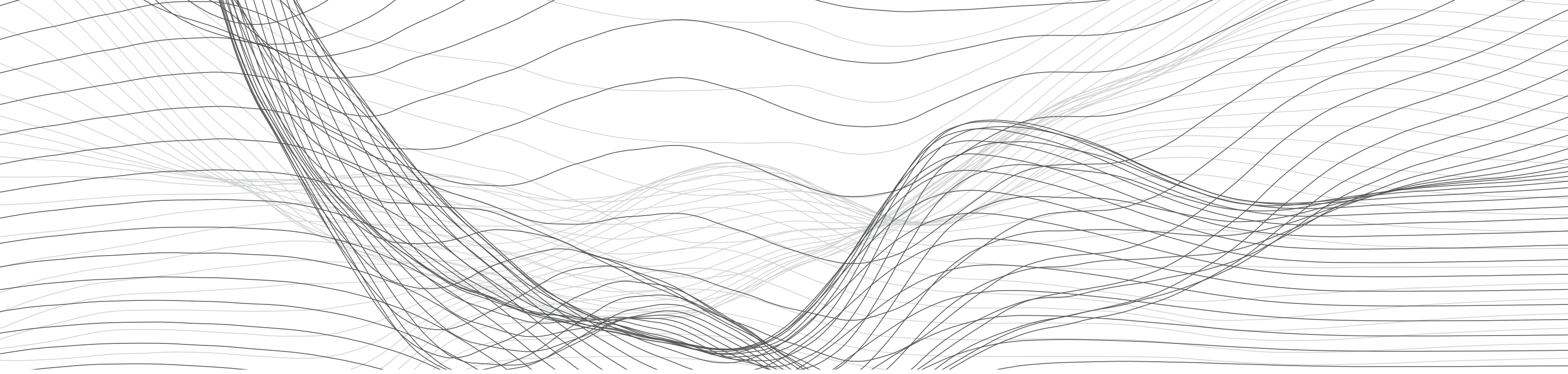

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Fiscal Policy in a Monetary Union with Downward Nominal Wage Rigidity[*]

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Abstract

We estimate an open economy DSGE model to study the fiscal policy implications of downward nominal wage rigidity (DNWR) in a monetary union. DNWR has significantly exacerbated the recession in the southern euro area countries and is important for the design of fiscal policy. We show that a cut in social security contributions paid by employers (equivalent to wage subsidies) is particularly effective in a deep recession with limited wage adjustment. Such cuts strengthen domestic demand and international competitiveness. Compared to government expenditure increases, the reduction in social security contributions provides more persistent growth effects and enhances the fiscal position. Non-linear estimation methods establish a strong state-dependence of policy.

JEL classification: E3 · F41 · F45.
Keywords: Downward nominal wage rigidity · Currency Union · Fiscal policy · Nonlinear estimation

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1 Introduction

The aftermath of the 2008-2009 financial crisis and the European debt crisis featured a policy dilemma. The deep recession in the southern euro area (EA) countries required a strong fiscal reaction. Fiscal policy is critical in a monetary union with asymmetric shocks or when the zero lower bound (ZLB) on nominal interest rates becomes binding. However, the countries with the deepest economic contraction also faced tight constraints on their debt and fiscal policy. The COVID-19 crisis renders this problem acute again. The political challenge of a union-wide fiscal policy raises the question of which measures could be pursued directly by countries in the southern EA.[1] Given these circumstances, a fiscal strategy should ideally meet the following two requirements: first, it should have large multiplier effects in a deep recession; and second, the policy should minimize budgetary costs. The two criteria do not necessarily coincide. Two alternative strategies with similar multiplier effects entail different budgetary costs if they affect tax bases differently.

What specific macroeconomic circumstances should one care about when designing fiscal measures? In addition to debt stability concerns, the crisis has revealed sizable competitiveness problems. Significant wage adjustment needs have arisen in the bust episode because of the high wage growth that occurred during the boom. Low productivity growth and protracted low inflation have exacerbated downward pressure on wages. As we will show below, downward nominal wage rigidity (DNWR) is a key aspect creating friction because of these circumstances. The asymmetry of DNWR prevents or hampers a downward adjustment of nominal wages, which is consistent with the fact that despite sizable increases in unemployment, nominal wages failed to adjust downward in the recession - an idea going back to Keynes (1936). This nominal friction is especially relevant in a monetary union, which prevents an exchange rate devaluation (Schmitt-Grohé and Uribe, 2016).

To empirically assess the implications of DNWR for aggregate fluctuations and policy, we augment an open economy model with a nonlinear DNWR constraint, modeled as a lower bound on the growth rate of nominal wages. Given the importance of competitiveness considerations, a three-region setting captures detailed trade flows and the monetary union aspect, where the euro exchange rate provides an additional transmission channel. We estimate the model nonlinearly with full information methods and focus on Spain because of its striking boom-bust cycle. Our estimates show that the asymmetry of DNWR sharply exacerbated the double-dip recession. The amplification stemming from the missing wage adjustment due to DNWR accounts for approximately 40 percent of the real GDP loss in 2013-15.

The macroeconomic relevance and asymmetry of DNWR motivate targeted fiscal policy

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[1] The European Commission's Recovery and Resilience Facility implemented in light of the massive contraction during the COVID-pandemic is a step in this direction. Another strategy is to ask countries with fiscal space within the EA to conduct more expansionary fiscal policies and rely on spillover effects, particularly at the ZLB (Blanchard et al., 2016). However, the latter proposal only has low prospects for being implemented.

intervention. We analyze the relative effectiveness of higher spending and tax cuts by comparing an increase in government consumption to a reduction of *employers'* social security contributions (SSCs). The latter is equivalent to wage subsidies in our framework. Both proposals have received considerable attention in the recent academic and policy debate.[2]

Given the nonlinearity of DNWR, the policy outcomes crucially depend on the economy's cyclical conditions. Therefore, our assessment devotes special attention to the estimated economic conditions and provides close links to the data. Because of the limited fiscal space available to governments in the southern EA, we are particularly interested in the degree of self-financing of the two budgetary measures. Accordingly, our model setup and estimation data include a detailed account of the government budget.

The estimated model shows that a cut in SSCs is an attractive policy option in a crisis. First, the policy persistently strengthens domestic demand and international competitiveness. Lower effective production costs and higher labor demand propagate via the following three main channels: One, households increase consumption as employment growth leads to higher wage income. Two, employment growth also raises the marginal product of capital and, thereby, investment. Finally, in an open economy, lower wage costs translate into competitiveness gains, which improve net exports.

Second, SSC cuts are much more effective in a deep recession, where DNWR amplifies their expansionary effects. With high downward pressure on nominal wages, the initial wage response remains muted in reaction to the expansionary policy, keeping labor costs lower for longer. Moreover, the policy targets the nonlinear DNWR constraint and directly affects the distortions from high wage costs. In summary, when the constraint binds, wage costs are reduced more substantially and competitiveness is improved more, underlining the strong state-dependence. Depending on the recession's length and severity, the SSC multiplier is more than twice as large under DNWR.

Third, the positive demand effects increase tax revenues and enhance the government budget balance. While the SSC multiplier remains smaller than the expenditure multiplier, it yields more persistent GDP effects and expands the tax bases. These two features reduce the budgetary cost, making this policy attractive for countries with limited fiscal space. However, despite the amplification in a deep crisis, it is not self-financing and increases the public debt-to-GDP ratio.

Related literature. Fiscal policy discussions often focus on the ZLB constraint. With nominal rates at the ZLB, raising government expenditure increases inflation and reduces the real interest rate. Christiano et al. (2011) show that the fiscal spending multiplier, therefore, rises at

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[2] For example, Shen and Yang (2018) find that in a closed economy, DNWR enhances the expansionary effects of government spending through reductions in unemployment and positive income effects. In an open economy with fixed exchange rates, SSC reductions can mimic an exchange rate devaluation, similar in spirit to the wage subsidies proposed by Schmitt-Grohé and Uribe (2016). However, lower prices following this policy may increase real interest rates, reducing aggregate demand.

the ZLB, while Coenen et al. (2012) find that it also exceeds multipliers of revenue reductions.[3] However, these results may not directly translate to the open economy context (Corsetti et al., 2013). For instance, Farhi and Werning (2014) argue that the fiscal spending multiplier in a monetary union is below one since the competitiveness losses offset the real interest rate reducing effect. As a revenue-based alternative, Farhi et al. (2014) advocate for mimicking an exchange rate devaluation by switching from payroll taxes to value-added taxes, which should improve competitiveness.[4] However, Galí and Monacelli (2016) are skeptical about the efficiency of this fiscal devaluation strategy in a monetary union, where the endogenous interest rate channel is much weaker.[5,6]

All of these studies abstract from the DNWR, which, as we show, is a central feature of the recent boom-bust-cycle. Schmitt-Grohé and Uribe (2016) argue that under DNWR, wage subsidies have large multiplier effects in open economies with fixed exchange rates. They also provide empirical evidence that DNWR has been prevalent in southern European economies. Shen and Yang (2018) examine government spending multipliers under DNWR in a closed economy. Bianchi et al. (2019) study the optimal fiscal stabilization policy in a model with DNWR and endogenous sovereign default calibrated for Spain. They focus on the trade-off between expansionary spending policies to fight a recession and debt stabilization, even if the latter policy deepens the recession.

We differ from these previous studies on DNWR in the following aspects. First, our paper considers *alternative fiscal policies* and emphasizes their self-financing properties given the budgetary space in southern EA countries. Understanding the debt impact of these policies is a central contribution. For this purpose, we use a rich quantitative framework with multiple tax revenues and expenditure components. This consideration also distinguishes our paper from Born et al. (2019) and Bianchi and Mondragon (2018).

Second, we *estimate* a multi-region model suitable for quantitative policy analysis.[7] The literature on fiscal policy using estimated nonlinear models is very scarce. In particular, it has so far ignored the nonlinearity stemming from DNWR, despite its importance in a monetary union or fixed exchange rate regimes. In this regard, we find a strong state-dependence of fiscal policy with larger multipliers in a deep recession. The nonlinear estimation also allows us to reflect the posterior uncertainty of our estimates. For example, our credible sets of the

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[3] There remains uncertainty about the inflationary impact of such measures (see, e.g., the discussion of Blanchard et al., 2016 by Lindé and Trabandt, 2018).

[4] See also, for example, Martin and Philippon (2017) and Engler et al. (2017).

[5] Galí and Monacelli (2016) argue that lower labor costs transmit not only via competitive gains (trade channel) but crucially depend on the monetary policy reaction. An inflation-targeting central bank lowers the policy rate in response to the fall in wage costs and inflation. This expansionary policy stimulates aggregate demand and employment in a Keynesian environment with sluggish price adjustment. In a monetary union, this channel is weaker, reducing the effectiveness of the fiscal devaluation strategy.

[6] Our analysis broadens these findings by considering the ZLB constraint.

[7] Moreover, our model treats DNWR as an occasionally binding constraint and includes distortionary taxation and elastic labor supply.

parameter estimates do not support a self-financing of the fiscal strategies despite the large multipliers under DNWR.

Third, in contrast to the existing literature, the rich estimated model quantifies *competing transmission mechanisms and state-dependence*. It offers an empirical perspective with multiple channels relevant for fiscal policy, i.e., DNWR, liquidity-constrained households, and international competitiveness. In particular, the latter plays a key role in a monetary union. With this consideration at the heart of our analysis, we employ a three-region setting to capture trade within the EA and with respect to the rest of the world (RoW).

Another strand of empirical literature shows that a limited wage adjustment, despite a deep recession, is an important stylized fact in the EA crisis. OECD (2014) provides micro evidence for increased DNWR in the southern EA. Using administrative data for Spain, the study shows that the incidence of wage freezes at zero increased from 3% in 2008 to 22% in 2012. Holden and Wulfsberg (2008) provide industry-level evidence for DNWR for OECD countries over the period of 1973-1999. They find that, while the fraction of wage cuts prevented by DNWR had decreased over the sample, the number of industries affected by DNWR had increased. Branten et al. (2018) document the prevalence of DNWR before, during and after the great financial crisis in a large group of EU countries. They find that DNWR "tends to be strongly prevalent even in periods of slow growth and low wage inflation".[8] To the best of our knowledge, we are the first to assess the strength and macroeconomic implications of DNWR through the lens of an estimated macro model.

Road map. Section 2 presents the model and discusses the wage frictions we consider. Section 3 outlines the nonlinear estimation strategy. Section 4 shows how DNWR affects the macroeconomic performance, while Section 5 analyzes targeted policy options in this environment. Section 6 concludes.

2 Model

This section lays out the economic model. We embed a downward nominal wage constraint into a DSGE model, where the trade in goods and one international asset connect the domestic economy (Spain), the rest of the euro area (REA), and the rest of the world.

Given our research questions, we include a richer fiscal policy set than other empirical DSGE models such as Smets and Wouters (2007) and its successors. The domestic fiscal authority

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[8] A survey conducted in 2009 by the ESCB Wage Dynamics Network also concludes that downward wage rigidity is prevalent. The survey asked firms, "Over the last five years, has the base wage of some employees in your firm ever been cut?". Only a small percentage of firms (0.8%) reported cuts in base wages (ECB, 2012). Gottschalk (2005), Daly et al. (2012), and Barattieri et al. (2014) report similar findings using US microdata. Fehr and Goette (2005) use Swiss data to show the macroeconomic relevance of DNWR.

provides transfers and purchases public consumption and investment goods. It levies different distortionary taxes and issues bonds to finance its spending. The model includes additional features, such as habit formation, liquidity-constrained households, variable capacity utilization, as well as price and wage stickiness. These features enhance the empirical plausibility of DSGE models. For brevity, this section concentrates on the main elements of the domestic economy and the nonlinearity imposed by the DNWR constraint. Appendix A contains additional details.

2.1 Households

A continuum of households $j \in [0,1]$ consists of two types. Both provide labor to unions and choose consumption C_{jt}. A share $(1-\omega^s)$ are liquidity-constrained (superscript c) consumers that provide labor to unions and do not participate in financial markets. The remaining households ("savers", superscript s) own firms and hold a financial asset portfolio B_{jt} to maximize their lifetime utility, as follows:

$$\max_{C_{jt},B_{jt}} E_0 \sum_{t=0}^{\infty} \beta^t \Theta_t \left(\frac{\left(C_{jt} - hC_{t-1}\right)^{1-\theta}}{1-\theta} - \omega^N \frac{N_{jt}^{1+\theta^N}}{1+\theta^N} + \sum_{\mathcal{Q}} B_{jt}^{\mathcal{Q}} (\varepsilon_t^{\mathcal{Q}} - \alpha^{\mathcal{Q}}) \right) \tag{1}$$

subject to a sequence of budget constraints

$$P_t^C (1+\tau^C) C_{jt}^s + B_{jt} = \left(1-\tau_t^N\right) W_t N_{jt}^s + R_t^r B_{jt-1} + TR_{jt}^s - T_{jt}^s \varepsilon_t^T, \tag{2}$$

where Θ_t introduces a shock to the discount factor β.[9] Parameters h and θ determine external habit formation and risk aversion, respectively. θ^N and ω^N govern the Frisch elasticity of the labor supply and the weight of labor disutility, respectively. N_{jt} denotes hours worked. The portfolio B_{jt} with gross nominal return R_t^r consists of risk-free domestic bonds (rf), government bonds (g), one internationally traded asset (bw), and domestic firm shares (S), indexed $\mathcal{Q} \in \{rf, g, bw, S\}$, respectively. The return on firm shares is $R_t^S = (P_t^S + div_t)/P_{t-1}^S$.[10]

Risk premium shocks are significant drivers of aggregate fluctuations in estimated New Keynesian models such as Smets and Wouters (2007). Fisher (2015) provides structural interpretation for this shock type. By incorporating assets in the utility function, he re-interprets the shock as a structural shock to the demand for safe and liquid assets. We follow this approach and explicitly include assets in the utility function. In this formulation, the return differences are driven by exogenous preference shocks $\varepsilon_t^{\mathcal{Q}}$ and asset-specific intercepts $\alpha^{\mathcal{Q}}$, which capture steady-state risk premia (risk-free assets imply $\alpha^{rf} = 0$).[11]

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[9] The specification $\Theta_{t+1}/\Theta_t = \exp\left(\varepsilon_t^C\right)$ implies that the Euler equations feature a time t shock ε_t^C.

[10] For brevity, we use the same time index t for bonds and shares. However, note that bond returns are pre-determined, whereas the stock market return is uncertain at time t.

[11] See also Krishnamurthy and Vissing-Jorgensen (2012), who incorporate bonds in the utility function. Other estimated macroeconomic models use similar shocks. See, e.g., Christiano et al. (2015), Del Negro et al. (2017),

In eq. (2), P_t^C and τ^C denote the consumption deflator and the consumption tax rate, respectively. R_t^r denotes the gross nominal return from asset holdings. τ_t^N, W_t, and TR_{jt}^s, are the labor tax rate, the nominal wage rate, and (net) government transfers, respectively. T_{jt}^s are lump-sum taxes paid by savers disturbed by a shock ε_t^T. Liquidity-constrained households consume their net disposable income (wage minus taxes) given the following budget constraint:

$$P_t^C(1+\tau^C)C_{jt}^c = \left(1-\tau_t^N\right) W_t N_{jt}^c + TR_{jt}^c - T_{jt}^c \varepsilon_t^T. \tag{3}$$

Total private consumption aggregates over household types, as follows: $C_t = \omega^s C_t^s + (1-\omega^s) C_t^c$.

2.2 Labor markets

We augment a standard New Keynesian wage Phillips curve model with a DNWR constraint. Each household supplies a continuum of differentiated labor services (indexed by l) to unions. A competitive labor packer buys these labor services from unions and sells the bundle to intermediate firms. The demand from labor packers for labor type l follows from profit-maximization, as follows:

$$N_{lt} = \left(\frac{W_{lt}}{W_t}\right)^{-\sigma^n} N_t, \tag{4}$$

where W_{lt} is the nominal wage rate for labor type l. $\sigma^n > 1$ denotes the elasticity of substitution across labor types.

Unions set wages by maximizing the households' utility, subject to (4), the joint household budget constraint and a DNWR constraint (5). They aim for real consumption wages (W_{lt}/P_t^C) to be consistent with the marginal rate of substitution between leisure and consumption (mrs_t, weighted average of both household types). Due to monopolistic competition, unions set wages at a stochastic wage markup μ_t^w.[12] μ_t^w also captures nominal wage stickiness stemming from wage adjustment costs of the form $\Gamma_t^W = \frac{(\sigma^n-1)\gamma^w}{2} W_t N_t \left(\pi_t^W - \pi^w\right)^2$, where γ^w is a parameter and π_t^W denotes the quarterly wage inflation. The nonlinear DNWR constraint dictates that nominal wage growth must exceed a fixed γ, as follows:

$$\frac{W_{lt}}{W_{lt-1}} \geq \gamma. \tag{5}$$

The corresponding complementary slackness condition is

$$\lambda_t^W \left(\frac{W_{lt}}{W_{lt-1}} - \gamma\right) = 0, \tag{6}$$

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and Gust et al. (2017), for closed economy models. We extend this approach to international and other assets. By generating a wedge between the return on assets and safe bonds, ε_t^{rf} acts as a financial shock. It also captures precautionary savings. ε_t^S is an exogenous shock to investment-specific risk premia.

