsilon}_t^{\mathcal{G}}, \tilde{\varepsilon}_t^{TRG}\}$

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

and

$$\log\left(\frac{1+TRG_t/GDP_t}{1+TRG/GDP}\right) = \rho^{TRG} \log\left(\frac{1+TRG_{t-1}/GDP_{t-1}}{1+TRG/GDP}\right) + \tilde{\varepsilon}_t^{TRG}$$

where $\{\rho^{\mathcal{G}}, \rho^{TRG}\} \in [0,1)$, and $\{G, TRG, GDP\}$ are steady-state constants. To finance expenditures, the government receives time invariant transfers from abroad totaling TRE and levies taxes $\tau_t^{\mathcal{L}}$ on households' labor income, $\tau_t^{\mathcal{SP}}$ on manufacturers' payroll, $\tau_t^{\mathcal{C}}$ on households' consumption, $\tau_t^{\mathcal{K}}$ on capital, and $\tau^{\mathcal{D}}$ on distributors' profits. The latter is assumed time invariant, whereas taxes on payroll, consumption and capital follow first-order autoregressive processes with iid-normal innovations $\tilde{\varepsilon}_t^{\tau x}$

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

with $0 \leq \rho^{\tau x} < 1$, and where τ^x is a steady-state constant. Labor taxes are the endogenous fiscal instrument.

The government may issue one-period bonds $B_t^{\mathcal{G}}$ 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. The budget constraint is

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

where RV_t denotes overall tax revenues. Government debt is held by asset holders, *i.e.* there is full home bias. These can nevertheless borrow from international debt markets to buy domestic government bonds. 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 takes the form

$$\frac{SG_t}{GDP_t} = (1-\rho^{SG})\left(\frac{SG_t}{GDP_t}\right)^{\text{target}} + \rho^{SG}\frac{SG_{t-1}}{GDP_{t-1}}$$
$$+ d^{GDP}\log\left(\frac{GDP_t}{GDP_t^{\text{ss}}}\right) - d^{G}\log\left(\frac{G_t/GDP_t}{G^{\text{ss}}/GDP^{\text{ss}}}\right) + \tilde{\varepsilon}_t^{SG}$$

where $0 \leq \rho^{SG} < 1$, $\log(GDP_t/GDP_t^{\text{ss}})$ is the gap relative to steady-state GDP and $\log((G_t/GDP_t)/(G^{\text{ss}}/GDP^{\text{ss}}))$ is the gap relative to steady-state public consumption-to-GDP ratio, and $\tilde{\varepsilon}_t^{SG}$ are iid-normal innovations. The fiscal balance is allowed to deviate from the pre-determined target level due to: *(i)* automatic stabilization policies, captured by the GDP gap term; *(ii)* budgetary pressures, captured by the public consumption-to-output ratio gap term; and *(iii)* discretionary policies, mimicked by innovations $\tilde{\varepsilon}_t^{SG}$. A positive innovation implies a contrationary fiscal policy pursued by setting labor taxes at a level above the one posited by the fiscal rule.

2.1.7. Rest of the world. In a monetary union the real exchange rate is $\vartheta_t = P_t^*/P_t$, implying $\vartheta_t/\vartheta t-1 = \pi_t^*/\pi_t$, where $\pi_t^* = P_t^*/P_{t-1}^*$ is the foreign inflation rate (the nominal exchange rate is assumed to be irrevocably set to unity). For tractability, trade and financial flows are restricted to euro area countries. We follow Adolfson *et al.* (2007b) and assume that in the rest of the world there exists a continuum of distributors $n \in [0,1]$, who demand $Y_t^{\mathcal{X}}(n)$ units of the final good from domestic exporters. This good is thereafter combined with foreign intermediate goods $Z_t^*(n)$ according to the following production function

$$Y_t^d(n) = \left((\alpha_t^*)^{\frac{1}{\xi^*}} \left(Y_t^{\mathcal{X}}(n)(1-\Gamma_t^{\mathcal{IX}}(n))\right)^{\frac{\xi^*-1}{\xi^*}} + (1-\alpha_t^*)^{\frac{1}{\xi^*}} \left(Z_t^*(n)\right)^{\frac{\xi^*-1}{\xi^*}} \right)^{\frac{\xi^*}{\xi^*-1}}$$

where $Y_t^d(n)$ is the relevant world demand for domestic exporters and ξ^* is the elasticity of substitution between intermediate goods and domestic exports. The home bias parameter α_t^* follows a first-order autoregressive process with iid-normal innovations $\tilde{\varepsilon}_t^{\alpha *}$

$$\log\left(\alpha_t^*/\alpha^*\right) = \rho^{\alpha *} \log\left(\alpha_{t-1}^*/\alpha^*\right) + \tilde{\varepsilon}_t^{\alpha *}$$

where $0 \leq \rho^{\alpha *} < 1$ and α^* is a steady-state constant. Changes in α_t^* will be interpreted as export penetration shocks. As in the case of home distributors, we impose a quadratic adjustment cost function on changes in the demand for domestic exports, of the form

$$\Gamma_t^{\mathcal{F}*}(n) = \frac{\varphi_{A\mathcal{X}}}{2}\left(\mathcal{A}_t^{\mathcal{F}*}(n) - 1\right)^2, \; \mathcal{A}_t^{\mathcal{F}*}(n) = \frac{X_t(n)/Y_t^d(n)}{X_{t-1}(n)/Y_{t-1}^d(n)}$$

Each foreign distributor selects the quantities $\{Y_t^{\mathcal{X}}(n), Z_t^*(n)\}_{s=0}^{\infty}$ to maximize the present discounted value of the dividends stream, and the solution yields the familiar demand for domestic goods

$$Y_t^{\mathcal{X}}\left(1-\Gamma_t^{\mathcal{F}*}\right) = \alpha_t^* \cdot \left(\frac{\vartheta_t}{\iota_t^{\mathcal{F}*}}\right)^{\xi_*} Y_t^d$$

where

$$\iota_t^{\mathcal{F}*} = 1 - \Gamma_t^{\mathcal{F}*} - \varphi_{A\mathcal{X}}\left(\mathcal{A}_t^{\mathcal{F}*} - 1\right)\mathcal{A}_t^{\mathcal{F}*}$$

We postulate that the relevant world demand Y_t^d for domestic exporters is given by an ADL equation depending on world output Y_t^*, specified is stationary form.

Letting $\log \tilde{Y}_t^d = \log Y_t^d - \log T_t$ and $\log \tilde{Y}_t^* = \log Y_t^* - \log T_t$, the ADL equation is

$$\log\left(\tilde{Y}_t^d/\tilde{Y}^d\right) = \rho^{yd}\log\left(\tilde{Y}_{t-1}^d/\tilde{Y}^d\right) + (1-\rho^{yd})\rho^{y*}\left(\tilde{Y}_t^*/\tilde{Y}^*\right) + \tilde{\varepsilon}_t^{yd}$$

where $\{\tilde{Y}^d, \tilde{Y}^*\}$ are steady-state constants, $0 \leq \rho^{yd} < 1$, $\rho^{y*} > 0$, and $\tilde{\varepsilon}_t^{yd}$ are iid-normal innovations.
The foreign economy is represented by a simple backward looking IS-AS-TR environment, encompassing foreign price inflation π_t^*, stationary foreign output $\tilde{Y}_t^*$, and the foreign interest rate i_t^*. Letting $r_t^* = i_t^*/\pi_{t+1}^*$, we assume

$$\log\left(\tilde{Y}_t^*/\tilde{Y}^*\right) = \rho_y \log\left(\tilde{Y}_{t-1}^*/\tilde{Y}^*\right) - (1-\rho_y)\rho_{y,i}\log\left(r_t^*/r^*\right) + \tilde{\varepsilon}_t^y$$

$$\log\left(\pi_t^*/\pi^*\right) = \rho_\pi \log\left(\pi_{t-1}^*/\pi^*\right) + (1-\rho_\pi)\rho_{\pi,y}\log\left(y_t^*/y^*\right) + \tilde{\varepsilon}_t^\pi$$

$$\log\left(i_t^*/i^*\right) = \rho_i \log\left(i_{t-1}^*/i^*\right) + (1-\rho_i)\left[\rho_{i,\pi}\log\sum_{s=1}^{4}\frac{\pi_{t-s}^*}{4\cdot\pi^*} + \rho_{i,y}\log\sum_{s=1}^{4}\frac{y_{t-s}^*}{4\cdot y^*}\right] + \tilde{\varepsilon}_t^i$$

where $\rho's$ are parameters and $\tilde{\varepsilon}_t$'s zero-mean Gaussian i.i.d. innovations.

2.2. The financial block: entrepreneurs and banks

Macro-financial linkages build on Bernanke *et al.* (1999b) and Christiano *et al.* (2014b), in which financial frictions affect the return on capital and therefore capital demand. 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, $(1-\tau_t^{\mathcal{K}})\left[R_t^{\mathcal{K}}u_t(l) - P_t a\big(u_t(l)\big)\right]$, where $a\big(u_t(l)\big)$ is the cost of capital utilization and $R_t^{\mathcal{K}}$ is taken as given. Capital effectively rented to manufacturers and used in production is $K_t = u_t\bar{K}_t$, and the resource cost associated with variable capital utilization is $RCU_t = P_t a\big(u_t\big)\bar{K}_t$.[4] The first-order condition, identical for all l, yields the equilibrium real rental rate of capital $R_t^{\mathcal{K}} = P_t\varphi_a \exp\left(\sigma_a(u_t - 1)\right)$.

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 $B_t^{\mathcal{E}}(l)$ from retail branches. They face the balance sheet constraint $P_t^{\mathcal{K}}\bar{K}_{t+1}(l) = B_t^{\mathcal{E}}(l) + N_t(l)$. After acquiring the capital stock from capital goods producers (but before

4. The cost of capital utilization $a\big(u_t(l)\big)$ takes the functional form $a\big(u_t(l)\big) = \frac{\varphi_a}{\sigma_a}\exp\left(\sigma_a\big(u_t(l)-1\big)-1\right)$, 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.

selecting the utilization rate), entrepreneurs experience an idiosyncratic shock ω_{t+1}^{l}, $\log\omega_{t+1}^{l} \sim \mathcal{N}\big(-0.5\big(\sigma_{t+1}^{\mathcal{E}}\big)^2, \big(\sigma_{t+1}^{\mathcal{E}}\big)^2\big)$, distributed independently over time and across entrepreneurs, affecting the value of capital. The standard deviation $\sigma_t^{\mathcal{E}}$ follows itself a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{\sigma\mathcal{E}}$

$$\log\left(\sigma_t^{\mathcal{E}}/\sigma^{\mathcal{E}}\right) = \rho^{\sigma\mathcal{E}}\log\left(\sigma_{t-1}^{\mathcal{E}}/\sigma^{\mathcal{E}}\right) + \tilde{\varepsilon}_t^{\sigma\mathcal{E}}$$

where $0 \leq \rho^{\sigma\mathcal{E}} < 1$ and $\sigma^{\mathcal{E}}$ denotes a steady-state constant. Entrepreneurs celebrate a standard debt contract with retail branches, specifying a nominal loan amount $B_t^{\mathcal{E}}(l)$ and a non-state contingent gross nominal retail interest rate, $i_t^B(l)$, to be paid if $\omega_{t+1}^l \geq \bar{\omega}_{t+1}^l$. The value for the endogenous threshold level for the idiosyncratic shock, $\bar{\omega}_{t+1}^l$, below which the entrepreneur cannot meet her debt obligations and is forced to declare bankruptcy, satisfies the condition $\bar{\omega}_{t+1}^l Ret_t^{\mathcal{K}} P_t^{\mathcal{K}} \bar{K}_{t+1}(l) = i_t^B(l) B_t^{\mathcal{E}}(l)$, where $Ret_t^{\mathcal{K}}$ is the entrepreneurs' *ex-ante* return on capital, defined by

$$Ret_t^{\mathcal{K}} = \mathrm{E}_t \frac{(1-\tau_t^{\mathcal{K}})\Big[R_t^{\mathcal{K}} u_t - P_t a(u_t)\Big] + (1-\delta)P_t^{\mathcal{K}} + \tau_t^{\mathcal{K}}\delta P_t^{\mathcal{K}}}{P_{t-1}^{\mathcal{K}}}$$

Retail branches must incur in a unitary repossession cost μ over the firm value to repossess the capital value of bankrupted and insolvent firms. Let $\mathfrak{F}(x) = \Pr[\omega_{t+1}^l < x]$ denote the cumulative distribution function and $\mathfrak{f}(x)$ the corresponding probability density function of ω_{t+1}^l. Since retail branches are perfectly competitive and the interest rate is state-contingent, their participation constraint corresponds to zero-expected *ex-ante* and *ex-post* profits

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

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 savers.

Maximizing the value of the entrepreneurial firm is equivalent to maximize the expected value of assets over the non-default region

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

The solution steps are identical to those in Bernanke *et al.* (1999b) and omitted for brevity. A fraction $\iota_t^{\mathcal{E}}$ of entrepreneurs goes out of business in every period, transferring the residual value of the firm to the household. Letting $G(\bar{\omega}_t^{\mathcal{K}}) = \int_0^{\bar{\omega}_t^{\mathcal{K}}} \omega_t^{\mathcal{K}} \mathfrak{f}^{\mathcal{K}}(\omega_t^{\mathcal{K}})\mathrm{d}\omega_t^{\mathcal{K}}$, aggregate net worth evolves over time according to

$$N_t = (1 - \iota_t^{\mathcal{E}})\tilde{N}_t + \theta^{nw}(\tilde{N}_t - N) + WT^{\mathcal{E}}$$

where $WT^{\mathcal{E}}$ are initial wealth transfers from households to new businessmen, $\tilde{N}$ is a steady-state constant, $\theta^{nw}(\tilde{N}_t - N)$ is a smoother element (used to better fit the data), with $\theta^{nw} \geq 0$, and

$$\tilde{N}_t = i_{t-1}N_{t-1} + P_{t-1}^{\mathcal{K}}\bar{K}_t\big[Ret_t^{\mathcal{K}}\big(1 - \mu_t^{\mathcal{K}}G(\bar{\omega}_t^{\mathcal{K}})\big) - i_{t-1}\big]$$

The share of entrepreneurs who become workers in the next period, $\iota_t^{\mathcal{E}}$, follows a first-order autoregressive process with an iid-normal error term $\tilde{\varepsilon}_t^{\mathcal{E}}$

$$\log\Big((1 + \iota_t^{\mathcal{E}})/(1 + \iota^{\mathcal{E}})\Big) = \rho^{\mathcal{E}}\log\Big((1 + \iota_{t-1}^{\mathcal{E}})/(1 + \iota^{\mathcal{E}})\Big) + \tilde{\varepsilon}_t^{\mathcal{E}}$$

where $0 \leq \rho^{\mathcal{E}} < 1$. Repossession costs total $RBC_t = \mu Ret_t^{\mathcal{K}} P_{t-1}^{\mathcal{K}}\bar{K}_t G(\bar{\omega}_t^{\mathcal{K}})$.

2.3. Market clearing conditions and GDP definition

Labor market clearing implies $U_t = U_t^{\mathcal{Z}} + \Gamma_t^{\mathcal{U}} + \Gamma_t^{\mathcal{V}}$. In the intermediate goods market, we have

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

In the final goods market

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

where $\mathbf{1}_x(\mathcal{F})$ is an indicator function which takes the value of 1 if $\mathcal{F} \in x$ and 0 otherwise, $\forall \mathcal{F} \in \{\mathcal{C}, \mathcal{I}, \mathcal{G}, \mathcal{X}\}$. Finally, nominal GDP is $GDP_t = P_tC_t + P_t^{\mathcal{G}}G_t + P_t^{\mathcal{I}}I_t + P_t^{\mathcal{X}}X_t - P_t^*M_t$.

2.4. Specific features

We estimate eight different model versions in this article, differing along three dimensions: the final goods structure, the fiscal environment, and the financial sector. In the version with no financial accelerator, capital goods producers are simultaneously the owners of the capital stock, and maximize the expected value of

$$\sum_{s=0}^{\infty}\Lambda_{t,t+s}^{N}\Big[(1-\tau_{t+s}^{\mathcal{K}})\big[R_{t+s}^{\mathcal{K}}u_{t+s}(i) - P_{t+s}a\big(u_{t+s}(i)\big)\big]\bar{K}_{t+s}(i) - P_{t+s}^{\mathcal{I}}I_{t+s}(i) + \tau_{t+s}^{\mathcal{K}}\delta P_{t+s}^{\mathcal{K}}\bar{K}_{t+s}(i)\Big]$$

The optimal capital utilization rate is identical to that previously depicted, whereas the equation for capital supply—which suppresses all the financial structure of the main model—is

$$Q_t = \Lambda_{t,t+1} \frac{\pi^{\mathcal{I}}_{t+1}}{\pi_{t+1}} \left[(1 - \tau^{\mathcal{K}}_{t+1}) \left[R^{\mathcal{K}}_{t+1} u_{t+1} - P_{t+1} a\big(u_{t+1}(i)\big) \right] + (1 - \delta(1 - \tau^{\mathcal{K}}_{t+1})) Q_{t+1} \right]$$

On the household side, lending to the entrepreneurial sector is no longer available and $B^{\mathcal{E}}_t = 0$. Both the risk and net worth destroying shocks cease to exist.

In the version with the simpler fiscal environment, the fiscal sector collapses to a lumpsum tax LT_t—which is simultaneously the endogenous fiscal instrument—and the budget is balanced at all times. This implies setting all tax rates and TRG_t to zero, and introducing LT_t in the households and government budget constraints. The only surviving shock process within the scope of the public sector is G_t, and government bonds become unavailable, $B^{\mathcal{G}}_t = 0$.

Finally, in the version with a single distributor, we drop the indexer F, assume identical final prices across the four sectors, and introduce perfectly-competitive retailers with the sole purpose of allocating the final good to different costumers—households, capital goods producers, the government, and foreign distributors. This is mostly equivalent to setting $\pi^{\mathcal{F}}_t = \pi_t, \forall F \in \{\mathcal{C}, \mathcal{I}, \mathcal{G}, \mathcal{X}\}$, and collapsing the four price-markup shocks into a single shock.

3. Estimation

We estimate eight models that range from the simpler version $B0$ to the more complex FG–A. The identifier A designates the presence of a financial accelerator; the identifier G designates the presence of an elaborated fiscal sector; the identifier F or B designates whether the model includes all distributors (F) or a single distributor (B); and the identifier 0 indicates that the model is estimated only with GDP growth instead of GDP components. All versions are exactly identified, estimated with quarterly observations for the 1999Q1–2019Q4 period, and with a database always featuring euro area inflation, output and interest rate.

The stochastic behavior of all models is driven by structural shocks categorized into seven branches, namely Households, Growth, Technology, Markups, Government, Financial and External (Table 1). Our discussion is primarily focused on the full-fledged model $FG{-}A$, but all results are available from the authors upon request.

3.1. Shocks and data

The $FG{-}A$ model is estimated for the Portuguese economy with twenty five observable time series (Table 2). On the real side, we take the logs and first differences of GDP, private consumption, public consumption and investment, private investment, exports, imports, wages, and hours worked. On the nominal side we consider inflation levels for private consumption, public consumption and investment, private investment, exports, and imports.

	Model versions							
	$B0$	$B0$–A	B	B–A	F	F–A	FG	FG–A
Households								
Preference shock $\tilde{\varepsilon}_t^{\eta}$			✓	✓	✓	✓	✓	✓
Growth								
Unit root labor-augmenting technology $\tilde{\varepsilon}_t^{g}$	✓	✓	✓	✓	✓	✓	✓	✓
Technology								
Stationary labor-augmenting $\tilde{\varepsilon}_t^{A}$	✓	✓	✓	✓	✓	✓	✓	✓
Private investment efficiency $\tilde{\varepsilon}_t^{\zeta}$			✓	✓	✓	✓	✓	✓
Markups								
Wages $\tilde{\varepsilon}_t^{\sigma^{\mathcal{U}}}$	✓	✓	✓	✓	✓	✓	✓	✓
Domestic prices, final good $\tilde{\varepsilon}_t^{\sigma^{\mathcal{MF}}}$	✓	✓	✓	✓				
Domestic prices, consumption goods $\tilde{\varepsilon}_t^{\sigma^{\mathcal{C}}}$					✓	✓	✓	✓
Domestic prices, investment goods $\tilde{\varepsilon}_t^{\sigma^{\mathcal{I}}}$					✓	✓	✓	✓
Domestic prices, government goods $\tilde{\varepsilon}_t^{\sigma^{\mathcal{G}}}$					✓	✓	✓	✓
Domestic prices, export goods $\tilde{\varepsilon}_t^{\sigma^{\mathcal{X}}}$					✓	✓	✓	✓
Government								
Public consumption and investment $\tilde{\varepsilon}_t^{\mathcal{G}}$			✓	✓	✓	✓	✓	✓
Lumpsum transfers $\tilde{\varepsilon}_t^{TRG}$							✓	✓
Tax rates, payroll $\tilde{\varepsilon}_t^{\tau^{SP}}$							✓	✓
Tax rates, consumption goods $\tilde{\varepsilon}_t^{\tau^{C}}$							✓	✓
Tax rates, capital goods $\tilde{\varepsilon}_t^{\tau^{K}}$							✓	✓
Fiscal rule $\tilde{\varepsilon}_t^{SG}$							✓	✓
Financial								
Borrowers' riskiness $\tilde{\varepsilon}_t^{\sigma^{\mathcal{E}}}$		✓		✓		✓		✓
Net worth $\tilde{\varepsilon}_t^{\gamma^{\mathcal{E}}}$		✓		✓		✓		✓
Nationwide risk $\tilde{\varepsilon}_t^{\Upsilon}$	✓	✓	✓	✓	✓	✓	✓	✓
External								
IS-AS-TR structure								
Inflation $\varepsilon_t^{\pi_t^*}$	✓	✓	✓	✓	✓	✓	✓	✓
Output shock $\varepsilon_t^{y^*}$	✓	✓	✓	✓	✓	✓	✓	✓
Interest rate $\varepsilon_t^{i_t^*}$	✓	✓	✓	✓	✓	✓	✓	✓
Other								
External demand $\tilde{\varepsilon}_t^{yd}$	✓	✓	✓	✓	✓	✓	✓	✓
Export penetration $\tilde{\varepsilon}_t^{\alpha*}$			✓	✓	✓	✓	✓	✓
Import penetration $\tilde{\varepsilon}_t^{\mathcal{AM}}$			✓	✓	✓	✓	✓	✓
Import price markup $\tilde{\varepsilon}_t^{\mathcal{M}}$					✓	✓	✓	✓
Memo: number of shocks								
Domestic	5	7	8	10	11	13	16	18
External	4	4	6	6	7	7	7	7
Total	9	11	14	16	18	20	23	25

Table 1. Innovations.

Notes: External shocks affecting output in the euro area (IS curve), inflation (AS curve) and the Taylor Rule (TR) are groupped for simplicity under the IS-AS-TR structure. All smoothed shocks follow autoregressive processes of order one except external demand, which follows an augmented distributed lag process of order one.

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 contributions (including both the employer and employee

	Model versions							
	$B0$	$B0$–A	B	B–A	F	F–A	FG	FG–A
Portugal								
GDP growth	✓	✓	✓	✓	✓	✓	✓	✓
Private consumption growth			✓	✓	✓	✓	✓	✓
Private investment growth			✓	✓	✓	✓	✓	✓
Public cons. & inv. growth			✓	✓	✓	✓	✓	✓
Exports growth			✓	✓	✓	✓	✓	✓
Imports growth			✓	✓	✓	✓	✓	✓
Hours worked (growth)	✓	✓	✓	✓	✓	✓	✓	✓
Wage growth	✓	✓	✓	✓	✓	✓	✓	✓
GDP inflation	✓	✓	✓	✓				
Private consumption inflation					✓	✓	✓	✓
Private investment inflation					✓	✓	✓	✓
Public cons. & inv. Inflation					✓	✓	✓	✓
Exports inflation					✓	✓	✓	✓
Imports inflation					✓	✓	✓	✓
Consumption tax revenue-GDP ratio							✓	✓
Labor tax revenue-GDP ratio							✓	✓
Payroll tax revenue-GDP ratio							✓	✓
Capital tax revenue-GDP ratio							✓	✓
HH transfers-GDP ratio							✓	✓
Nationwide risk	✓	✓	✓	✓	✓	✓	✓	✓
Corporate interest rate spread		✓		✓		✓		✓
Corporate loans growth		✓		✓		✓		✓
Euro area								
GDP growth	✓	✓	✓	✓	✓	✓	✓	✓
GDP inflation	✓	✓	✓	✓	✓	✓	✓	✓
Interest rate	✓	✓	✓	✓	✓	✓	✓	✓
Other variables								
External demand	✓	✓	✓	✓	✓	✓	✓	✓
Memo: total number of series	9	11	14	16	18	20	23	25

Table 2. Model version databases

Sources: Eurostat, Statistics Portugal and Banco de Portugal.

Notes: All quantities are *per capita*. Wages are computed by deflating nominal wages with the private consumption deflator. Loans are computed with nominal corporate loans and the GDP deflator. Seasonal adjustments were performed through the X12 ARIMA and ensuring that quarterly data aggregation matches published annual data.

components), and through the social benefits-to-GDP ratio. Two of these series—the revenue-to-GDP ratio from social security contributions 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.

On the financial side we consider: *(i)* the level for the corporate interest rate spread, computed as the difference between the interest rate paid by non-financial corporations on new loans and the 3-month Euribor; and *(ii)* the nationwide risk premium, measured by the differential between Portuguese and German short-term Treasury bills. Due to data shortages, we assume a stable risk premium over the 1999Q1-2004Q1 period, in line with the stability of yield spreads of longer maturities, and infer the differential from Portuguese and German corporate interest rates over 2011-2012, a period when Portugal was under international financial assistance and market prices were determined by factors not included in the model (liquidity problems, segmentation risks, market freezes, etc). In addition, we take the logs and first differences of loans granted to corporations, which includes the stock of loans and debt securities reported in the financial accounts data, comprising operations with all institutional sectors other than non-financial corporations.

Finally, the external side features euro area GDP growth, euro area GDP inflation, and the 3-month Euribor interest rate. External demand growth is based on an index capturing a trade-weighted average of foreign imports. Monetary policy is solely influenced by euro area variables due to the small-open economy assumption.

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, and allow for measurement errors to take into account measurement noise in macro data and facilitate the inclusion of data for all GDP components in addition to GDP itself, while avoiding stochastic singularity in the resource constraint. The variance of all measurement errors is calibrated at 5 percent of the variance of each data series.

B0-models are estimated with real GDP and the GDP deflator, alongside three additional domestic variables (hours worked, wages, and the nationwide risk) and external variables. B-models consider in addition all demand components, whereas F-models replace the GDP deflator by the deflators of all five demand components, exploiting the information from the more complex final goods structure. FG-models include five additional fiscal variables. Each model is also estimated with a financial accelerator mechanism—originating models B0-A, B-A, F-A and FG-A—and the database is concomitantly augmented with the corporate interest rate spread and the corporate loans growth. The structure of shocks is extended accordingly in each model so that they remain exactly identified. Hence, B-models include shocks related with demand components, F-models consider price-markup shocks in all final goods, and G-models assume a more elaborated fiscal rule and shock processes on various tax rates. Finally, A-models include a risk and a net worth shock.

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, preceded by an identification analysis to rule out some potential estimation issues. 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 3 parallel chains of 5 million draws each, and discard the first 2.5 million as the burn-in phase. The acceptance rate is around 25 percent for all estimated models. Convergence of the simulation is assessed through the diagnostics in Brooks and Gelman (1998).

3.3. Calibration

Table A.1 in the appendix provides a summary of the calibrated parameters of the model, whereas Table A.2 reports the steady state evaluated at the posterior mean. We set the interest rate target at 3.2 percent per year, matching the 1999–2007 (pre-financial crisis) average for the 3-month Euribor. The domestic interest rate differs from the target rate due to the nationwide risk premium, whose sensibility parameter is set to 0.0025. Steady-state inflation is set at 2 percent and the technology growth rate at 1.1 percent per year; the former in line with the ECB's price stability target and latter in line with both the pre-financial crisis average value for Portugal and the in-sample average value for the euro area.

The quarterly discount rate set to 0.998. Steady-state markups are not identified and thus we calibrate the wage markup at 40 percent, the intermediate goods price markup at around 10 percent, and the final goods price markup at 5 percent, except in the case of exporters and importers, where fiercer competition justifies a markup of 2.5 percent. The intermediate goods price adjustment cost is set to ensure a model dynamics similar to that of an implicit average price duration between 3 and 4 quarters. Importers price adjustment cost is not identified in all B-model versions due to the absence of imports inflation from the dataset, and hence we calibrate the value identically to the intermediate goods price adjustment cost.

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. Values at the posterior mean differ slightly from the initial calibrated values as some estimated parameters impact the steady state. The 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 -1.8 percent. The imports-to-GDP ratio results from a steady-state compatible trade balance, and the net foreign asset position is roughly -70 percent of GDP.

In the financial sector we endogenously calibrate the steady-state borrowers' riskiness $\sigma^{\mathcal{E}}$, monitoring cost μ, and the exit rate $\iota^{\mathcal{E}}$ at the prior mean, to match a leverage ratio of one, a default probability of 4 percent, and a credit spread of 2.7 percentage points. These targets are close to historical averages. Values at the posterior mean in Table A.2 differ slightly, influenced by the estimated monitoring cost μ.

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 some parameters during estimation. Specifically, we set 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. In practice, this approach leads just to marginal adjustments in the depreciation rate, which remains close to the initially calibrated value of 1.5 percent in all model versions—and close 1999–2019 average for productive capital. Additionally, in the full-fledged model, we undertake this same approach for government transfers to households, constantly re-calibrating the level variable TRG to match the transfers-to-GDP ratio.