[12] ε_t^U denotes the shock to the steady-state wage markup.

where λ_t^W denotes the Kuhn-Tucker multiplier on the DNWR constraint. $\lambda_t^W = 0$ when the constraint is slack and $\frac{W_{lt}}{W_{lt-1}} = \gamma$ when the constraint is binding.

The resulting wage Phillips curve accounts for the endogenous probability of a binding constraint. In a symmetric equilibrium, the real wage follows:

$$\left(mrs_t\right)^{1-\gamma^{wr}} \left(\frac{(1-\tau_{t-1}^N)W_{t-1}}{P_{t-1}^C}\right)^{\gamma^{wr}} = \frac{W_t}{P_t^C}(1-\tau_t^N)\mu_t^w + \hat{\lambda}_t^W - \beta_t E_t\left[\tilde{\lambda}_{t+1}^W\right] \tag{7}$$

where γ^{wr} parametrizes real wage rigidity as in Blanchard and Galí (2007). $\hat{\lambda}^W$ and $\tilde{\lambda}^W$ are proportional to λ^W to simplify the notation. Appendix A.4 provides the details.

2.3 Firms

Perfectly competitive firms produce the final good Y_t. A CES technology bundles EA intermediate goods as follows:

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{\sigma^y-1}{\sigma^y}} di\right]^{\frac{\sigma^y}{\sigma^y-1}}, \tag{8}$$

where Y_{it} denotes intermediate good index $i \in [0,1]$. $\sigma^y > 1$ is the elasticity of substitution. The production function for good i is

$$Y_{it} = (A_t N_{it})^{\alpha}\left(cu_{it}K_{it}^{tot}\right)^{1-\alpha}, \tag{9}$$

where A_t is an exogenous stochastic technology level subject to growth shocks. N_{it} and cu_{it} are firm i's labor input and capacity utilization, respectively. Gross investment I_{it} induces a law of motion for capital $K_{it+1} = K_{it}(1-\delta) + I_{it}$, with $0 < \delta < 1$. Total capital K_{it}^{tot} is the sum of private installed capital, K_{it}, and public capital, K_{it}^G: $K_{it}^{tot} = K_{it} + K_{it}^G$. Intermediate goods firms maximize dividends, which in each period t are

$$div_{it} = (1-\tau^K)P_{it}Y_{it} - (1+ssc_t)W_tN_{it} - P_t^I I_{it} + \tau^K \delta P_t^I K_{it-1} - \Gamma_{it}, \tag{10}$$

where τ^K, ssc_t, P_t^I, and δ are the corporate (capital) tax rate, SSCs paid by employers, the price of investment goods, and the depreciation rate, respectively. Γ_{it} collects the quadratic price and factor adjustment costs. Each firm i sets its price P_{it} in a monopolistically competitive market subject to price adjustment costs as in Rotemberg (1982), and the demand function of final good producers $Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\sigma^y} Y_t$.

2.4 Trade

Let $D_t \in \{C_t, G_t, I_t, I_t^G, X_t\}$ be the demand of households and the public sector, private and government investors, and exporters, respectively.[13] Perfectly competitive firms assemble D_t using domestic output and sector-specific imported inputs (M_t^D) in a CES production function, as follows:

$$D_t = A_t^{p,D}\left[\left(1-s_t^{M,D}\right)^{\frac{1}{\sigma^d}}(Y_t)^{\frac{\sigma^d-1}{\sigma^d}} + \left(s_t^{M,D}\right)^{\frac{1}{\sigma^d}}(M_t^D)^{\frac{\sigma^d-1}{\sigma^d}}\right]^{\frac{\sigma^d}{\sigma^d-1}}, \tag{11}$$

where $A_t^{p,D}$ denotes a productivity shock in sector D. $0 < s_t^{M,D} < 1$ is the sector-specific import share.[14] $\sigma^d > 0$ is the elasticity of substitution common across sectors.

2.5 Public sector

The government finances public consumption, public investment, transfers, and the servicing of the outstanding debt through SSCs and distortionary taxes on profits, labor, and consumption, as well as the issuance of one-period bonds, B_t^G. The expenditure components follow the following simple rules:

$$z_t - \bar{z} = \rho^z(z_{t-1} - \bar{z}) + \varepsilon_t^z, \tag{12}$$

where z_t includes the output shares of government consumption, government investment, and transfers $z \in \{G, I^G, TR_t\}$ with steady state $\bar{z}$.[15] ε_t^z are white noise disturbances. Public capital accumulates analogously to private capital.

The government budget constraint is as follows:

$$B_t^G = (1 + i_{t-1}^G)B_{t-1}^G - R_t^G + P_t^G G_t + P_t^{IG} I_t^G + TR_t P_t, \tag{13}$$

where nominal government revenues, R^G, are defined as follows:

$$R_t^G = \tau^K(P_t Y_t - (1 + ssc_t)W_t N_t - P_t^I \delta K_{t-1}) + (\tau_t^N + ssc_t)W_t N_t + \tau^C P_t^C C_t. \tag{14}$$

Labor taxes close the long-run budget as follows:

$$\tau_t^N = \rho^{tax}\tau_{t-1}^N + \eta^d\left(\frac{\Delta B_{t-1}^G}{Y_{t-1}P_{t-1}} - \bar{d}\right) + \eta^B\left(\frac{B_{t-1}^G}{Y_{t-1}P_{t-1}} - \bar{B}\right) + \varepsilon_t^{tax}, \tag{15}$$

where $\bar{d}$ and $\bar{B}$ are the targets of government deficit (ΔB^G) and government debt B^G with debt

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[13] We assume that the public and private demand parameters are identical.

[14] Thus, $s_t^{M,D} = s^{M,D}\varepsilon_t^{M,D}$ where $s^{M,D}$ denotes the steady-state import share of D.

[15] $z_t \equiv \frac{Z_t}{Y_t}$. We have also experimented with more complex fiscal rules and find similar results. We prefer the current formulation for its simplicity.

rule coefficients η^d and η^B, respectively. ρ^{tax} governs the persistence of the debt rule. ε_t^{tax} is a white noise shock.

The ECB's notional rate ("target rate") follows a standard Taylor rule, as follows:

$$i^{not}_{EA,t} = \rho^i_{EA} i_{EA,t-1} + \left(1 - \rho^i_{EA}\right) \left(-\bar{i} + \eta^{i\pi}_{EA} \left(\pi^{C,QA}_{EA,t} - \bar{\pi}^{C,QA}_{EA}\right) + \eta^{iy}_{EA} \tilde{y}_{EA,t}\right) , \tag{16}$$

where $\pi^{C,QA}_{EA,t}$, $\bar{\pi}^{C,QA}_{EA}$, and $\tilde{y}_{EA,t}$ denote the EA annualized inflation rate, EA steady-state inflation, and the EA output gap, respectively.[16] ρ^i_{EA}, $\eta^{i\pi}_{EA}$, and η^{iy}_{EA} govern interest rate inertia and the response to annualized inflation and the output gap, respectively. The notional rate, $i^{not}_{EA,t}$, equals the effective policy rate $i_{EA,t}$ only if it is above the ZLB. The effective policy rate satisfies

$$i_{EA,t} = \max\{i^{not}_{EA,t}, 0\} + \varepsilon^i_t, \tag{17}$$

where ε^i_t is a white noise monetary policy shock.

2.6 Remainder of the model

The stylized REA and RoW model blocks consist of an Euler equation, a production function, a New Keynesian Phillips curve, and a Taylor rule. Unless explicitly stated otherwise, the logarithm of all exogenous shock processes follows an AR(1) process with Gaussian innovations. Appendix A provides the remaining details.

3 Empirical strategy and estimates

3.1 Data

We estimate the model using data from 1999Q1 to 2018Q4, where the domestic economy corresponds to that of Spain. The REA aggregates the remaining EA countries based on Eurostat data. The RoW covers most of the world's GDP building on the IMF International Financial Statistics (IFS) and the World Economic Outlook (WEO) databases. In total, the estimation observes 38 data series, including government debt, government expenditure, government interest payments, transfers, and public investment. Appendix C provides details on the data sources and transformations.

3.2 Nonlinear estimation procedure

To account for the occasionally binding constraints on nominal wage growth and nominal interest rates, we build on OccBin (Guerrieri and Iacoviello 2015). This method handles the

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[16] See additional details on the specification in Appendix A.

constraints as different regimes of the same model, where the constraints are either slack or binding. Consequently, our model with ZLB and DNWR consists of the following four regimes: an unconstrained baseline; two variations, which include either a DNWR or a ZLB constraint leaving the other constraint slack; and a regime in which both constraints are active. Notably, the dynamics within any regime depend on its endogenous length. The expected duration, in turn, depends on the state variables and exogenous disturbances. As emphasized in Guerrieri and Iacoviello (2015), this interaction can result in highly nonlinear dynamics. Following Giovannini et al. (2021), we integrate the nonlinear solution into a specially adapted Kalman filter and estimate the model with the two occasionally binding constraints.[17] Appendix D reports additional details on the algorithm and convergence.

3.3 Calibration and posterior estimates

Table 1 reports the calibrated parameter values. We calibrate $\gamma = 1$. Thus, the DNWR constraint dictates that wage growth must be non-negative. This value also corresponds to the estimate (1.006) in Schmitt-Grohé and Uribe (2016), adjusted for foreign inflation and technology growth.[18] The other calibrated parameters match the long-run data output shares. The consumption and investment shares are 0.58 and 0.20 of GDP, respectively. We set the consumption and profit tax rates to 0.2 and 0.3, respectively. The steady-state SSC rate (0.084) corresponds to the observed average.[19] The labor tax rate ensures a balanced budget in the steady state. Following survey evidence (Dolls et al., 2012), we calibrate the share of Ricardian households to 0.69. The GDP share of Spain in the EA and that in the World GDP are approximately 11% and 2%, respectively. Import shares for consumption and investment goods are 0.23 and 0.30, respectively.[20]

Table 2 reports priors and posterior parameter estimates. The estimated habit persistence (0.67) mirrors the sluggish response of consumption to income. The estimated risk aversion (1.48) and inverse Frisch elasticity (3.59) align with other macro models. The import elasticity of 1.20 is rather low. We find significant real wage rigidities and investment adjustment costs. The estimated persistence of fiscal rules is high. Substantial habit persistence in the REA and RoW captures macroeconomic persistence in the absence of other frictions in the simplified model blocks. Appendix C reports additional estimated parameters and shock processes.

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[17] This method builds on a piecewise linear Kalman filter method instead of an inversion filter (as Guerrieri and Iacoviello, 2017), allowing for substantial speed gains and more flexible latent shock structures. We estimate the piecewise linear model approximation with a parallelized Metropolis-Hastings algorithm with 400,000 draws.

[18] The average quarterly inflation rate in Germany was 0.3%, and the average per capita GDP growth in the southern EA was approximately 0.3%. This calculation gives $1.006/(1.003 \times 1.003) \approx 1$. We have also experimented with $\gamma = 0.995$, and find similar results.

[19] Taken from the European Commission, DG TAXUD: `https://ec.europa.eu/taxation_customs/sites/taxation/files/social-contributions.xlsx`.

[20] We assume that the import shares, government investment and consumption shares equal those of the private sector.

	Households	
Intertemporal discount factor	β	0.998
Savers share	ω^s	0.690
Import share REA	s^M_{REA}	0.150
Import share RoW	s^M_{RoW}	0.039
Import share in consumption	$s^{M,C}$	0.227
Import share in investment	$s^{M,I}$	0.303
Import share in export	$s^{M,X}$	0.328
Weight of disutility of labor	ω^n	2.121
	Production & frictions	
Cobb-Douglas labor share	α	0.650
Depreciation of capital stock	δ	0.012
Linear capacity utilization adj. costs	$\gamma^{cu,1}$	0.017
Wage growth constraint (DNWR)	γ	1
Final goods demand elasticity	σ^y	111.091
Steady state wage markup	μ^w	1.200
	Fiscal policy	
Social security contributions	ssc	0.084
Consumption tax	τ^C	0.200
Corporate profit tax	τ^K	0.300
Labor tax	τ^N	0.301
Deficit target	$\bar{d}$	0.020
Debt target	$\bar{B}$	2.370
	Steady state ratios	
Share of Spain in World GDP (%)	size	1.854
Private consumption share in SS	C/Y	0.585
Private investment share in SS	I/Y	0.203
Govt consumption share in SS	C^G/Y	0.184
Govt investment share in SS	I^G/Y	0.035
Transfer share in SS	T/Y	0.137

Table 1: Selected calibrated structural parameters

		Prior distribution			Posterior distribution		
		Distr.	Mean	Std.	Mode	10%	90%
Preferences							
Habit persistence	h	Beta	0.50	0.10	0.67	0.58	0.77
Risk aversion	θ	Gamma	1.50	0.20	1.48	1.21	1.73
Inverse Frisch elasticity	θ^N	Gamma	5.00	1.00	3.59	2.56	4.68
Import price elasticity	σ^d	Gamma	2.00	0.40	1.20	1.09	1.32
Final good CES elasticity	σ^y	Gamma	0.50	0.20	0.47	0.15	0.78
Nominal and real frictions							
Price adjustment cost	γ^P	Gamma	40.00	20.00	26.87	16.39	37.62
Wage adjustment cost	γ^w	Gamma	5.00	2.00	12.54	7.90	17.27
Real wage rigidity	γ^{wr}	Beta	0.50	0.10	0.82	0.73	0.90
Employment adjustment cost	γ^N	Gamma	20.00	15.00	0.05	0.00	0.10
Capacity utilization adjustment cost	$\gamma^{cu,2}$	Gamma	0.01	0.00	0.01	0.01	0.01
Investment adjustment cost	$\gamma^{I,1}$	Gamma	20.00	15.00	12.95	5.16	21.39
Investment adjustment cost (slope)	$\gamma^{I,2}$	Gamma	20.00	15.00	52.81	22.74	77.35
Fiscal policy							
Gov. expenditure persistence	ρ^G	Beta	0.70	0.10	0.94	0.91	0.97
Gov. investment persistence	ρ^{IG}	Beta	0.70	0.10	0.92	0.90	0.93
Gov. transfer persistence	ρ^τ	Beta	0.50	0.20	0.92	0.88	0.97
Debt rule persistence	ρ^T	Beta	0.70	0.10	0.95	0.94	0.97
LS taxes response to deficit	η^d	Beta	0.03	0.01	0.03	0.02	0.04
LS taxes response to debt	η^B	Beta	0.02	0.01	0.01	0.00	0.01
REA region							
Habit persistence	h^{REA}	Beta	0.70	0.10	0.82	0.76	0.87
Phillips curve slope	$\phi^{y,REA}$	Beta	0.50	0.20	0.02	0.01	0.03
Price elasticity	$\sigma^{c,REA}$	Gamma	2.00	0.40	1.17	1.06	1.27
Risk aversion	θ^{REA}	Gamma	1.50	0.20	1.45	1.17	1.78
RoW region							
Habit persistence	h^{RoW}	Beta	0.70	0.10	0.87	0.83	0.91
Phillips curve slope	$\phi^{y,RoW}$	Beta	0.50	0.20	0.03	0.02	0.04
Price elasticity	$\sigma^{c,RoW}$	Gamma	1.50	0.20	1.84	1.39	2.31
Risk aversion	θ^{RoW}	Gamma	2.00	0.40	1.24	1.10	1.36

Table 2: Selected estimated structural parameters

4 Macroeconomic relevance of downward nominal wage rigidity

Before turning to our policy analysis, it is useful to highlight the macroeconomic relevance of the DNWR constraint through the lens of our estimated model. For this purpose, Figure 1 presents four simulations.

1. The first simulation (solid blue) is our *benchmark*. It feeds the estimated shocks into the baseline model with the occasionally binding DNWR constraint. By construction, the shocks recover the observed time series. The implied Kuhn-Tucker multiplier estimates the strength of DNWR, with a more negative value indicating more downward pressure.

2. The second simulation (dashed red) quantifies the macroeconomic amplification stemming from DNWR. For this purpose, it feeds the same set of estimated shocks into a model variant *without the DNWR constraint*, providing a counterfactual path of endogenous variables in the absence of the wage growth constraint.

3. The third simulation (dotted yellow) provides a "*no-demand slump*" scenario by additionally eliminating adverse domestic demand shocks (starting in 2009Q2) in a model version without the DNWR constraint.

4. The last simulation (dashed-dotted purple) feeds all the estimated shocks into a model *without ZLB* to quantify the amplification from this constraint.

The simulations show that DNWR was a central friction during the double-dip recession, explaining its depth. In 2009, when real GDP and hours worked contracted sharply, the DNWR was most acute, as indicated by the spike of the Kuhn-Tucker multiplier. At this point, the observed (blue) and counterfactual (dashed red) series diverge substantially. While GDP and hours fall sharply in the data, they remain relatively higher in the counterfactual path because, in the absence of DNWR, nominal wages help absorb adverse shocks. This adjustment strongly reduces the cyclical amplification and the adverse macroeconomic impacts of negative demand shocks. At the same time, the terms of trade improve more. This real exchange rate depreciation further stabilizes aggregate demand and employment. Overall, the effects of DNWR are quantitatively significant; in 2016, the gap between the two models amounts to approximately 3.5% of the real GDP, suggesting that DNWR explains approximately 40% of the severe recession in Spain.

Adverse demand shocks explain most of the remaining output contraction. In our "no-demand slump" scenario (yellow), which eliminates the DNWR constraint *and* all adverse demand shocks, the GDP hardly falls. By contrast, given Spain's share in the EA, we find only a limited role for the ZLB. While the last simulation (dashed-dotted purple) shows that the ZLB

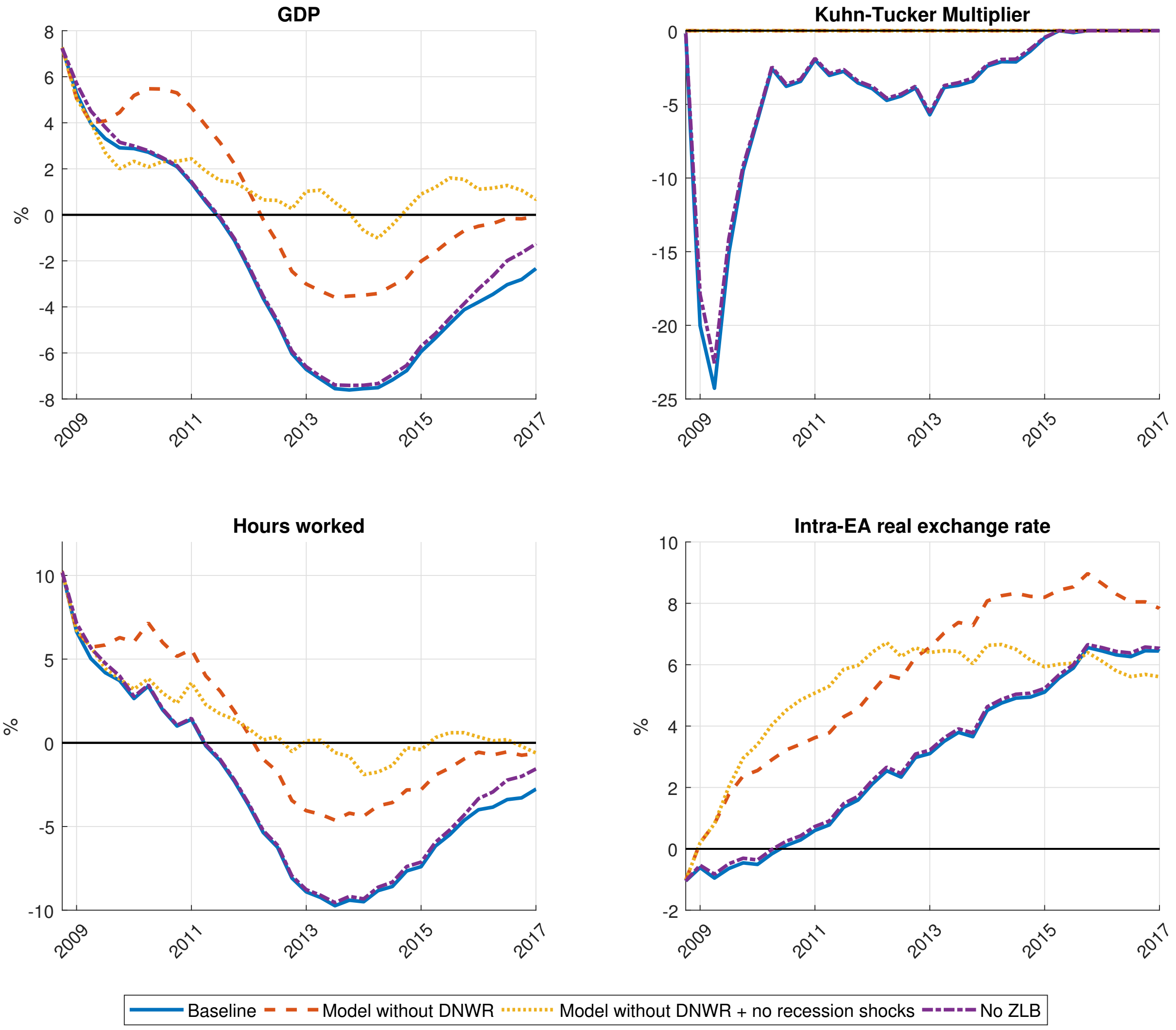

Figure 1: Macroeconomic amplification and downward nominal wage rigidity: Counterfactuals

Notes: This figure displays all the variables in percent deviation from trend (average GDP growth rate). The real exchange rate here is the price of foreign output in terms of domestic output, i.e., an upward movement indicates a depreciation. The solid blue line shows the observed variables (and estimates of the Kuhn-Tucker multiplier). The dashed red line shows smoothed estimates of the variables in a model without the DNWR constraint feeding in the estimated shocks. The dotted yellow line shows smoothed estimates in a simulation without the DNWR constraint and without stochastic demand shocks, i.e., $\varepsilon_{\tau}^{\mathcal{Z}} = 0$ for $\tau \in \{2009Q2, ..., 2018Q4\}$ and $\mathcal{Z} \in \{rf, S, C\}$. The purple dashed-dotted line displays simulations without the ZLB constraint.

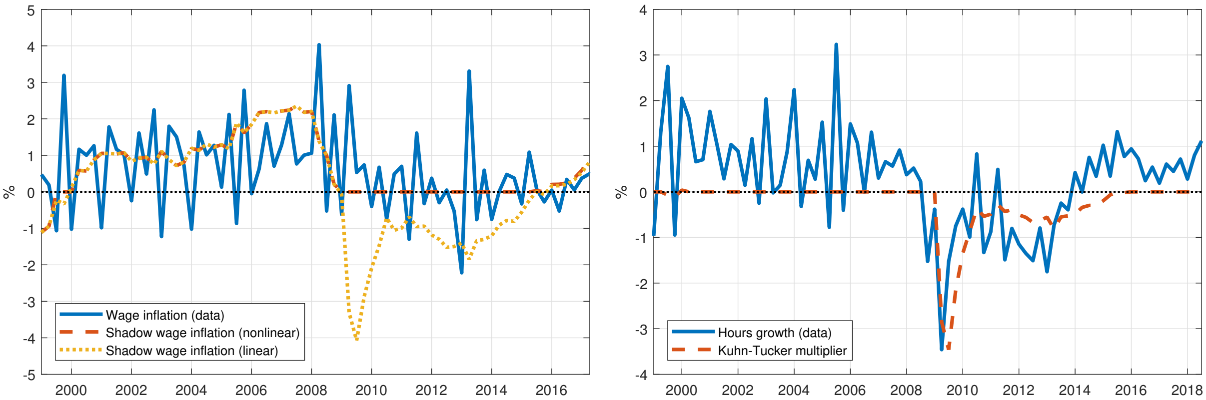

Figure 2: Wage inflation, hours worked, and DNWR

Notes: Left panel: The solid blue line shows the observed quarterly wage inflation. The dashed red (dotted yellow) line shows the smoothed estimates of wage inflation in the nonlinear model (a model without DNWR constraint), excluding the wage markup shock in period t. *Right panel*: The blue solid (dashed red) line shows the observed quarterly growth in hours worked (smoothed estimates of the Kuhn-Tucker multiplier on the DNWR constraint (λ^W)).

the ZLB is weaker than the distortion estimated for the DNWR constraint. In particular, the ZLB plays a negligible role in intra-EA competitiveness during this period.

Figure 2 shows that the estimated DNWR constraint captures the aggregate labor market dynamics well. As shown in the left panel, the quarterly wage inflation (solid blue) is volatile. The model fits these data mainly via the wage markup shock (ε_t^U), which enters the right-hand side of the wage eq. (7). The red dashed line shows the smoothed wage inflation series without the markup shock.

When considering the onset of the crisis, the labor demand and hours worked (right panel) contracted sharply. Given these fundamentals, the wage eq. (7) absent DNWR would predict a decrease in wages. In the data, however, the nominal wages remained relatively high. The limited wage response, thus, suggests that downward rigidities played an essential role in this period. Indeed, the estimated Kuhn-Tucker multiplier suggests a binding DNWR constraint around the same time. The right panel also shows that the multiplier (scaled) strongly co-moves with hours growth. It tracks unemployment in Spain during the recession(s); when unemployment increased in 2009 and 2012, the nominal wages remained high, and the binding DNWR substantially amplified adverse demand shocks. The next section analyzes the efficacy of different fiscal policy measures in this crisis environment.

5 Fiscal policy options under DNWR

This section considers the fiscal policy implications of DNWR in a monetary union, focusing on prototypical strategies. We are interested in their performance in a deep crisis and apply nonlinear methods (laid out in Section 5.2) to capture this aspect. Section 5.3 highlights the different macroeconomic transmission of the two strategies, while Section 5.4 inspects the role of state-dependence.

5.1 Two prototypical fiscal strategies

Our analysis distinguishes two fiscal stabilization strategies, as follows: reducing SSCs paid by firms and increasing government expenditure. Both capture central elements in the debate. In light of the externalities generated by DNWR, Schmitt-Grohé and Uribe (2016) propose wage subsidies (which are equivalent to SSC cuts in our model) as an optimal policy. Advocates of government spending point towards the beneficial real interest rate effects if the policy generates inflation. In an open economy, the DNWR constraint has *a priori* ambiguous consequences for government expenditure. On the one hand, the more muted (wage) inflation response implies a higher real interest rate. On the other hand, it mitigates adverse competitiveness effects.

To be clear, we do not study the optimal fiscal policy but focus on simple policy implementations. By contrast, the optimal fiscal policy in Schmitt-Grohé and Uribe (2016) entails a volatile path for wage subsidies (SSC reductions). In addition to practical implementation issues, a negative welfare effect can be implied if financed via government spending and if government spending enters the utility function.

5.2 Simulation experiments

We now discuss the implementation of our policy experiments in the nonlinear model.

The nonlinear algorithm. We generate state-dependent impulse response functions (IRFs) to policy changes in SSCs and government expenditure. As a starting point, our estimation provides smoothed endogenous variables α_t (including observed time series), estimated shocks η_t, and regime sequences R_t for each period. This state vector (α_t, η_t, R_t) provides the (same) initial condition for all of our following simulations. To recover the state-dependent IRFs, we subtract the effects of the initial conditions - obtained by running a simulation using only the initial conditions without any policy changes - from the total effects (including policy shocks). Thus, the IRFs account for the occasionally binding constraints *and* the observed and estimated latent variables. Starting in 2009Q4, when the estimated DNWR constraint was most severe, the simulations quantitatively assess the fiscal policy in an economic crisis.

Policy setup. We consider an ex-ante stimulus of 1% of GDP.[21] Thus, both measures entail ex ante identical budgetary costs. Ex post, however, the fiscal impact will be different due to the

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[21] For the SSC cut, this value corresponds to a temporary reduction in the SSC rate from 8.4% to 6.8%.

different transmission mechanisms and effects on the tax bases. The simulations assume that both policies last exogenously for approximately five years, mirroring the endogenous length of the DNWR regime.[22]

5.3 Macro effects of SSC cuts and government spending

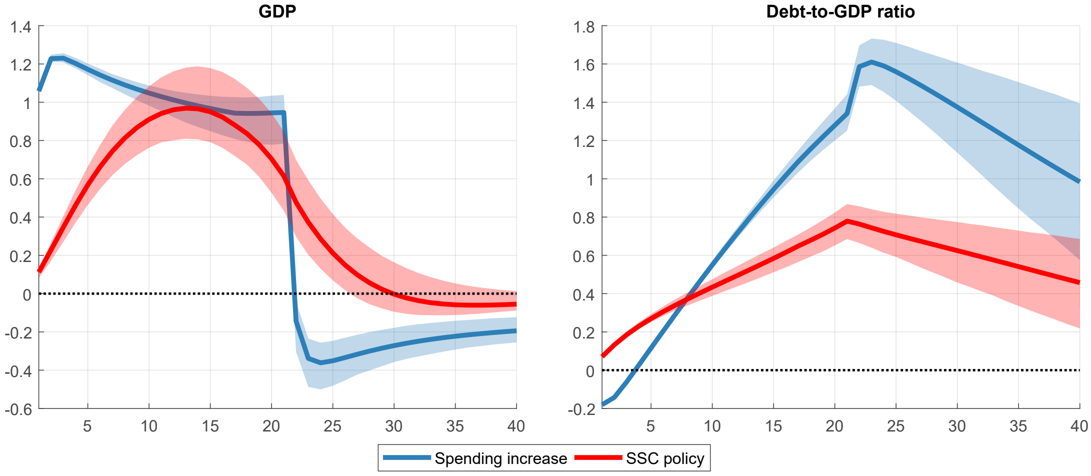

Figure 3: Macroeconomic effects of SSC cuts vs. spending increases

Notes: Red (blue) lines show the relative paths for an SSC cut (government expenditure shock) using the posterior mode of the parameter estimates. The shaded areas indicate 90% probability bands based on the posterior distribution of the structural parameters. We construct the state-dependent impulse response function as described in Section 5.2. The horizontal axis shows quarters. We express GDP (debt-to-GDP ratio) as the percent (percentage point) changes from a no-policy change baseline. Periods are quarters.

Real GDP growth. Both fiscal strategies yield similar and substantial positive peak GDP effects above one percent (Figure 3). While the SSC policy leads to a more gradual expansion than the expenditure increase, its output gains persist after the policy is discontinued.

Macroeconomic transmission. Figure 5 shows that the impact across demand components and the macroeconomic transmission differ substantially. The SSC policy lowers the production costs and expands aggregate demand via consumption, investment, and exports. First, the real wage income increases because of higher employment, allowing *both* households to consume more, as shown in Figure 4. Second, the fall in nominal wage costs raises employment

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[22] Technically, we model both policies as MA(21)-processes: $X_t = \sum_{q=0}^{21} \varepsilon^X_{t-q}$. The (ex-ante) fiscal efforts are thus identical on average and identical in each period. We have also run our main experiments assuming that fiscal policies are conditional on the DNWR regime, i.e., the government implements fiscal measures only as long as the DNWR constraint binds, and similar results were found.

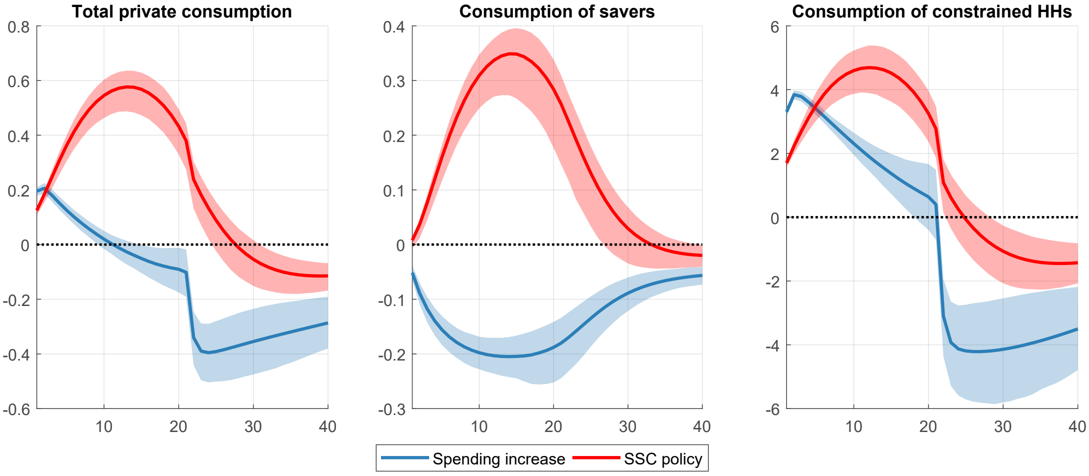

Figure 4: Macroeconomic effects of SSC cuts vs. spending increases: Private consumption

Notes: We express all variables as percent changes from a no-policy change baseline. For further details, see the description below Figure 3.

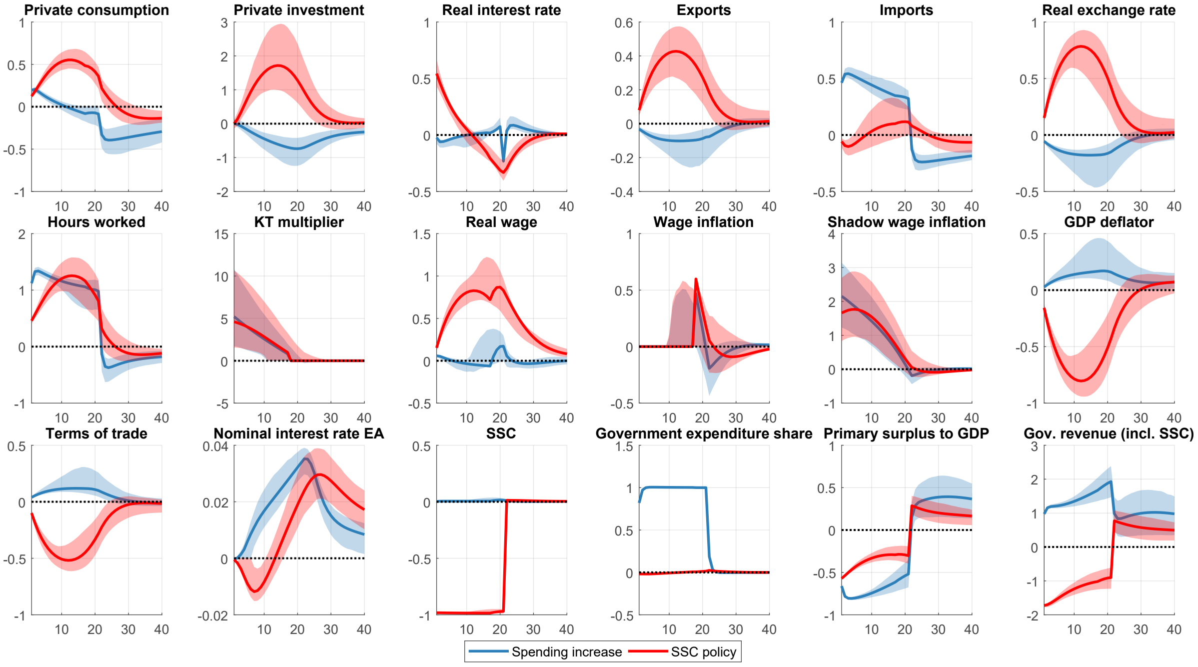

Figure 5: Macroeconomic effects of SSC cuts vs. spending increases: Details

Notes: We express all variables as percent changes from a no-policy change baseline except interest rates, inflation rates, SSCs, government expenditure, and the primary surplus over GDP, which are expressed in percentage point changes. Interest rates and inflation rates are annualized. The real exchange rate is the price of foreign output in terms of domestic output, i.e., an upward movement indicates a depreciation. Unless explicitly stated, all variables refer to Spain. For further details, see the description below Figure 3.

and the marginal product of capital. As a result, private investment increases.[23] Third, the marginal cost reduction outweighs the price effects of rising aggregate demand. In an open economy, the falling domestic prices then mimic an exchange rate devaluation, which improves the competitiveness and net exports. In summary, these effects increase the level of real GDP by approximately one percent after approximately ten quarters (at the posterior mode).

Regarding the expenditure increase, the crowding in remains small and vanishes after ten quarters. Initially, a higher net wage income allows liquidity-constrained households to consume more. However, the effects are smaller and more short-lived compared to those of the SSC policy (Figure 4). For savers, the real interest rate effect stemming from higher inflation does not lead to higher consumption. Concerning net exports, higher government spending reduces exports because of the real appreciation relative to the REA. Overall, the effects contrast with those of the SSC cut, which increases private consumption, investment, and exports. While the expenditure policy has a larger impact multiplier, its real GDP gains stem from government consumption (as opposed to private consumption) and are limited to the implementation time, disappearing after the stimulus ends.

Budgetary implications. The contrasting policy transmission implies different budgetary effects. This consideration is important since limited fiscal space and debt concerns were central to the EA crisis. All taxes (consumption tax, labor tax, and corporate tax) generate relatively more revenue in the SSC scenario. Because of the persistent increase in consumption, wage income, and profits, the fiscal shock has attractive self-financing properties. The increase in the wage sum is at the source of relatively more labor and consumption tax revenues. It further implies that SSC revenues do not drop one-to-one with the statutory rate. The corporate tax base increases relatively more strongly because lower costs translate into a profit increase. In summary, on the revenue side, reducing SSCs is preferable to higher expenditure.

The response of other expenditure components depends on the fiscal rules. Here, we assume that real expenditures, namely, government purchases, government investment, and transfers, remain constant.[24] Because SSC cuts generate less debt than spending increases, they also entail relatively fewer interest payments on the government debt.[25]

Overall, the distribution across public versus private and domestic versus foreign demand components differs markedly between the two fiscal strategies. Expanding government demand

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[23] Even though prices decline initially, the impact on the expected real rate remains limited. With the expenditure increase (see below), the real rate falls on impact and increases in the following years (as prices gradually return to the base).

[24] That is, we set $\rho^z = 1$ in eq. (12).

[25] Bianchi et al. 2019, in a model with DNWR and an endogenous sovereign default calibrated to Spain, show that the optimal fiscal policy depends on the country's initial debt level. When the debt stock is relatively low, government spending optimally expands in recessions. When the debt level is relatively high, it is optimal to raise spending and the default. For intermediate debt levels, however, the optimal fiscal response is characterized by austerity.

does not increase private demand, and crowding out effects dominate in the medium run. The additional expenditure does not directly exploit the fact that nominal wages remain constant despite increasing labor demand. Therefore, its stabilizing effects are not as persistent and vanish quickly after the regime switch. Additionally, government spending appears less attractive in terms of financing properties. It is less tax rich due to crowding out of investment and the relatively smaller gains in corporate profits and employment. By contrast, the SSC cut entails a positive effect on tax bases. It persistently increases private demand and exports. The latter resembles the composition effect more closely if the EA south would have a monetary policy instrument available. Our results, therefore, lend support to SSC cuts as a fiscal measure in a monetary union (or economies with exchange rate pegs) under limited budgetary space. Nonetheless, the policy is not self-financing and increases the public debt-to-GDP ratio.