Import shares at the posterior mean deviate slightly from the prior mean as they are affected by the estimated elasticity of substitution parameters that enter the production function of final goods distributors—a price that we pay to favor the model dynamics.

3.4. Prior selection and posterior analysis

Our priors represent a compromise between looseness and convergence, namely when we chose to tighten 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 IS-AS-TR model follow either beta or gamma distributions, depending on whether they are comprised between zero and one, or unbounded from above.

Tables 3 to 5 document the prior-posterior analysis. These results, jointly with the posterior plots presented in Appendix B for the full-fledged model, suggest that data is informative about estimated parameters, with a few exceptions.[5] Posteriors are in general tighter then priors or centered at different points of the support.

5. Posterior plots for the remaining models are naturally different but do not convey a distinct message. They are all well-behaved and depict a hump-shaped pattern. The appendix presents additional outputs and estimation byproducts that are not mentioned in the main text. Some results are only presented for the full-fledged model for space reasons.

	param.	prior			posterior mean							
		dist.	mean	s.d.	B0	B0-A	B	B-A	F	F-A	FG	FG-A
Nominal adjustment costs												
Wage	$\varphi_{\mathcal{V}}$	Γ	125.0	25.0	160.8	191.2	113.8	137.6	130.1	169.1	80.8	147.3
Final goods	$\varphi_{P\mathcal{F}}$	Γ	125.0	25.0	144.6	125.2	187.8	173.9				
Private consumption	$\varphi_{P\mathcal{C}}$	Γ	125.0	25.0					243.6	216.4	174.3	200.5
Private investment	$\varphi_{P\mathcal{I}}$	Γ	125.0	25.0					112.1	107.0	98.9	97.2
Public cons. & inv.	$\varphi_{P\mathcal{G}}$	Γ	125.0	25.0					147.7	128.2	125.9	126.1
Exports	$\varphi_{P\mathcal{X}}$	Γ	125.0	25.0					177.9	158.9	143.5	148.6
Imports	$\varphi_{P\mathcal{IM}}$	Γ	125.0	25.0					126.0	121.3	126.8	122.5
Real adjustment costs												
Labor	$\varphi_{\mathcal{U}}$	Γ	25.0	5.0	25.9	10.4	33.6	16.6	30.5	15.1	11.7	12.8
Investment	S''	Γ	5.0	1.0	4.9	4.5	8.1	6.6	9.2	8.1	9.3	7.9
Capital utiliz. Rate	σ_a	Γ	5.0	1.0	4.6	3.2	4.4	2.6	3.5	2.3	3.1	2.7
Import content adj. costs												
Domestic distributors	$\varphi_{A\mathcal{M}}$	Γ	2.00	0.40	1.52	1.99	0.84	1.12				
Domestic distributors of consumption goods	$\varphi_{A\mathcal{MC}}$	Γ	2.00	0.40					1.31	1.67	1.63	1.82
Domestic distributors of investmento goods	$\varphi_{A\mathcal{MI}}$	Γ	2.00	0.40					1.87	1.96	1.93	1.94
Domestic distributors of government goods	$\varphi_{A\mathcal{MG}}$	Γ	2.00	0.40					1.92	1.96	1.95	1.98
Domestic distributors of export goods	$\varphi_{A\mathcal{MX}}$	Γ	2.00	0.40					1.34	1.76	1.52	1.72
Foreign distributors	$\varphi_{A\mathcal{X}}$	Γ	2.00	0.40	1.85	1.96	1.48	1.47	1.58	1.63	1.57	1.59
Technology												
EoS, final goods	$\xi_{\mathcal{F}}$	Γ	1.50	0.15	1.48	1.50	1.64	1.66				
EoS, consumer goods	$\xi_{\mathcal{C}}$	Γ	1.50	0.15					1.55	1.58	1.47	1.68
EoS, investment goods	$\xi_{\mathcal{I}}$	Γ	1.50	0.15					1.55	1.52	1.50	1.48
EoS, government goods	$\xi_{\mathcal{G}}$	Γ	1.50	0.15					1.52	1.55	1.49	1.57
EoS, export goods	$\xi_{\mathcal{X}}$	Γ	1.50	0.15					1.55	1.59	1.46	1.50
EoS, foreign distributors	ξ_*	Γ	1.50	0.15	1.44	1.37	1.43	1.42	1.39	1.34	1.36	1.29
Preference parameters												
Share of hand-to-mouth	ψ	β	0.50	0.10	0.33	0.30	0.41	0.39	0.39	0.38	0.44	0.47
Inverse Frisch elasticity	σ_L	Γ	0.50	0.10	0.39	0.38	0.44	0.43	0.44	0.42	0.64	0.56
Habit persistence	ν	β	0.75	0.10	0.21	0.14	0.89	0.93	0.90	0.92	0.90	0.89
Miscellaneous parameters												
FR sensibility to GDP	d^{GDP}	Γ	0.5	0.10							0.21	0.16
FR sensibility to G/GDP	d^{G}	Γ	0.5	0.10							1.13	1.09
Repossession cost	μ	β	0.33	0.08		0.48		0.45		0.48		0.34
Net Worth smoother	θ^{nw}	β	0.50	0.10		0.19		0.30		0.28		0.22

Table 3. Estimated structural parameters.

Notes: Based on 3 parallel chains of 5 million draws each, after a burn-in of 2.5 million draws. Γ stands for the gamma distribution, and β for the beta distribution. EoS stands for Elasticity of Substitution and FR for Fiscal Rule.

The share of hand-to-mouth households at the prior mean is set at 50 percent, reflecting an identical partition between asset holders and hand-to-mouth households. Results at the posterior mean suggest a lower value. The deviation from the prior is larger for simpler models, possibly because in more complex models asset holders have a larger set of financial instruments at their disposal to smooth consumption, which results into a lower estimated mass. The parameter controlling the degree of habit persistence is set at 0.75 and the inverse Frisch elasticity at 0.5 at the prior mean. The posterior mean suggests higher habit persistence, around 0.9, except in the case of simpler (0-type) models in which private consumption is not part of the dataset. In this case, there is no information on the level of consumption smoothness, and the distribution of habit persistence is shifted towards zero. The inverse Frisch elasticity is weakly identified, and posterior distributions do not deviate substantially from the prior's. Nonetheless, the posterior mean is slightly below 0.5, except for those models embodying a more elaborated fiscal stance (G-type models).

	param.	prior			posterior mean							
		dist.	mean	s.d.	B0	B0-A	B	B-A	F	F-A	FG	FG-A
Persistence, Markups												
Wage	$\rho^{\sigma\mathcal{U}}$	β	0.50	0.15	0.191	0.209	0.169	0.172	0.168	0.158	0.113	0.119
Final goods	$\rho^{\sigma\mathcal{F}}$	β	0.50	0.15	0.402	0.308	0.404	0.261				
Private consumption	$\rho^{\sigma\mathcal{C}}$	β	0.50	0.15					0.637	0.605	0.587	0.538
Private investment	$\rho^{\sigma\mathcal{I}}$	β	0.50	0.15					0.244	0.222	0.217	0.205
Public cons. & inv.	$\rho^{\sigma\mathcal{G}}$	β	0.50	0.15					0.818	0.797	0.825	0.786
Exports	$\rho^{\sigma\mathcal{X}}$	β	0.50	0.15					0.563	0.629	0.608	0.640
Imports	$\rho^{\sigma\mathcal{IM}}$	β	0.50	0.15					0.716	0.749	0.727	0.744
Persistence, Demand												
Preference	ρ^{η}	β	0.50	0.15			0.316	0.288	0.231	0.245	0.236	0.272
Public cons. & inv.	$\rho^{\mathcal{G}}$	β	0.50	0.15			0.918	0.916	0.916	0.912	0.900	0.893
Export market share	$\rho^{\alpha*}$	β	0.50	0.15			0.184	0.175	0.206	0.197	0.210	0.213
Persistence, Technology												
Unit root tech growth	ρ^{g}	β	0.75	0.10	0.881	0.875	0.723	0.603	0.741	0.634	0.747	0.617
Labor augmenting stationary tech	ρ^{A}	β	0.50	0.15	0.639	0.950	0.447	0.924	0.412	0.864	0.693	0.851
Investment efficiency	ρ^{ζ}	β	0.50	0.15			0.244	0.222	0.216	0.222	0.211	0.179
Imports efficiency	$\rho^{\mathcal{M}}$	β	0.50	0.15			0.331	0.299	0.120	0.143	0.124	0.125
Persistence, Fiscal authorities												
Household transfers	ρ^{TRG}	β	0.50	0.15							0.453	0.481
Taxes on consumption	$\rho^{\tau\mathcal{C}}$	β	0.50	0.15							0.760	0.848
Taxes on payroll	$\rho^{\tau\mathcal{SP}}$	β	0.50	0.15							0.344	0.341
Taxes on capital	$\rho^{\tau\mathcal{K}}$	β	0.50	0.15							0.146	0.178
Fiscal rule	ρ^{SG}	β	0.50	0.15							0.226	0.242
Persistence, Financial												
Nationwide risk	ρ^{Υ}	β	0.50	0.15	0.933	0.916	0.971	0.943	0.954	0.920	0.948	0.922
Borrowers' riskiness	$\rho^{\sigma\mathcal{E}}$	β	0.50	0.15		0.978		0.945		0.939		0.913
Net worth destruction	$\rho^{\mathcal{E}}$	β	0.50	0.15		0.714		0.819		0.779		0.762
IS-AS-TR												
IS parameter	ρ_{y}	β	0.50	0.15	0.941	0.937	0.845	0.921	0.852	0.914	0.822	0.799
IS parameter	$\rho_{y,i}$	Γ	0.20	0.05	0.204	0.199	0.201	0.198	0.206	0.201	0.203	0.202
AS parameter	ρ_{π}	β	0.50	0.15	0.326	0.312	0.396	0.358	0.376	0.338	0.466	0.438
AS parameter	$\rho_{\pi,y}$	Γ	0.20	0.05	0.094	0.110	0.168	0.154	0.171	0.153	0.191	0.182
TR parameter	ρ_{i}	β	0.50	0.15	0.789	0.835	0.804	0.822	0.782	0.806	0.844	0.840
TR parameter	$\rho_{i,y}$	Γ	0.20	0.05	0.241	0.235	0.202	0.210	0.216	0.206	0.162	0.165
TR parameter	$\rho_{i,\pi}$	Γ	1.50	0.15	1.320	1.414	1.445	1.436	1.468	1.440	1.448	1.438
WDR parameter	ρ^{yd}	β	0.50	0.15	0.384	0.365	0.388	0.371	0.363	0.383	0.359	0.334
WDR parameter	ρ^{y*}	Γ	5.00	1.50	5.010	5.203	6.062	5.830	5.546	5.779	5.616	5.743

Table 4. Estimated persistence parameters.

Notes: See Table 3.

Prior means 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 means pinpoint harsher wage adjustment costs and higher price adjustment costs in private consumption and exports, for most model versions.[6] On the opposite direction, private investment depicts milder adjustment costs. There are no important differences between prior and posterior means for public consumption and imported goods, and posterior distributions for these parameters suggests that data is largely uninformative.

6. The noteworthy exception is the wage adjustment cost in the FG-model version.

	param.	prior			posterior mean							
		dist.	mean	s.d.	B0	B0-A	B	B-A	F	F-A	FG	FG-A
Markups												
Wage	se($\tilde{\varepsilon}_t^{\sigma\mathcal{U}}$)	Inv-Γ	0.01	$+\infty$	0.149	0.101	0.104	0.066	0.112	0.078	0.075	0.068
Final goods	se($\tilde{\varepsilon}_t^{\sigma\mathcal{F}}$)	Inv-Γ	0.01	$+\infty$	0.038	0.033	0.048	0.044				
Private consumption	se($\tilde{\varepsilon}_t^{\sigma\mathcal{C}}$)	Inv-Γ	0.01	$+\infty$					0.027	0.024	0.021	0.024
Private investment	se($\tilde{\varepsilon}_t^{\sigma\mathcal{I}}$)	Inv-Γ	0.01	$+\infty$					0.130	0.126	0.135	0.128
Public cons. & inv.	se($\tilde{\varepsilon}_t^{\sigma\mathcal{G}}$)	Inv-Γ	0.01	$+\infty$					0.032	0.030	0.031	0.032
Exports	se($\tilde{\varepsilon}_t^{\sigma\mathcal{X}}$)	Inv-Γ	0.01	$+\infty$					0.034	0.031	0.029	0.030
Imports	se($\tilde{\varepsilon}_t^{\sigma\mathcal{IM}}$)	Inv-Γ	0.01	$+\infty$					0.047	0.044	0.045	0.046
Demand												
Preferences	se($\tilde{\varepsilon}_t^{\eta}$)	Inv-Γ	0.01	$+\infty$			0.088	0.134	0.083	0.115	0.084	0.082
Public cons. & inv.	se($\tilde{\varepsilon}_t^{G}$)	Inv-Γ	0.01	$+\infty$			0.014	0.013	0.013	0.013	0.013	0.014
Export market share	se($\tilde{\varepsilon}_t^{\alpha *}$)	Inv-Γ	0.01	$+\infty$			0.059	0.056	0.060	0.059	0.056	0.058
Technology & preferences												
Unit root technology	10se($\tilde{\varepsilon}_t^{g}$)	Inv-Γ	0.01	$+\infty$	0.020	0.020	0.024	0.025	0.024	0.026	0.021	0.025
Stationary technology	se($\tilde{\varepsilon}_t^{A}$)	Inv-Γ	0.01	$+\infty$	0.012	0.013	0.012	0.014	0.011	0.012	0.009	0.011
Investment efficiency	se($\tilde{\varepsilon}_t^{\zeta}$)	Inv-Γ	0.01	$+\infty$			0.026	0.023	0.025	0.024	0.025	0.023
Imports efficiency	se($\tilde{\varepsilon}_t^{A\mathcal{M}}$)	Inv-Γ	0.01	$+\infty$			0.035	0.038	0.043	0.049	0.040	0.045
Fiscal authorities												
Household transfers	se($\tilde{\varepsilon}_t^{TRG}$)	Inv-Γ	0.01	$+\infty$							0.005	0.005
Taxes on consumption	se($\tilde{\varepsilon}_t^{\tau\mathcal{C}}$)	Inv-Γ	0.01	$+\infty$							0.007	0.006
Taxes on payroll	se($\tilde{\varepsilon}_t^{\tau\mathcal{SP}}$)	Inv-Γ	0.01	$+\infty$							0.004	0.004
Taxes on capital	se($\tilde{\varepsilon}_t^{\tau\mathcal{K}}$)	Inv-Γ	0.01	$+\infty$							0.030	0.025
Fiscal rule	se($\tilde{\varepsilon}_t^{SG}$)	Inv-Γ	0.01	$+\infty$							0.008	0.008
Financial sector												
Nationwide risk	10se($\tilde{\varepsilon}_t^{\Upsilon}$)	Inv-Γ	0.01	$+\infty$	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Borrowers' riskiness	se($\tilde{\varepsilon}_t^{\sigma\mathcal{E}}$)	Inv-Γ	0.01	$+\infty$		0.025		0.024		0.025		0.028
Net worth destruction	se($\tilde{\varepsilon}_t^{\mathcal{E}}$)	Inv-Γ	0.01	$+\infty$		0.013		0.016		0.016		0.017
Foreign												
Foreign GDP	10se($\tilde{\varepsilon}_t^{Y*}$)	Inv-Γ	0.01	$+\infty$	0.041	0.040	0.034	0.034	0.047	0.043	0.038	0.037
Foreign inflation	10se($\tilde{\varepsilon}_t^{\pi *}$)	Inv-Γ	0.01	$+\infty$	0.015	0.015	0.016	0.015	0.016	0.015	0.019	0.019
Foreign interest rate	10se($\tilde{\varepsilon}_t^{i*}$)	Inv-Γ	0.01	$+\infty$	0.009	0.009	0.010	0.009	0.010	0.010	0.010	0.009
Foreign demand	10se($\tilde{\varepsilon}_t^{yd}$)	Inv-Γ	0.01	$+\infty$	0.061	0.055	0.034	0.031	0.038	0.033	0.037	0.030

Table 5. Estimated standard error of innovations.

Notes: See Table 3. Inv-Γ stands for the inverse gamma distribution.

Prior means concerning real adjustment costs were selected to ensure plausible *ex-ante* labor, investment, and utilization rate dynamics. Results for the labor stickiness coefficient are mixed, with the posterior mean below the prior mean in models embodying either a financial accelerator or an elaborated fiscal stance (A- and G-type models). Data is very informative, and suggest that these mechanisms create endogenous inertia that requires a lower wage stickiness coefficient. The capital utilization rate sluggishness coefficient is smaller at the posterior mean in all models, whereas the coefficient respecting investment sluggishness in larger (except in 0-type models). More importantly, posterior means are systematically lower in model versions embodying financial frictions, *vis-à-vis* their no-accelerator setups. This evidence suggests that models embodying financial frictions tend to depict higher degrees of endogenous inertia, hence requiring lower exogenous adjustment costs to explain the same dataset. Posterior distributions are tighter and centered at different values of the support as compared with their prior analogs.

Adjustment costs in import contents were tuned to deliver plausible real exchange rate fluctuations at the prior mean. Posterior distributions in general do not deviate substantially from the prior ones; nonetheless posterior means are in general lower as compared with prior mean. Technology parameters are mildly identified, and posterior distributions do not differ substantially from prior ones. The larger deviation occur in foreign distributors.

The parameters d^{GDP} and d^{G} in the fiscal policy rule are set to 0.5 at the prior mean. The values at the posterior mean suggests that fiscal balance is only mildly pro-cyclical, $d^{GDP} < 0.5$, and that increases in public consumption push up the deficit significantly, $d^{G} > 0.5$ (*i.e.,* not fully financed with contemporary taxation). These parameters are well identified. The posterior distribution for d^{GDP} is tighter than the prior's and centered at a lower value of the support, while the posterior distribution for d^{G} is centered at a higher value of the support. The net worth smoother parameter at the posterior mean in the model versions with financial frictions (A-type models) is below the prior mean, and the posterior distribution is substantially tighter than the prior's. This parameter plays an important role in fitting the data, contributing to better capture the dynamics depicted by net worth and concomitantly implying better second moments on financial variables. The posterior mean for the repossession cost is larger than the prior mean in all but the full-fledged model. Data is informative since posterior distributions are tighter than priors' analogs.

Priors for persistence parameters and for the standard deviation of innovations are harmonized as much as possible. Prior means of autoregressive parameters are set at 0.5 and standard deviations are set at 0.15. The exception is the persistence of the growth shock, which has a larger value at the prior mean. Innovations have infinitely loose priors, and are scaled to the same mean. At the posterior mean, wage markups and private consumption markups depict smaller degrees of exogenous persistence, whereas the remaining markup shocks depict larger degrees of persistence. On the demand and fiscal sides, shocks are largely transitory, with the exception of public consumption and indirect taxes. The unit root technology growth rate and the labor augmenting stationary technology both depict larger persistence levels at the posterior mean *vis-à-vis* the prior's, whereas the remaining technology shocks are largely transitory. Financial shocks are highly persistent, possibly reflect long-lasting effects triggered by the financial and sovereign debt crises in the Portuguese economy.

Within the IS-AS-TR framework, the IS curve depicts large persistence levels. Inflation developments seem to be weakly linked to output, with mild degrees of inertia. The Taylor Rule suggests a mild link between monetary policy and output and some persistence in interest rate movements. The coefficient which measures the sensibility of monetary policy to inflation developments is below but close to the prior value of 1.5, a result induced by the prior tightness. External demand is highly linked to foreign output developments.

As for innovations, we note that the financial accelerator contributes to reduce the volatility depicted by innovations to wage markups, while slightly increasing that of the preference shock (with the exception of the G-type model). Increases in the model's complexity seem to downplay the role of wage markup and foreign demand shocks.

4. Model properties

This section compares several estimation byproduts across models, namely smoothed data, trend growth, smoothed shock processes, historical and variance decompositions, selected second moments, and impulse response functions. Estimation byproducts are evaluated at the posterior mean. As in the previous section, we focus primarily on the full-fledged model $FG–A$, but all results are available from the authors upon request.

4.1. Observed and smoothed data

Observed data series used in estimation and smoothed data without measurement errors in Model $FG–A$ are very similar (Figure C.1 in Appendix C). The most important difference occurs in the corporate interest rate spread—a measure of the external finance premium. The financial part of the model is conditioned by one-period contracts, and the external finance premium lacks the inertia depicted by the data. Albeit not shown, all model versions share similar patterns.

4.2. Trend growth

The technology level T_t pertaining the manufacturer's production function represents the stochastic trend of the model, and enters all measurement equations embodying first-order integrated observables, *e.g.* GDP.

Technology growth over the 1999-2019 period in the full-fledged model $FG–A$ depicts a lower frequency movement than the Portuguese quarter-on-quarter GDP growth (Figure 2), and decreases systematically in crises times (highlighted in gray). Negative unit-root technology innovations $\tilde{\varepsilon}_t^g$ are particularly noticeable over the 2008 financial turmoil, pushing down all GDP components as well as foreign output. The role of technology growth over the 2011-12 sovereign debt crisis is downplayed, due to the lower degree of co-movement in real variables, particularly between domestic and foreign output.

In general, technology growth seems qualitatively indistinguishable across models. Excluding models $B0$ and $B0–A$, trend growth differentials against model $FG–A$ stand in general around ± 0.1 pp. Models $B0$ and $B0–A$ feature much more volatile growth rates due to the absence of GDP components from the measurement equation and concomitantly of associated shock processes.

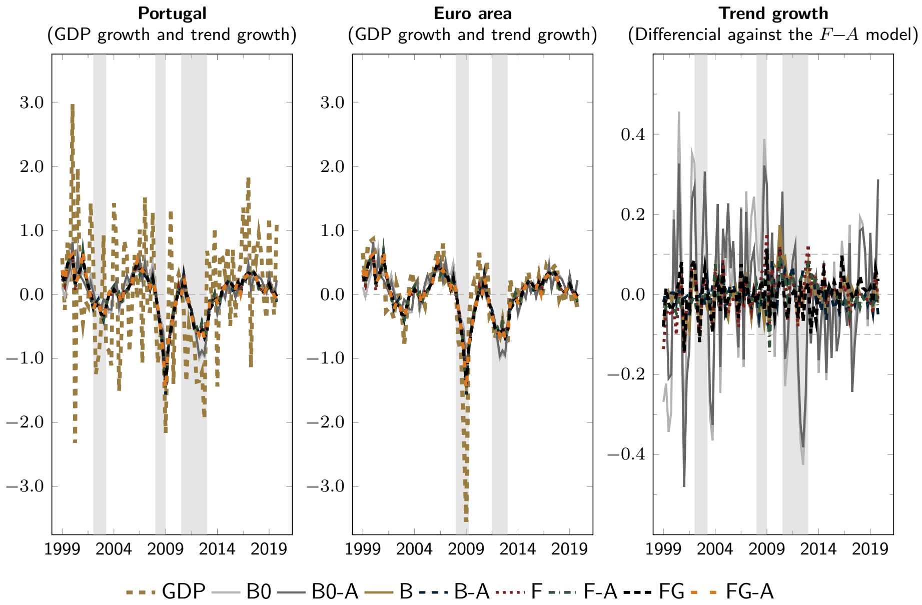


Figure 2: GDP and trend growth.

Notes: All data are demeaned. GDP growth is measured by quarter-on-quarter log differences. Vertical bars highlight recession periods in Portugal (see Figure 1) and in the euro area (dated by the Euro Area Business Cycle Network in the 2008Q1-2009Q2 and 2011Q3-2013Q1 periods). Recession periods for Portugal are also included in the left pane. Here, positive/negative values indicate higher/lower values in model x *vis-à-vis* model $FG–A$, where $x \in \{B0, B–A0, B, B–A, F, F–A, FG\}$.

4.3. Smoothed shock processes

Figure 3 depicts the smoothed shock processes for the full-fledged $FG–A$ model, as well as the associated innovations. All shocks are superimposed over the three Portuguese crises periods in the last twenty years. The first recession has both domestic and worldwide flavors. Lower technology growth and euro area output were accompanied by an investment slowdown (lower investment efficiency), an exogenous fall in household demand (through the preference shock), and some deterioration in financial conditions. The latter is mimicked by an increase in borrowers' riskiness and a fall in net worth. The nationwide risk premium is assumed flat over this period. The interest rate decline and the increase in transfers contributed to cushion the slump and promoted the recovery, although fiscal policy also included an increase in implicit tax rates and a volatile public consumption.

The 2008 global financial crisis was characterized by a worldwide collapse in technology growth, output, and trade and import markups at the beginning of 2009. Though triggered by the subprime crisis in the United States that spread worldwide, the events had confined impacts on the Portuguese financial side. The

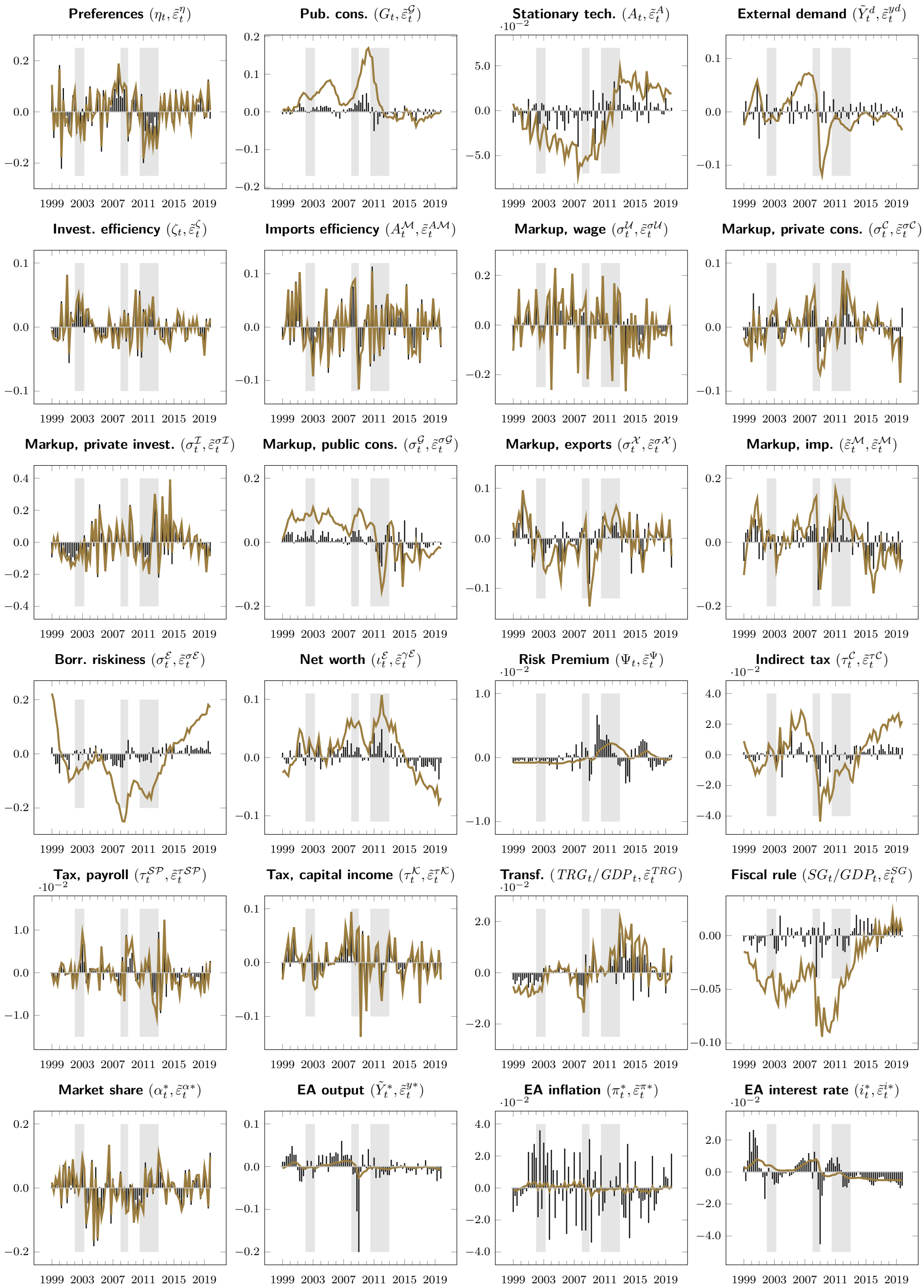


Figure 3: Smoothed shock processes and innovations in the $FG\text{–}A$ model.

Notes: Results are in deviations from steady-state values. Vertical gray bars highlight recession periods (see Figure 1 for details). The pair (x_t, ε_t) in the title of each graph identify the shock x_t, reported in lines, and the innovation ε_t, reported in bars, respectively. The growth rate is omitted and represented alternatively in Figure 2.

2008-2010 increase in borrowers' riskiness and the fall in net worth were moderately confined. The crisis was also accompanied by a contraction in household demand, lightened up by the preference shock.

The aftermath of the financial crisis is marked by a set of fiscal measures to hasten the recovery, notably an unprecedented increase in public consumption and household transfers, and a decline in indirect taxes. These events are accompanied by a raising risk premium, and preceded the 2011-12 sovereign debt crisis. As opposed to the 2008 downturn, this crisis has a greater internal nature, despite the concomitant decline in worldwide growth and output. The financial assistance programme that came into force in mid-2011 triggered a set of corrective measures aimed, amongst other objectives, at bringing the fiscal budget into balance. Public consumption and household transfers were severely pushed back, and indirect taxes increased. There is no visible impact on fiscal rule perturbations, since labor taxes—which also increased—were endogenously driven through the estimated fiscal rule parameters. The economic environment reflected also a severe contraction from the household demand shock. The risk premium decreased gradually since the 2012 peak, achieving the steady-state level during 2014.