5.4 State dependence

DNWR is important for both policy outcomes. To quantify its role, we compare the fiscal strategies in two model versions, i.e., with and without the nominal wage constraint. As above, we consider policy shocks of 1% of GDP (ex ante). Both simulations apply the same initial conditions.

Figure 6a shows that the SSC multiplier (red, dashed line) substantially increases in the presence of a binding nominal wage constraint. We show additional details in Appendix B. During a deep recession, DNWR prevents nominal wages from falling below the floor on wage growth. Under such circumstances, the expansionary policy does not increase nominal wages immediately. As long as the "shadow" wage inflation remains negative, the SSC cut generates no upward pressure on nominal wages. As a result, this policy reduces the wage costs substantially more in the constrained wage regime than in the unconstrained regime, and the corresponding increase in labor demand is stronger. Even though the real wages increase less under DNWR, the real wage income increases more because of higher employment growth. This effect expands household consumption. Additionally, since the nominal wage costs fall more, investment increases more and lower prices improve competitiveness and exports. As a consequence, all demand components increase more under DNWR.

Figure 6b also shows that the government spending multiplier is larger under DNWR.[26] Government spending shocks transmit mainly via the employment channel and the real interest rate channel. DNWR affects both. Under DNWR, nominal wage costs initially do not increase in the constrained regime. The sufficient downward pressure caused by the deep recession mutes the nominal wage growth and strengthens labor demand. The positive employment effects reduce the crowding out in the medium-run. At the same time, the delayed inflation response reduces the positive effects stemming from lower real interest rates. Thus, the employment

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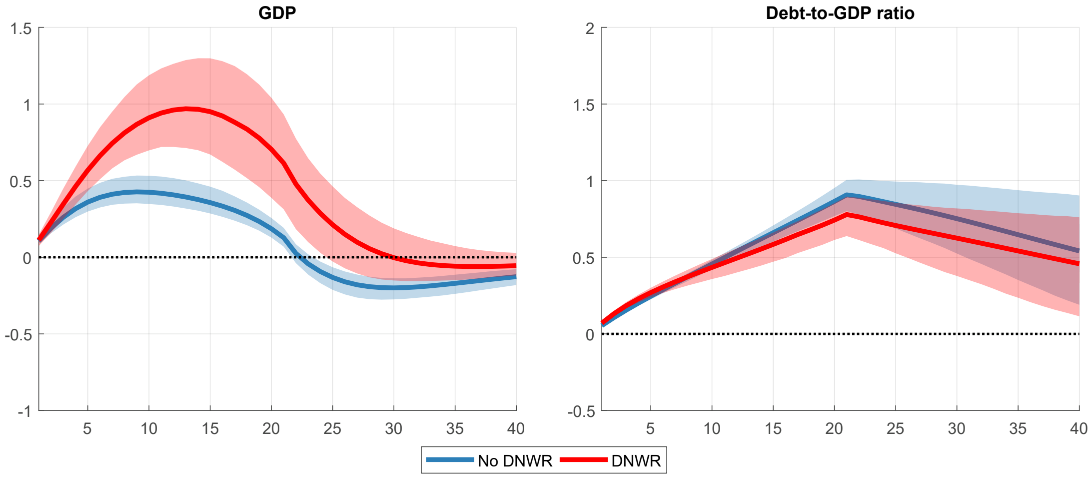
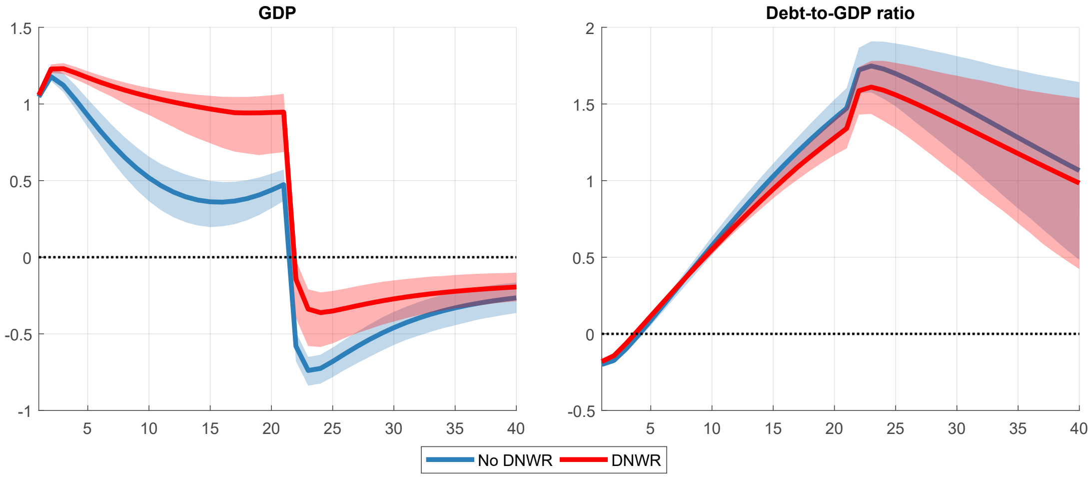
[26] See also Appendix B for details.



(a) SSC cuts



(b) Spending increases

Figure 6: State-dependence of fiscal policy

Notes: The red (blue) lines show relative paths for the baseline model (model without DNWR) using the posterior mode of the parameter estimates. The shaded areas indicate the 90% probability bands. For further details, see the description below Figure 3.

effect dominates the real interest rate effect (the latter declines less because of lower inflation).[27] However, this amplification remains more modest than for SSC cuts since the demand expansion does not directly exploit the fact that nominal wages will (initially) remain constant.

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[27] The real interest effect is larger in the absence of DNWR. In the monetary union (or at the ZLB), nominal interest rates remain almost constant.

6 Conclusion

The double-dip recession (2008-09 and 2011-2013) in several southern EA countries has been coupled with sizable competitiveness problems. Significant wage adjustment needs have arisen in the bust period because of high wage growth during the boom period. Downward nominal wage rigidity (DNWR) has prevented an adjustment of nominal wages and has led to a massive unemployment increase. Moreover, the monetary union rules out a large devaluation (see, e.g., Schmitt-Grohé and Uribe 2016), and the common standard monetary policy at the ZLB cannot provide sufficient stimulus.

How much stabilization can domestic fiscal policy achieve in this environment? Using an estimated nonlinear DSGE model, we compare the following two fiscal strategies: a cut in social security contributions (SSCs) paid by employers and increased government expenditure. The former targets the DNWR constraint and facilitates labor market clearing. For an open economy in a monetary union, this policy is particularly effective under DNWR; while the impact multiplier of government expenditure is large, the SSC reduction entails more persistent GDP effects through private demand and pronounced competitiveness gains. We show that the outcome of fiscal policy strongly depends on the cyclical conditions. Depending on the recession's severity, the SSC multiplier can be more than twice as large.

Debt stability concerns have been a central element of the crisis. The economy's adjustment to an SSC reduction is tax-rich because of its expansionary effects on tax bases. These features make this policy attractive for southern EA members suffering from limited fiscal space.

Future work should investigate the factors behind DNWR in more detail. In light of the strong externalities generated by DNWR, a natural question to ask is what type of structural reforms would help improve the smooth functioning of labor markets. This question is particularly relevant for Spain, where labor market reforms aimed at enhancing wage flexibility and competitiveness are ongoing. The distributional consequences of DNWR are another exciting avenue for future research.

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A Model details

The model shares many standard elements with Albonico et al. (2019).

A.1 Exogenous shock processes

Unless stated otherwise, the logarithm of ε_t^x follows an autoregressive process of order one with innovation ϵ_t^x

$$\log \varepsilon_t^x = \rho^x \log \varepsilon_{t-1}^x + u_t^x, \quad u_t^x \sim iid\mathcal{N}(0, \sigma^x) \tag{A.1}$$

where ρ^x and σ^x denote the autocorrelation coefficient and standard deviation of shock of type x, respectively.

A.2 REA and RoW economies

We model the REA and RoW economies as symmetric open economies, indexed $k \in \{REA, RoW\}$. We consider a production function, a New Keynesian Phillips curve, an aggregate budget constraint, an Euler equation, and a monetary policy rule. A perfectly competitive sector bundles imported and domestic goods.

Monopolistically competitive intermediate good producers use labor to manufacture domestic goods according to a linear production function.

$$Y_{k,t} = A_{k,t} N_{k,t}, \tag{A.2}$$

where $A_{k,t}$ captures a stochastic productivity trend and $N_{k,t} = Actr_{k,t} Pop_{k,t}$ is the active population in the economy. Price setting follows a New Keynesian Phillips curve with slope ϕ_k^y, as follows:

$$\pi_{k,t}^Y - \bar{\pi}_k^Y = \beta_{k,t} \frac{\lambda_{k,t+1}}{\lambda_{k,t}} (\pi_{k,t+1}^Y - \bar{\pi}_k^Y) + \phi_k^y \log \frac{Y_{k,t}}{\bar{Y}_k} + \varepsilon_{k,t}^Y, \tag{A.3}$$

where $\beta_{k,t} = \beta \exp(\varepsilon_{k,t}^C)$ is a stochastic discount factor and $\lambda_{k,t} = (C_{k,t} - h_k C_{k,t-1})^{-\theta_k}$ is the marginal utility of consumption with habit parameter h_k and risk aversion parameter θ_k. $\varepsilon_{k,t}^Y$ is a cost push shock.

The aggregate budget constraint in k is given by

$$P_{k,t} Y_{k,t} + D_{k,t} = P_{k,t}^C C_{k,t} + TB_{k,t}, \tag{A.4}$$

where $D_{k,t}$ are dividends from intermediate good producers. $TB_{k,t} = P_{k,t}^X X_{k,t} - P_{k,t}^M M_{k,t}$ are net exports, where $P_{k,t}^X$ and $X_{k,t}(P_{k,t}^M$, and $M_{k,t})$ denote export (import) prices and volumes, respectively. The consumption Euler equation is

$$1 = E_t \left[\Lambda_{k,t,t+1}^* \frac{R_{k,t}}{1 + \pi_{k,t+1}^{C,*}} \right], \tag{A.5}$$

where $\Lambda_{k,t,t+1} = \beta_{k,t} \frac{\lambda_{k,t+1}}{\lambda_{k,t}}$.

Monetary policy in the EA and the RoW follows Taylor (1993) rules. Notional interest rates $i_{k,t}^{not}$

respond sluggishly to deviations of inflation and the output gap from their respective target levels.[28] Slightly abusing the notation, let k denote here EA and RoW.

$$i^{not}_{k,t} - \bar{i} = \rho^i_k(i_{k,t-1} - \bar{i}) + (1-\rho^i_k)\left[\eta^{i\pi}_k 0.25\left(\pi^{C,QA}_{k,t} - \bar{\pi}^{C,QA}\right) + \eta^{iy}_k \tilde{y}_{k,t-1}\right] \tag{A.6}$$

where $\bar{i} = 0.02$. $\pi^{C,QA}_t$ denotes the quarterly annualized inflation and $\bar{\pi}^{C,QA}$ is its steady state value.[29] ρ^i_k, $\eta^{i,\pi}_k$, and $\eta^{i,y}_k$ govern the interest rate inertia and the response to annualized inflation and the output gap ($\tilde{y}_{k,t-1}$), respectively.

In the EA, the notional rate is equal to the effective policy rate i_t only if it is above the ZLB. The EA effective policy rate satisfies

$$i_{EA,t} = \max\{i^{not}_{EA,t}, 0\} + \varepsilon^i_{EA,t}, \tag{A.7}$$

and the RoW policy rate satisfies

$$i_{RoW,t} = i^{not}_{RoW,t} + \varepsilon^i_{RoW,t}, \tag{A.8}$$

where $\varepsilon^i_{k,t}$ is a white noise monetary policy shock.

Final aggregate demand $C_{k,t}$ (in the absence of investment and government spending in REA and RoW) is a combination of the domestic output, $Y_{k,t}$, and imported goods, $M_{k,t}$, using the following CES function with substitution elasticity σ^c_k:

$$C_{k,t} = A^p_{k,t}\left[\left(1 - s^M_{k,t}\right)^{\frac{1}{\sigma^c_k}} \left(Y^C_{k,t}\right)^{\frac{\sigma^c_k - 1}{\sigma^c_k}} + \left(s^M_{k,t}\right)^{\frac{1}{\sigma^c_k}} \left(M^C_{k,t}\right)^{\frac{\sigma^c_k - 1}{\sigma^c_k}}\right]^{\frac{\sigma^c_k}{\sigma^c_k - 1}}, \tag{A.9}$$

where $s^M_{k,t} = \exp(\varepsilon^M_{k,t})s^M_k$ denotes the stochastic import share with shock $\varepsilon^M_{k,t}$. Profit maximization implies the demand for domestic and foreign goods, as follows:

$$Y^C_{k,t} = (A^p_{k,t})^{\sigma^c_k - 1}(1 - s^M_{k,t})\left(\frac{P^Y_{k,t}}{P^C_{k,t}}\right)^{\sigma^c_k} C_{k,t}, \tag{A.10}$$

$$M^C_{k,t} = (A^p_{k,t})^{\sigma^c_k - 1} s^M_{k,t}\left(\frac{P^M_{k,t}}{P^C_{k,t}}\right)^{\sigma^c_k} C_{k,t}, \tag{A.11}$$

where the consumer price deflator $P^C_{k,t}$ satisfies the following:

$$P^C_{k,t} = \frac{1}{A^p_{k,t}}\left[(1 - s^M_{k,t})(P^Y_{k,t})^{1-\sigma^c_k} + s^M_{k,t}(P^M_{k,t})^{1-\sigma^c_k}\right]^{\frac{1}{1-\sigma^c_k}}. \tag{A.12}$$

The total nominal exports for REA and RoW to destination l are defined as follows:

$$P^X_{k,t}X_{k,t} = P^X_{l,k,t}M_{l,k,t}, \tag{A.13}$$

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[28] The output gap is measured as the (log) difference between actual and potential output. The potential output at date t is the output level that would prevail if the labor input equaled hours worked in the absence of nominal wage rigidity and TFP equaled its trend component.

[29] That is, $\pi^{C,QA}_t = \log\left(\sum_{r=0}^{3} P^C_{t-r}\right) - \log\left(\sum_{r=4}^{7} P^C_{t-r}\right)$.

with the bilateral export price being defined as the domestic price subject to a bilateral price shock, as follows:

$$P^X_{l,k,t} = \exp(\varepsilon^X_{l,k,t}) P^Y_{k,t}. \tag{A.14}$$

A.3 Households in ES

Saver households are identical and make identical choices. The first order necessary conditions in a symmetric equilibrium are for each $\mathcal{Q} \in \{B, rf, S, G\}$, as follows:

$$1 = E_t\left[\Lambda^s_{t,t+1} \frac{R^{\mathcal{Q}}_t + \varepsilon^{\mathcal{Q}}_t - \alpha^{\mathcal{Q}}}{1 + \pi^{C,vat}_{t+1}}\right], \tag{A.15}$$

where $\alpha^{rf} = 0$, $\lambda^s_t = (C^s_t - h^s C^s_{t-1})^{-\theta}$, and $\Lambda^s_{t,t+1} = \beta_t \frac{\lambda^s_{t+1}}{\lambda^s_t}$. Investment in foreign bonds follows a standard uncovered interest rate parity (UIP) condition:

$$E_t\left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right] i^W_t = i^{rf}_t + rprem^W_t, \tag{A.16}$$

where i^W_t and $rprem^W_t$ are the return and risk premium on the foreign bond, respectively.

A.4 Labor markets in ES

Labor packers. Labor packers have access to a CES production technology:

$$N_t = \left(\int_0^1 N_{jt}^{\frac{\sigma^n - 1}{\sigma^n}} dj\right)^{\frac{\sigma^n}{\sigma^n - 1}} \tag{A.17}$$

where σ^n denotes the substitution elasticity. The labor packers maximize output as follows:

$$\max_{\{N_{jt}\}} W_t N_t - \int_0^1 W_{jt} N_{jt} dj = W_t \left(\int_0^1 N_{jt}^{\frac{\sigma^n - 1}{\sigma^n}} dj\right)^{\frac{\sigma^n}{\sigma^n - 1}} - \int_0^1 W_{jt} N_{jt} dj. \tag{A.18}$$

Combining the first-order condition with a zero-profit condition gives the packers' labor demand

$$N_{jt} = \left(\frac{W_{jt}}{W_t}\right)^{-\sigma^n} N_t. \tag{A.19}$$

Unions. Trade unions maximize a discounted future stream of utility

$$\max_{W_{jt}} U_{j0} = \sum_{t=0}^{\infty} \beta^t u(C_{jt}, N_{jt}, \cdot). \tag{A.20}$$

Utility maximization is subject to a nonlinear downward nominal wage rigidity (DNWR) constraint, which dictates that wage growth must be positive:

$$\frac{W_{jt}}{W_{jt-1}} - 1 \geq 0. \tag{A.21}$$

Additional constraints are the demand from labor packers (A.19) and the joint household budget constraint:

$$P_t^{c,vat} C_{jt} + \Gamma_t^W + \omega^s B_{jt} = (1-\tau_t^N) W_{jt} N_{jt} + TR_{jt} - T_{jt} + \omega^s \left(R_t^r B_{jt-1} + \Pi_t \right), \tag{A.22}$$

where $\Gamma_t^W = \frac{(\sigma^n - 1)\gamma^w}{2} W_t N_t \left(\pi_t^W - \pi^w \right)^2$ captures the wage adjustment costs and π_t^W denotes the quarterly wage inflation.

Allowing for real wage rigidity as in Blanchard and Galí (2007) and imposing a symmetric equilibrium, the labor supply follows the following:

$$\begin{aligned} \left(\frac{\mu^w U_{N,t}}{\lambda_t} \right)^{1-\gamma^{wr}} \left[\frac{(1-\tau_t^N) W_{t-1}}{P_{t-1}^C} \right]^{\gamma^{wr}} &= \\ \frac{W_t}{P_t^C} \left[(1-\tau_t^N) + \frac{\partial \Gamma_t^W}{\partial W_t} \right] - \beta_t E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{1}{P_{t+1}^C} \frac{\partial \Gamma_{t+1}^W}{\partial W_{t+1}} - \tilde{\lambda}_{t+1}^W \right] &+ \hat{\lambda}_t^W \pi_t^W + \frac{W_t}{P_t^C} \varepsilon_t^U, \end{aligned} \tag{A.23}$$

where $U_{N,t} \equiv \frac{\partial U_t}{\partial N_t}$ denotes the average marginal disutility from labor across household groups. $\lambda_t = \omega^s \lambda_t^s + (1-\omega^s) \lambda_t^c$ denotes the aggregated marginal utility of consumption, and $\mu^w = \frac{\sigma^n}{1-\sigma^n}$ is the gross wage markup. $P_t^{C,vat} = (1+\tau^C) P_t^C$. Finally, $\hat{\lambda}_t^W = \lambda_t^W \frac{(\mu^w - 1)}{N_t \lambda_t} \pi_t^W$ and $\tilde{\lambda}_{t+1}^W = \lambda_{t+1}^W \frac{(\mu^w - 1)}{N_t \lambda_t} \pi_{t+1}^W$.