As models get richer, exogenous shocks can sometimes be replaced by inner mechanisms, leading to different paths for smoothed variables. Government related perturbations played an important role over specific time periods, which simpler models do not capture and attribute to alternative sources. Nevertheless, smoothed shock processes are to a great extent similar across our estimated model versions, including those affecting investment efficiency, wage markup, preferences, net worth and borrowers' riskiness (Figure 4). The most noteworthy exception is stationary technology, whose role is shifted towards financial sources with the introduction of the financial sector.

4.4. GDP growth historical decomposition

We now decompose the year-on-year GDP growth into structural shocks using the full-fledged $FG\text{--}A$ model, primarily focusing our discussion on the three crisis periods hitting the Portuguese economy (Figure 5).[7] Results suggest that shocks grouped under the categories 'households,' 'growth' and 'external' are key to understand output behavior over the last two decades. They primarily lie in the first and third quadrants of the reported scatter plots and thus explain both expansion and recession phases. A closer inspection reveals that their contributions, particularly of 'households' and 'growth,' are also endowed with a high degree of endogenous persistence. The co-movement between GDP growth and external drivers was absent during the third crises, as these shocks depicted a counter-cyclical behavior during this period.

7. Figure D.1 in Appendix D reports the historical decomposition for the complete 1999Q1-2019Q4 period under the lens of the full-fledged $FG\text{--}A$ model.

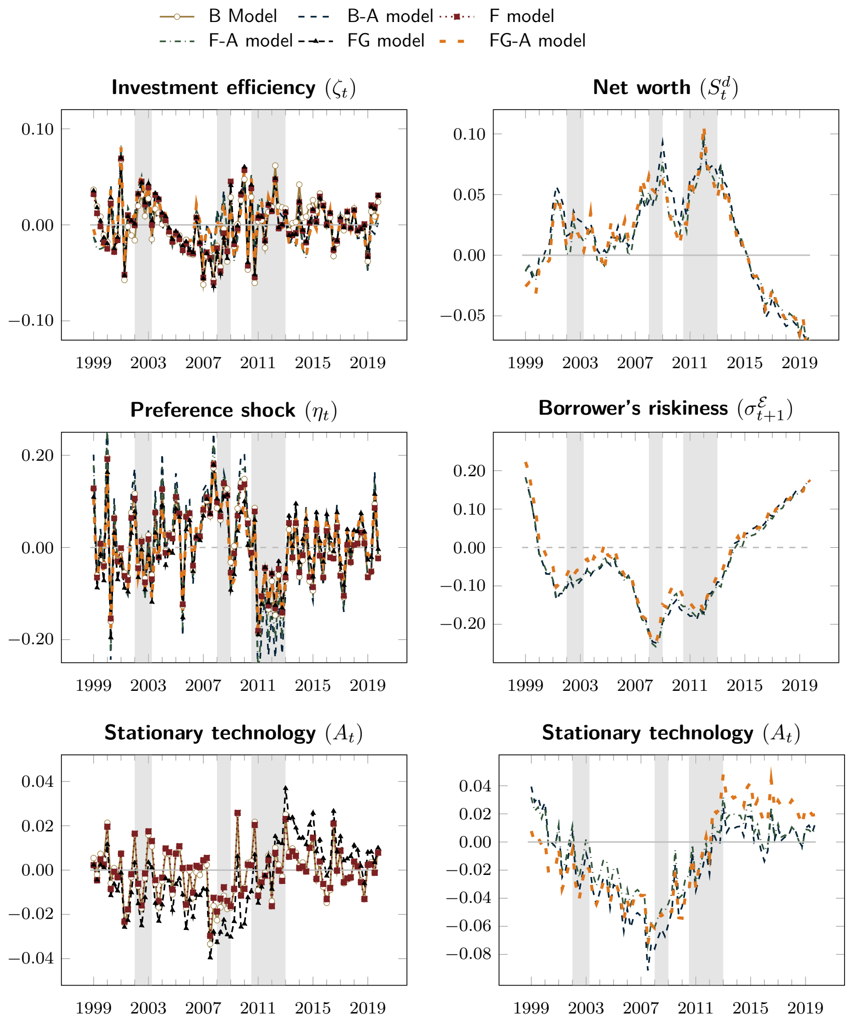


Figure 4: Selected smoothed shock processes, comparison across models.

Notes: Results are in deviations from steady state. Vertical gray bars highlight recession periods (see Figure 1 for details). Lines with markers refer to models without financial intermediaries. The stationary shock is splitted into two figures, comprising models with and without a financial accelerator.

Financial factors also tend to cluster in the first and third quadrants, producing systematic pro-cyclical impacts, although with contributions to GDP growth in general confined to ± 0.75 pp. There are exceptions to this co-movement, for instance during the second crisis—a feature that we discuss in more detail below.

The remaining categories are largely acyclical. They nevertheless play important roles during certain periods. For instance, technology has substantially influenced

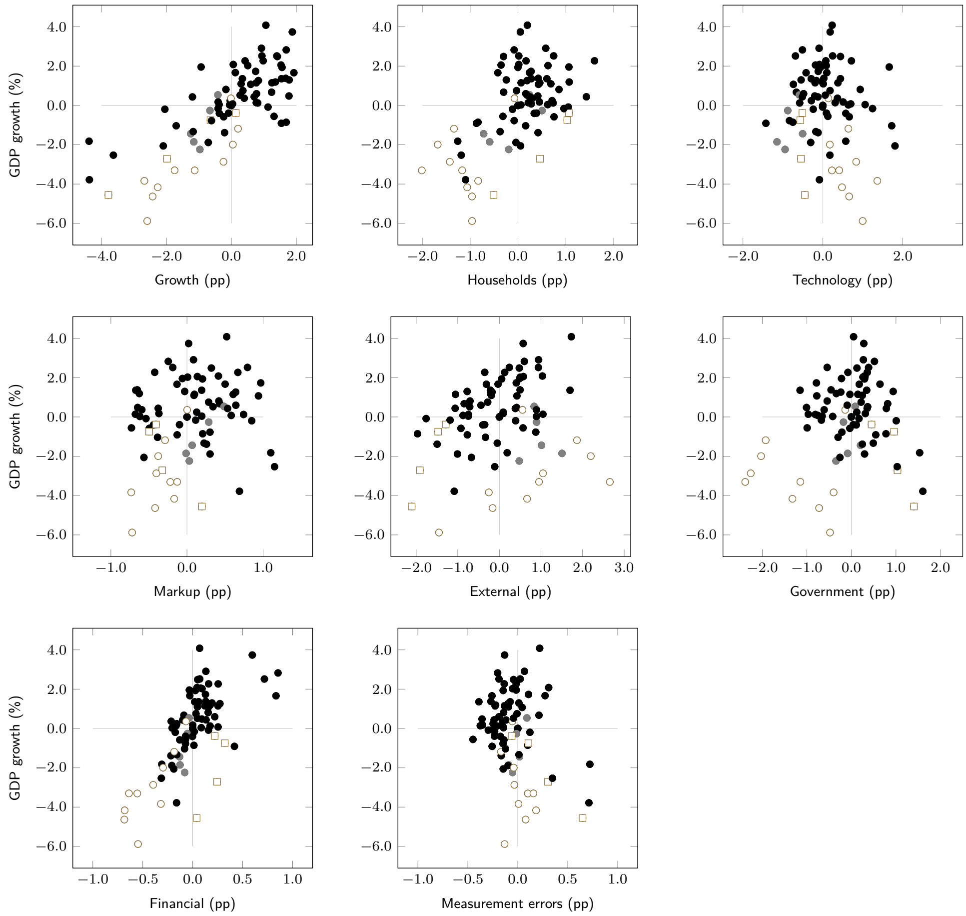


Figure 5: GDP growth and contributions using Model $FG\text{–}A$.

Notes: x-axis reports the contribution of each category in percentage points (pp) to year-on-year GDP growth, the later reported in the y-axis. The first crisis period (2002Q1-2003Q2) is highlithed with gray circles, the second (2008Q1-2009Q1) with white squares, and the third (2010Q3-2013Q1) with white circles, excluding the first quarter of each period.

output behavior during the first crises (with contributions to GDP growth attaining values close to -1pp), while markups flash out during the second and third crises (with contributions to GDP growth also attaining values close to -1pp). Fiscal policy, measured by the contribution of 'government,' is also largely acyclical, oscillating between a counter-cyclical nature, *e.g.* during the second crisis period (reaching a maximum contribution of 1.5pp), and a pro-cyclical stance, *e.g.* during the third crisis (attaining a minimum contribution of -2.4pp). Nonetheless, it has contributed decisively to explain GDP developments during crisis periods, due to their sizable contributions. Measurement errors are small and largely acyclical.

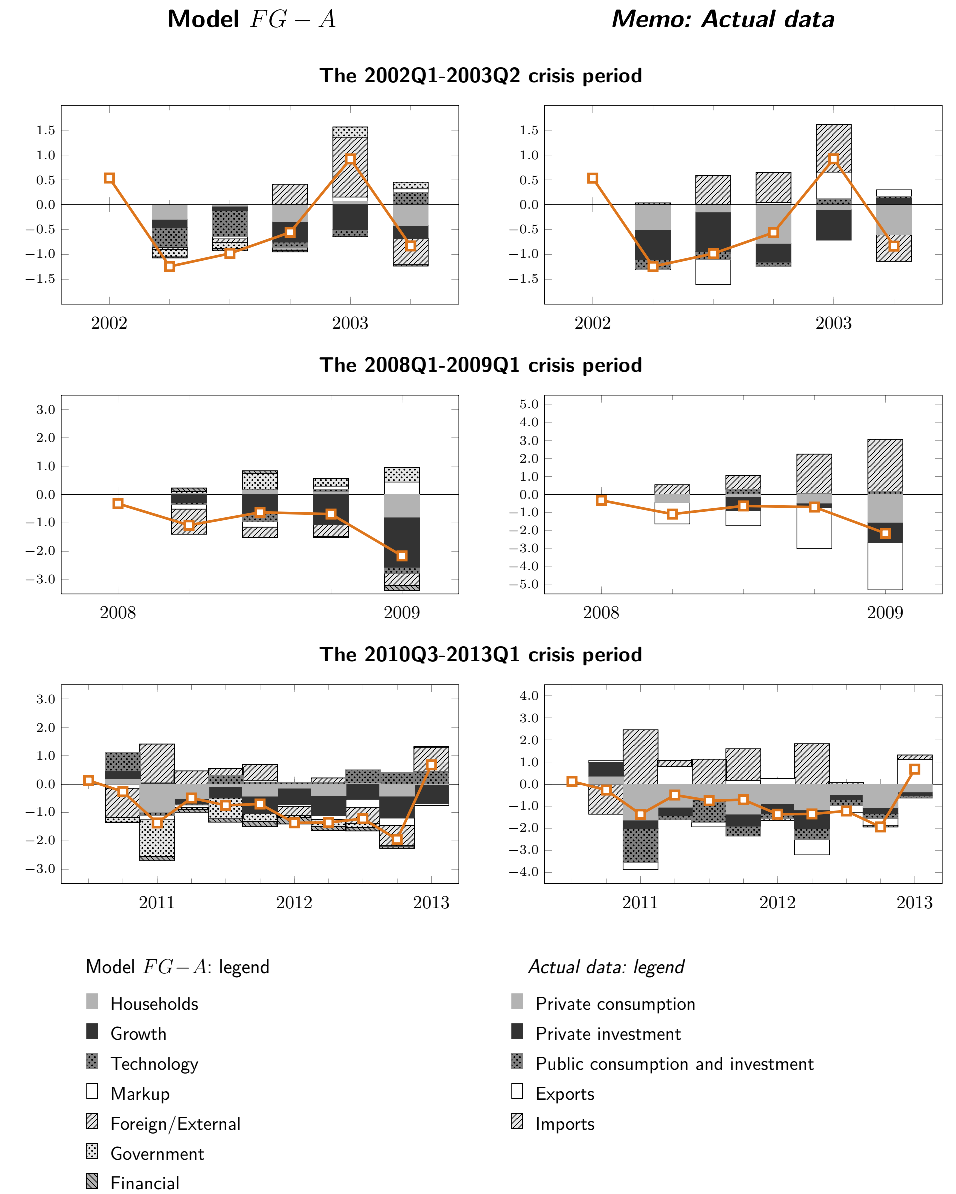


Figure 6: Historical decompositions for GDP growth in crisis times.

Notes: Model-based lines refer to GDP growth, measured by quarter-on-quarter differences in logs of real GDP per capita, excluding inventories. Results are in deviations from steady state. Actual GDP growth, measured in percentage, is demeaned. See Table 1 for the categorization of individual innovations.

We now turn to the main drivers of crisis periods in Portugal (Figure 6). According to model $FG–A$, the historical decomposition of quarter-on-quarter GDP growth between 2002Q1 and 2003Q2 is primarily marked by negative impacts from perturbations in growth (reflecting a worldwide decrease in economic activity), households demand (which contributed to the fall in private consumption), and technology (particularly investment efficiency). The volatility in external demand impacted the category 'external,' which oscillates between positive and negative contributions, against a background of positive contributions from lower interest rates. Financial disturbances also depicted recessive effects, amid a credit reduction coupled with slightly higher interest rates spreads. Fiscal policy had a neutral stance, featuring expansionary disturbances in transfers, but also tax increases and volatile public consumption.[8] Markups shocks had negligible impacts.

The 2008Q1-2009Q1 crisis was dominated by disturbances in the categories 'growth' and 'external.' The former reflects the international nature of the crisis, whereas the latter arises in the aftermath of the collapse in worldwide trade, with effects outweighing the downfall in interest rates in 2008Q4 and 2009Q1. The remaining negative impacts are explained by the contraction in household demand, namely in the beginning of 2009 (which depressed private consumption). Fiscal policy (measured by the 'government' category) behaved counter-cyclically and contributed to stabilize the economy during 2008, driven by higher spending and lower consumption taxes.[9] Financial factors contributed negatively to GDP growth by the end of 2008, nearly one year after the beginning of the financial crisis—a topic that we address below.

The 2010Q3-2013Q1 crisis was primarily driven by growth, government and household disturbances. The pro-cyclical fiscal policy that resulted from a historically high sovereign risk premium and from the concomitant financial assistance programme that came into force in 2011 was mirrored into lower public consumption and investment, lower transfers and higher taxes.[10] The financial side was marked by lower credit and a sharp increase in the external finance premium. The contribution of external factors turned from negative at the beginning of the period into positive, impelled by higher external demand and thus exports.[11] All markup innovations depicted a negative impact on GDP growth over 2012, with the exception of wage markups. The decrease in wages pushed down the cost of inputs and increased domestic competitiveness, leading to higher demand for domestically produced goods.

8. The normal VAT rate increased from 17 to 19 percent in June 2002.

9. The normal VAT rate decreased from 21 to 20 percent in July 2008.

10. The low, intermediate and normal VAT rates were increased by 1pp in July 2010, to 6, 13 and 21 percent, respectively. The normal tax rate was once again revised in January 2011, to 23 percent.

11. We estimated a large negative import penetration shock effect in 2010Q4, triggering a large expansion in imports. In this quarter, imports grew around 4 percent more than total domestic or final demands.

We now compare the cumulative impact on the GDP level across all models (Figure 7).[12] When included, household perturbations are always a key determinant of output developments. Their negative contribution to GDP is particularly severe over the third crisis across all models, and systematically more severe in versions embodying a financial accelerator.

Growth shocks depict invariably the largest contributions to GDP, though their importance is larger in simpler models, namely in $B0$- and $B0$–A-versions. Simpler models do get the storytelling right, but exacerbate the importance of the growth shock due to the lack of additional mechanisms.

The magnitude and sign associated with the contribution of external factors to GDP is model dependent. The sign is positive during the second crisis in versions $B0$ and $B0$–A, dominated by the expansionary effects of lower interest rates, but turns negative after adding all real demand components to the database, and even more negative after adding detailed nominal developments in more complex models. During the third crisis, the contribution of external disturbances remains negative for all but the most complex FG and FG–A models, *i.e.* until we consider a rich fiscal environment. The presence of a detailed tax structure creates a large procyclical impact, which changes the interpretation of impacts triggered by external demand and import penetration shocks.

The sign and importance of markup disturbances is also model and time dependent. For instance, their large negative contribution turns negligible during the first crisis in F-type models, which endogenously account for the demand components' deflators. During the third crisis, the positive contribution of markup shocks in simpler models turns negative in F-type models.

Government disturbances have systematically the same sign across models, but their importance grows with the model's complexity, namely when we consider the rich fiscal environment coupled with fiscal data. The cumulative impact is virtually nil across all models during the first crisis; positive during the second crisis, and negative during the third crisis.

The financial accelerator boosts the importance of financial disturbances, particularly during the third crisis. The impact is larger in the simplest $B0-A$ model. Enriching the model with more mechanisms diverts the explanatory forces of financial data into alternative sources.

Finally, the first and second crisis are associated with negligible contributions of 'technology' disturbances. The third crisis is associated with a positive contribution in most estimated models, particularly in those featuring financial intermediaries.

12. Figures E.1-E.3 in Appendix E interprets quarter-on-quarter GDP growth over crisis times through the lens of all models. Figure F.1 in Appendix F reports the contributions to year-on-year growth rates over the entire sample period for models B, B–A, F and F–A.

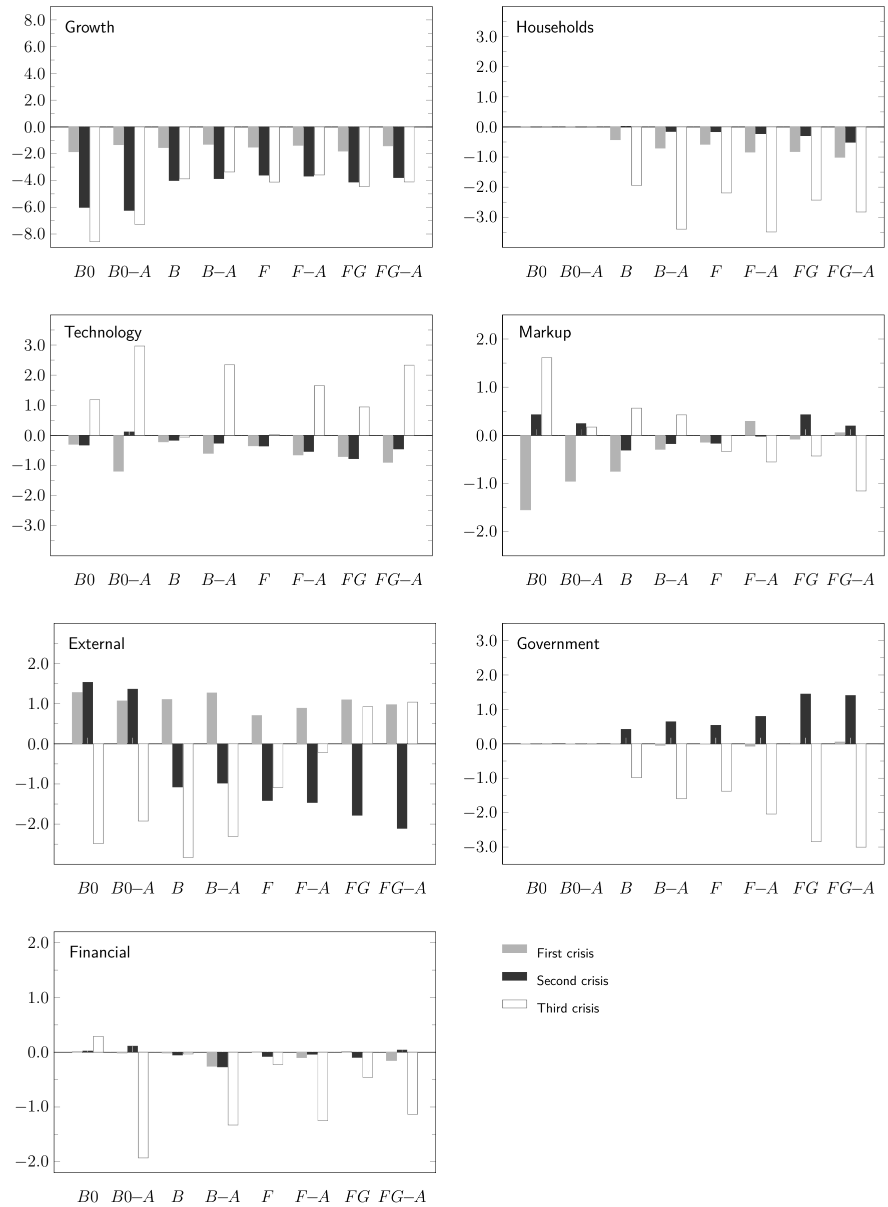


Figure 7: Historical decomposition of total GDP change in crisis times.

Notes: Results are in deviations from steady state. The results decompose the cumulative decrease over the first, second and third crisis, totalling around -2.7, -4.5 and -8.8 percent, respectively. See Table 1 for the categorization of individual innovations.

4.5. The role played by financial intermediaries

In this section we start by presenting a Bayesian model comparison between the versions with and without financial intermediaries (Table 6). Results show

	Model versions							
	$B0$	$B0–A$	B	$B–A$	F	$F–A$	FG	$FG–A$
Log Marginal Density	3063.86	3070.14	4322.72	4356.37	5368.75	5393.25	6877.92	6925.55
Change		6.28		33.65		24.5		47.63
Bayes Ratio		0.9981		1.0		1.0		1.0

Table 6. Bayesian model comparison.

Notes: The change is measured in log points. All models are exactly identified and each model x has the same database as model $x–A$, $x \in \{B0, B, F, FG\}$.

that excluding the financial accelerator from the model is rejected in favor of its inclusion, regardless of models' complexity. These results re-enforce the previous assessment that omitting financial variables leads to the exclusion of an important mechanism behind output dynamics.

Risk and net worth disturbances explain the bulk of the corporate credit growth and the interest rate spread (Figure 8). The implied leverage of non-financial corporations is in line with actual data in all models, both in normal and crisis times. The period preceding the second crisis is somewhat an exception, as both disturbances imply relatively higher leverage, and concomitantly larger interest rate spreads *vis-à-vis* the observed data.

The stock of loans and debt securities reported in the Portuguese financial accounts has not depicted a stable cyclical behavior since 1999. Credit decreased over the first and most of the third crises, but increased during the second recessive period. In turn, interest rate spreads increased in all crises, but more substantially over the 2008Q4-2009Q1 period,[13] and during the third crisis. We identify no negative contribution from financial disturbances to GDP growth during the global financial crisis, a fact explained by the positive corporate credit growth (*i.e.* increasing leverage), with little reflection in the external finance premium side, at least until 2008Q4. Since fewer credit implies *ceteris paribus* less risk, the negative or absent co-movement between credit growth and interest rate spreads is matched in all models with compensating effects from risk and net worth disturbances.[14]

The increase in borrower's riskiness since 2012, coupled with a fall in the net worth destroying shock, successfully matches the observed de-leveraging path witnessed by the Portuguese economy. The interest rate spread stands at relatively

13. In the aftermath of the Lehman Bros' bankruptcy of September 15, and almost an year after the beginning of the second crisis.

14. All models endogenously propagate higher spreads through risk and net worth disturbances. Risk disturbances trigger a pro-cyclical credit behavior, whereas net worth disturbances generate a counter-cyclical credit behavior. These propagation mechanisms are in line with Christiano *et al.* (2014b). Impulse response functions of both shocks are available in Appendix G. Actual credit expands during the second crisis even if we ignore the stock of debt securities, or focus exclusively on the total stock of loans of other monetary and financial institutions (non-consolidated data).

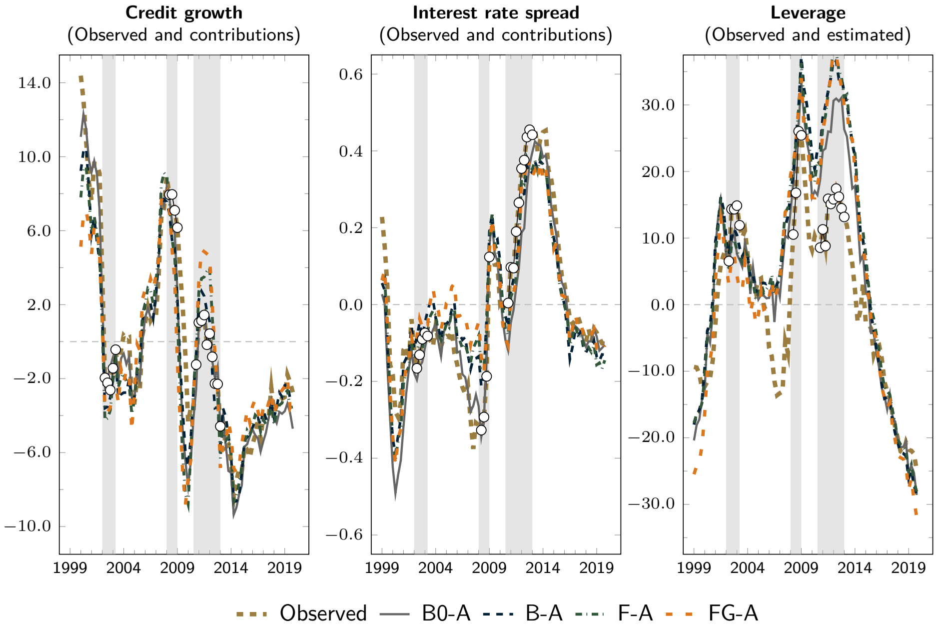


Figure 8: Financial intermediation data in Portugal, and contributions of financial factors in each model to the data series.

Notes: All data are demeaned. Credit growth refers to year-on-year changes (in logs). This series and the interest rate spread are used in estimation. Leverage (not used in estimation and reported for reference only) refers to the loans-to-net worth ratio, where observed net worth corresponds to the stock of non-financial corporations liabilities in the form of shares and other equity (financial accounts data at market values). Vertical bars highlight recession periods (see Figure 1 for details), while white circles identify points in actual data during crisis times. Contributions of financial factors include the risk and net worth shocks.

high levels in 2019, even though leverage is at historically low levels, which is only sustainable if firms are making decisions in a riskier environment.[15]

4.6. Variance decomposition

We now focus on the forecast error variance decomposition for stationary GDP at horizons of 1, 3, and 50 years (Figure 9). In the full-fledged $FG{-}A$ model external factors play the most important role at all horizons, but particularly in the short run. Larger horizons are associated with a more balanced decomposition,

15. It should be noted that the zero-profit intermediary institutions are solely involved in risk-free activities—as in Bernanke *et al.* (1999a) or Christiano *et al.* (2014b)—, and thus any riskier environment in the economy is only imputed to the entrepreneurial sector, a working hypothesis that deserves some attention in future work.

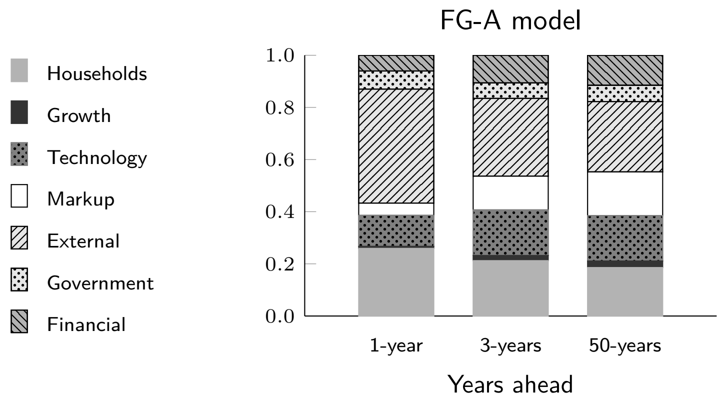


Figure 9: Forecast error variance decomposition for GDP.

Notes: GDP is stationarized by the level of technology. See Table 1 for the categorization of individual innovations.

with markups, technology and financial factors increasing in important relative to shorter horizons.

Simpler $B0$ and $B0–A$ models concentrate forecast error variance contributors in growth, which is converted to external and technology in more complex models. Introducing a final goods sector and a richer fiscal environment increases the role played by households, technology, external, and government factors in business cycle fluctuations, while pushing down that of markup and financial shocks (in models featuring the mechanism). This assessment is broadly valid for all forecast horizons (Figure 10). Without financial intermediation the contribution of financial factors is negligible.

4.7. Standard deviations and correlations

Standard deviations generated by all models are close to their data counterparts (Table 7). Models embodying a financial sector generate slightly more volatility in private investment and corporate credit growth *vis-à-vis* the data. In the model, there is a strong link between leverage and the external finance premium, as an increase in the former is immediately reflected in the latter. The link is weaker in the data, with movements in credit not necessarily depicting a contemporaneous impact in the external finance premium. All models—especially those without a financial sector—are endowed with higher volatility in private investment inflation *vis-à-vis* the data. Standard deviations concerning the remaining GDP components are close to their data counterparts. On the fiscal side, the adjustment towards the target government deficit triggers excess volatility in labor taxes—the endogenous fiscal instrument.