A.5 Intermediate goods in ES

Each firm $i \in [0,1]$ produces a variety of domestic goods, which are imperfect substitutes for the varieties of goods produced by other firms. Firms combine total capital, K_{it-1}^{tot}, and labor, N_{it} in a Cobb-Douglas production function:

$$Y_{it} = \left[A_t (N_{it}) \right]^{\alpha} \left[cu_{it} K_{it-1}^{tot} \right]^{1-\alpha} - A_t \Phi_i, \tag{A.24}$$

where α is the steady-state labor share, A_t represents labor-augmenting productivity common to all firms in the differentiated goods sector, and cu_{it} denotes firm-specific capital utilization. Φ_i captures fixed costs in production. Total capital is a sum of private installed capital, K_{it}, and public capital, K_{it}^G:

$$K_{it}^{tot} = K_{it} + K_{it}^G. \tag{A.25}$$

A_t follows

$$\log(A_t) - \log(A_{t-1}) = g^A + \varepsilon_t^A, \tag{A.26}$$

where g^A is the long-run growth of technology. ε_t^A is a permanent technological shock.

The period t profit of an intermediate goods firm i is given by:

$$\Pi_{it}^f = (1-\tau^K) \left(\frac{P_{it}}{P_t} Y_{it} - \frac{W_t}{P_t} N_{it} (1 + ssc) \right) + \tau^K \delta \frac{P_t^I}{P_t} K_{it-1} - \frac{P_t^I}{P_t} I_{it} - \Gamma_{it}, \tag{A.27}$$

where I_{it} is the physical investment at price P_{it}^I, ssc are social security contributions, τ^K is the corporate tax and δ is the capital depreciation rate.

Firms face quadratic factor adjustment costs, Γ_{it}, measured in terms of the production input factors, as follows:

$$\Gamma_{it} = \Gamma_{it}^P + \Gamma_{it}^N + \Gamma_{it}^I + \Gamma_{it}^{cu} \tag{A.28}$$

Specifically, the adjustment costs associated with the output price P_{it}, labor input N_{it}, investment I_{it}, and capacity utilization cu_{it} are as follows:

$$\Gamma_{it}^P = \sigma^Y \frac{\gamma^P}{2} Y_t \left[\frac{P_{it}}{P_{it-1}} - \exp(\bar{\pi}) \right]^2, \tag{A.29}$$

$$\Gamma_{it}^N = \frac{\gamma^N}{2} Y_t \left[\frac{N_{it}}{N_{it-1}} - \exp(g^{pop}) \right]^2, \tag{A.30}$$

$$\Gamma_{it}^I = \frac{P_t^I}{P_t} \left[\frac{\gamma^{I,1}}{2} K_{t-1} \Big(\frac{I_{it}}{K_{t-1}} - \delta_t^K \Big)^2 + \frac{\gamma^{I,2}}{2} \frac{(I_{it} - I_{it-1} \exp(g^Y + g^{P^I}))^2}{K_{t-1}} \right], \tag{A.31}$$

$$\Gamma_{it}^{cu} = \frac{P_t^I}{P_t} K_{it-1}^{tot} \left[\gamma^{cu,1}(cu_{it} - 1) + \frac{\gamma^{cu,2}}{2} (cu_{it} - 1)^2 \right], \tag{A.32}$$

where the γ-parameters capture the degree of adjustment costs. g^{pop}, g^Y, and g^{PI} are trend factors of population, GDP and prices for investment goods, respectively. $\delta_t^K \neq \delta$ is a function of the depreciation rate adjusted for the capital trend to have zero adjustment costs on the trend-path.[30] $\bar{\pi}$ denotes steady state inflation.

Monopolistically competitive firms maximize the real value of the firm, the discounted stream of expected future profits, subject to a downward-sloping demand function, $Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\sigma^y} Y_t$, the production technology (A.24), and a capital accumulation equation, $K_{it} = I_{it} + (1-\delta)K_{it-1}$. P_{it} is the price of intermediate inputs and the corresponding price index is as follows:

$$P_t = \left(\int_0^1 (P_{it})^{1-\sigma^y} di \right)^{\frac{1}{1-\sigma^y}}. \tag{A.33}$$

Firm i's problem is:

$$\max_{\{P_{it}, N_{it}, I_{it}, cu_{it}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} D_t^S \Pi_{it}^f, \tag{A.34}$$

where the stochastic discount factor, D_t^S, is:

$$D_t^S = \frac{1 + r_t^S}{\Pi_{r=t}^S (1 + r_r^S)} \tag{A.35}$$

with $1 + r_{t+1}^S = \frac{1+i_{t+1}^S}{1+\pi_{t+1}}$ being the real stock return.

Given the Lagrange multiplier associated with the technology constraint, μ^y, the FOCs with respect to labor, capital, investment, and capital utilization are given by the following:

$$(1 - \tau^K) \frac{W_t}{P_t} = \alpha \left(\mu_t^y - \varepsilon_t^{ND} \right) \frac{Y_t}{N_t} - \frac{\partial \Gamma_t^N}{\partial N_t} + E_t \Big[\frac{1 + \pi_{t+1}}{1 + i_{t+1}^s} \frac{\partial \Gamma_{t+1}^N}{\partial N_t} \Big], \tag{A.36}$$

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[30] We specify $\delta_t^K = \exp(g^Y + g^{PI}) - (1 - \delta)$ so that $\frac{I}{K} - \delta^k \neq 0$ along the trend path. g^Y and g^{PI} are trend factors of GDP and prices for investment goods, respectively.

$$Q_t = E_t\left[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{P^I_{t+1}}{P_{t+1}}\frac{P_t}{P^I_t}\left(\tau^K\delta - \frac{\partial\Gamma^{cu}_t}{\partial K_{t-1}} + Q_{t+1}(1-\delta) + (1-\alpha)\mu^Y_{t+1}\frac{P_{t+1}}{P^I_{t+1}}\frac{Y_{kt+1}}{K^{tot}_t}\right)\right], \tag{A.37}$$

$$\begin{aligned} Q_t = &\Big[1+\gamma^{I,1}\Big(\frac{I_t}{K_{t-1}} - \delta^K_t\Big) + \gamma^{I,2}\frac{(I_t - I_{t-1}\exp(g^Y + g^{P^I}))}{K_{t-1}}\Big] \\ -&E_t\Big[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{P^I_{t+1}}{P_{t+1}}\frac{P_t}{P^I_t}\exp(g^Y + g^{P^I})\gamma^{I,2}\frac{(I_{t+1} - I_t\exp(g^Y + g^{P^I}))}{K_t}\Big], \end{aligned} \tag{A.38}$$

$$\mu^y_t(1-\alpha)\frac{Y_t}{cu_t}\frac{P_t}{P^I_t} = K^{tot}_{t-1}\Big[\gamma^{cu,1} + \gamma^{cu,2}(cu_t - 1)\Big], \tag{A.39}$$

where $Q_t = \mu_t / \frac{P^I_t}{P_t}$. In a symmetric equilibrium, $P^Y_{i,k,t} = P^Y_{k,t}$, the FOC with respect to the output price $P^Y_{i,k,t}$ yields the New Keynesian Phillips curve, as follows:

$$\begin{aligned} \mu^y_t\sigma^Y = &(1-\tau^K)(\sigma^Y - 1) + \sigma^Y\gamma^P\frac{P_t}{P_{t-1}}\Big(\pi_t - \bar{\pi}\Big) \\ &- \sigma^Y\gamma^P\left[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{P_{t+1}}{P_t}\frac{Y_{t+1}}{Y_t}\Big(\pi_{t+1} - \bar{\pi}\Big)\right] + \sigma^Y\varepsilon^\mu_t, \end{aligned}$$

where ε^μ_t is the inverse of the markup shock.

A.6 Trade

Demand for domestic and imported components follows the following: $Y_t = \left(A^{p,D}_t\right)^{\sigma^d-1}\left(1-s^{M,D}_t\right)\left(\frac{P_t}{P^D_t}\right)^{-\sigma^d} D_t$ and $M^D_t = \left(A^{p,D}_t\right)^{\sigma^d-1} s^{M,D}_t \left(\frac{P^M_t}{P^D_t}\right)^{-\sigma^d} D_t$, where the price deflator associated with D_t is

$$P^D_t = \left(A^{p,D}_t\right)^{-1}\left[(1-s^{M,D}_t)(P_t)^{1-\sigma^d} + s^{M,D}_t(P^M_t)^{1-\sigma^d}\right]^{\frac{1}{1-\sigma^d}}. \tag{A.40}$$

P^M_t denotes the source weighted import prices.

A.7 Asset market clearing

We normalize $B^S_t = 1$, B^{rf}_t are zero in net supply and $B_t = B^B_t$. The internationally traded bond B^{bw}_t has a zero net supply globally.

B Additional results on state dependence

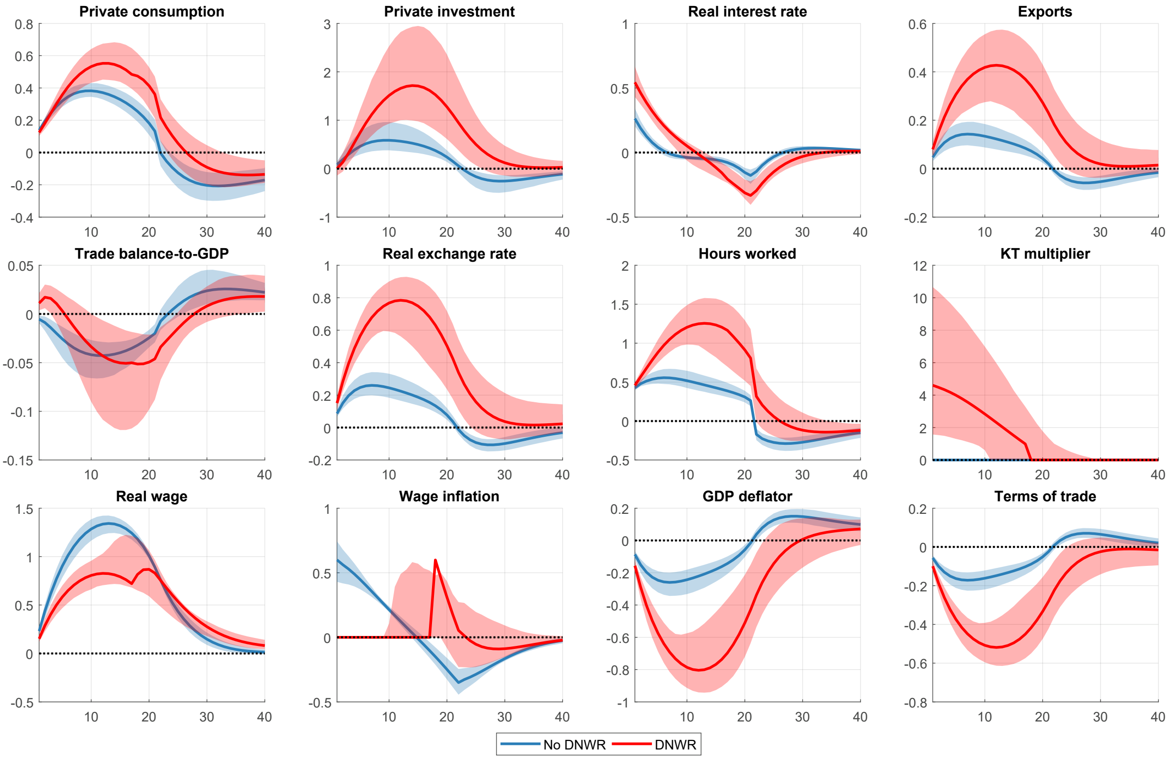


Figure B.1: State-dependence of SSC cuts

Notes: The red (blue) lines show the relative paths for an SSC cut (government expenditure shock) using the posterior mode of the parameter estimates. The shaded areas indicate the 90% probability bands based on the posterior distribution of the structural parameters. We express all variables as percent changes from a no-policy change baseline except interest rates, inflation rates, SSC, and government expenditure, which are expressed in percentage point changes. The interest rates and inflation rates are annualized. The real exchange rate is the price of foreign output in terms of domestic output, i.e., an upward movement indicates a depreciation. For further details, see the description below Figure 3.

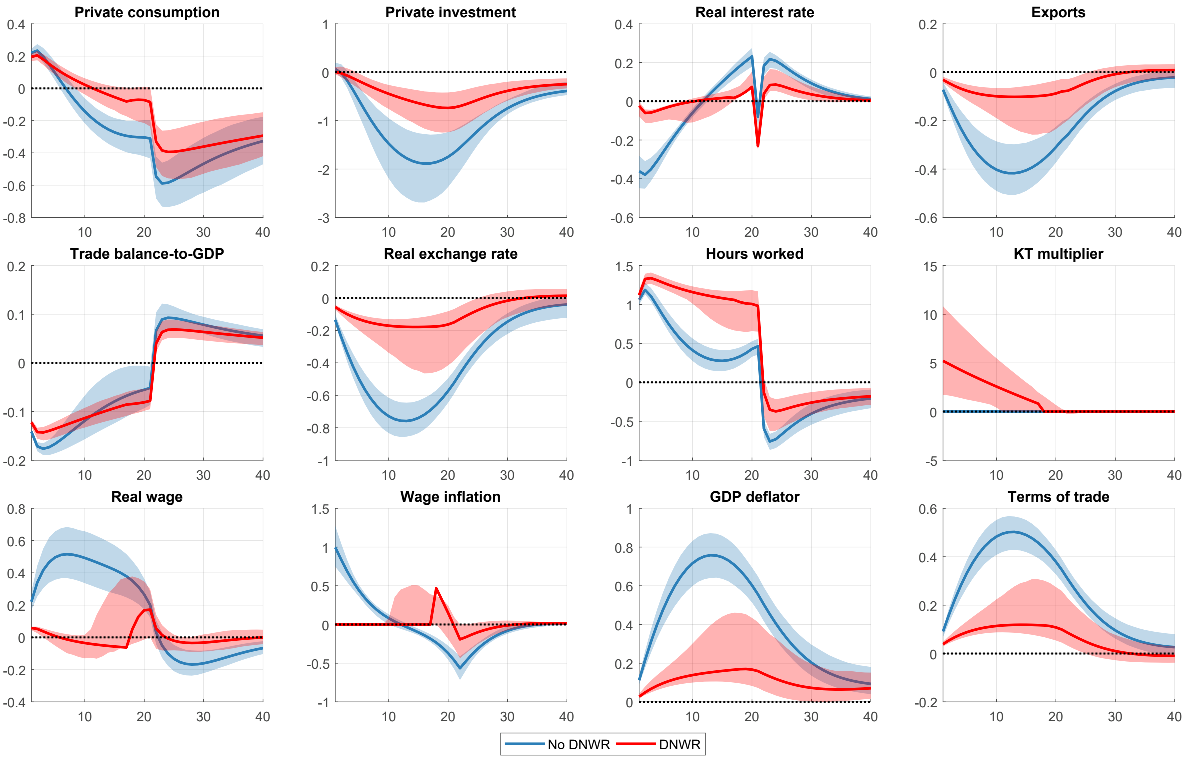


Figure B.2: State-dependence of spending increases

Notes: The red (blue) lines show the relative paths for an SSC cut (government expenditure shock) using the posterior mode of the parameter estimates. The shaded areas indicate the 90% probability bands based on the posterior distribution of the structural parameters. We express all variables as percent changes from a no-policy change baseline except interest rates, inflation rates, SSC, and government expenditure, which are expressed in percentage point changes. The interest rates and inflation rates are annualized. The real exchange rate is the price of foreign output in terms of domestic output, i.e., an upward movement indicates a depreciation. For further details, see the description below Figure 3.

C Data, calibration, and posterior estimates

C.1 Data sources

The data on social security contributions come from the European Commission, DG TAXUD, "Taxes on labour", Table 47, where we take the average value of the data sample until 2018.

For the estimation, we use quarterly and annual data for the period 1999Q1 to 2018Q4 based on the data set of the European Commission's Global Multi-country Model (Albonico et al., 2019). This appendix repeats the description for convenience.

The data for Italy and the rest of the euro area aggregate (REA) are taken from Eurostat (in particular, from the European System of National Account ESA95). Bilateral trade flows are based on trade shares from the GTAP trade matrices for trade in goods and services. The Rest of the World (RoW) data are annual data and are constructed using IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases.

The series for GDP and prices in the RoW start in 1999 and are constructed on the basis of data for the following 58 countries: Albania, Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Egypt, Georgia, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Israel, Japan, Jordan, Korea, Lebanon, Libya, FYR Macedonia, Malaysia, Mexico, Moldova, Montenegro, Morocco, New Zealand, Nigeria, Norway, Philippines, Poland, Romania, Russia, Saudi Arabia, Serbia, Singapore, South Africa, Sweden, Switzerland, Syria, Taiwan, Thailand, Tunisia, Turkey, Ukraine, United Arab Emirates, United Kingdom, USA and Venezuela. When not available, we obtain quarterly frequency data by interpolating annual data using the TRAMO-SEATS package developed by Gómez and Maravall (1996).

Table C.1 lists the observed time series. The GDP deflators and the relative prices of aggregates are computed as the ratios of the current price value to the chained indexed volume. The trend component of total factor productivity is computed using the DMM package developed by Fiorentini et al. (2012). The obtained series at quarterly frequency is then used to estimate the potential output.

We make a few transformations to the raw investment series. In particular, we compute the deflator of public investments based on annual data and then obtain its quarterly frequency counterpart through interpolation. This series together with nominal public investments is then used to compute real quarterly public investments. To assure consistency between nominal GDP and the sum of the nominal components of aggregate demand, we impute the change in inventories to the series of investments.

Figures C.3 to C.5 display the observed time series after removing loglinear trends.

	Spain
$\log \frac{B^g}{Y}$	Log of nominal gov. bonds share
$\log \frac{C^g}{Y}$	Log of nominal gov. consumption share
$\log \frac{C}{Y}$	Log of nominal consumption share
$\log \frac{i^g}{Y}$	Log of nominal gov. interest payments share
$\log \frac{I^g}{Y}$	Log of nominal gov. investment share
$\log \frac{I}{Y}$	Log of nominal investment share
$\log(N)$	Log of hours
$\log \frac{P^{c,vat}}{P}$	Log of consumption price final to observed GDP price
$\log \frac{P^g}{P}$	Log of gov. observed price to observed GDP price
$\log \frac{P^{IG}}{P}$	Log of govt. investment price to observed GDP price
$\log \frac{P^I}{P}$	Log of observed total investment price to observed GDP price
$\log \frac{P^M}{P}$	Log of import price to observed GDP price
$\log(Pop)$	Log of population
$\log \frac{P^X}{P}$	Log of export price to GDP price
$\log(P)$	Log of observed GDP price
$\log(t\bar{f}p)$	Log of TFP trend
$\log \frac{T}{Y}$	Log of nominal gov transfers share
$\log \frac{W}{Y}$	Nominal wage share
$\log \frac{X}{Y}$	Log of nominal export share
$\log(Y)$	Log of observed GDP
$\log \frac{TB}{Y}$	Nominal trade balance share
	Rest of the Euro Area
i_{EA}	EA nominal Interest rate
$\log(e_{EA})$	Log effective nominal exchange rate
$\log \frac{P^M}{P}$	Log of import price to observed GDP price
$\log(Pop)$	Log of population
$\log \frac{P^X}{P}$	Log of export price to GDP price
$\log(P)$	Log of observed GDP price
$\log(Y)$	Log of observed GDP
$\log(\bar{Y})$	Log of GDP trend
$\log \frac{TB}{Y}$	Nominal trade balance share
$\log \frac{X}{Y}$	Nominal export share of EA
	Rest of the World
i_{RoW}	RoW nominal Interest rate
$\log(Pop)$	Log of population
$\log(P)$	Log of observed GDP price
$\log(Y)$	Log of observed GDP
$\log(\bar{Y})$	Log of GDP trend

Table C.1: List of observables.

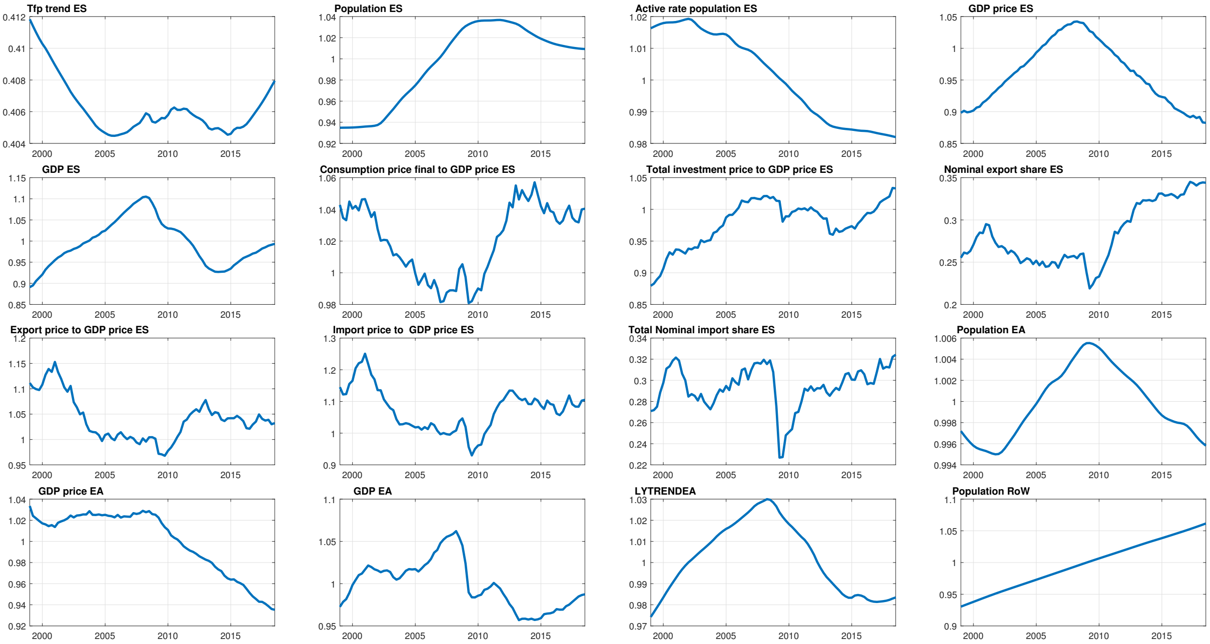


Figure C.3: Time series of observed variables

Notes: This figure displays the observed time series after removing (if applicable) the loglinear trends in population, technology and prices.

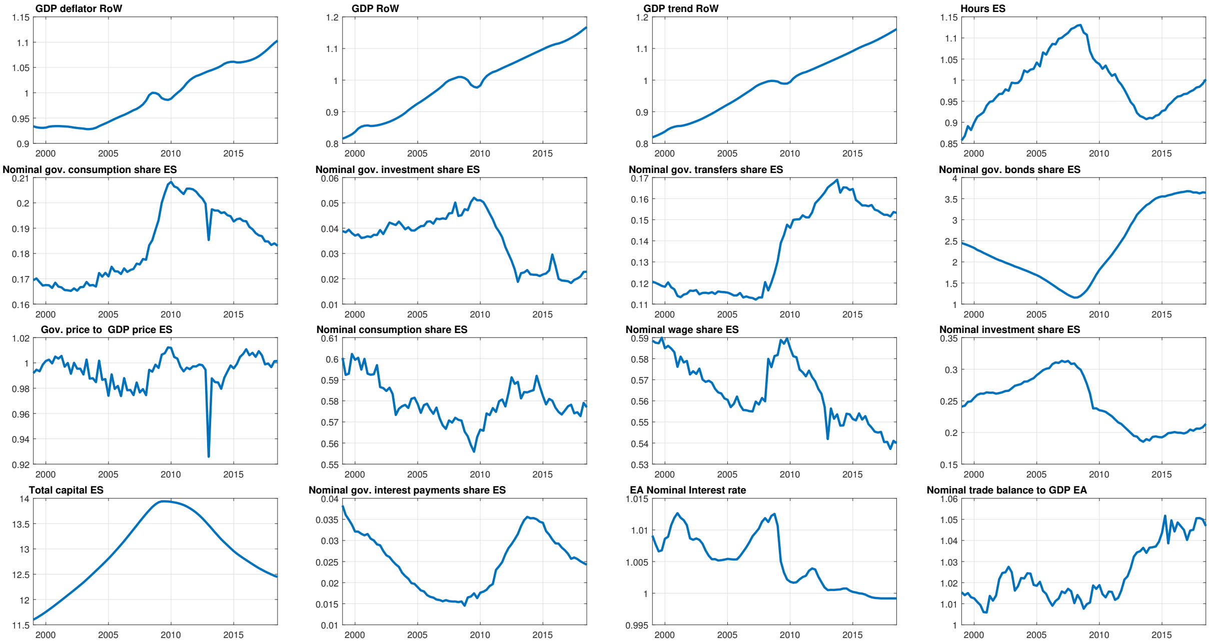
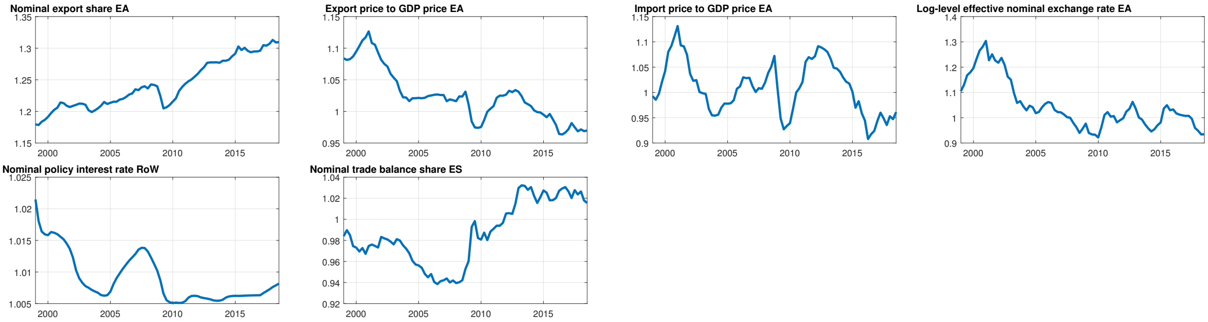


Figure C.4: Time series of observed variables

Notes: This figure displays the observed time series after removing (if applicable) the loglinear trends in population, technology and prices.


Nominal export share EA

Export price to GDP price EA

Import price to GDP price EA

Log-level effective nominal exchange rate EA

Nominal policy interest rate RoW

Nominal trade balance share ES

Figure C.5: Time series of observed variables

Notes: This figure displays the observed time series after removing (if applicable) the loglinear trends in population, technology and prices.

C.2 Additional calibrated parameters

Table C.2 reports additional calibrated parameters. The risk preferences match the steady-state risk premia. The monetary policy parameters are taken from an estimated two country model version where the EA is the detailed domestic economy (isomorphic to Spain in the model considered here; see also Albonico et al. 2019).

	Households	
Preference for government bonds	$\alpha^{B} * 100$	0.038
Preference for stocks	$\alpha^{S} * 100$	0.119
Preference for foreign bonds	$\alpha^{BW} * 100$	-0.537
	Monetary policy	
Response to annualized inflation EA	$\eta^{i\pi}_{EA}$	1.278
Response to output gap EA	η^{iy}_{EA}	0.099
Interest rate inertia EA	ρ^{i}_{EA}	0.866
Response to annualized inflation RoW	$\eta^{i\pi}_{RoW}$	1.250
Response to output gap RoW	η^{iy}_{RoW}	0.285
Interest rate inertia RoW	ρ^{i}_{RoW}	0.944

Table C.2: Selected calibrated structural parameters

C.3 Posterior estimates

Table C.3 reports estimated shock processes omitting shocks that explain only a negligible part of fluctuations in the main macroeconomic aggregates such as GDP and inflation.

		Prior distribution			Posterior distribution		
		Distr.	Mean	Std.	Mode	10%	90%
Autocorrelations of forcing variables							
Gov. risk premium	ρ^{B}	Beta	0.50	0.20	0.86	0.67	0.98
Discount factor	ρ^{C}	Beta	0.50	0.20	0.78	0.67	0.88
Flight to safety	ρ^{rf}	Beta	0.85	0.05	0.97	0.95	0.99
Investment risk premium	ρ^{S}	Beta	0.85	0.05	0.90	0.83	0.96
Labor demand	ρ^{ND}	Beta	0.50	0.20	0.79	0.72	0.86
Phillips curve	ρ^{Y}	Beta	0.50	0.20	0.71	0.58	0.84
Discount factor REA	ρ^{C}_{REA}	Beta	0.50	0.20	0.68	0.59	0.78
Export price REA	ρ^{PX}_{REA}	Beta	0.50	0.20	0.95	0.94	0.97
Important content REA	ρ^{M}_{REA}	Beta	0.50	0.20	0.97	0.95	0.98
Phillips curve REA	ρ^{Y}_{REA}	Beta	0.50	0.20	0.27	0.07	0.47
Discount factor RoW	ρ^{C}_{RoW}	Beta	0.50	0.20	0.88	0.82	0.93
Export price RoW	ρ^{PX}_{RoW}	Beta	0.50	0.20	0.86	0.79	0.93
Import content RoW	ρ^{M}_{RoW}	Beta	0.50	0.20	0.97	0.95	0.98
Phillips curve RoW	ρ^{Y}_{RoW}	Beta	0.50	0.20	0.67	0.55	0.79
Standard deviations (%) of innovations to forcing variables							
Government investment	ε^{IG}	Gamma	1.00	0.40	0.28	0.24	0.31
Government consumption	ε^{G}	Gamma	1.00	0.40	0.12	0.11	0.14
Government transfers	ε^{T}	Gamma	1.00	0.40	0.23	0.19	0.26
Debt rule shock	ε^{tax}	Gamma	1.00	0.40	1.97	1.70	2.25
TFP	ε^{A}	Gamma	0.20	0.04	0.09	0.08	0.11
Gov. risk premium	ε^{B}	Gamma	1.00	0.40	0.06	0.04	0.09
Discount factor	ε^{C}	Gamma	1.00	0.40	1.22	0.66	1.76
Investment risk premium	ε^{S}	Gamma	0.10	0.04	0.13	0.06	0.19
Price mark-up	ε^{MUY}	Gamma	2.00	0.80	4.43	3.07	5.69
Labor supply	ε^{U}	Gamma	1.00	0.40	0.77	0.67	0.88
Labor demand	ε^{ND}	Gamma	0.50	0.20	1.46	1.27	1.68
Flight to safety	ε^{rf}	Gamma	0.10	0.04	0.08	0.06	0.09
Trade share	ε^{M}	Gamma	1.00	0.40	2.66	2.32	3.01
Monetary policy EA	ε^{i}_{EA}	Gamma	1.00	0.40	0.10	0.09	0.11
International bond preferences EA	ε^{BW}_{EA}	Gamma	1.00	0.40	0.09	0.05	0.16
Export price REA	ε^{X}_{REA}	Gamma	1.00	0.40	0.34	0.30	0.38
Discount factor REA	ε^{C}_{REA}	Gamma	1.00	0.40	1.62	0.90	2.37
Import shock REA	ε^{M}_{REA}	Gamma	1.00	0.40	1.94	1.68	2.18
Phillips curve REA	ε^{Y}_{REA}	Gamma	1.00	0.40	0.17	0.13	0.21
TFP REA	ε^{A}_{EA}	Gamma	0.60	0.20	0.02	0.02	0.03
Export price RoW	ε^{X}_{RoW}	Gamma	1.00	0.40	2.50	2.21	2.80
Discount factor RoW	ε^{C}_{RoW}	Gamma	1.00	0.40	0.57	0.24	0.88
Import shock RoW	ε^{M}_{RoW}	Gamma	1.00	0.40	2.42	2.08	2.79
Phillips curve RoW	ε^{Y}_{RoW}	Gamma	1.00	0.40	0.06	0.04	0.08
Monetary policy RoW	ε^{i}_{RoW}	Gamma	1.00	0.40	0.07	0.06	0.08
TFP RoW	ε^{A}_{RoW}	Gamma	0.60	0.20	0.03	0.02	0.04

Table C.3: Exogenous processes

D Nonlinear estimation

D.1 Overview

We build on the OccBin toolkit (Guerrieri and Iacoviello 2015) to account for the occasionally binding constraint on nominal interest rates. This method handles the constraints as different regimes of the same model in which the constraints are either slack or binding. Consequently, our model consists of the following four regimes: an unconstrained baseline; two variations, which include either a DNWR or a ZLB constraint leaving the other constraint slack; and a regime in which both constraints are active. Importantly, the dynamics in all regimes depend on the endogenous length of that regime. The expected duration, in turn, depends on the state variables and exogenous disturbances. As emphasized in Guerrieri and Iacoviello (2015), this interaction can result in highly nonlinear dynamics.

Following Giovannini et al. (2021), we integrate the nonlinear solution into a specially adapted Kalman filter and estimate the model with the occasionally binding constraint. This approach is based on the so-called Piecewise Kalman Filter (PKF), a particular form of a nonlinear filter where the state-space representation becomes time-varying. At each time period, the filter proceeds in two steps. The first, the prediction step, is standard in the filtering of nonlinear models. The second (update) step is tailored to the piecewise linear model. In summary, the update step entails an iterative convergence procedure for the temporary binding regime materializing in each period, which ensures that the occasionally binding constraints are not violated. Giovannini et al. (2021) embed this iterative algorithm into a diffuse Kalman filter.

D.2 Details of the algorithm

The algorithm follows Giovannini et al. (2021). Let us define the local linear representation of the policy function of the DSGE model featuring OBC solved with the piecewise linear approach:

$$x_t = \mathbf{T}(x_{t-1}, \varepsilon_t)x_{t-1} + \mathbf{C}(x_{t-1}, \varepsilon_t) + \mathbf{R}(x_{t-1}, \varepsilon_t)\varepsilon_t \tag{D.41}$$

where x_t is the vector of endogenous variables in deviation from the steady state of the 'baseline' (normal time) regime. ε_t is the vector of shocks. The reduced form matrices **T** **C** and **R** are state-dependent. They are functions of the lagged states and the current period shocks (note that $\mathbf{C}(0, 0) = 0$ under the 'baseline' regime equilibrium).

In every period t, the piecewise linear solution ensures that, given the lagged states and the current shocks, the constraints are never violated for all periods $s \in [t, \infty)$. The state matrices need to be updated in the new period $t + 1$. A new shock in $t + 1$ can change the future sequence of state matrices expected given the shock in t, $\mathbf{T}_s(x_{t-1}, \varepsilon_t)$ $\mathbf{C}_s(x_{t-1}, \varepsilon_t)$ and $\mathbf{R}_s(x_{t-1}, \varepsilon_t)$. The one step recursion of the solution algorithm implies, in general, that:

$$\begin{aligned}
\mathbf{T}(x_{t-1}, \varepsilon_t) &\neq \mathbf{T}(x_t, \varepsilon_{t+1}) \\
\mathbf{C}(x_{t-1}, \varepsilon_t) &\neq \mathbf{C}(x_t, \varepsilon_{t+1}) \\
\mathbf{R}(x_{t-1}, \varepsilon_t) &\neq \mathbf{R}(x_t, \varepsilon_{t+1})
\end{aligned}$$

To simplify the notation, let us re-define the state matrices as follows:

$$\begin{aligned}\mathbf{T}_{t|t} &= \mathbf{T}(x_{t-1}, \varepsilon_t) \\ \mathbf{C}_{t|t} &= \mathbf{C}(x_{t-1}, \varepsilon_t) \\ \mathbf{R}_{t|t} &= \mathbf{R}(x_{t-1}, \varepsilon_t)\end{aligned}$$

$$\begin{aligned}\mathbf{T}_{t|t-1} &= \mathbf{T}(x_{t-1}, 0) \\ \mathbf{C}_{t|t-1} &= \mathbf{C}(x_{t-1}, 0) \\ \mathbf{R}_{t|t-1} &= \mathbf{R}(x_{t-1}, 0)\end{aligned}$$

State filtering and the likelihood. Assume we want to estimate the deep parameters of the model, given a set of observables y_t linked to x_t by the observation equation

$$y_t = \mathbf{H}x_t \tag{D.42}$$

where, for simplicity and without loss of generality, we assume no observation error. Let z_t denote the observations for y_t.[31]

Given the initial state mean and variance:

$$x_0, \mathbf{P}_0$$

and denoting their 'best' estimate thereof at any time $t-1$ as

$$x_{t-1|t-1}, \mathbf{P}_{t-1|t-1}, \tag{D.43}$$

the prediction step for states and observables reads:

$$\begin{aligned}x_{t|t-1} &= \mathbf{T}_{t|t-1} \cdot x_{t-1|t-1} + \mathbf{C}_{t|t-1} \\ \mathbf{P}_{t|t-1} &= \mathbf{T}_{t|t-1} \cdot \mathbf{P}_{t-1|t-1} \cdot \mathbf{T}'_{t|t-1} \\ y_{t|t-1} &= \mathbf{H}x_{t|t-1} \\ \mathbf{F}_t &= \mathbf{H} \cdot \mathbf{P}_{t|t-1} \cdot \mathbf{H}'\end{aligned} \tag{D.44}$$

The prediction step (D.44) is standard in filtering of nonlinear models, e.g., it is the same as for the extended Kalman Filter.

The update step is the critical element of the piecewise linear Kalman filter (PKF). It is tailored to the piecewise linear solution. The update step entails the following iterative procedure, which mimics the analog iterative procedure applied to simulate the model with the piecewise linear approach.

---

[31] We initialize the filter with the unconditional mean and variance of the 'baseline' regime with diffuse priors.