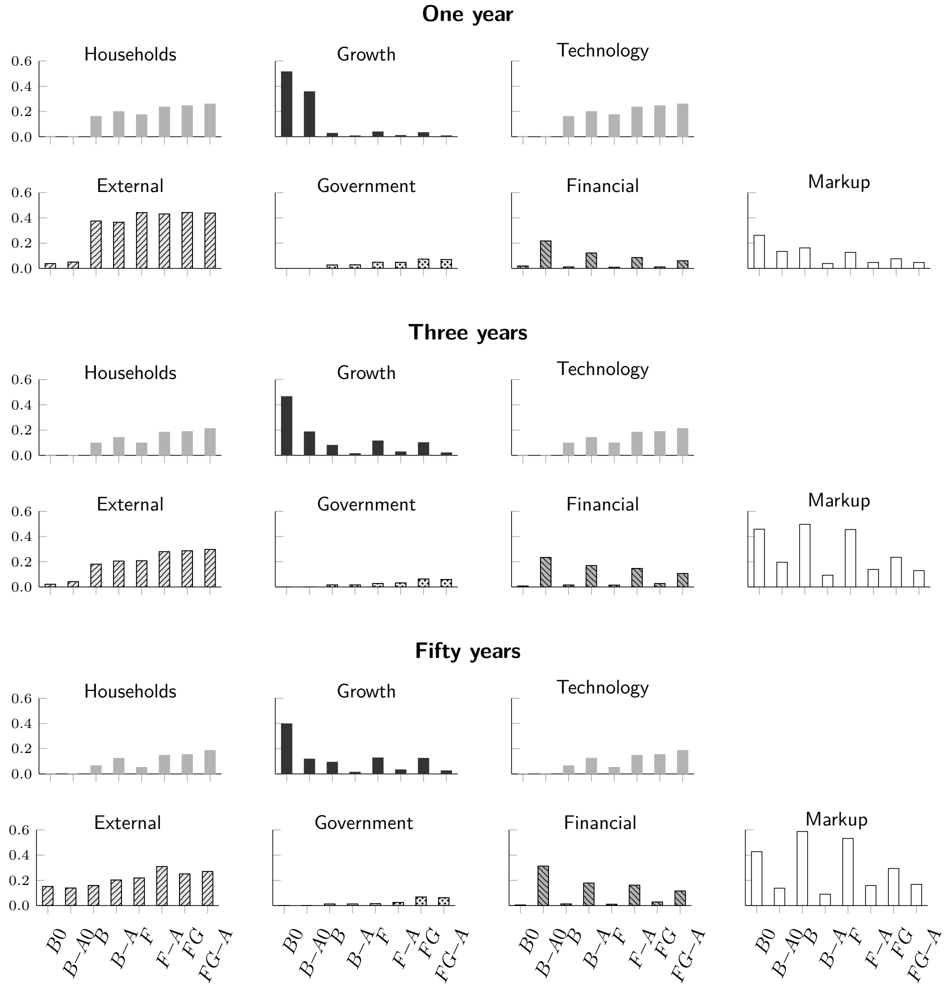


Figure 10: Forecast error variance decomposition for GDP across all models.

Notes: See Table 1 for the categorization of individual innovations.

Models also perform relatively well when explaining correlations with GDP growth (Table 8), with a few exceptions. Most models depict a usual slight underprediction of correlations concerning GDP components. The correlation with imports growth is marginally negative in models with financial intermediaries, but slightly positive in the data. On the nominal side, correlations between inflation rates and GDP growth in all models are relatively close to their data counterparts. The most noteworthy exceptions are investment inflation—which is slightly above zero in all models but negative in the data—and export inflation—which is slightly overpredicted. On the financial side, corporate loans seem to be acyclical both in models and the data, except in the simplest $B–A$ model. The correlation with euro

	Data	B0	B0-A	B	B-A	F	F-A	FG	FG-A
GDP growth	0.99	0.96	1.00	0.94	1.06	0.94	1.04	0.97	1.00
Private consumption growth	0.94			1.05	1.04	0.96	1.00	0.94	0.96
Private investment growth	2.73			2.78	2.90	2.91	2.97	2.73	2.77
Public cons. & inv. growth	1.43			1.47	1.41	1.41	1.40	1.39	1.44
Exports growth	2.61			2.50	2.44	2.77	2.71	2.56	2.67
Imports growth	2.58			2.52	2.36	2.59	2.54	2.27	2.42
Labor	1.11	1.21	1.16	1.19	1.22	1.23	1.25	1.34	1.19
Wage growth	1.30	1.44	1.42	1.46	1.39	1.34	1.29	1.40	1.33
GDP inflation	0.56	0.58	0.57	0.63	0.59				
Private consumption inflation	0.48					0.51	0.51	0.47	0.47
Private investment inflation	1.85					2.01	1.98	2.22	2.13
Public cons. & inv. Inflation	0.98					0.98	0.94	0.97	0.95
Exports inflation	1.04					1.03	1.03	0.98	1.03
Imports inflation	1.72					1.64	1.62	1.58	1.67
EA GDP growth	0.60	0.60	0.58	0.50	0.47	0.61	0.56	0.51	0.51
External demand growth	1.73	1.61	1.61	1.49	1.44	1.87	1.75	1.59	1.61
World inflation	0.20	0.19	0.20	0.20	0.21	0.22	0.23	0.25	0.24
Interest rate	0.43	0.42	0.41	0.29	0.36	0.37	0.42	0.30	0.27
Consumption tax revenue-GDP ratio	0.75							0.64	0.66
Labor tax revenue-GDP ratio	1.13							1.61	1.66
Payroll tax revenue-GDP ratio	0.29							0.34	0.32
Capital tax revenue-GDP ratio	0.51							0.66	0.64
HH transfers-GDP ratio	0.68							0.66	0.65
Nationwide risk	0.09	0.10	0.09	0.11	0.10	0.10	0.09	0.09	0.08
External finance premium	0.22		0.25		0.23		0.23		0.25
Corporate loans growth	1.60		1.54		1.65		1.66		1.75

Table 7. Models' standard deviations.

Notes: Results using actual data are based on the 1999Q1–2019Q4 period.

area real output, inflation and external demand is matched by all models, while the correlation with interest rates is only matched in more complex models, particularly those with financial sector. Some theoretical restrictions required in DSGE modeling impact negatively co-movements in some variables, such as between domestic GDP growth and the consumption tax revenue- or the labor tax revenue-to-GDP ratios.

4.8. Impulse response functions

Finally, we describe the most important features of impulse responses, plotted in Appendix G.[16] A pervasive property common to all estimated models is the law of one price, which conditions the medium term by triggering 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 short-run dynamics.

Impulse responses of most shocks are remarkably similar across A-models, depicting comparable movements on impact. Most models deliver impulse responses falling within the 90% Highest Posterior Density intervals of those from the

16. We excluded the simpler versions $B0$ and $B0–A$, but results are available upon request.

	Data	B0	B0-A	B	B-A	F	F-A	FG	FG-A
GDP growth	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Private consumption growth	0.64			0.45	0.46	0.50	0.50	0.56	0.54
Private investment growth	0.50			0.36	0.40	0.34	0.35	0.34	0.35
Public cons. & inv. growth	0.30			0.25	0.25	0.31	0.31	0.32	0.32
Exports growth	0.58			0.48	0.51	0.41	0.43	0.46	0.46
Imports growth	0.18			0.01	-0.13	0.02	-0.09	0.02	-0.03
Labor tax revenue-GDP ratio	0.40	0.53	0.52	0.51	0.61	0.62	0.66	0.72	0.64
Wage growth	-0.06	0.05	0.12	-0.08	-0.04	-0.09	-0.07	-0.03	-0.04
GDP inflation	-0.04	-0.04	-0.13	0.15	0.10				
Private consumption inflation	0.05					0.25	0.20	0.25	0.23
Private investment inflation	-0.08					0.09	0.07	0.04	0.06
Public cons. & inv. Inflation	0.20					0.19	0.14	0.14	0.14
Exports inflation	0.05					0.28	0.23	0.23	0.22
Imports inflation	0.22					0.18	0.19	0.20	0.20
EA GDP growth	0.33	0.45	0.40	0.46	0.40	0.45	0.40	0.43	0.41
External demand growth	0.30	0.19	0.20	0.31	0.31	0.30	0.30	0.32	0.32
EA GDP inflation	0.02	0.03	0.04	0.04	0.05	0.03	0.04	0.02	0.02
Interest rate	-0.08	0.07	0.02	-0.01	-0.03	0.00	-0.02	-0.06	-0.06
Consumption tax revenue-GDP ratio	0.17							-0.05	-0.04
Labor tax revenue-GDP ratio	0.15							-0.06	-0.02
Payroll tax revenue-GDP ratio	-0.01							0.00	-0.09
Capital tax revenue-GDP ratio	0.09							0.35	0.20
HH transfers-GDP ratio	0.02							0.00	0.00
Nationwide risk	-0.20	-0.04	-0.02	-0.01	0.00	-0.02	0.00	-0.02	-0.02
External finance premium	-0.13		-0.31		-0.18		-0.18		-0.15
Corporate loans growth	0.04		0.35		-0.07		-0.08		-0.02

Table 8. Models' correlations with GDP growth.

Notes: Results using actual data are based on the 1999Q1–2019Q4 period.

full-fledged $FG\!-\!A$ model. Domestic inflationary processes, which trigger no response from the euro area monetary authority, reduce the real cost of borrowing of non-financial corporations and create expansionary effects that outweigh the deterioration in the trade balance driven by the price-competitiveness loss. The final impact on output and inflation is conditioned by the presence of a fiscal authority empowered with stabilization objectives. These mechanisms can be found, for instance, in impulse responses to the preference shock η_t and to the wage markup shock $\sigma_t^{\mathcal{U}}$.

The preference shock in the $FG\!-\!A$ model implies a direct boost in private consumption and GDP, increasing inflation. Households become more willing to work, and firms increase production while reducing the real wage. The competitiveness loss triggers a deterioration in the trade balance. On the financial side there is an improvement dictated by inflation, which pushes down the real cost of credit and limits the impact of lower capital demand. Entrepreneurs use the extra funds to decrease credit while barely adjusting investment. In models B, F and FG, investment declines since this channel is absent, and inflation becomes more reactive, bringing about a larger deterioration in the trade balance.

The wage markup shock in the FG–A model triggers an increase in real wages, pushing down hours worked and increasing inflation. The competitiveness loss due to higher relative prices *vis-à-vis* the euro area leads to a deterioration in the trade balance, and hastens the GDP downfall. Private investment depicts a smaller decline in the model versions embodying a financial sector, since inflation pushes down the real cost of credit and hence diminishes the financial burden of capital holders. The trade balance deterioration is model-dependent and the GDP reduction more contained when the fiscal authority reduces labor taxes for stabilization purposes (Model FG).

The cyclical behavior of credit is conditioned by the type of shock hitting the economy. Credit is counter-cyclical under the investment efficiency technology shock ζ_t (or the net worth destroying shock $\gamma_t^{\mathcal{E}}$), but pro-cyclical under the risk shock $\sigma_{t+1}^{\mathcal{E}}$, as in Christiano *et al.* (2014b). The investment efficiency technology shock in the $FG–A$ model has a direct impact on private investment, reducing GDP and both labor and capital equilibrium levels. The inward shift of capital supply brings along a recessive environment and lower inflation, but raises credit, which emerges as counter-cyclical and limits the fall in investment. Net worth remains broadly unchanged, balanced on the one hand by larger interest outlays and on the other by a higher Tobin's Q. The reduction in inflation is larger and terms of trade improve further in models without financial intermediaries, shifting demand away from foreign goods. The entrepreneurs' risk shock in the $FG–A$ model raises the probability of default and therefore the credit spread. Firms reduce the demand for (more expensive) credit, which emerges as pro-cyclical, halting investment projects. Inflation shows a high volatility, influenced on the one hand by lower domestic demand, but on the other by the direct resource destruction.

Finally, models without financial intermediaries still feature the nationwide risk shock Ψ_t in the category financial (see Table 1). The nationwide risk shock has a direct negative impact on households' consumption, raising the interest rate premium paid by indebted asset holders. The demand for inputs concomitantly declines, pushing wages, hours worked and capital downwards. Labor taxes increase to cope with larger interest outlays in the model versions with a fiscal environment. On the financial side, a higher nationwide interest rate raises the cost of credit, and thus 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. Models without financial intermediaries are more interest rate sensitive, with investment depicting a larger fall. The fall of inflation is, in addition, more significant (notably in models B and F), with stronger impacts on the trade balance.

5. Concluding remarks

We estimate eight different model versions, differing on the disaggregation of the final goods structure, the existence of a financial sector, and the complexity of the fiscal environment. The full-fledged model identifies disturbances in the household sector, in union-wide technology, in the external environment, and in the fiscal stance, as pivotal to explain the three crisis periods that have impacted the Portuguese economy over the last twenty years. More complex model-versions reduce the ability of risk and net worth disturbances in explaining output dynamics, because financial developments become “more endogenously driven” by the state of the economy. Simpler models exacerbate the importance of the union-wide technology, interest rates, and markup disturbances.

Future work should be targeted to the estimation of these models during the most recent period, embracing the COVID-19 pandemic. The estimation challenges are great, for numerous reasons. First, the first-order solution of the model is a bad approximation when the dimension of the underlying shocks is substantially large. Second, higher-order solutions for medium-sized models require complex estimation methods that are not yet well-developed in the literature. Third, shocks during the COVID-19 pandemic are endowed with a highly idiosyncratic nature, as opposed with the remaining history, something which would ideally imply setting up specific shocks.

Appendix A: Calibrated parameters and steady-state relationships

	parameter	B0	B0-A	B	B-A	F	F-A	FG	FG-A
Nominal adjustment costs									
Manufacturers price adj. cost	$\varphi_{P\mathcal{Z}}$	125	125	125	125	125	125	125	125
Importers price adj. cost	$\varphi_{P\mathcal{IM}}$	125	125	125	125				
Wage and price markups									
Wage markup	$\sigma^{\mathcal{U}}$	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Manufacturers' price markup	$\sigma^{\mathcal{Z}}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Importers' price markup	$\sigma^{\mathcal{IM}}$	0.03	0.03	0.03	0.03				
Distributors' price markup									
Final goods	$\sigma^{\mathcal{F}}$	0.05	0.05	0.05	0.05				
Private consumption	$\sigma^{\mathcal{C}}$					0.05	0.05	0.05	0.05
Private investment	$\sigma^{\mathcal{I}}$					0.05	0.05	0.05	0.05
Gov consump. & invest.	$\sigma^{\mathcal{G}}$					0.05	0.05	0.05	0.05
Exports	$\sigma^{\mathcal{X}}$					0.03	0.03	0.03	0.03
Households parameters									
Discount rate	$\beta^{\mathcal{A}}$	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998
Technology									
Technology growth rate	g	1.0027	1.0027	1.0027	1.0027	1.0027	1.0027	1.0027	1.0027
Quasi-labor income share	$\alpha^{\mathcal{U}}$	0.78	0.59	0.78	0.59	0.78	0.59	0.77	0.54
Depreciation rate	$\delta^{\mathcal{K}}$	0.015	0.016	0.015	0.015	0.015	0.016	0.015	0.015
Home bias									
Final goods	$\alpha^{\mathcal{F}}$	0.72	0.66	0.72	0.66				
Private consumption	$\alpha^{\mathcal{C}}$					0.79	0.74	0.75	0.68
Private investment	$\alpha^{\mathcal{I}}$					0.62	0.55	0.64	0.55
Gov consump. & invest.	$\alpha^{\mathcal{G}}$					0.89	0.86	0.90	0.86
Exports	$\alpha^{\mathcal{X}}$					0.54	0.47	0.56	0.47
Government parameters									
Consumption tax rate	$\tau^{\mathcal{C}}$							0.29	0.29
Capital income tax rate	$\tau^{\mathcal{K}}$							0.38	0.31
Dividends tax rate	$\tau^{\mathcal{D}}$							0.15	0.15
Employers' payroll tax rate	$\tau^{\mathcal{SP}}$							0.22	0.22
Target debt to GDP ratio	$B/(4 \cdot GDP)$							0.60	0.60
Financial frictions									
Borrowers Riskiness	$\sigma^{\mathcal{E}}$		0.30		0.30		0.30		0.30
Exit rate	$\iota^{\mathcal{E}}$		0.04		0.04		0.04		0.04
Miscellaneous									
Export market share	α^{*}			0.030	0.030	0.030	0.030	0.030	0.030
ECB interest rate target	i^{*}	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008
Inflation	π^{*}	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005
Risk Premium sensibility	φ_{BF}	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Net Foreign Assets target	B^{*}_{GDP}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.1. Calibrated parameters.

Notes: The model is quarterly and parameters are not annualized. Databases of each model version and associated stochastic processes are clarified in Tables 1 and 2.

	data	B0	B0-A	B	B-A	F	F-A	FG	FG-A
Expenditure (GDP ratio)									
Private consumption	0.64	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Private investment	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Public consumption & investment	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Exports	0.31	0.35	0.35	0.34	0.32	0.35	0.33	0.35	0.33
Imports	0.34	0.36	0.35	0.35	0.32	0.35	0.33	0.35	0.33
Import shares (output ratio)									
Final goods	0.32	0.26	0.26	0.26	0.24				
Private consumption	0.27					0.19	0.18	0.25	0.22
Private investment	0.46					0.36	0.36	0.36	0.36
Public consumption & investment	0.11					0.10	0.10	0.10	0.09
Exports	0.45					0.43	0.42	0.43	0.43
Labor income share	0.66	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Government (GDP ratio, in %)									
Public debt	94.1							60.00	60.00
Fiscal surplus	-5.0							-1.83	-1.83
Total revenues	34.7							36.38	36.38
Consumption tax	14.1							14.07	14.06
Labor income tax	6.0							7.67	7.69
Employers' payroll tax	11.4							11.40	11.40
Capital income tax	3.2							3.24	3.23
Household transfers	15.2							14.90	14.90
External account (GDP ratio, in %)									
Net foreign assets (annualized)	-88.6	-67.60	-67.60	-67.60	-67.60	-67.60	-67.60	-67.60	-67.60
Current and capital accounts	-4.2	-2.06	-2.06	-2.06	-2.06	-2.06	-2.06	-2.06	-2.06
Trade balance	-4.6	-0.33	-0.26	-0.31	-0.19	-0.32	-0.22	-0.31	-0.20
Financial sector									
Leverage ratio	1.0		0.92		0.93		0.92		0.99
Probability of default (in %)	5.1		3.32		3.59		3.33		4.84
Credit spread (in pp)	2.3		1.76		1.80		1.76		1.98

Table A.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 1999–2019 period, except for import contents, which were taken from Rua and Cardoso (2019), and the credit spread, which is an average until 2007. The values for public debt, net foreign assets, default probability and credit spread are annualized. See Table A.1 for additional notes.

Appendix B: Prior and posterior plots

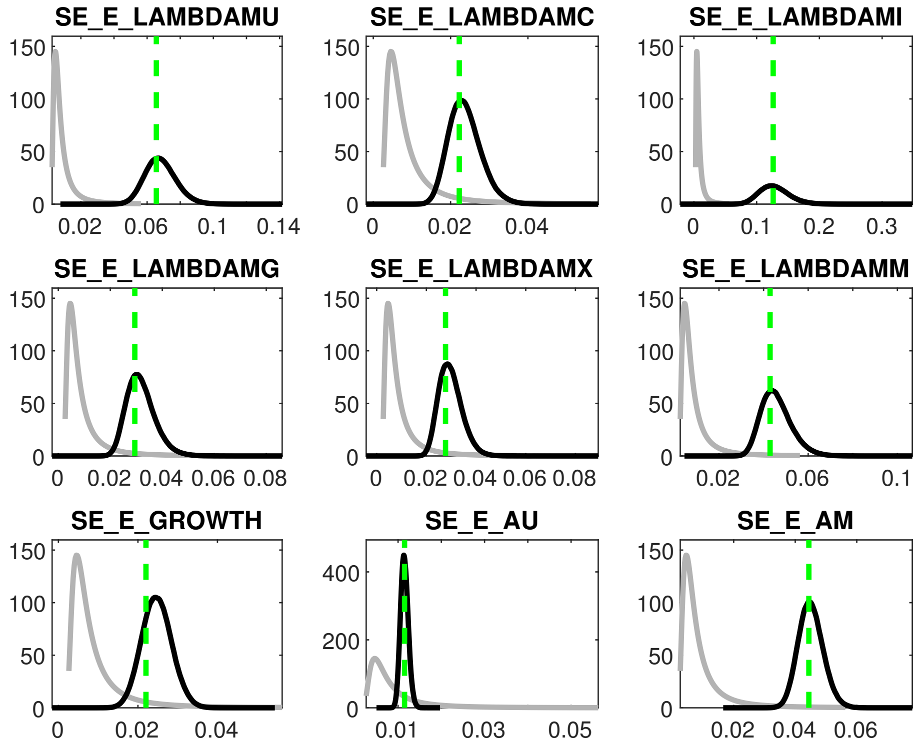


Figure B.1: Priors and posteriors. Notes: SE_E_LAMBDAMU $=$ $\text{s.e.}(\tilde{\varepsilon}_t^{\sigma\mathcal{U}})$; SE_E_LAMBDAMC $=$ $\text{s.e.}(\tilde{\varepsilon}_t^{\sigma\mathcal{C}})$; SE_E_LAMBDAMI $=$ $\text{s.e.}(\tilde{\varepsilon}_t^{\sigma\mathcal{I}})$; SE_E_LAMBDAMG $=$ $\text{s.e.}(\tilde{\varepsilon}_t^{\sigma\mathcal{G}})$;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

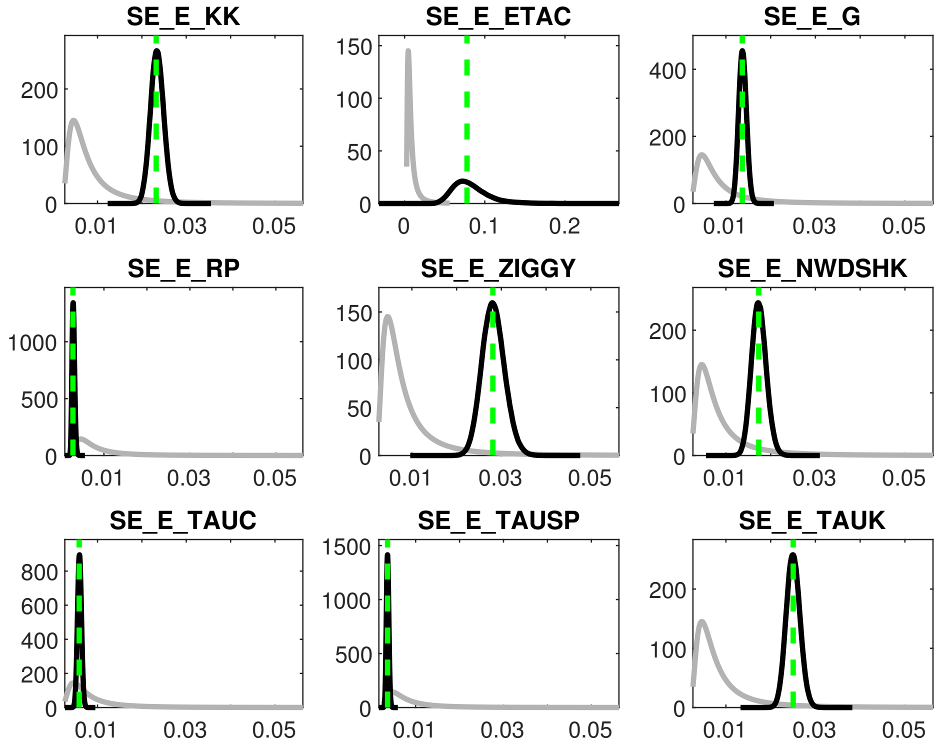


Figure B.2: Priors and posteriors. Notes: SE_E_KK = $\text{s.e.}(\tilde{\varepsilon}_t^{\zeta})$; SE_E_ETAC = $\text{s.e.}(\tilde{\varepsilon}_t^{\eta})$; SE_E_G = $\text{s.e.}(\tilde{\varepsilon}_t^{\mathcal{G}})$; SE_E_RP = $\text{s.e.}(\tilde{\varepsilon}_t^{\Upsilon})$; SE_E_ZIGGY = $\text{s.e.}(\tilde{\varepsilon}_t^{\sigma\mathcal{E}})$; SE_E_NWDSHK = $\text{s.e.}(\tilde{\varepsilon}_t^{\mathcal{E}})$; SE_E_TAUC = $\text{s.e.}(\tilde{\varepsilon}_t^{\tau C})$; SE_E_TAUSP = $\text{s.e.}(\tilde{\varepsilon}_t^{\tau SP})$; SE_E_TAUK = $\text{s.e.}(\tilde{\varepsilon}_t^{\tau K})$.

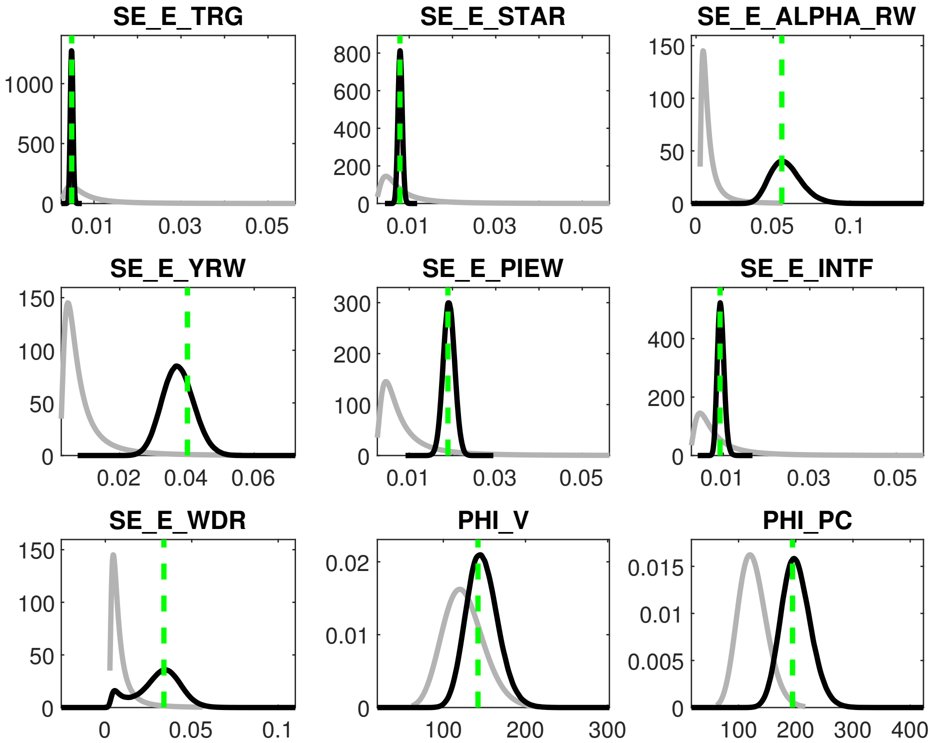


Figure B.3: Priors and posteriors. Notes: SE_E_TRG = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{TRG})$; SE_E_STAR = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{SG})$; SE_E_ALPHA_RW = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{\alpha*})$; SE_E_YRW = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{Y*})$; SE_E_PIEW = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{\pi*})$; SE_E_INTF = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{i*})$; SE_E_WDR = $\mathrm{s.e.}(\tilde{\varepsilon}_t^{yd})$; PHI_V = $\varphi_{\mathcal{V}}$; PHI_PC = φ_{PC}.

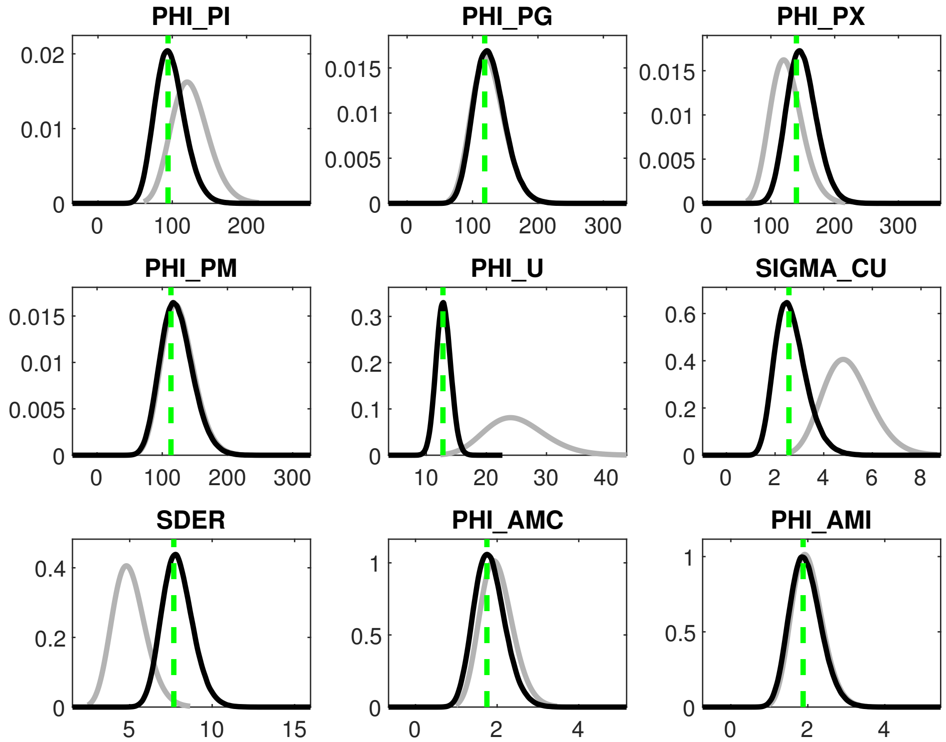


Figure B.4: Priors and posteriors. Notes: PHI_PI = $\varphi_{\mathcal{PI}}$; PHI_PG = $\varphi_{\mathcal{PG}}$; PHI_PX = $\varphi_{\mathcal{PX}}$; PHI_PM = $\varphi_{\mathcal{PIM}}$; PHI_U = $\varphi_{\mathcal{U}}$; SIGMA_CU = σ_a; SDER = S''; PHI_AMC = $\varphi_{\mathcal{AC}}$; PHI_AMI = $\varphi_{\mathcal{AI}}$.

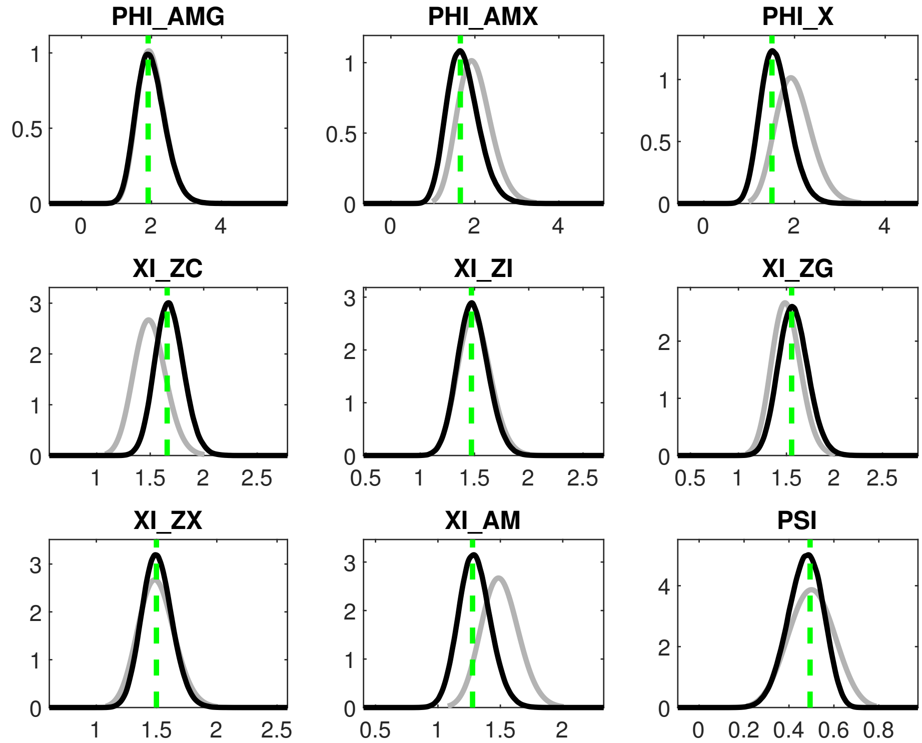


Figure B.5: Priors and posteriors. Notes: PHI_AMG = $\varphi_{\mathcal{AG}}$; PHI_AMX = $\varphi_{\mathcal{AX}}$; PHI_X = $\varphi_{\mathcal{IX}}$; XI_ZC = $\xi_{\mathcal{C}}$; XI_ZI = $\xi_{\mathcal{I}}$; XI_ZG = $\xi_{\mathcal{G}}$; XI_ZX = $\xi_{\mathcal{X}}$; XI_AM = ξ_{*}; PSI = ψ.

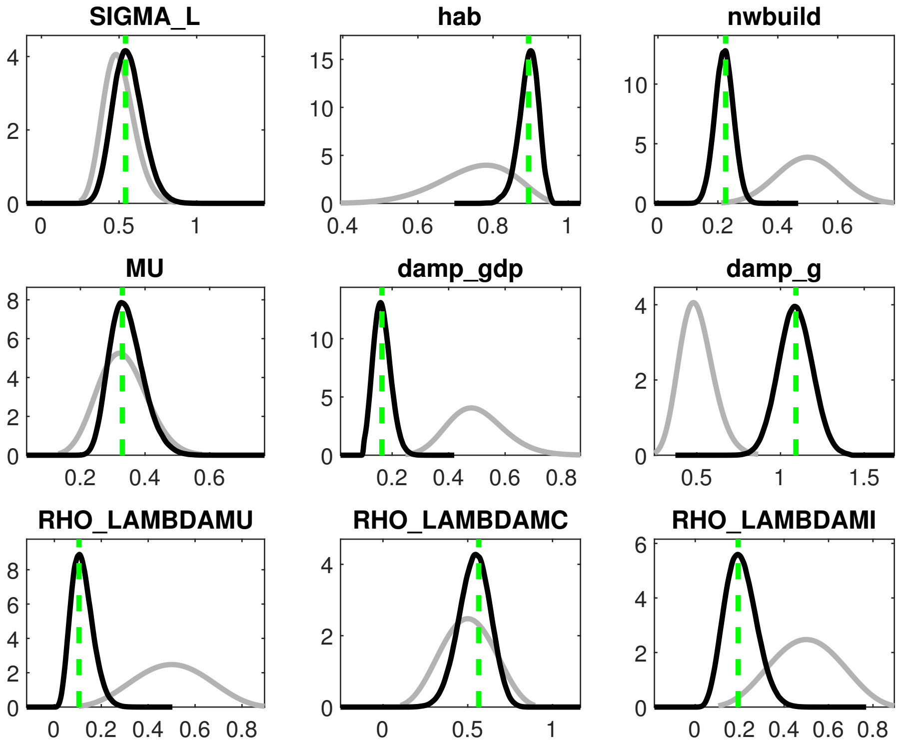


Figure B.6: Priors and posteriors. Notes: SIGMA_L = σ_L; hab = ν; nwbuild = θ^{nw}; MU = μ; damp_gdp = d^{GDP}; damp_g = d^G; RHO_LAMBDAMU = $\rho^{\sigma\mathcal{U}}$; RHO_LAMBDAMC = $\rho^{\sigma\mathcal{C}}$; RHO_LAMBDAMI = $\rho^{\sigma\mathcal{I}}$.

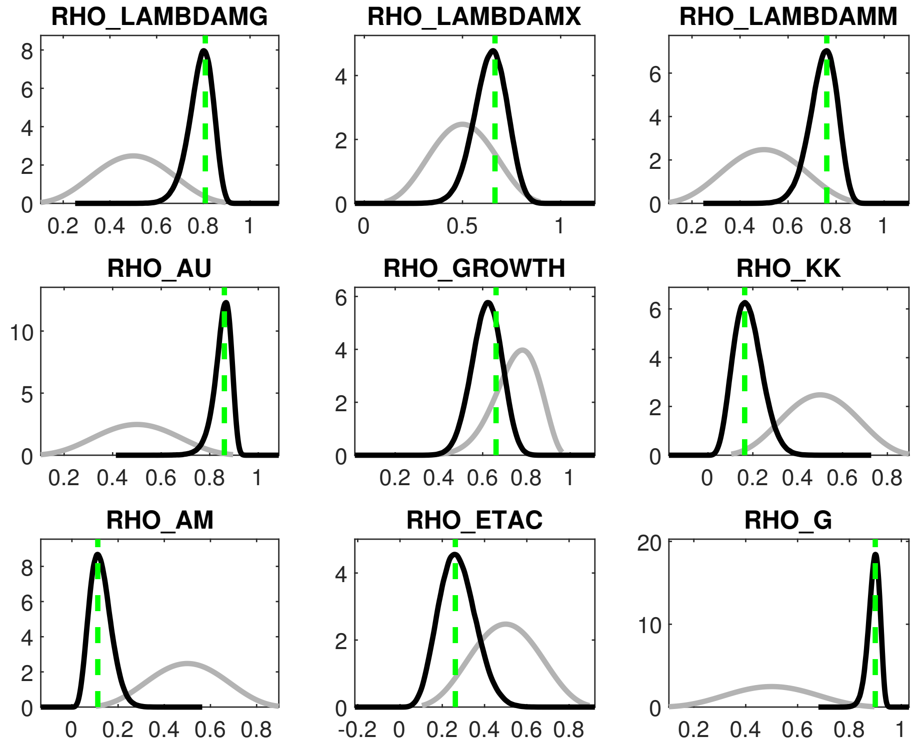


Figure B.7: Priors and posteriors. Notes: RHO_LAMBDAMG = $\rho^{\sigma\mathcal{G}}$; RHO_LAMBDAMX = $\rho^{\sigma\mathcal{X}}$; RHO_LAMBDAMM = $\rho^{\sigma\mathcal{IM}}$; RHO_AU = ρ^{A}; RHO_GROWTH = ρ^{g}; RHO_KK = ρ^{ζ}; RHO_AM = $\rho^{\mathcal{M}}$; RHO_ETAC = ρ^{η}; RHO_G = $\rho^{\mathcal{G}}$.

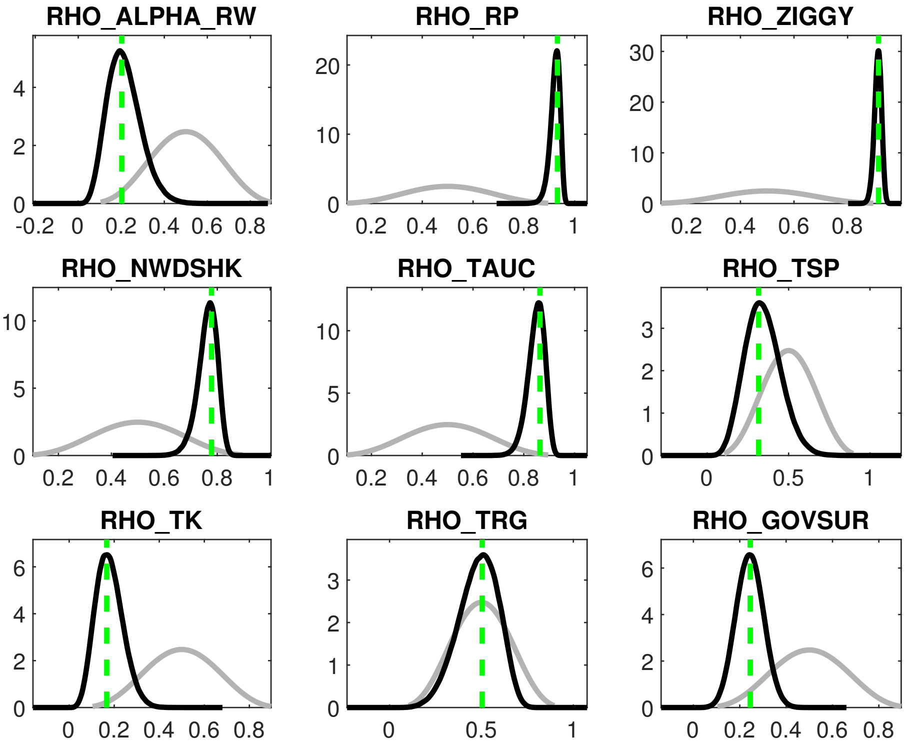


Figure B.8: Priors and posteriors. Notes: RHO_ALPHA_RW = $\rho^{\alpha *}$; RHO_RP = ρ^{Υ}; RHO_ZIGGY = $\rho^{\sigma \mathcal{E}}$; RHO_NWDSHK = $\rho^{\mathcal{E}}$; RHO_TAUC = $\rho^{\tau \mathcal{C}}$; RHO_TSP = $\rho^{\tau \mathcal{SP}}$; RHO_TK = $\rho^{\tau \mathcal{K}}$; RHO_TRG = ρ^{TRG}; RHO_GOVSUR = ρ^{SG}.

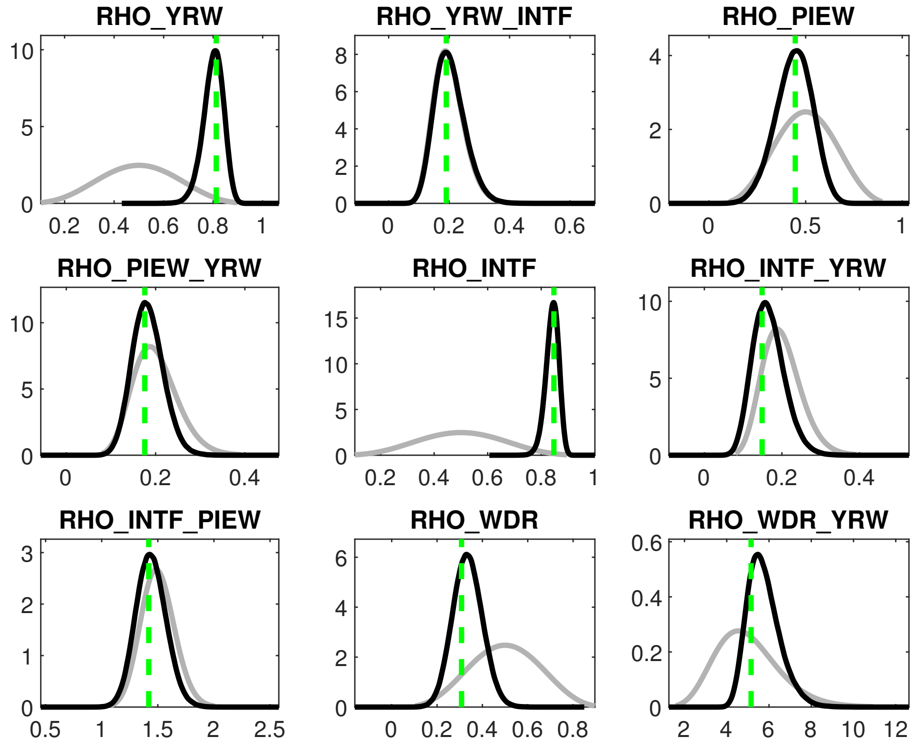


Figure B.9: Priors and posteriors. Notes: RHO_YRW = ρ_y; RHO_YRW_INTF = $-\rho_{y,i}$; RHO_PIEW = ρ_π; RHO_PIEW_YRW = $\rho_{\pi,y}$; RHO_INTF = ρ_i; RHO_INTF_YRW = $\rho_{i,y}$; RHO_INTF_PIEW = $\rho_{i,\pi}$; RHO_WDR = ρ^{yd}; RHO_WDR_YRW = ρ^{y*}.

Appendix C: Observed and smoothed data in the $FG\text{–}A$ model

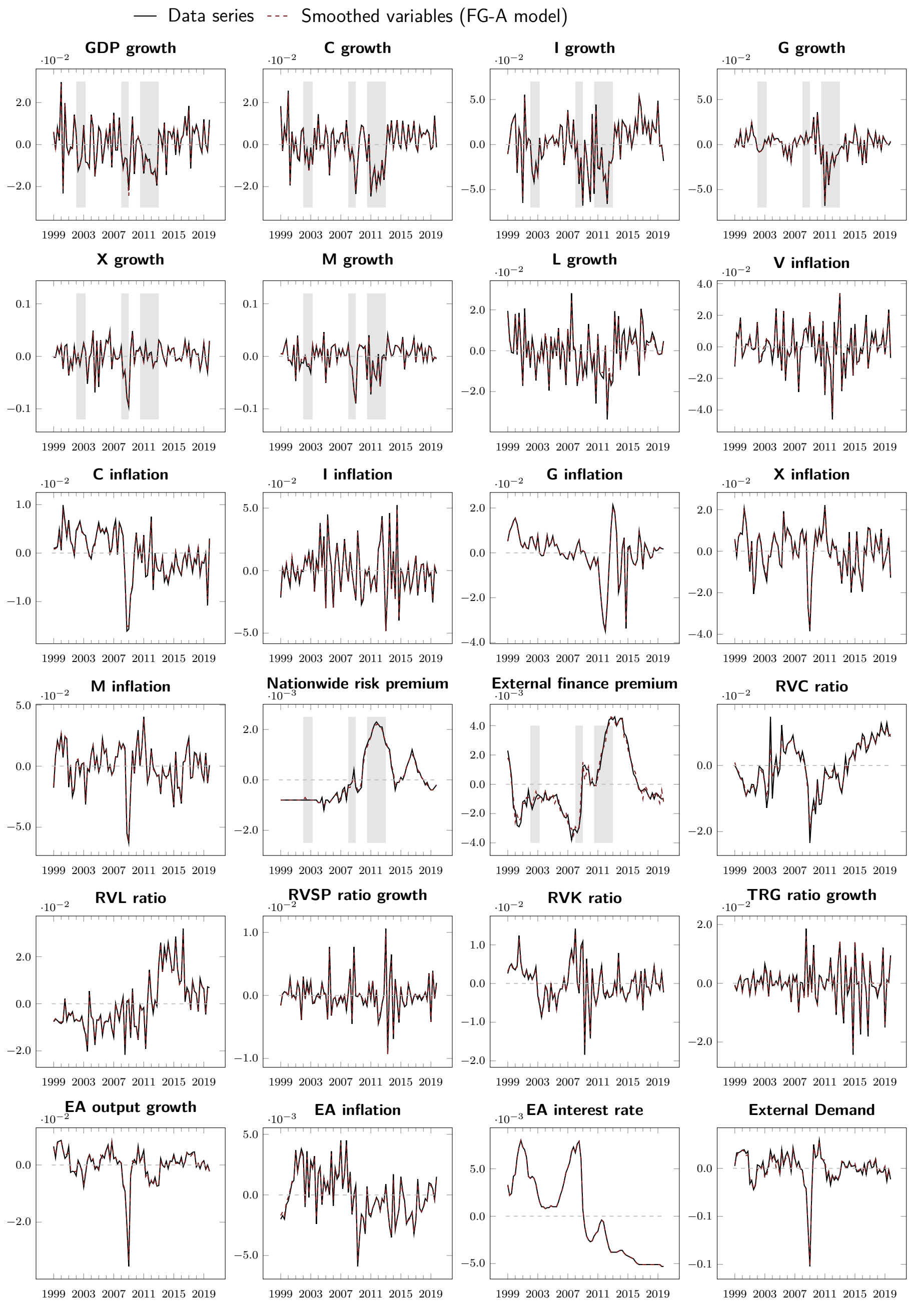


Figure C.1: Data series used in estimation (solid black line, demeaned) and smoothed data without measurement error (red dashed line, deviations from steady state).

Notes: We omitted corporate loans data to save space. Actual values are presented in Figure 8.

Appendix D: GDP growth through the lens of the $FG–A$ model

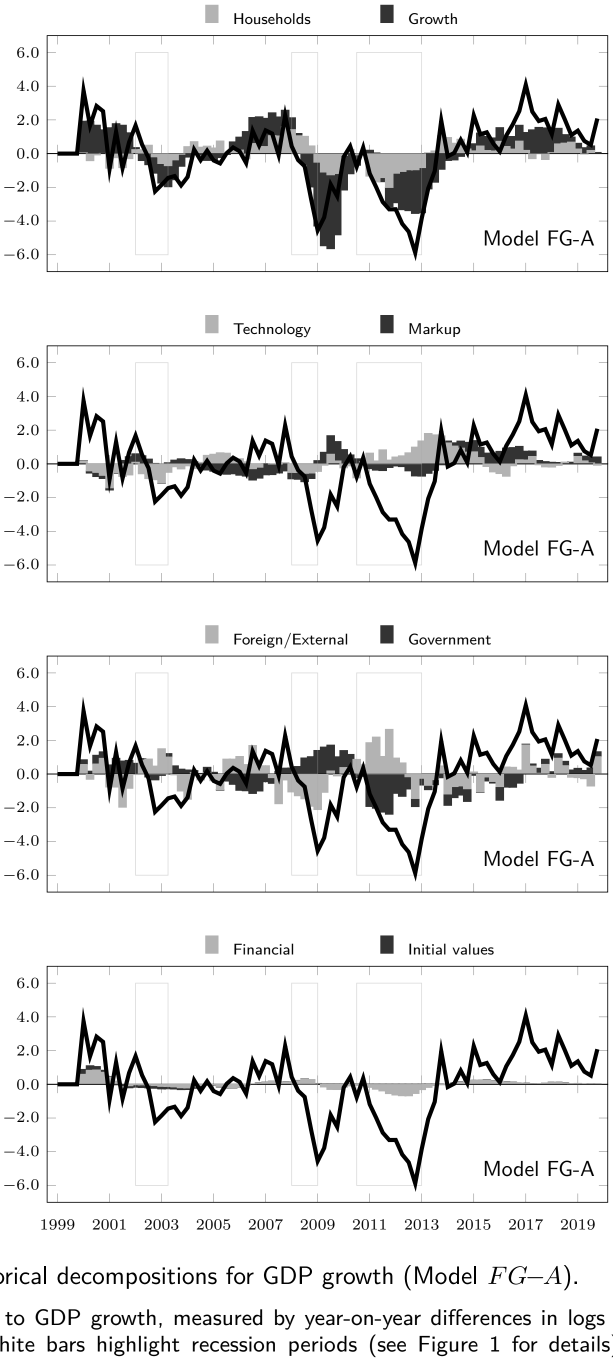
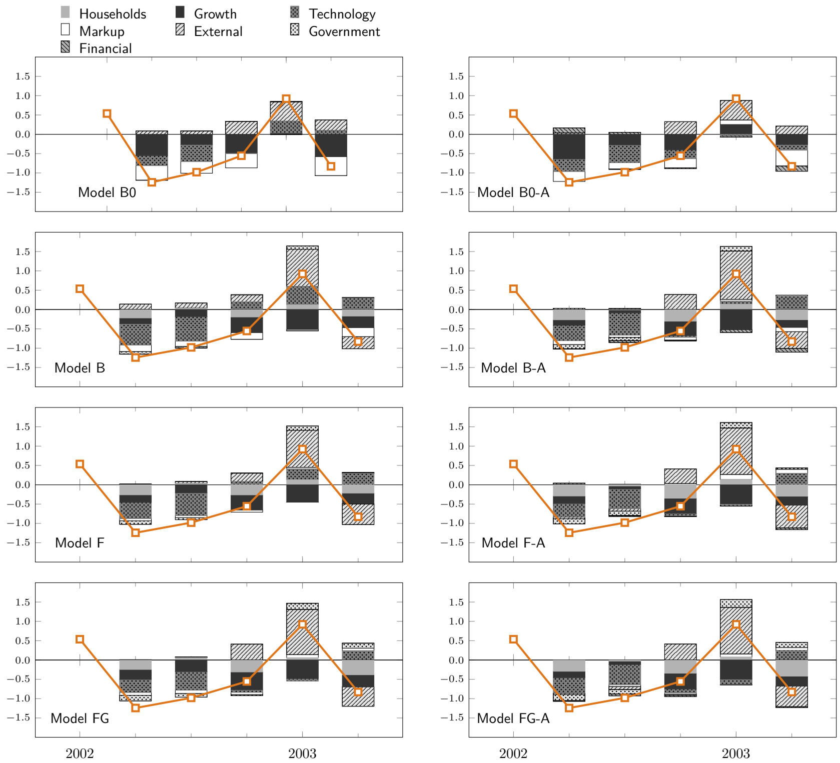


Figure D.1: Historical decompositions for GDP growth (Model $FG–A$).

Notes: Lines refer to GDP growth, measured by year-on-year differences in logs of real GDP per capita. Vertical white bars highlight recession periods (see Figure 1 for details). Results are in deviations from steady state.

Appendix E: Crisis times in Portugal

Historical decomposition of the 2002Q1-2003Q2 crisis period



Memo: Actual GDP growth and contributions from selected components

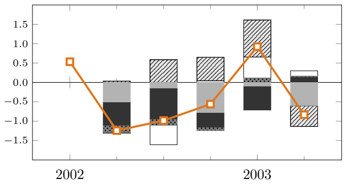


Figure E.1: Alternative historical decompositions for GDP growth.

Notes: Model-based lines refer to GDP growth, measured by quarter-on-quarter differences in logs of real GDP per capita, excluding inventories. Results are in deviations from steady state. Actual GDP growth is measured in percentage.

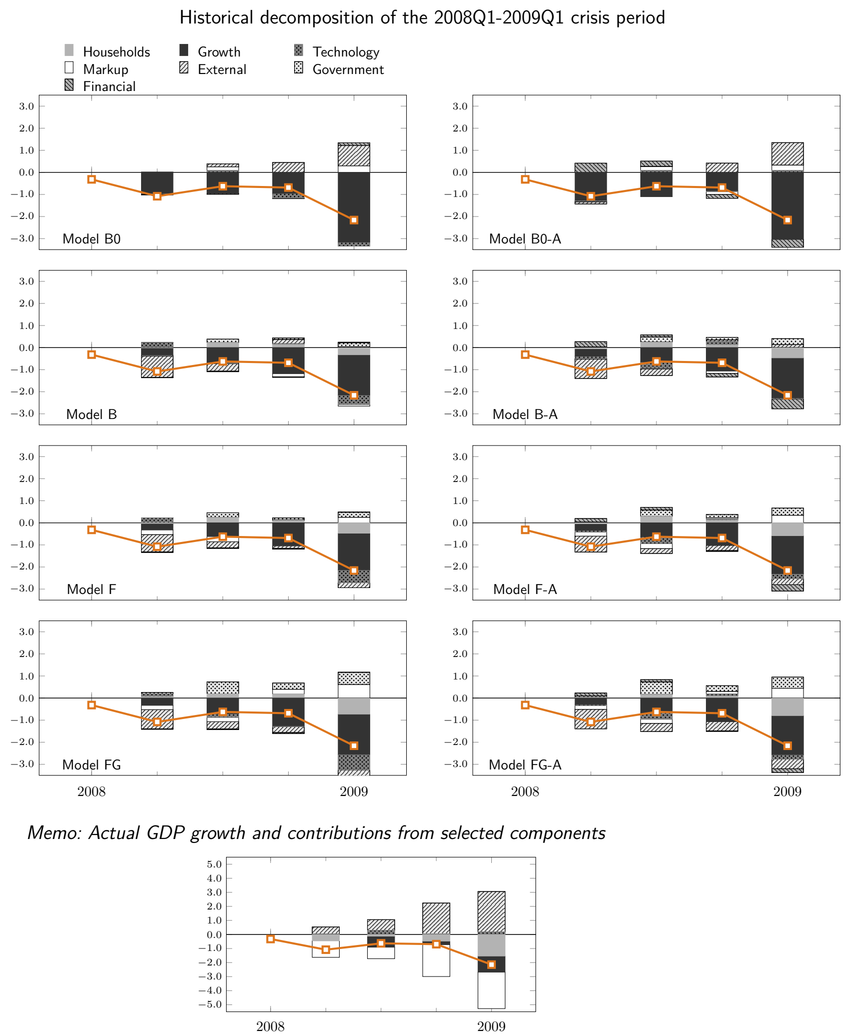
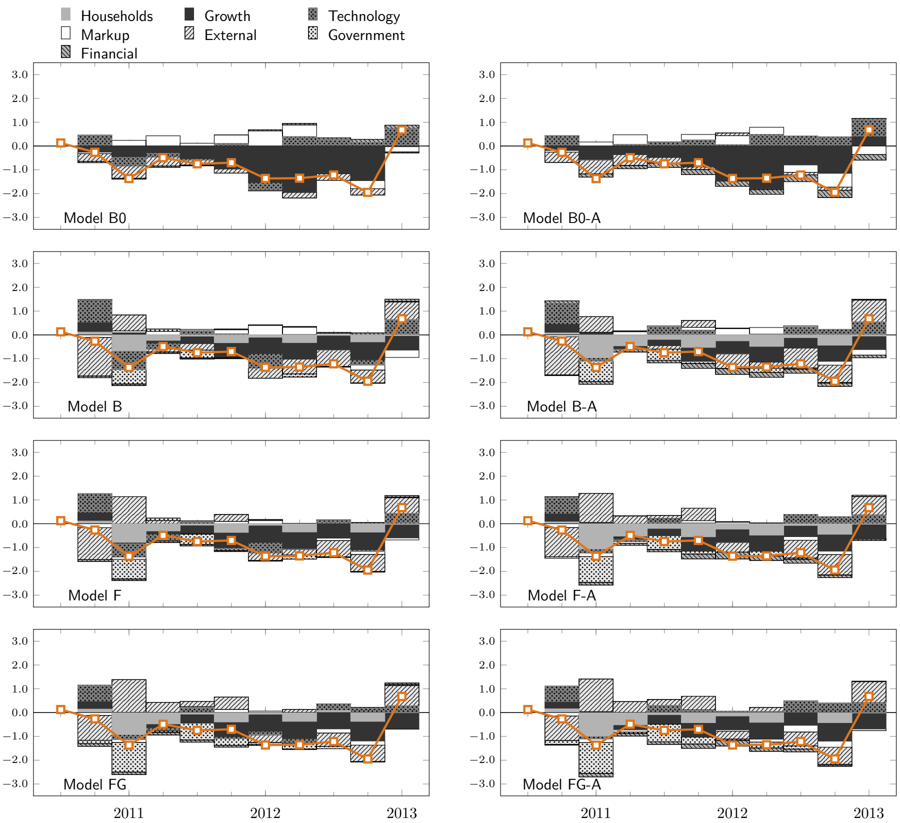


Figure E.2: Historical decompositions for GDP growth.

Notes: See Figure E.1.

Historical decomposition of the 2010Q3-2013Q1 crisis period



Memo: Actual GDP growth and contributions from selected components

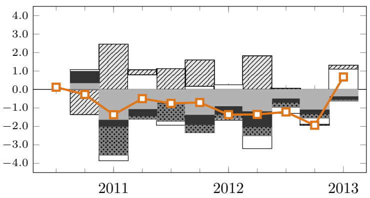


Figure E.3: Historical decompositions for GDP growth.

Notes: See Figure E.1.