We initialize the guess of the updated state matrices as:

$$\begin{aligned}\mathbf{T}(\mathbf{0})_{t|t} &= \mathbf{T}_{t|t-1}\\ \mathbf{R}(\mathbf{0})_{t|t} &= \mathbf{R}_{t|t-1}\\ \mathbf{C}(\mathbf{0})_{t|t} &= \mathbf{C}_{t|t-1}\end{aligned}$$

Then, we iterate until convergence. Each iteration j follows the algorithm:

1. take the prediction step for the guess matrices $\mathbf{T}(j-1)_{t|t}$,$\mathbf{R}(j-1)_{t|t}$, $\mathbf{C}(j-)_{t|t}$:

$$\begin{aligned}x(j)_{t|t-1} &= \mathbf{T}(j-1)_{t|t}\cdot x_{t-1|t-1}+\mathbf{C}(j-1)_{t|t}\\ \mathbf{P}(j)_{t|t-1} &= \mathbf{T}(j-1)_{t|t}\cdot \mathbf{P}_{t-1|t-1}\cdot \mathbf{T}'(j-1)_{t|t}+\mathbf{R}(j-1)_{t|t}\cdot \mathbf{Q}\cdot \mathbf{R}'(j-1)_{t|t}\\ y(j)_{t|t-1} &= \mathbf{H}x(j)_{t|t-1}\\ \mathbf{F}(j)_t &= \mathbf{H}\cdot \mathbf{P}(j)_{t|t-1}\cdot \mathbf{H}'\\ v_t(j) &= z_t-y(j)_{t|t-1}\end{aligned}\tag{D.45}$$

2. update state and covariance given the guess matrices

$$\begin{aligned}\mathbf{K}_t(j) &= \mathbf{P}(j)_{t|t-1}\cdot \mathbf{H}'\\ x(j)_{t|t} &= x_{t|t-1}(j)+\mathbf{K}_t(j)\mathbf{F}_\mathbf{t}(j)^{-1}v(j)_t\\ \mathbf{P}(j)_{t|t} &= \mathbf{P}(j)_{t|t-1}-\mathbf{K}(j)_t\mathbf{F}_\mathbf{t}(j)^{-1}\mathbf{K}(j)_t'\end{aligned}\tag{D.46}$$

3. perform a one step backward iteration (a smoother step) to also update the state in $t-1$ given t and estimate the shock in t, i.e., for $s=t,t-1$

$$\begin{aligned}L_s &= \mathbb{I}-\mathbf{K}(j)_s\mathbf{F}_\mathbf{s}(j)^{-1}\mathbf{H}\\ r(j)_s &= \mathbf{H}'\mathbf{F}_\mathbf{s}(j)^{-1}v_s(j)+L_s'\mathbf{T}'(j-1)_{s|s}r(j)_{s+1}\\ x(j)_{s|t} &= x_{s|s-1}(j)+\mathbf{P}(j)_{s|s-1}\cdot r(j)_s\\ \varepsilon(j)_{s|t} &= \mathbf{Q}\cdot \mathbf{R}'(j-1)\cdot r(j)_s\end{aligned}\tag{D.47}$$

   where the backward one step recursion is initialized by $r_{t+1}=0$.

4. project the piecewise linear model given the initial condition $x(j)_{t-1|t}$ and shock $\varepsilon(j)_{t|t}$ for $s\in(t,\infty)$ and obtain the updated matrices $\mathbf{T}(j)_{t|t}$,$\mathbf{R}(j)_{t|t}$, $\mathbf{C}(j)_{t|t}$

   (a) if the updated state matrices are different from the guessed ones, update the guess matrices to $\mathbf{T}(j)_{t|t}$,$\mathbf{R}(j)_{t|t}$, $\mathbf{C}(j)_{t|t}$ and restart from 1) with $j+1$

   (b) otherwise, proceed to $t+1$ and until T, by setting updated state matrices

$$\begin{aligned}\mathbf{T}_{t|t} &= \mathbf{T}(j)_{t|t}=\mathbf{T}(j-1)_{t|t}\\ \mathbf{R}_{t|t} &= \mathbf{R}(j)_{t|t}=\mathbf{R}(j-1)_{t|t}\\ \mathbf{C}_{t|t} &= \mathbf{C}(j)_{t|t}=\mathbf{C}(j-1)_{t|t},\end{aligned}$$

as well as states and covariances

$$\begin{aligned} x_{t|t} &= x(j)_{t|t} \\ \mathbf{P}_{t|t} &= \mathbf{P}(j)_{t|t} \end{aligned}$$

Note that the updating algorithm applies one backward smoothing step for each period t. Each step of the algorithm is simple since it applies the standard Kalman filter formula, using the guess state matrices. For the piecewise linear solution method, this filtering and updating algorithm is optimal in the least-squares sense. Typically, one iteration is sufficient for the convergence of the updating step. In case of failed convergence, we give a penalty to the likelihood and attempt the use of a new proposal for the deep parameters.

Given the prediction error

$$v_t(j) = z_t - y(j)_{t|t-1} \tag{D.48}$$

we can compute the log-likelihood density of the data at time t as follows:

$$\mathcal{L}_t = \log(\det(\mathbf{F(j)_t})) + v(j)'_t \cdot \mathbf{F(j)_t}^{-1} \cdot v(j)_t + n_t \log(2\pi) \tag{D.49}$$

where j denotes the updated state matrices at the end of the update step and n_t denotes the number of observables available at time t.

D.3 Additional estimation results

D.3.1 Convergence

Table D.4 reports the inefficiency factor for all the estimated parameters and for all chains.

Table D.4: MCMC Inefficiency factors per block

Parameter	*Block* 1	*Block* 2	*Block* 3	*Block* 4
$SE_{\epsilon^{APC}_{ES}}$	513.450	514.668	414.143	510.975
$SE_{\epsilon^{APG}_{ES}}$	482.295	466.395	491.147	535.633
$SE_{\epsilon^{API}_{ES}}$	522.562	419.004	512.179	561.910
$SE_{\epsilon^{ND}_{ES}}$	441.035	400.741	477.224	536.646
$SE_{\epsilon^{FQ}_{ES}}$	515.091	472.454	378.025	528.452
$SE_{\epsilon^{G}_{ES}}$	473.256	475.862	438.475	573.601
$SE_{\epsilon^{LAYTREND}_{ES}}$	413.906	472.046	418.901	521.933
$SE_{\epsilon^{IG}_{ES}}$	484.428	445.152	381.092	463.376
$SE_{\epsilon^{M}_{ES}}$	540.894	547.379	455.124	501.503
$SE_{\epsilon^{MUY}_{ES}}$	403.470	443.540	514.271	539.850

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Table D.4: (continued)

Parameter	*Block* 1	*Block* 2	*Block* 3	*Block* 4
$SE_{\epsilon^{PX}_{ES}}$	447.852	541.068	444.731	490.370
$SE_{\epsilon^{T}_{ES}}$	520.410	462.747	536.079	496.052
$SE_{\epsilon^{TAX}_{ES}}$	508.727	532.456	438.957	592.496
$SE_{\epsilon^{UC}_{ES}}$	539.625	478.377	410.350	479.078
$SE_{\epsilon^{U}_{ES}}$	418.766	434.113	423.518	499.778
$SE_{\epsilon_{B,ES,ES}}$	541.108	597.225	497.995	606.429
$SE_{\epsilon_{S,ES,ES}}$	364.687	485.089	492.467	503.587
$SE_{\epsilon^{INV}_{ES}}$	538.999	467.226	566.906	616.491
$SE_{\epsilon^{PX}_{REA}}$	402.145	482.351	484.888	516.228
$SE_{\epsilon^{B}W_{EA}}$	572.788	603.503	443.109	359.872
$SE_{\epsilon^{I}NOM_{EA}}$	435.918	399.421	523.921	467.739
$SE_{\epsilon^{M}_{REA}}$	435.851	456.224	405.621	424.232
$SE_{\epsilon^{UC}_{REA}}$	509.983	548.110	576.906	590.034
$SE_{\epsilon^{Y}_{REA}}$	462.685	517.340	405.768	540.897
$SE_{\epsilon^{GAYTREND}_{REA}}$	410.957	353.162	485.121	443.442
$SE_{\epsilon^{LAYTREND}_{REA}}$	238.429	318.293	487.856	578.530
$SE_{\epsilon^{inom}_{RoW}}$	400.117	399.817	481.464	576.744
$SE_{\epsilon^{M}_{RoW}}$	396.406	437.949	514.282	544.585
$SE_{\epsilon^{M}_{ES,RoW}}$	457.688	468.623	461.306	559.827
$SE_{\epsilon^{PX}_{ES,RoW}}$	437.606	487.547	448.489	526.071
$SE_{\epsilon^{PX}_{REA,RoW}}$	555.031	510.931	426.027	556.488
$SE_{\epsilon^{UC}_{RoW}}$	532.867	668.419	439.499	453.313
$SE_{\epsilon^{Y}_{RoW}}$	543.907	497.911	501.524	554.241
$SE_{\epsilon^{GAYTREND}_{RoW}}$	514.592	385.410	471.767	507.731
$SE_{\epsilon^{AY}_{RoW}}$	493.572	397.596	310.150	402.747
$\rho_{FQ,ES}$	506.097	593.369	445.935	668.543
α^{bw}_{ES}	493.840	485.120	512.258	462.952
η^{BT}_{ES}	488.165	456.999	494.268	568.286
η^{DEFT}_{ES}	546.755	517.624	509.812	560.597
FC_{ES}	526.031	359.706	523.847	539.463
$\gamma^{I,1}_{ES}$	542.091	425.485	439.740	527.568
$\gamma^{I,2}_{ES}$	524.236	599.241	529.627	555.294
γ^{n}_{ES}	540.283	363.363	385.039	383.145
γ^{p}_{ES}	491.836	592.304	525.001	617.689
$\gamma^{u,2}_{ES}$	486.436	483.333	483.071	497.541
γ^{w}_{ES}	463.926	492.006	510.471	548.881

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Table D.4: (continued)

Parameter	*Block* 1	*Block* 2	*Block* 3	*Block* 4
γ_{ES}^{wr}	530.396	484.996	432.568	550.614
FN_{ES}	389.971	413.257	421.039	566.864
h_{ES}	513.390	567.098	382.956	482.189
ρ_{ES}^{G}	493.214	383.909	471.247	560.081
ρ_{ES}^{IG}	402.023	483.989	497.130	497.937
ρ_{ES}^{T}	430.718	546.726	430.984	549.353
ρ_{ES}^{INV}	506.404	527.638	510.143	581.378
ρ_{ES}^{INV2}	384.179	627.741	385.103	575.935
$\rho_{APC,ES}$	474.080	340.187	435.582	521.208
$\rho_{APG,ES}$	579.870	505.773	425.197	452.109
$\rho_{API,ES}$	431.264	514.572	445.181	597.099
ρ_{ES}^{M}	554.028	403.694	531.770	551.088
ρ_{ES}^{MUY}	433.215	449.156	401.877	456.631
$\rho_{ND,ES}$	426.278	342.518	416.036	525.956
$\rho_{P,ES}$	540.045	491.842	473.269	433.222
$\rho_{PX,ES}$	541.503	410.450	459.014	568.487
$\rho_{TAX,ES}$	513.536	363.286	383.584	458.776
σ_{ES}^{FM}	527.577	429.304	409.506	567.220
σ_{ES}^{o}	543.739	535.456	495.745	552.014
σ_{ES}^{z}	498.992	516.235	399.223	521.348
θ_{ES}^{N}	570.811	493.849	435.420	504.536
θ_{ES}	477.928	504.068	403.719	542.242
$\rho_{B,ES,ES}$	413.313	708.378	508.337	625.011
$\rho_{S,ES,ES}$	523.256	594.160	445.167	353.158
ρ_{REA}^{PX}	439.256	480.535	551.200	499.159
RHO_BW_EA	602.927	609.761	494.344	363.080
α_{REA}^{bw}	447.549	474.054	509.348	459.566
h_{REA}	546.806	504.596	564.758	545.858
$\rho_{REA}^{GAYTREND}$	470.846	562.546	503.033	546.036
ρ_{REA}^{M}	312.285	457.965	505.673	501.415
ϕ_{REA}^{y}	409.612	339.723	471.107	452.330
ρ_{REA}^{P}	475.559	504.711	554.583	536.527
ρ_{REA}^{Y}	578.582	543.642	516.592	578.751
σ_{REA}^{C}	370.575	416.271	422.998	351.832
σ_{REA}^{FM}	435.989	434.863	418.753	487.338
θ_{REA}	631.615	455.482	486.481	658.044
$rp_{R}^{BW}oW$	504.354	544.216	595.825	574.176

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Table D.4: (continued)

Parameter	*Block* 1	*Block* 2	*Block* 3	*Block* 4
α^{bw}_{RoW}	406.375	474.492	506.570	467.829
h_{RoW}	515.428	618.373	538.686	607.961
ρ^{M}_{RoW}	423.750	462.660	473.692	334.470
ϕ^{y}_{RoW}	323.566	444.919	335.380	422.921
ρ^{P}_{RoW}	550.673	649.713	397.355	417.738
ρ^{Y}_{RoW}	505.109	479.215	466.954	551.356
$\rho^{M}_{ES,RoW}$	470.276	485.534	472.999	543.169
$\rho^{PX}_{ES,RoW}$	466.183	469.725	478.739	580.064
$\rho^{PX}_{REA,RoW}$	569.269	417.977	516.357	494.966
σ^{C}_{RoW}	399.367	341.307	321.616	620.024
σ^{FM}_{RoW}	558.974	369.176	586.383	524.528
θ_{RoW}	437.715	509.470	463.328	425.124

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D.3.2 Priors and Posteriors

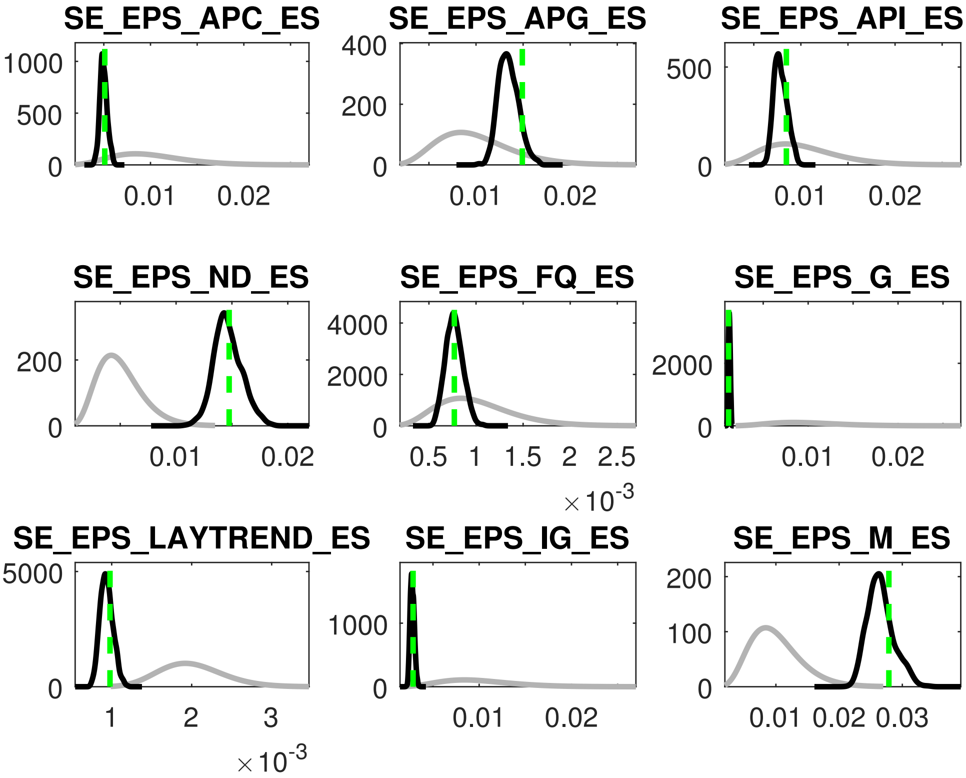

Figure D.6: Priors and posteriors.

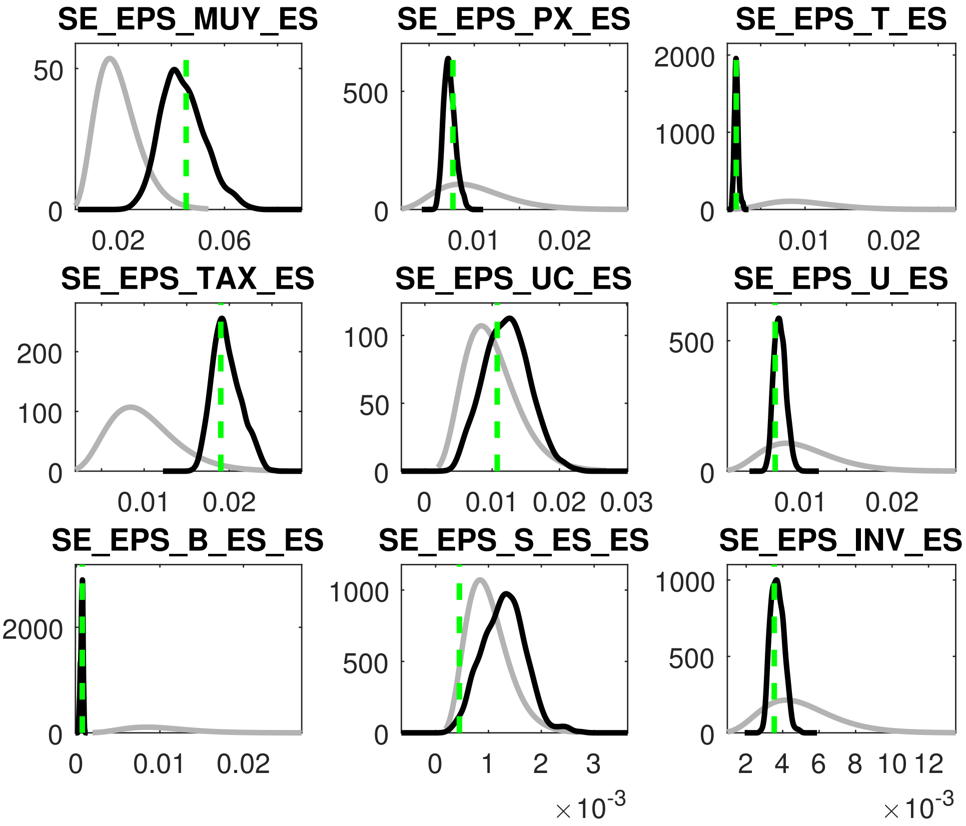

Figure D.7: Priors and posteriors.

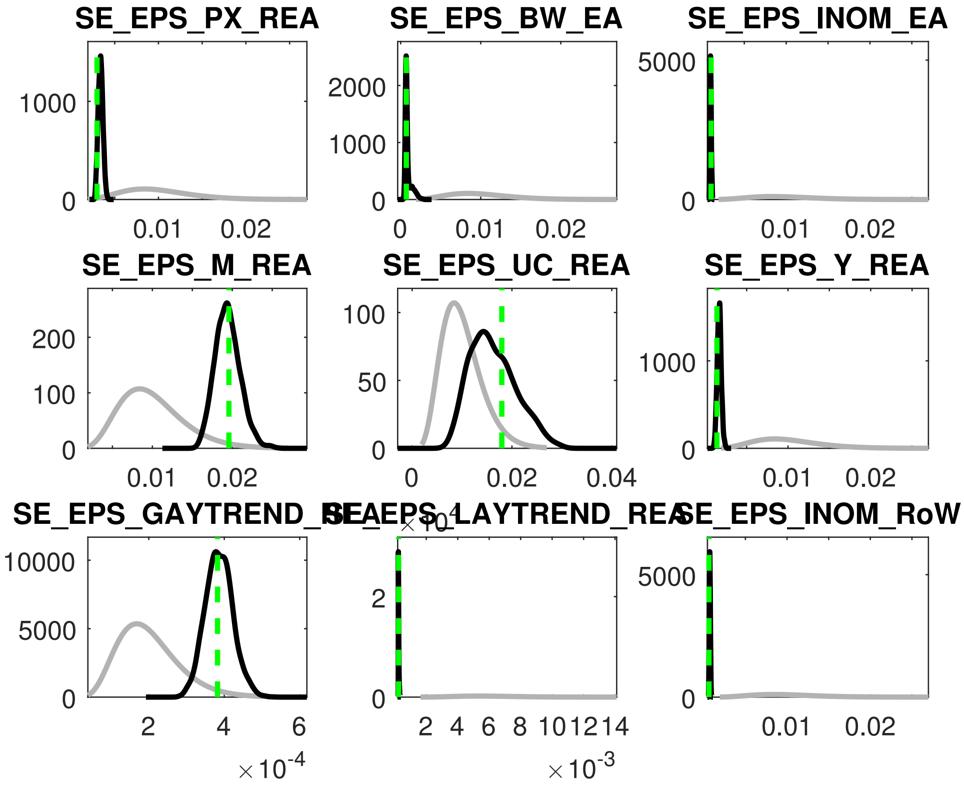

Figure D.8: Priors and posteriors.

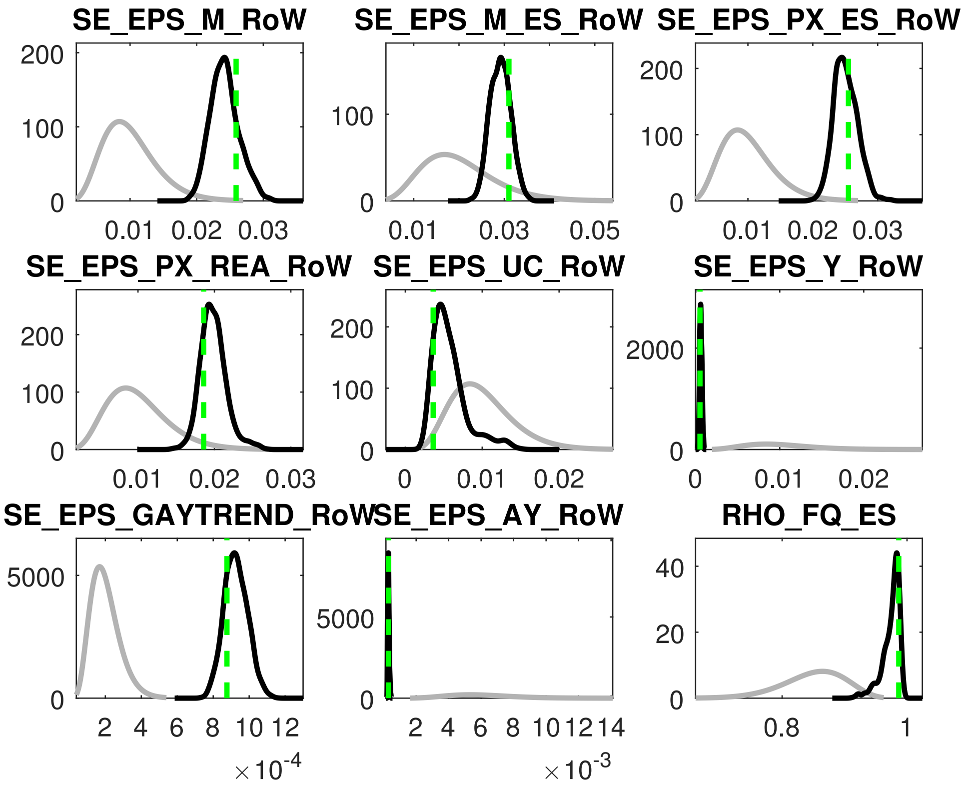

Figure D.9: Priors and posteriors.

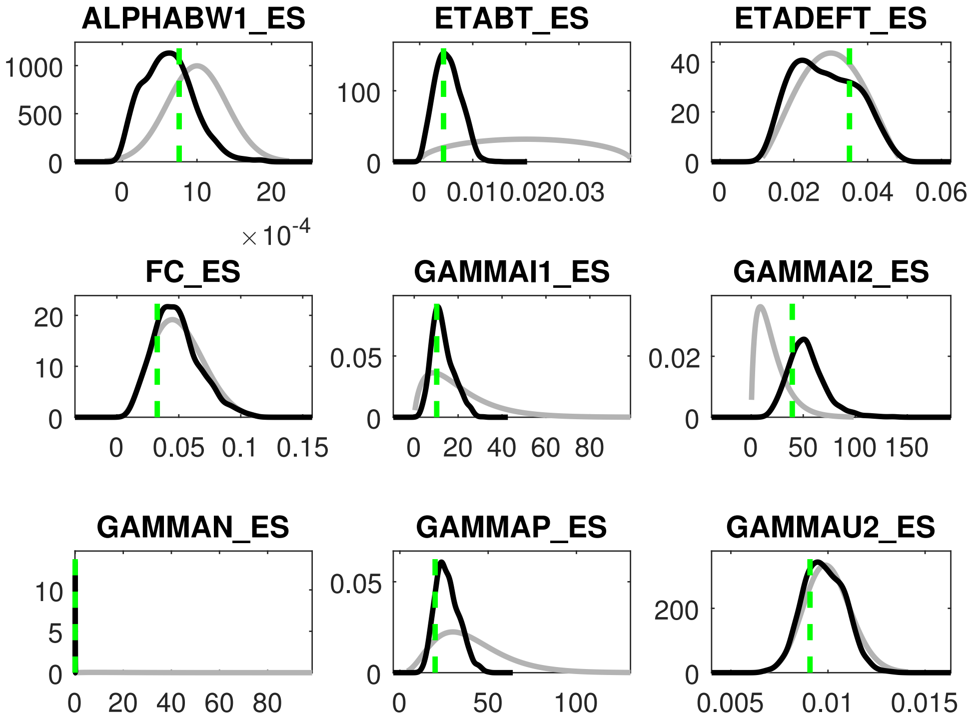

Figure D.10: Priors and posteriors.

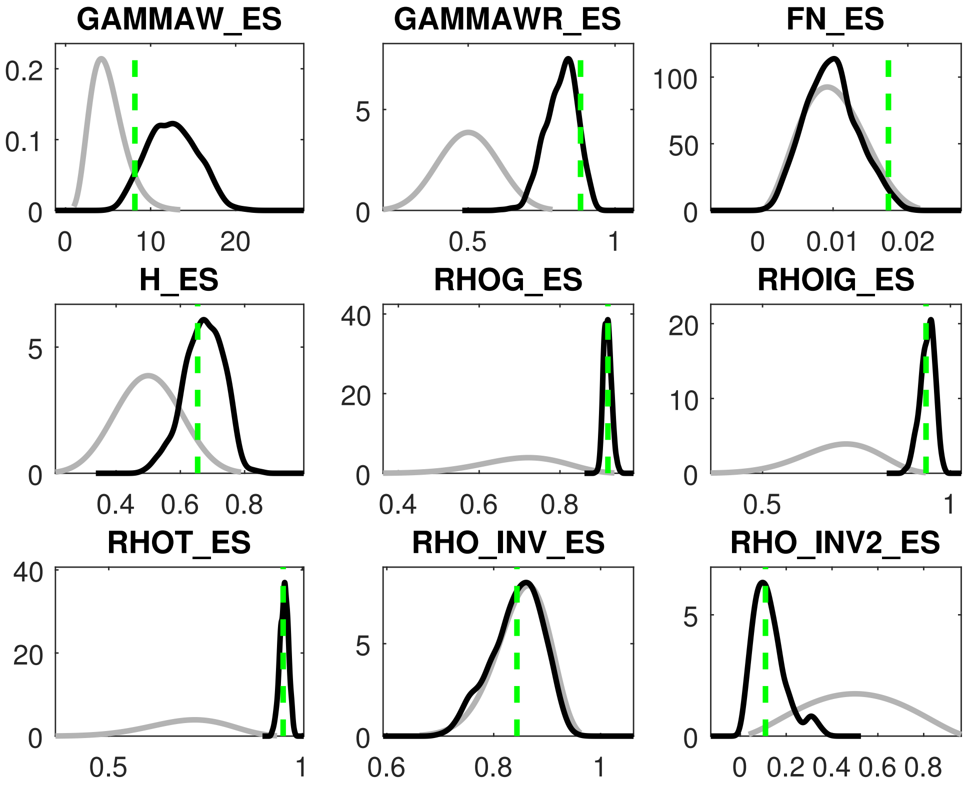

Figure D.11: Priors and posteriors.

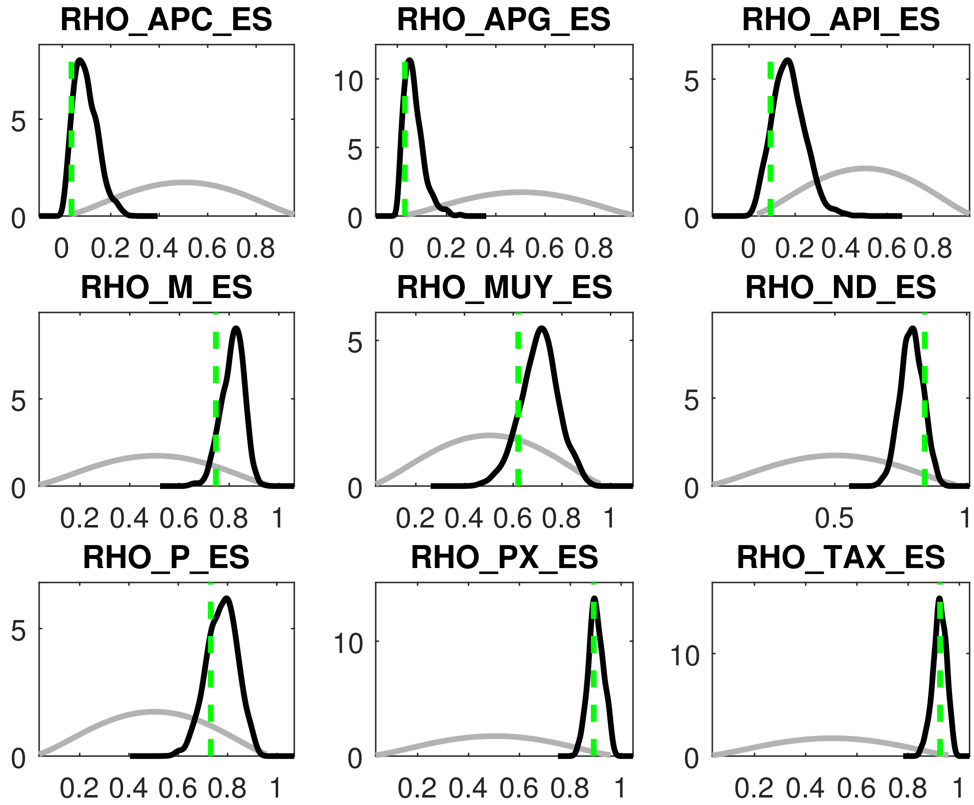

Figure D.12: Priors and posteriors.

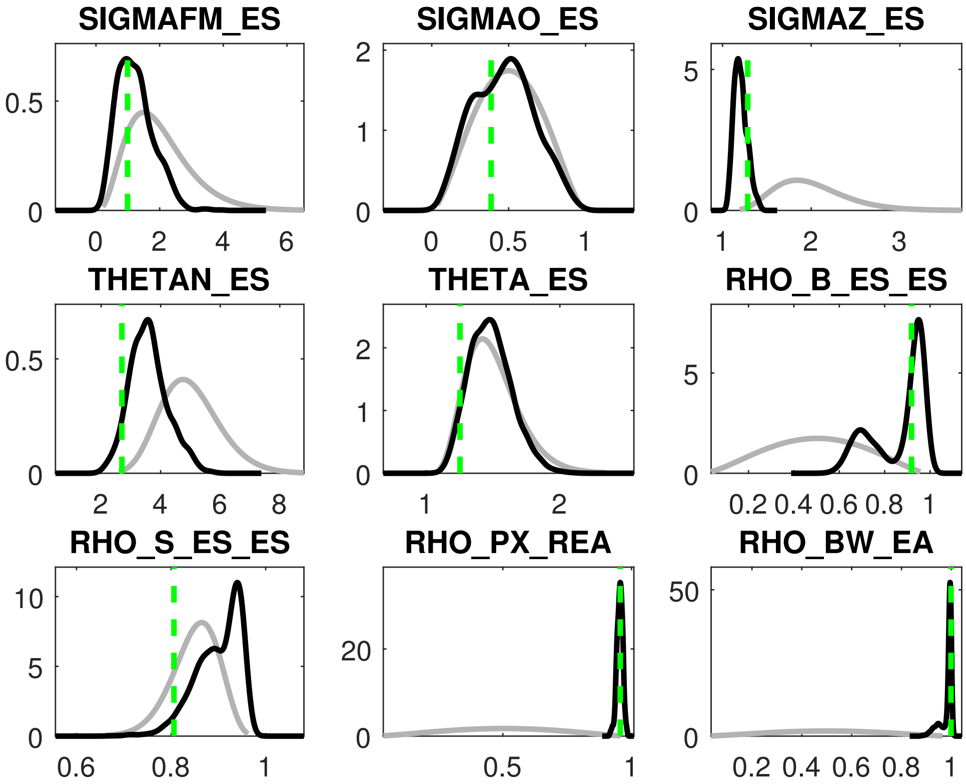

Figure D.13: Priors and posteriors.

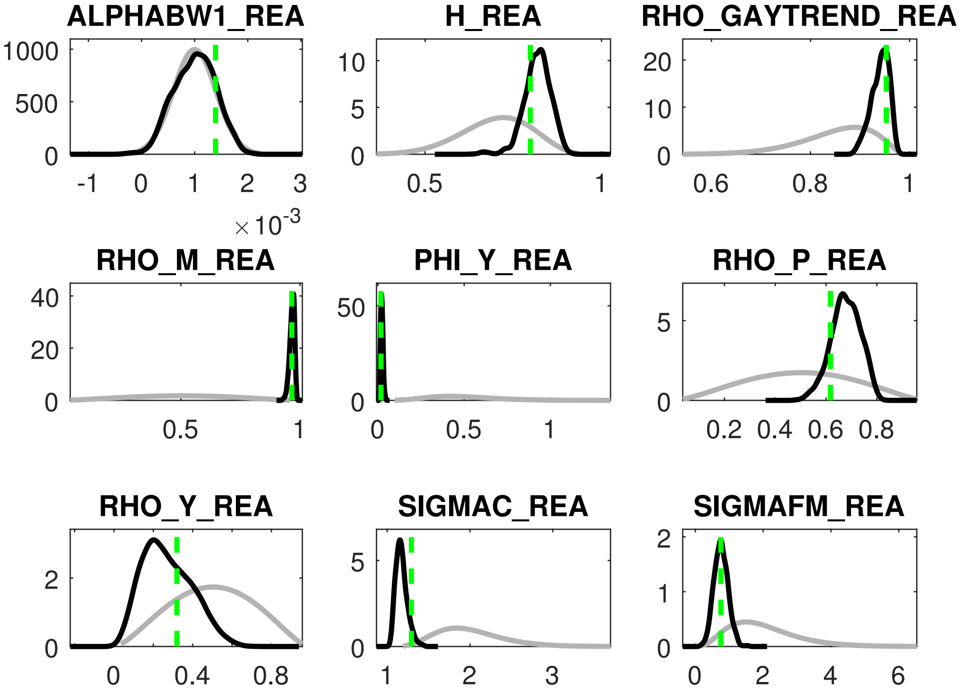

Figure D.14: Priors and posteriors.

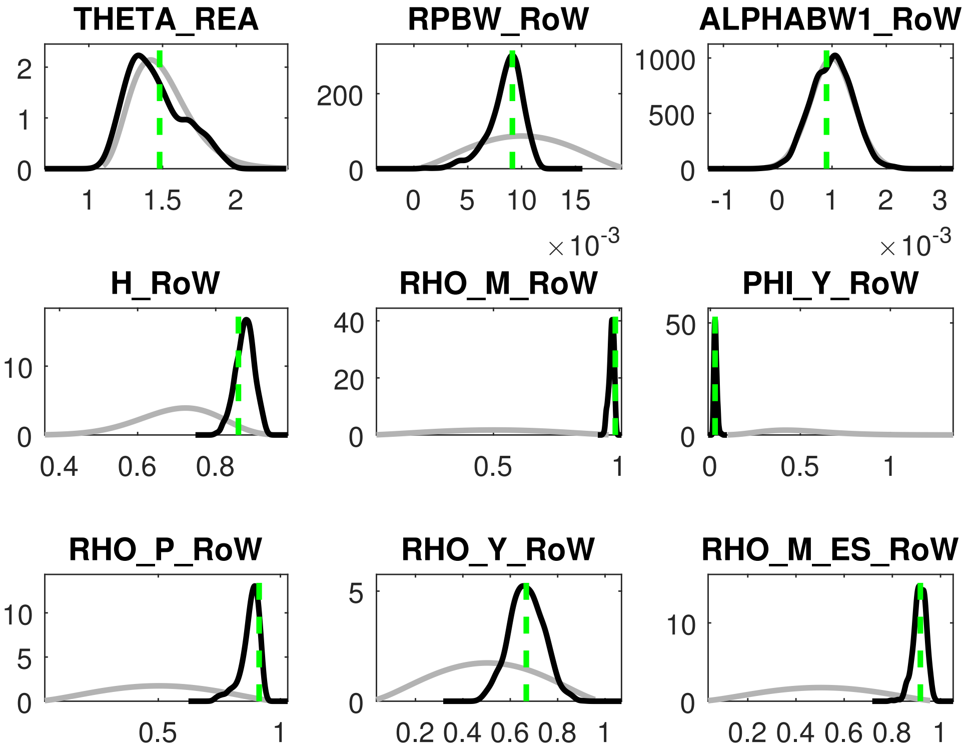

Figure D.15: Priors and posteriors.

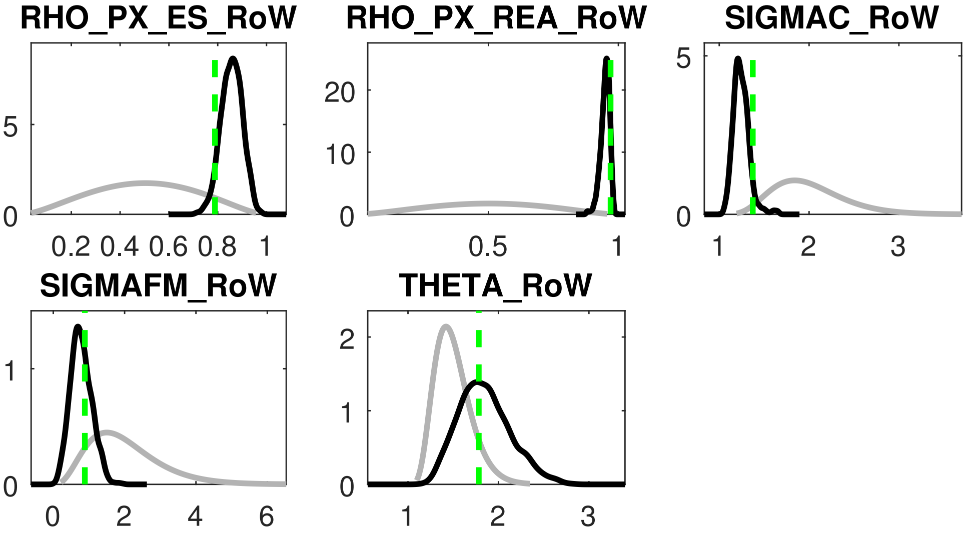

Figure D.16: Priors and posteriors.

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