Appendix F: Alternative historical decompositions for GDP growth

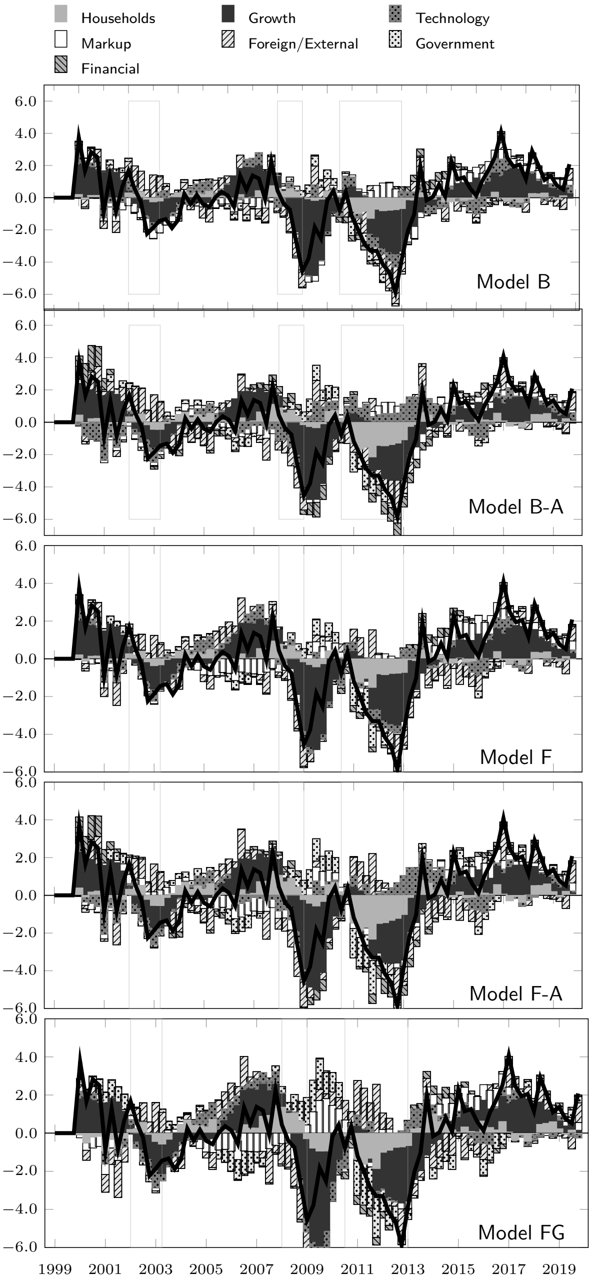


Figure F.1: Historical decompositions for GDP growth.

Notes: See Figure D.1 for details.

Appendix G: Impulse response functions

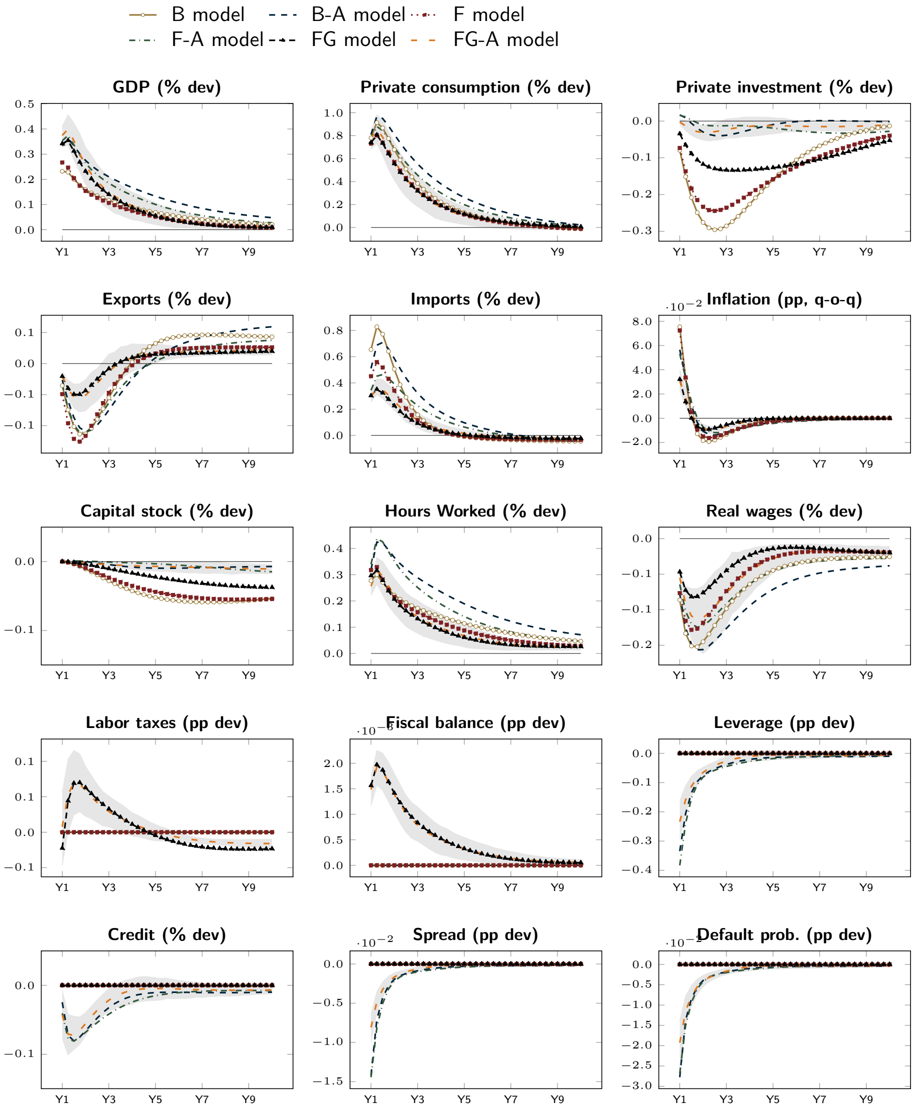


Figure G.1: Preference shock, η_t.
(deviations from steady state)

Notes: Shaded areas refer to 90% Highest Posterior Density intervals of the $FG{-}A$ model. Lines with markers correspond to models without financial intermediaries.

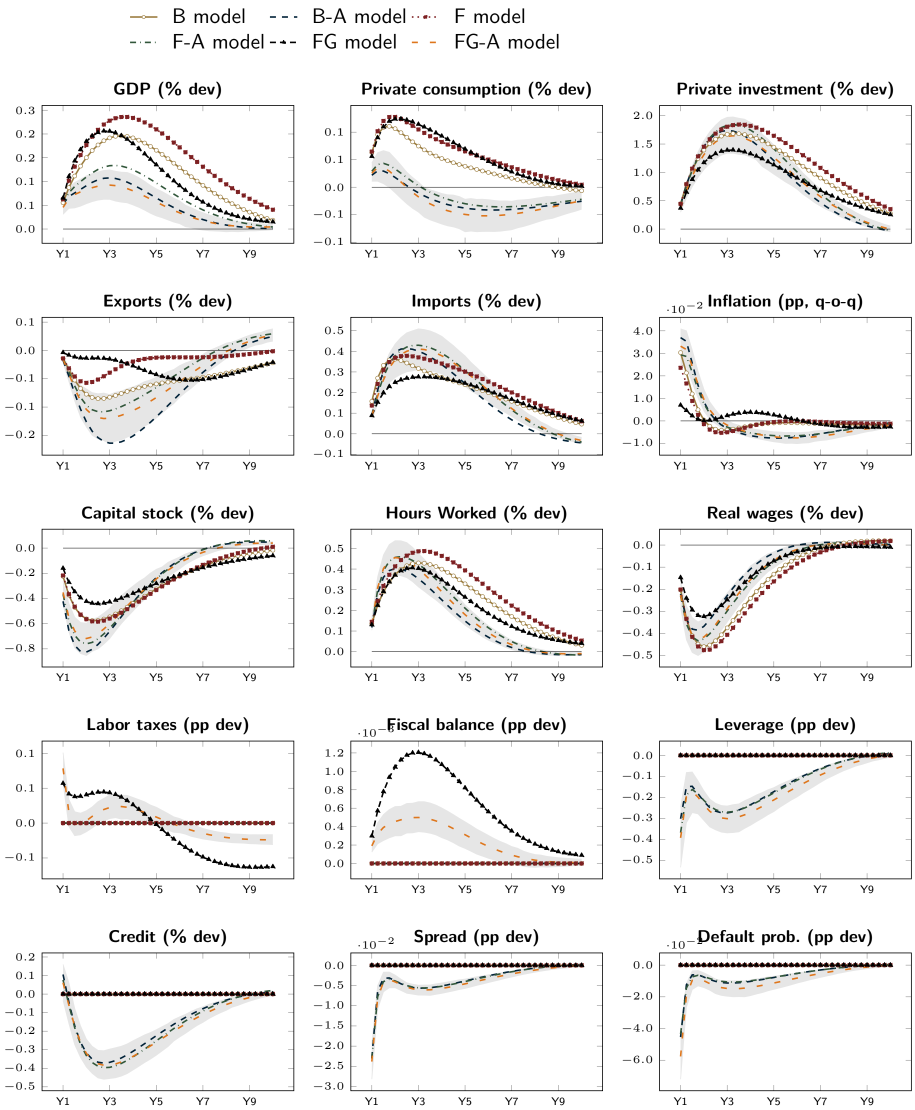


Figure G.2: Growth shock, g_t.
(deviations from steady state)

Notes: See Figure G.1.

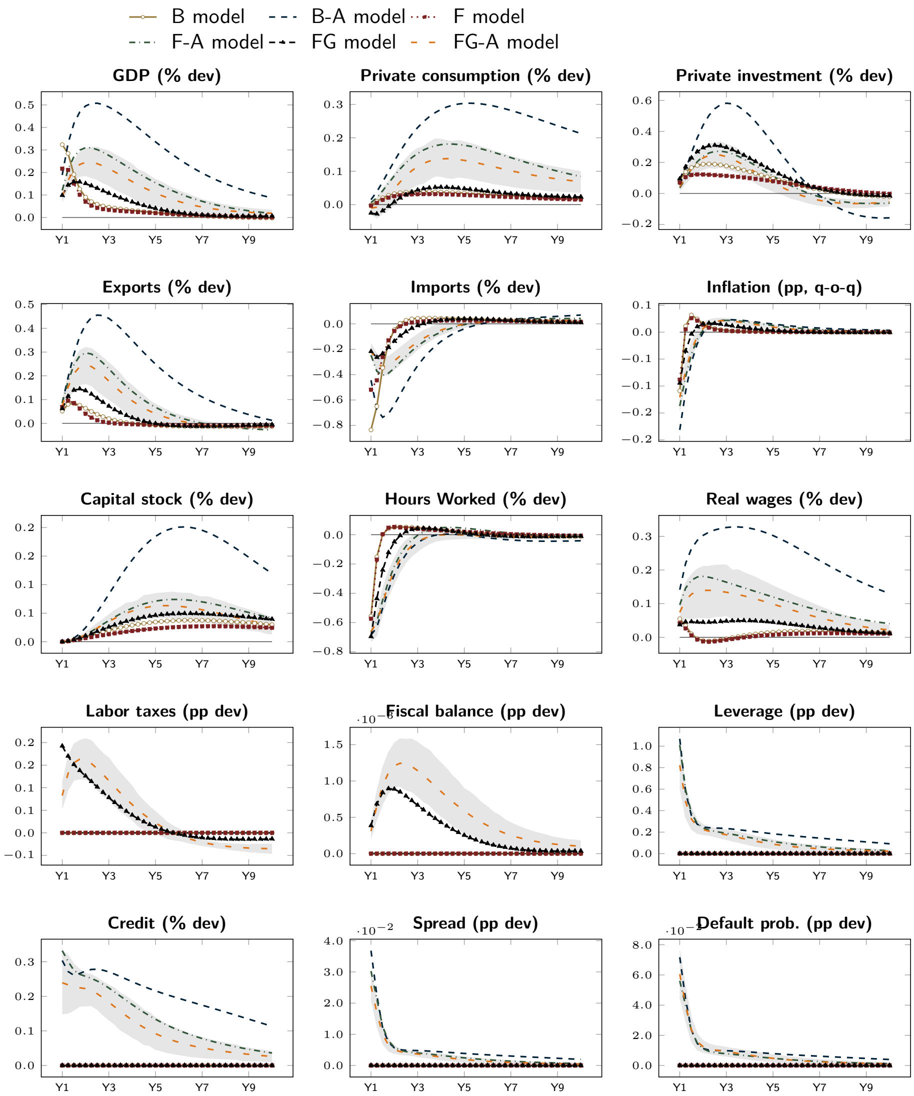


Figure G.3: Labor augmenting productivity shock, A_t.
(deviations from steady state)

Notes: See Figure G.1.

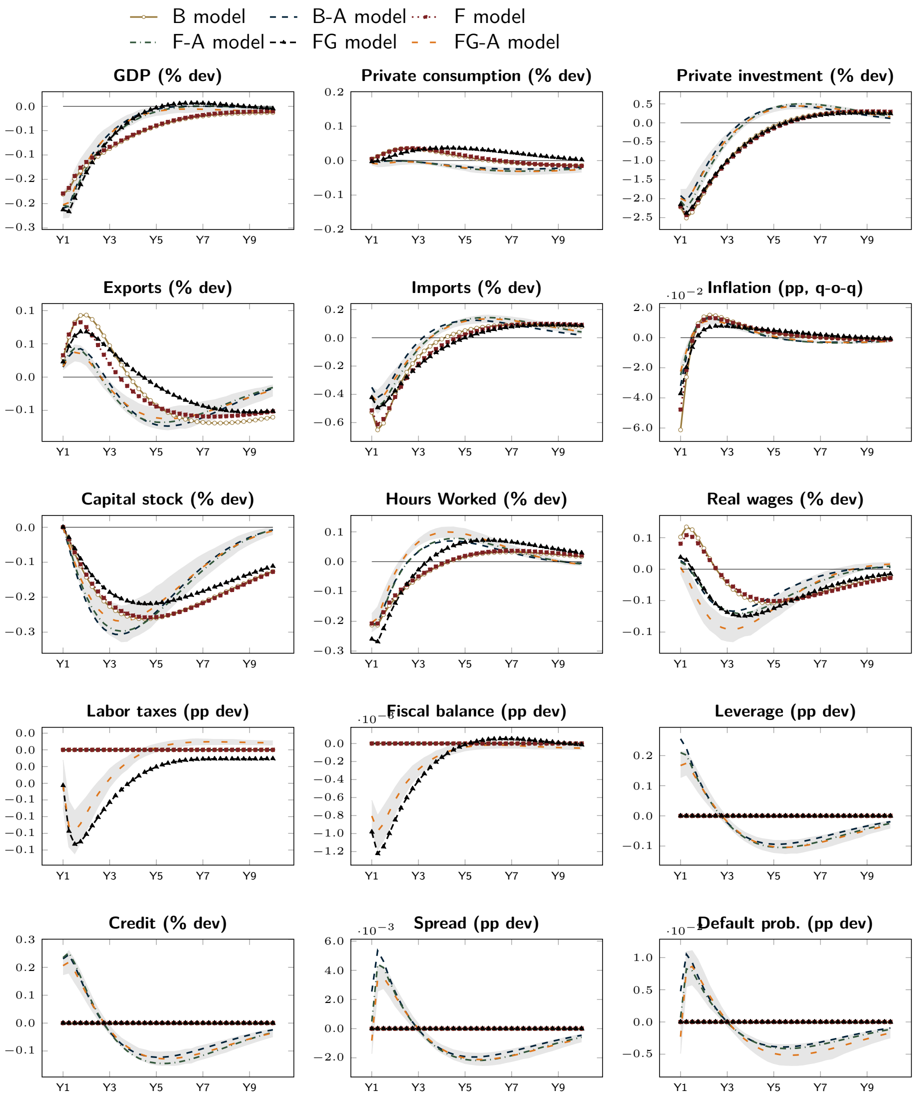


Figure G.4: Investment efficiency technology shock, ζ_t.
(deviations from steady state)

Notes: See Figure G.1.

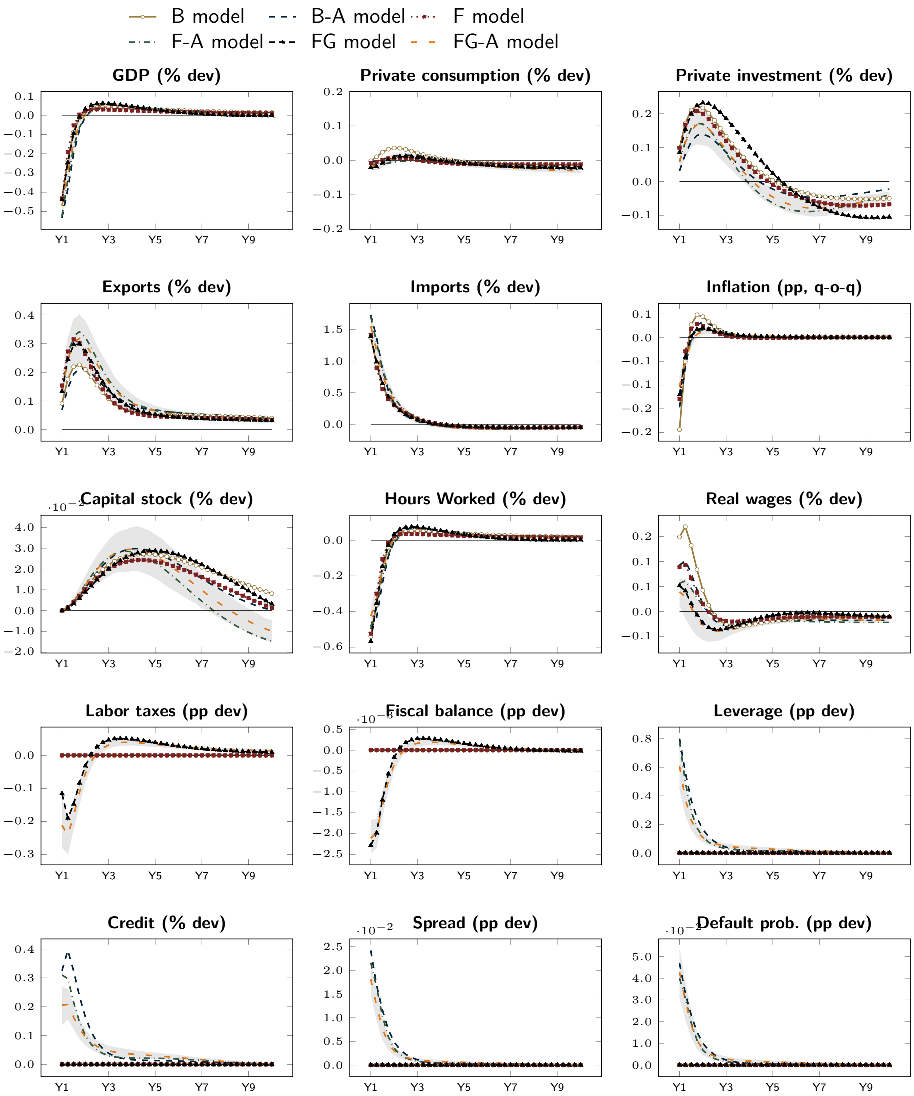


Figure G.5: Import penetration shock, $A_t^{\mathcal{M}}$.
(deviations from steady state)

Notes: See Figure G.1.

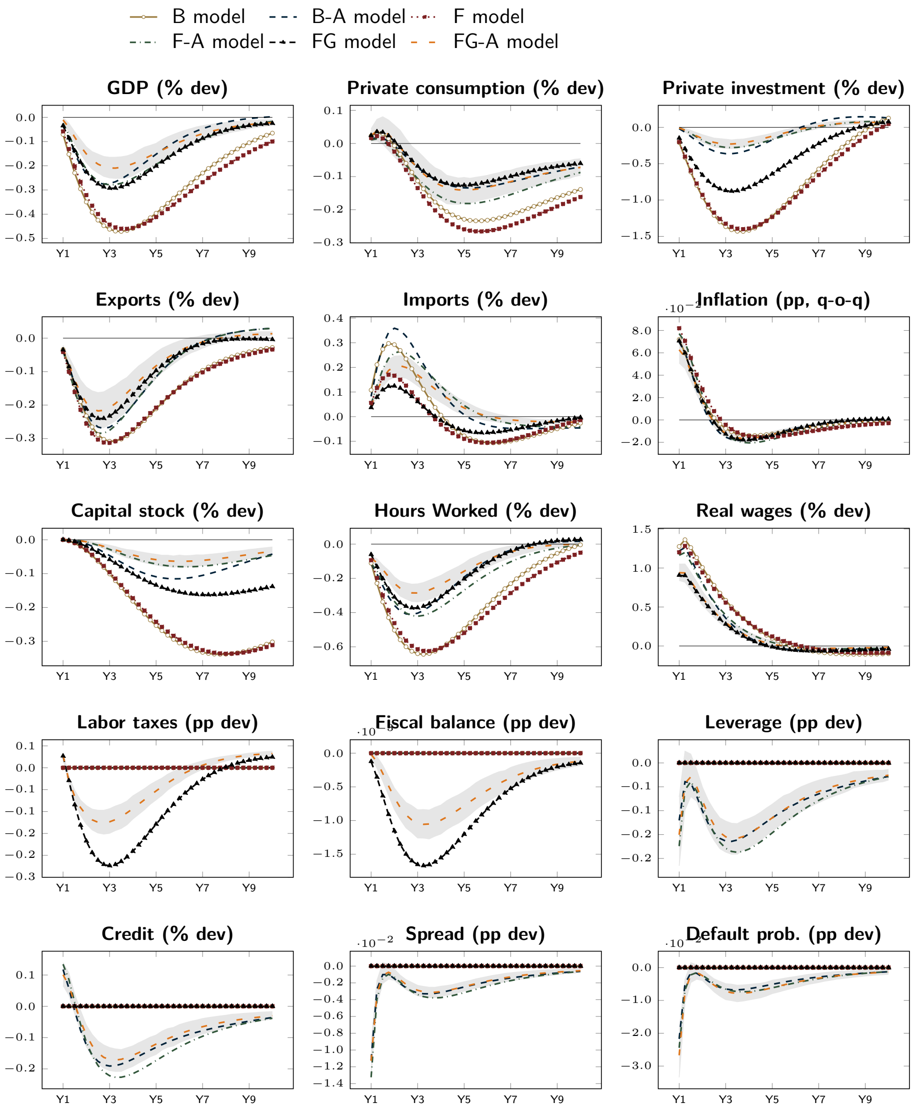


Figure G.6: Wage markup shock, $\sigma_t^{\mathcal{U}}$.
(deviations from steady state)

Notes: See Figure G.1.

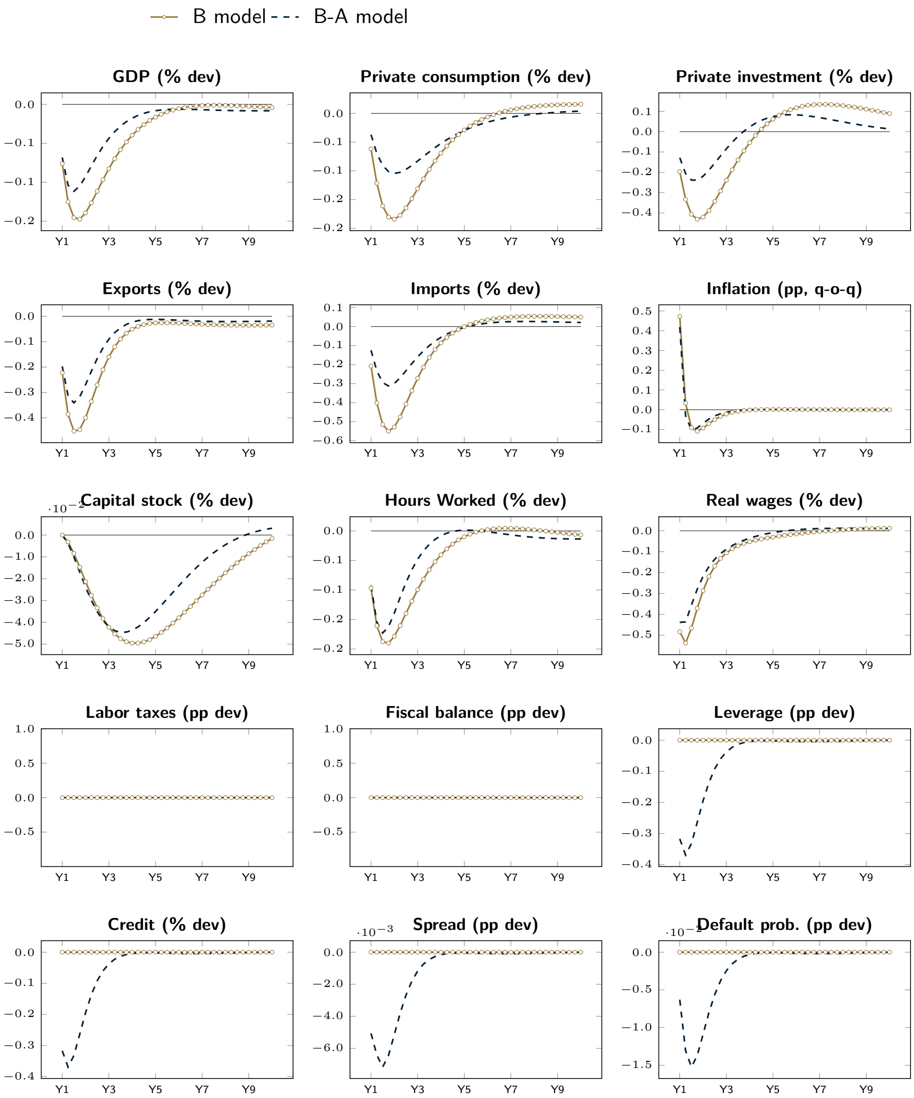


Figure G.7: Final goods price markup shock, $\sigma_t^{\mathcal{F}}$.
(deviations from steady state)

Notes: See Figure G.1.

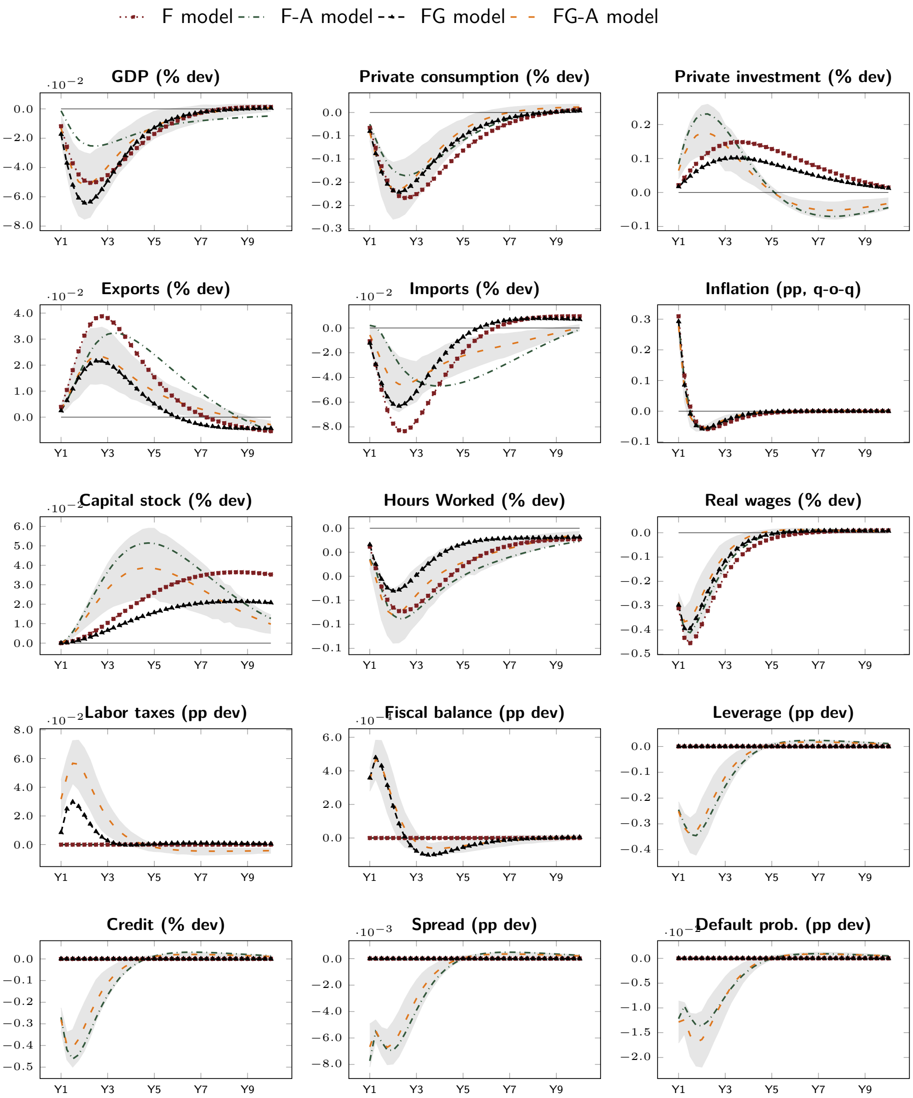


Figure G.8: Private consumption goods price markup shock, $\sigma_t^{\mathcal{C}}$.
(deviations from steady state)

Notes: See Figure G.1.

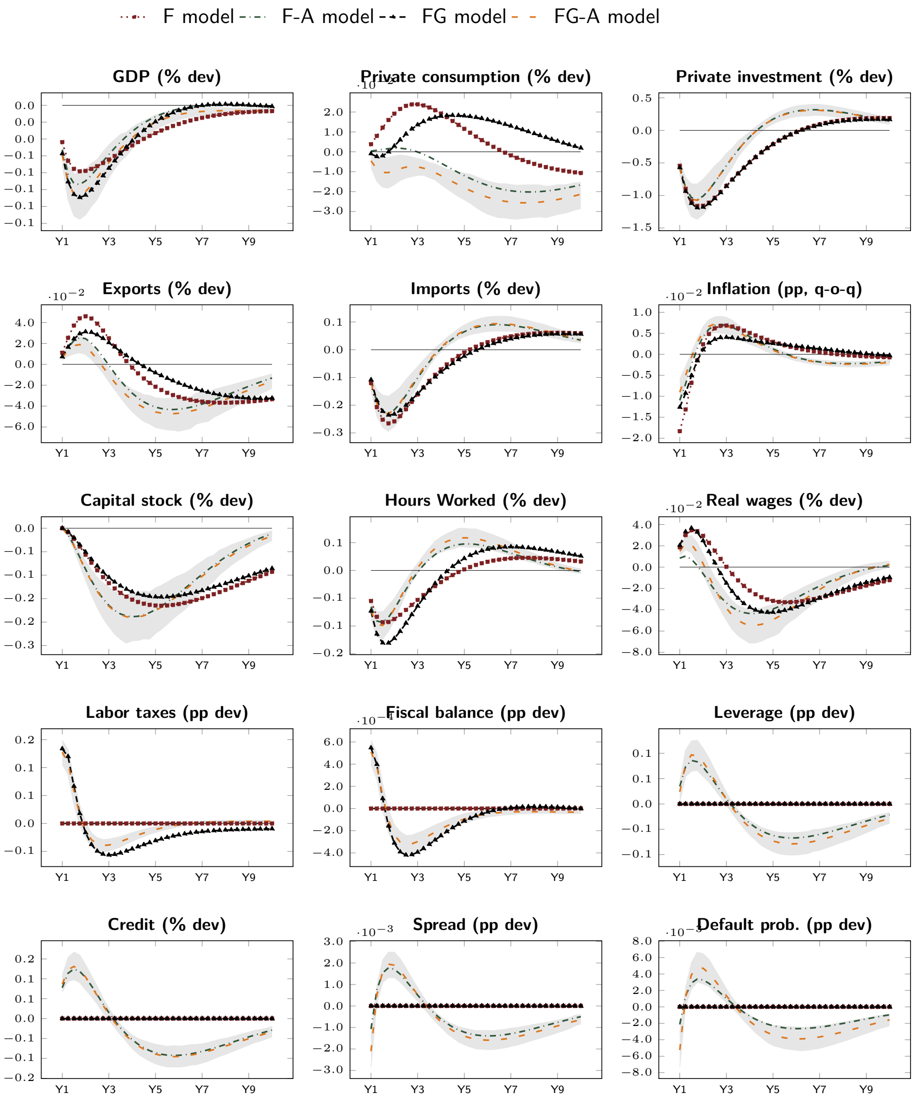


Figure G.9: Investment goods price markup shock, $\sigma_t^{\mathcal{I}}$.
(deviations from steady state)

Notes: See Figure G.1.

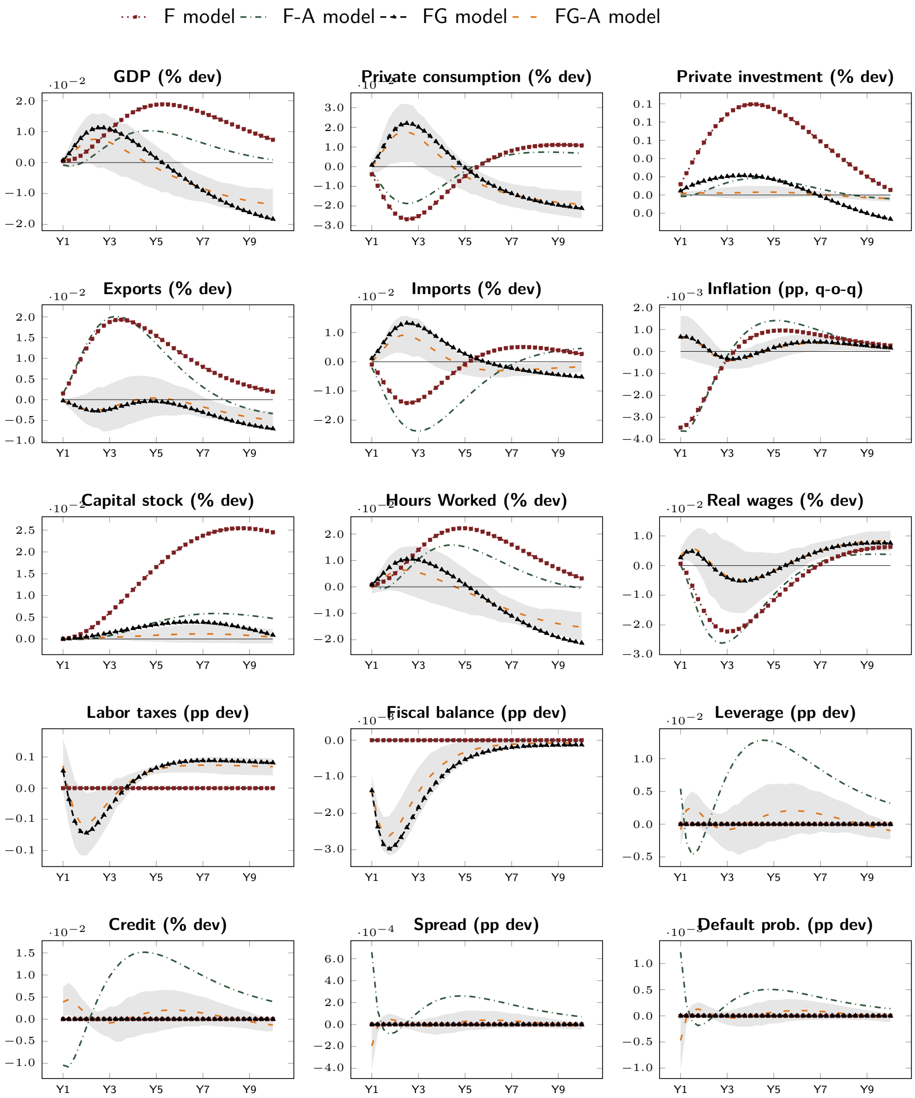


Figure G.10: Public consumption goods price markup shock, $\sigma_t^{\mathcal{G}}$.
(deviations from steady state)

Notes: See Figure G.1.

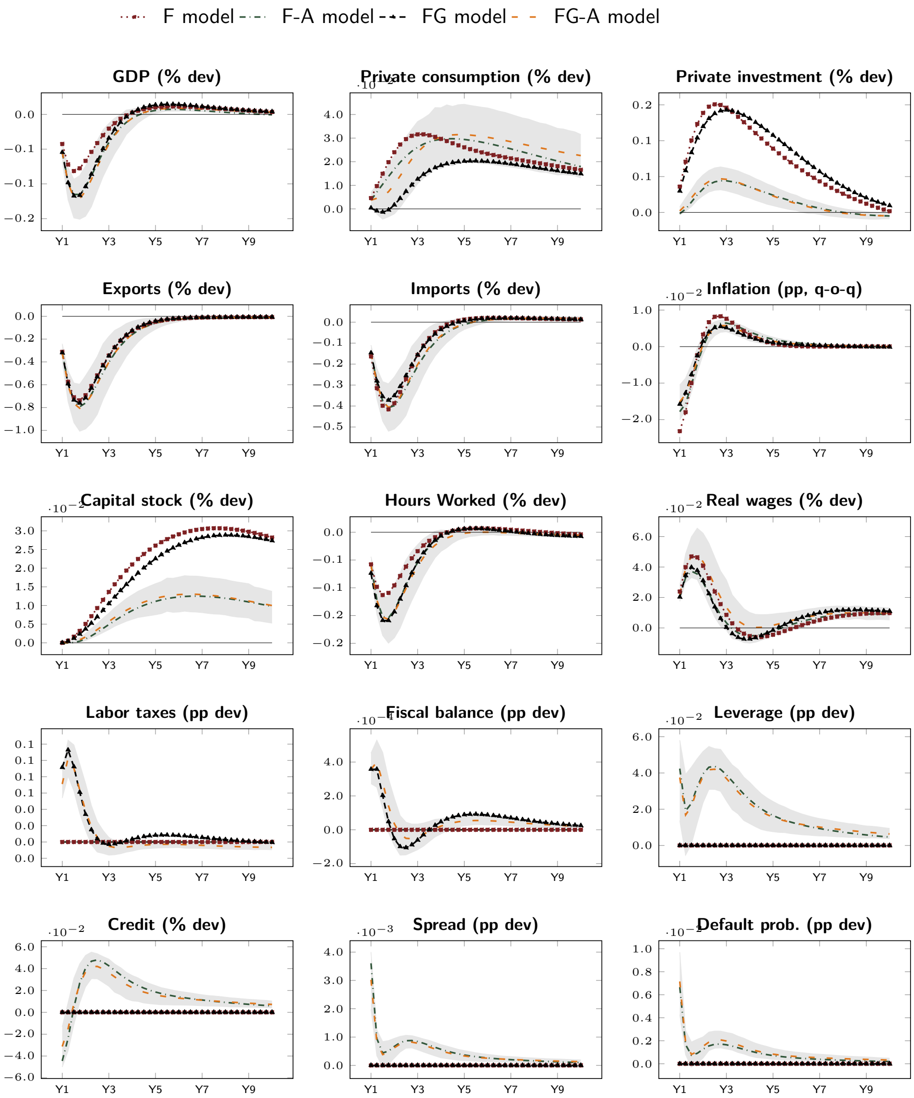


Figure G.11: Export goods price markup shock, $\sigma_t^{\mathcal{X}}$.
(deviations from steady state)

Notes: See Figure G.1.

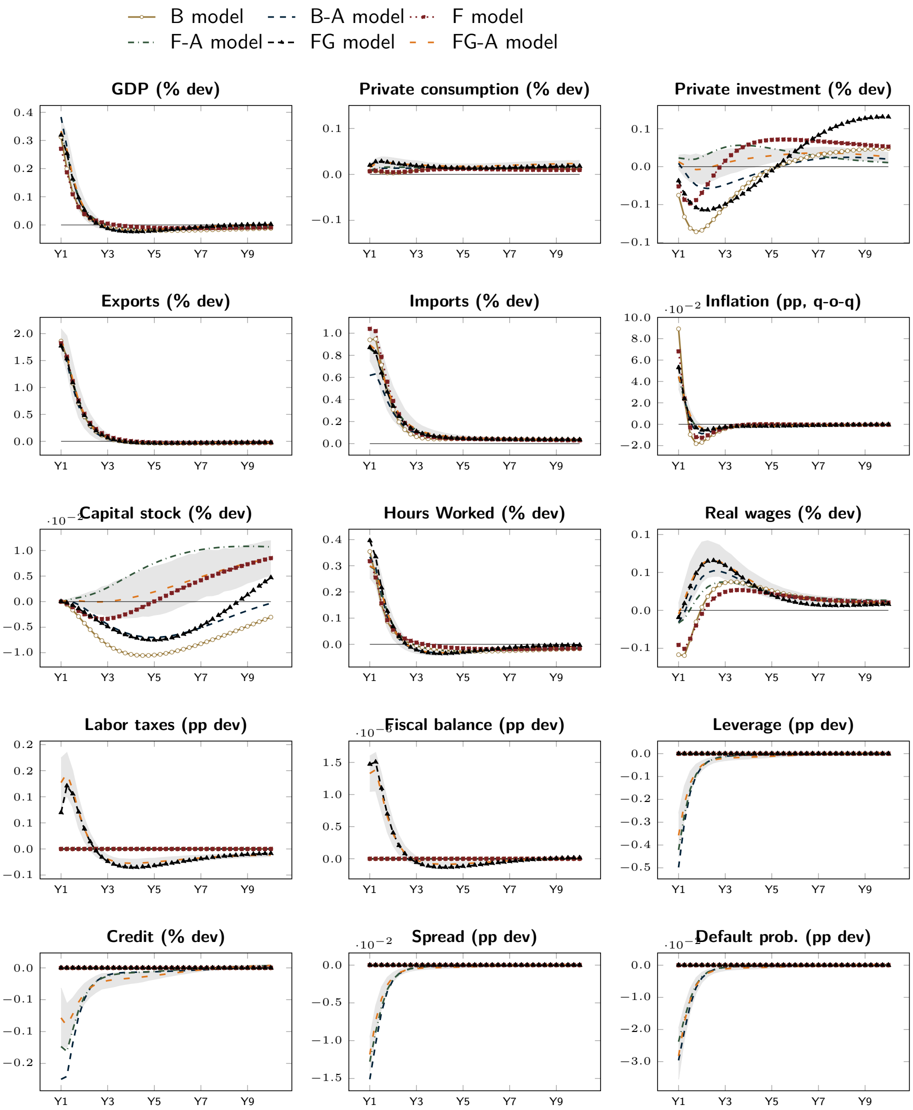


Figure G.12: Export penetration shock, α_t^*.
(deviations from steady state)

Notes: See Figure G.1.

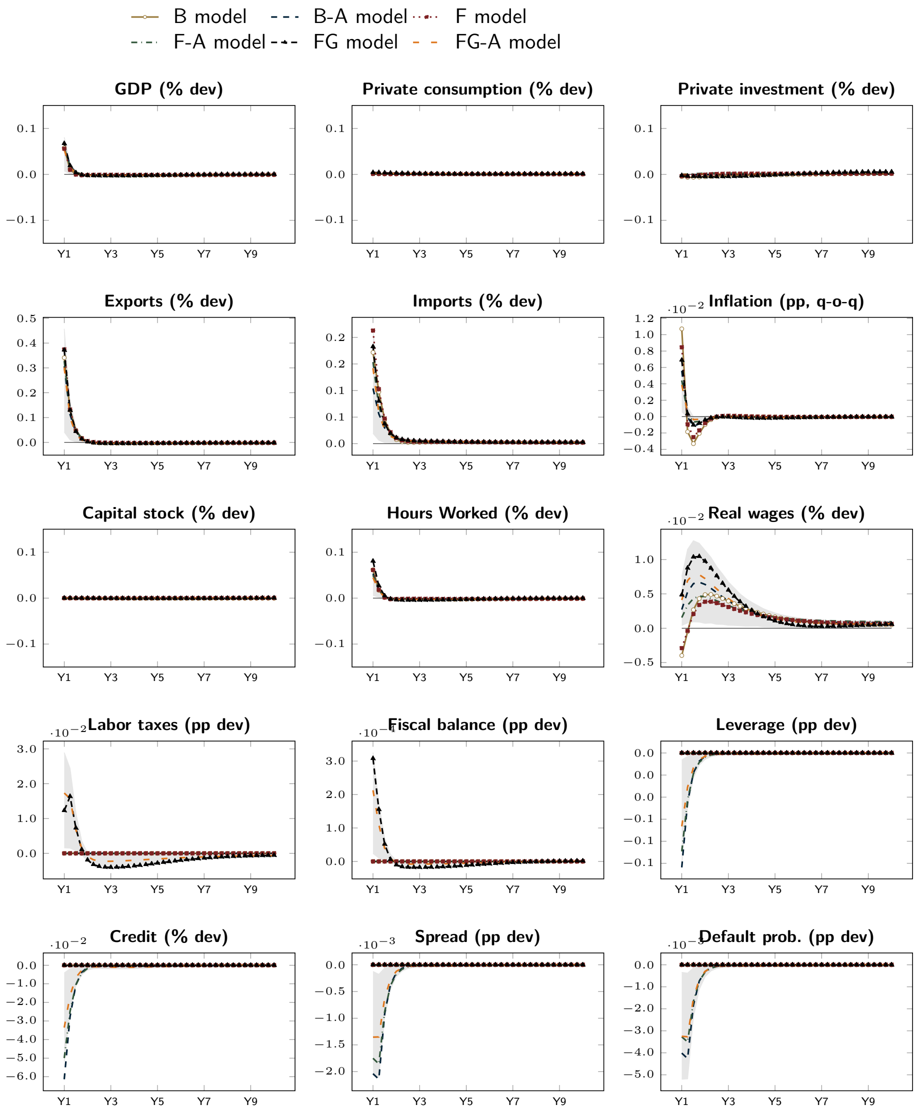


Figure G.13: World demand shock, y_t^d.
(deviations from steady state)

Notes: See Figure G.1.

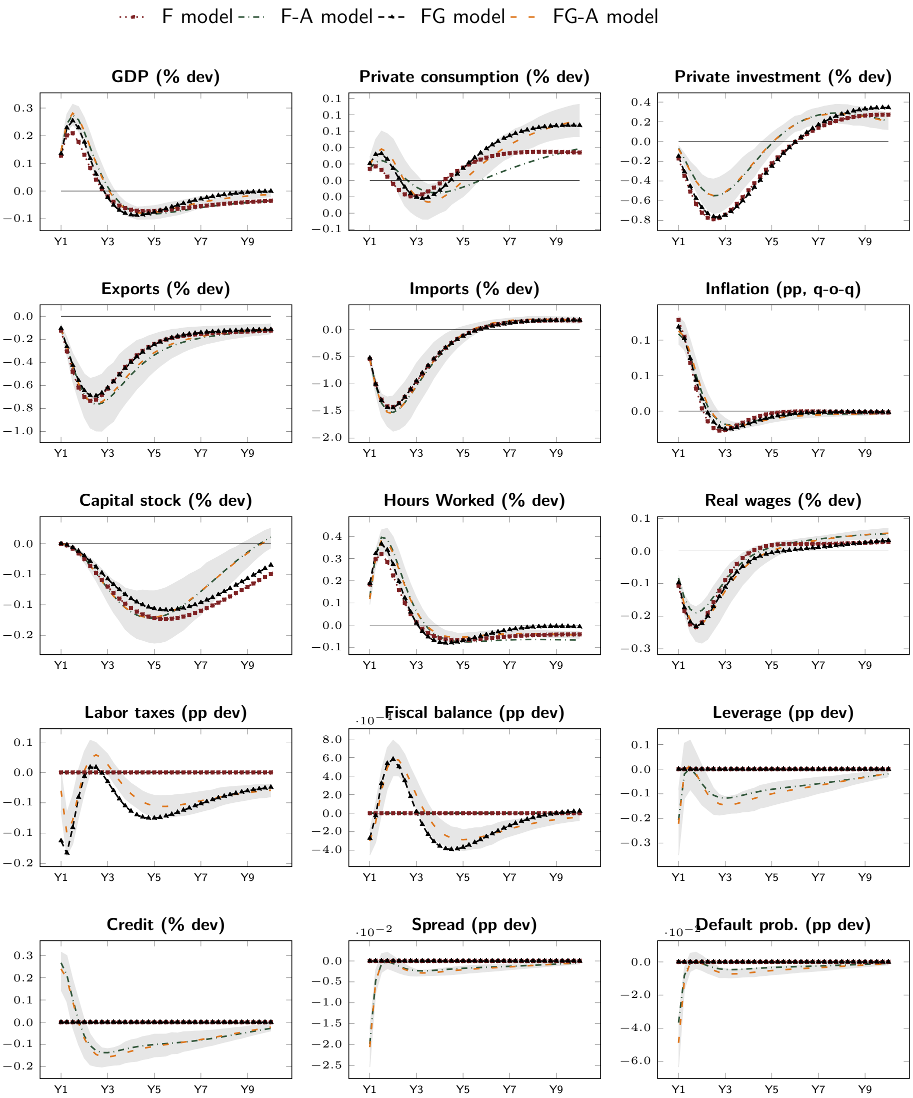


Figure G.14: Imports goods price markup shock, $\sigma_t^{\mathcal{IM}}$.
(deviations from steady state)

Notes: See Figure G.1.

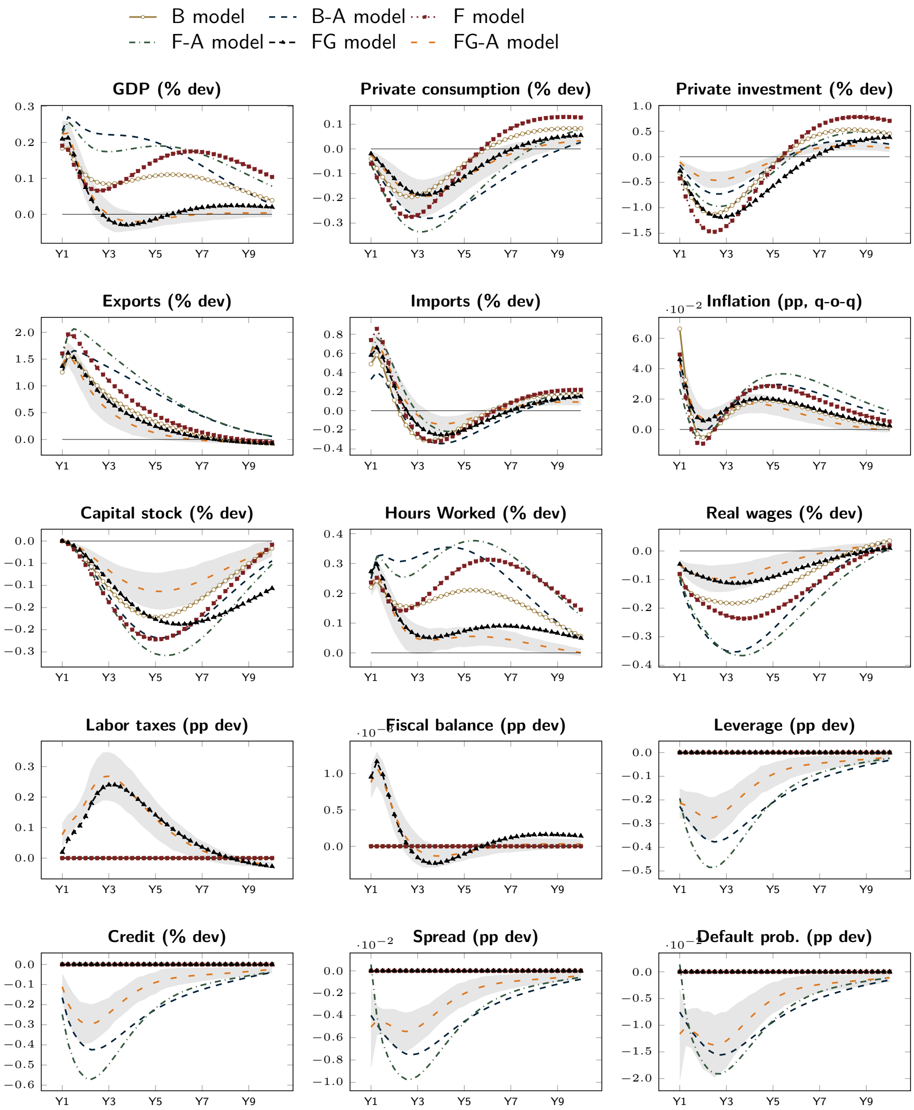


Figure G.15: Euro area output shock, y_t^*.
(deviations from steady state)

Notes: See Figure G.1.

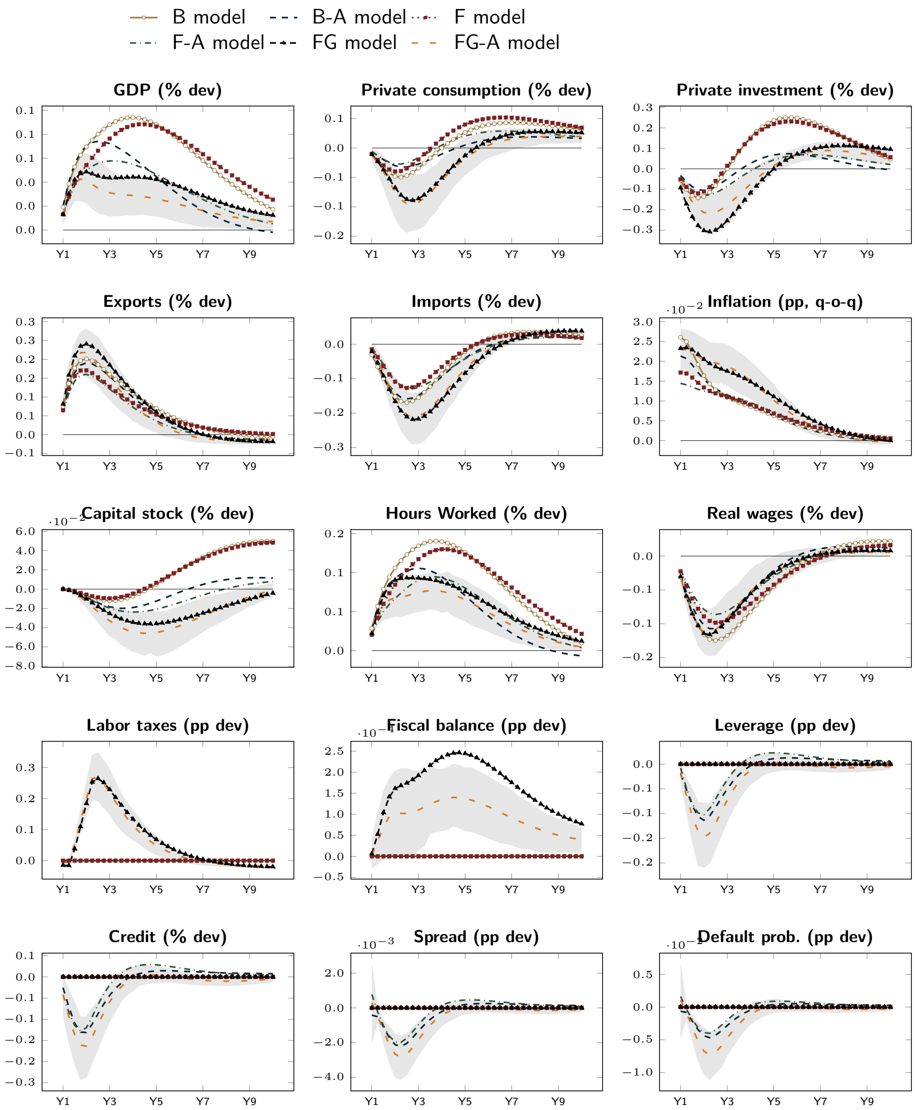


Figure G.16: Foreign inflation shock, π_t^*.
(deviations from steady state)

Notes: See Figure G.1.

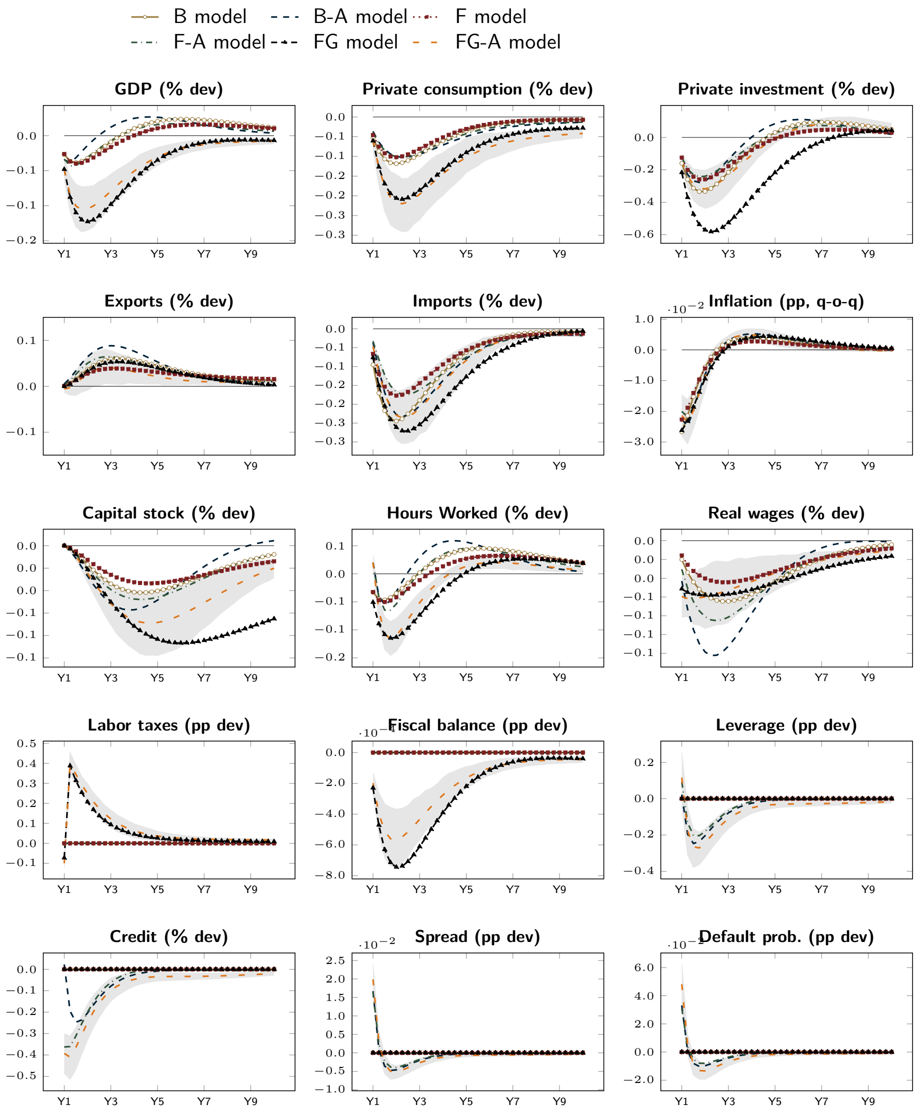


Figure G.17: Interest rate, i_t^*.
(deviations from steady state)

Notes: See Figure G.1.

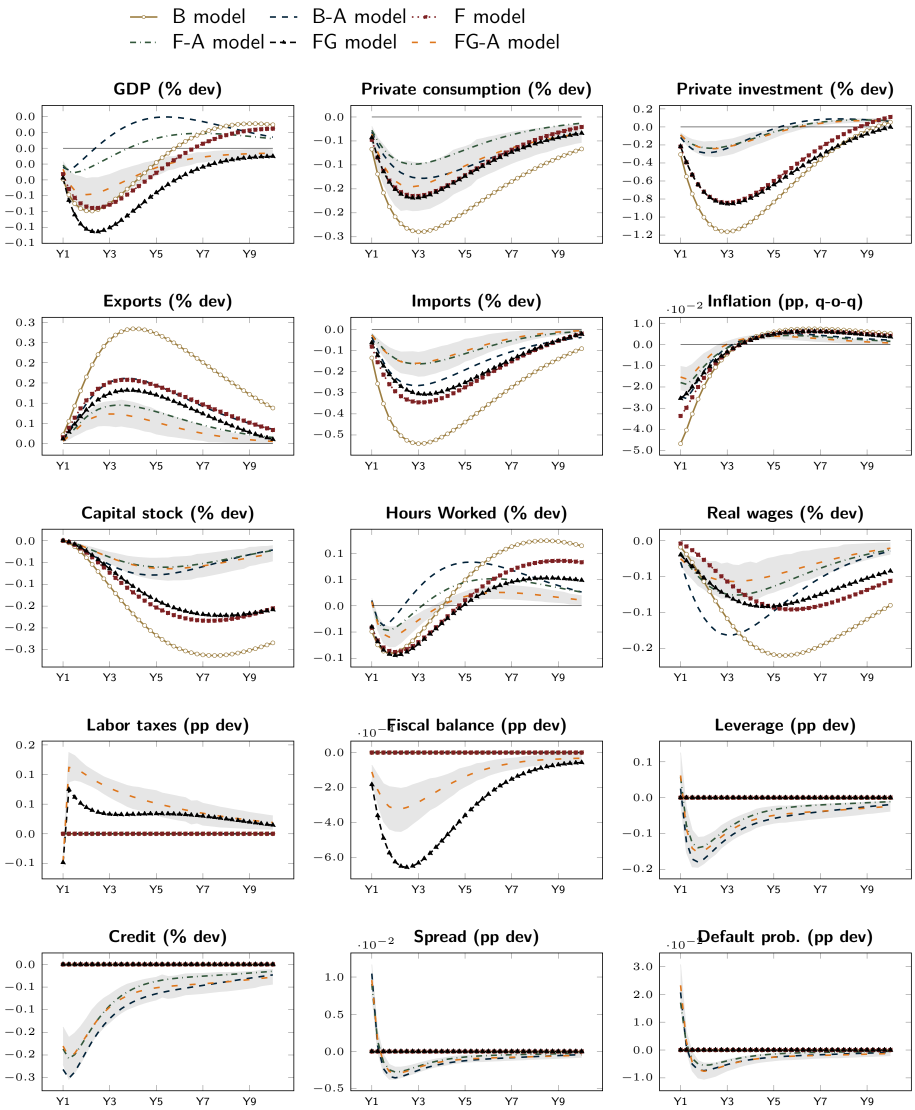


Figure G.18: Nationwide risk shock, Ψ_t.
(deviations from steady state)

Notes: See Figure G.1.

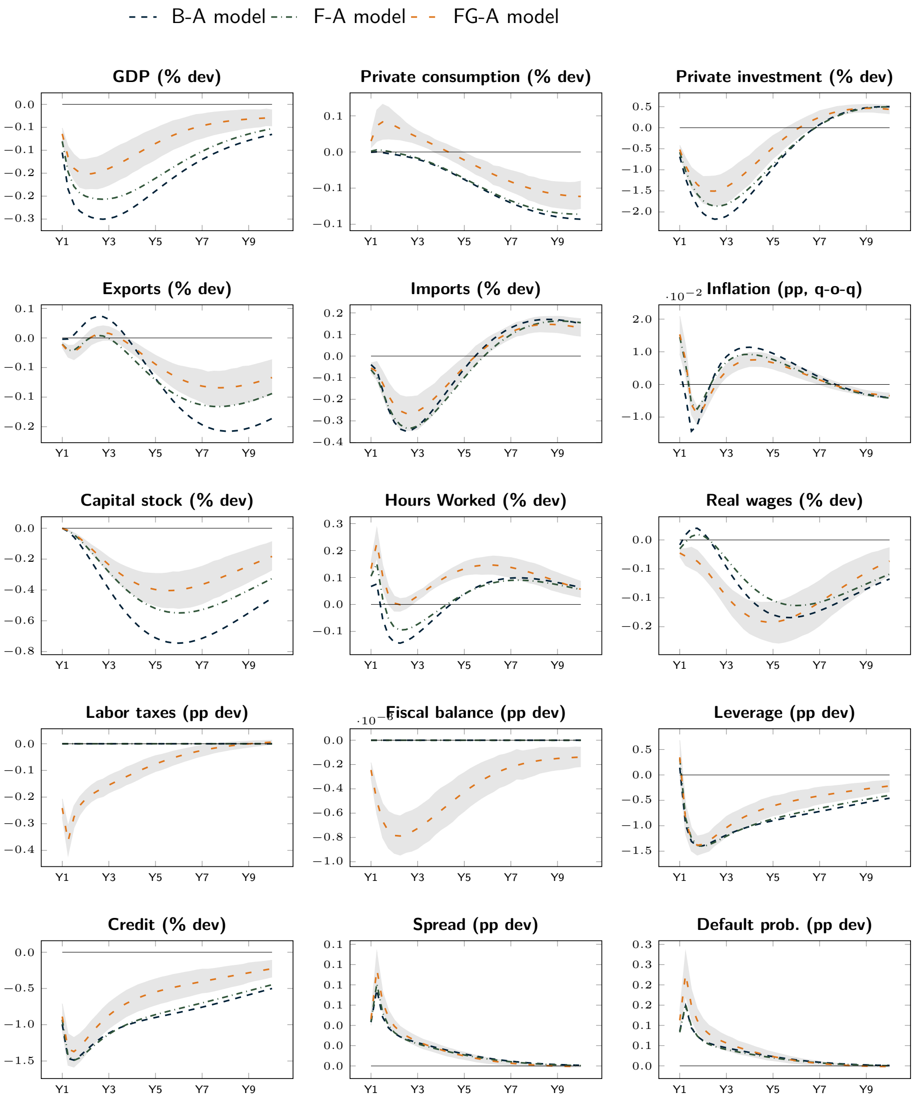


Figure G.19: Entrepreneurs' risk shock, $\sigma^{\mathcal{E}}_{t+1}$.
(deviations from steady state)

Notes: See Figure G.1.

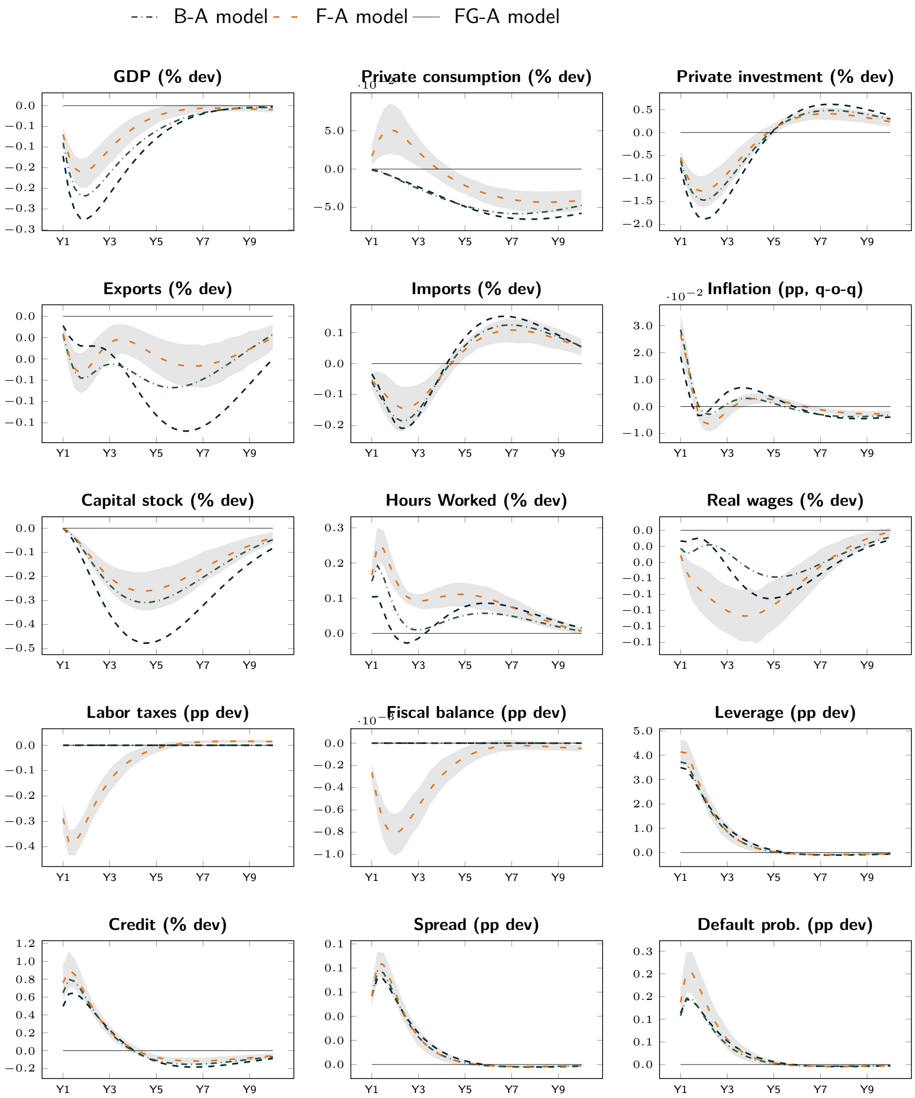


Figure G.20: Net worth shock, $\gamma_t^{\mathcal{E}}$.
(deviations from steady state)

Notes: See Figure G.1.

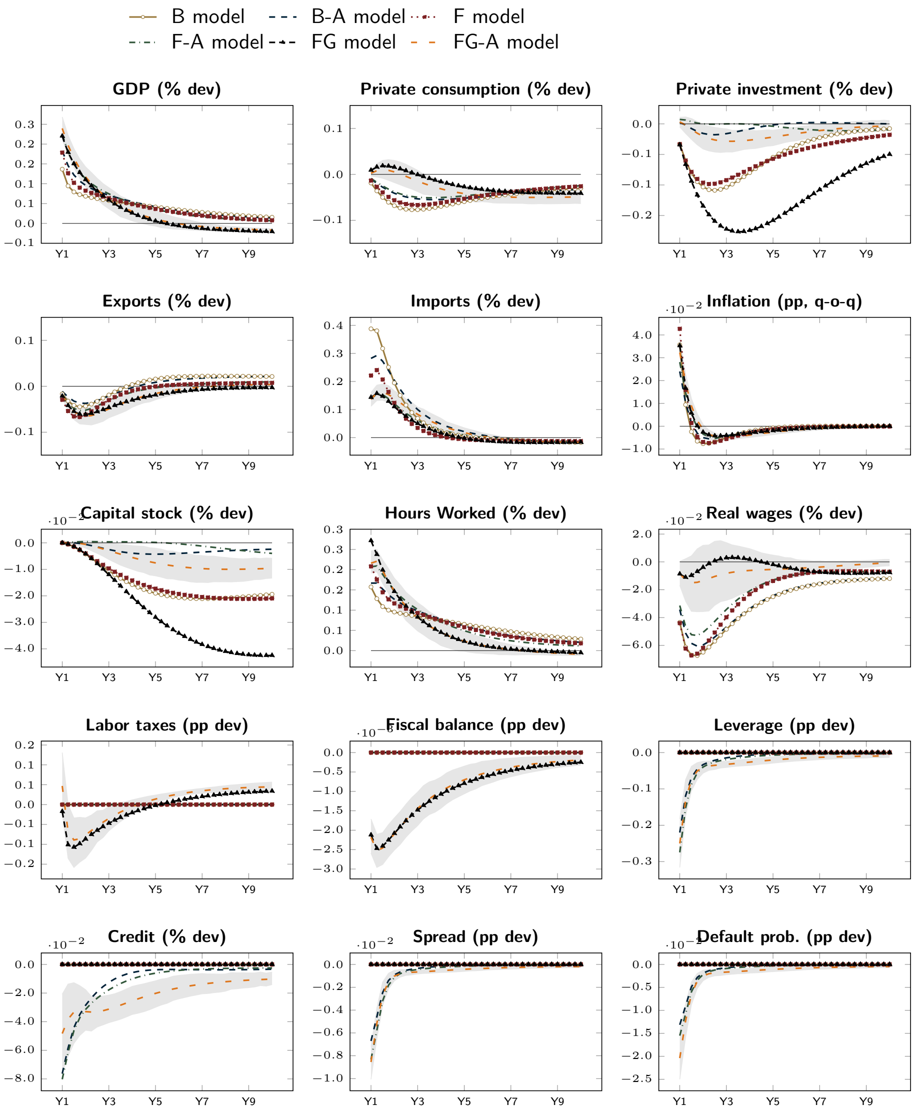


Figure G.21: Public consumption shock, G_t.
(deviations from steady state)

Notes: See Figure G.1.

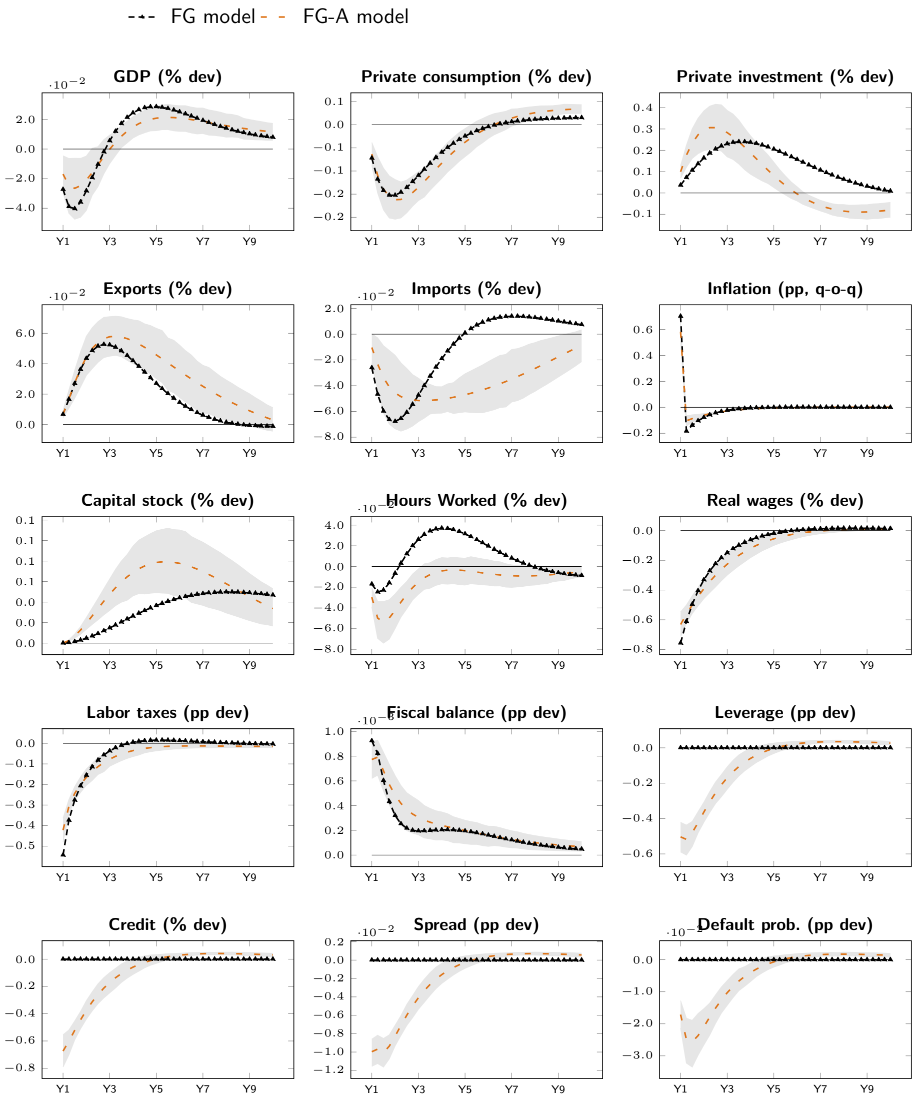


Figure G.22: Private consumption tax shock, $\tau_t^{\mathcal{C}}$.
(deviations from steady state)

Notes: See Figure G.1.

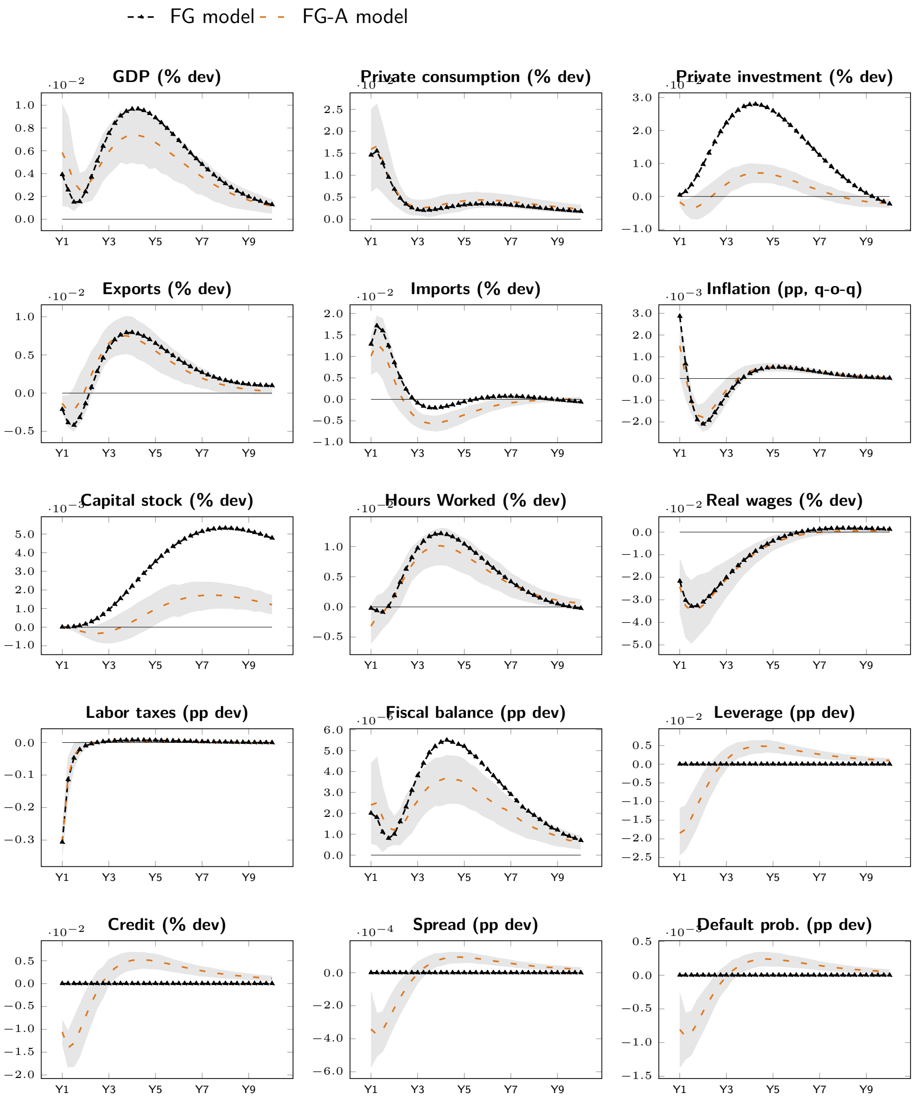


Figure G.23: Payroll tax shock, $\tau_t^{\mathcal{SP}}$.
(deviations from steady state)

Notes: See Figure G.1.

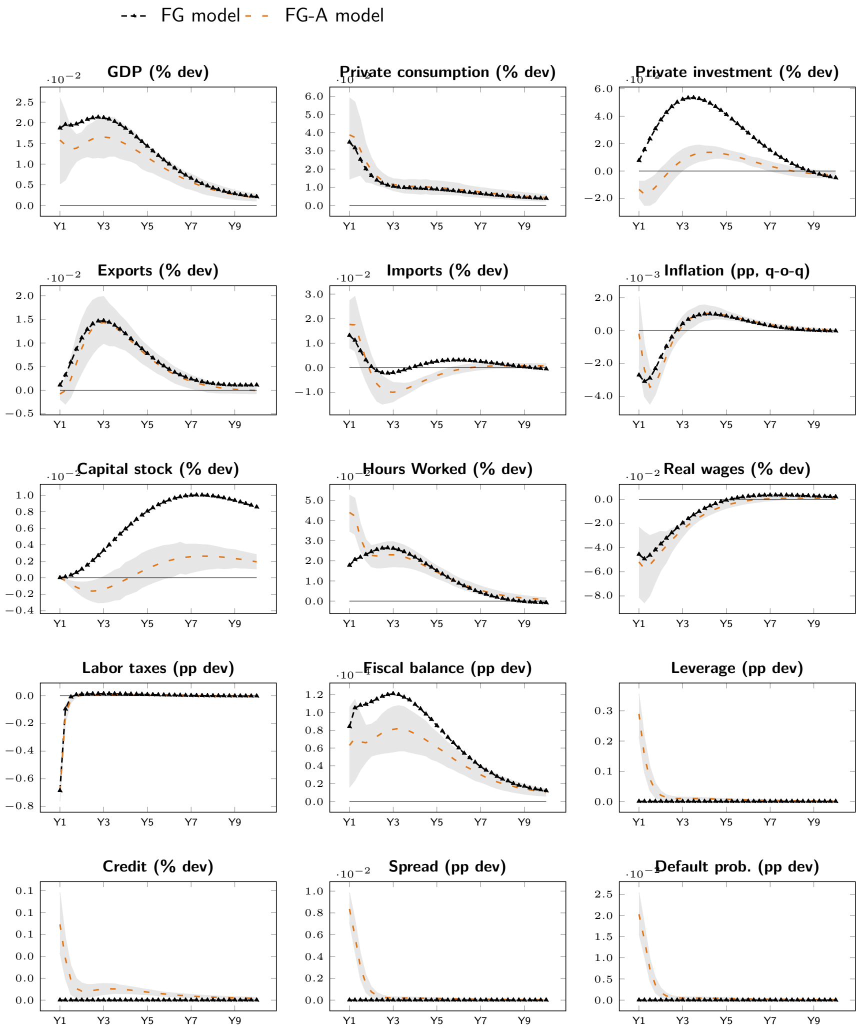


Figure G.24: Capital tax shock, $\tau_t^{\mathcal{K}}$.
(deviations from steady state)

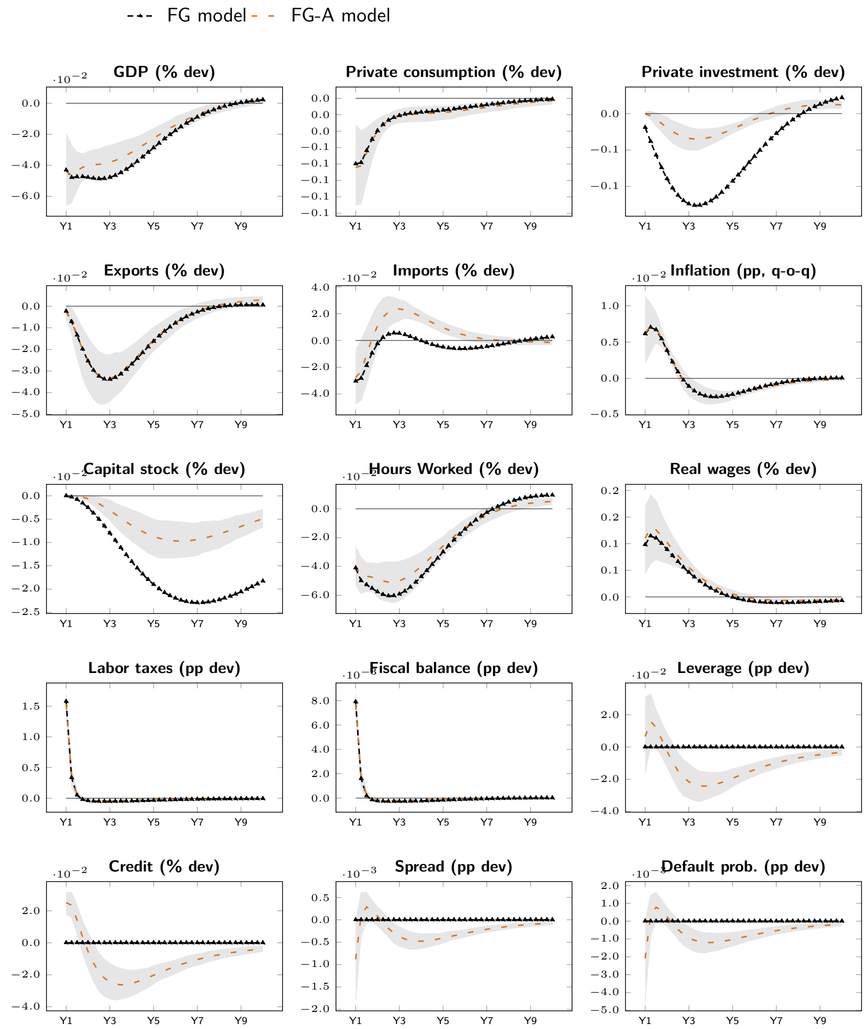


Figure G.25: Fiscal rule shock, ε_t^{SG}.
(deviations from steady state)

Notes: See Figure G.1.

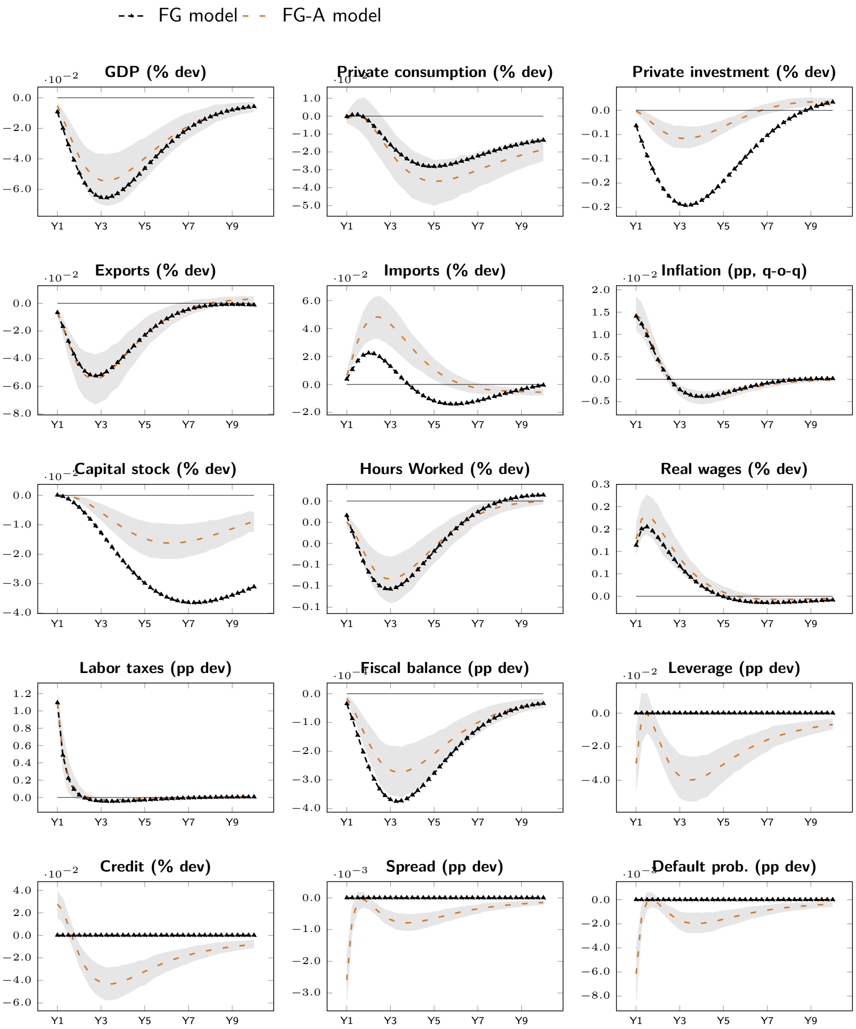


Figure G.26: Lumpsum transfers shock, TRG_t.
(deviations from steady state)

Notes: See Figure G.1.

References

Adolfson, Malin, Stefan Laséen, Jesper Lindé, and Mattias Villani (2007a). "Bayesian estimation of an open economy DSGE model with incomplete pass-through." *Journal of International Economics*, 72(2), 481–511.

Adolfson, Malin, Stefan Laseén, Jesper Lindé, and Mattias Villani (2007b). "Bayesian estimation of an open economy DSGE model with incomplete pass-through." *Journal of International Economics*, 72, 481–511.

Bernanke, Ben S., Mark Gertler, and Simon Gilchrist (1999a). "The financial accelerator in a quantitative business cycle framework." In *Handbook of Macroeconomics*, *Handbook of Macroeconomics*, vol. 1, edited by J. B. Taylor and M. Woodford, chap. 21, pp. 1341–1393. Elsevier.

Bernanke, Ben S, Mark Gertler, and Simon Gilchrist (1999b). "The financial accelerator in a quantitative business cycle framework." *Handbook of macroeconomics*, 1, 1341–1393.

Brooks, Stephen P and Andrew Gelman (1998). "General methods for monitoring convergence of iterative simulations." *Journal of computational and graphical statistics*, 7(4), 434–455.

Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans (2005). "Nominal rigidities and the dynamis effects of a shock to monetary policy." *Journal of Political Economy*, 113(1).

Christiano, Lawrence J, Roberto Motto, and Massimo Rostagno (2014a). "Risk shocks." *American Economic Review*, 104(1), 27–65.

Christiano, Lawrence J., Roberto Motto, and Massimo Rostagno (2014b). "Risk Shocks." *American Economic Review*, 104(1), 27–65.

Christiano, Lawrence J, Mathias Trabandt, and Karl Walentin (2011). "Introducing financial frictions and unemployment into a small open economy model." *Journal of Economic Dynamics and Control*, 35(12), 1999–2041.

Júlio, P. and J. Maria (2017). "Output in the Portuguese post-2008 period: A general equilibrium narrative." *Banco de Portugal Economic Studies*, III(2).

Ratto, Marco, Werner Roeger, and Jan in't Veld (2009). "QUEST III: An estimated open-economy DSGE model of the euro area with fiscal and monetary policy." *economic Modelling*, 26(1), 222–233.

Rua, António and Fátima Cardoso (2019). "The import content of final demand in Portugal: Nominal and real evolution." *Economic Bulletin and Financial Stability Report Articles and Banco de Portugal Economic Studies*.

Smets, Frank and Rafael Wouters (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3), 586–606.

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