Uncertainty shocks in currency unions*

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Abstract

Uncertainty shocks cause economic activity to contract and more so, if monetary policy is constrained by an effective lower bound on interest rates. In this paper, we investigate whether countries within currency unions are also particularly prone to suffer from the adverse effects of heightened uncertainty because they lack monetary independence. First, we estimate a Bayesian VAR on quarterly time series for Spain. We find that country-specific uncertainty shocks impact economic activity adversely. Second, we calibrate a DSGE model of a small open economy and show that it is able to account for the evidence. Finally, we show that currency-union membership strongly *reduces* the effects of uncertainty shocks because it anchors long-run expectations of the price level and thus alleviates precautionary price setting in the face of increased uncertainty.

Keywords: Uncertainty shocks, exchange rate regime, monetary policy, Euro area, euro crisis

JEL-Codes: F41, E44

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1 Introduction

Economic performance in the euro area has been weak in the decade following the global financial crisis, notably in the southern periphery. This period has also been a characterized by heightened economic uncertainty. Figure 1 shows this for realized stock market volatility in Spain. While uncertainty might be the result of poor economic performance, a number of recent contributions show that the converse holds as well: uncertainty causes economic activity to contract (e.g. Baker et al., 2016; Basu and Bundick, 2017; Bloom, 2009; Born and Pfeifer, 2014a; Fernández-Villaverde, Guerrón-Quintana, Kuester, et al., 2015, and many others). By now it also well understood that monetary policy plays a key role when it comes to containing the adverse effects of uncertainty. Johannsen (2014), Basu and Bundick (2017), and Fernández-Villaverde, Guerrón-Quintana, Kuester, et al. (2015), in particular, show that once the effective lower bound constrains monetary policy in lowering interest rates, the impact of uncertainty shocks is strongly amplified.[1] Against this background, we ask to what extent surrendering monetary independence within a currency union makes economies more prone to suffer from the adverse effects of uncertainty shocks.

Membership in a currency union, however, does not constrain monetary policy in exactly same way as the effective lower bound on interest rates. First, as a country surrenders monetary independence to a common central bank, union-wide monetary policy may still be conducted with a view towards country-specific conditions. Second, even if a country has a negligible weight in the common central banks' objective, currency-union membership gives rise to benefits in terms of monetary stability. The price level in the union serves as a long-run nominal anchor via relative purchasing power parity (Corsetti et al., 2013). This, in turn, stabilizes inflation expectations and prevents deflationary spirals which jeopardize economic stability in economies with floating exchange rates once the effective lower bound becomes binding. It is thus important to systematically analyze how currency-union membership (or a credible exchange rate peg) impacts the transmission of uncertainty shocks.

In order to do so, we proceed in two steps. First, we establish time-series evidence

[1]Plante et al. (forthcoming) show how the ZLB in turn can give rise to endogenous uncertainty.

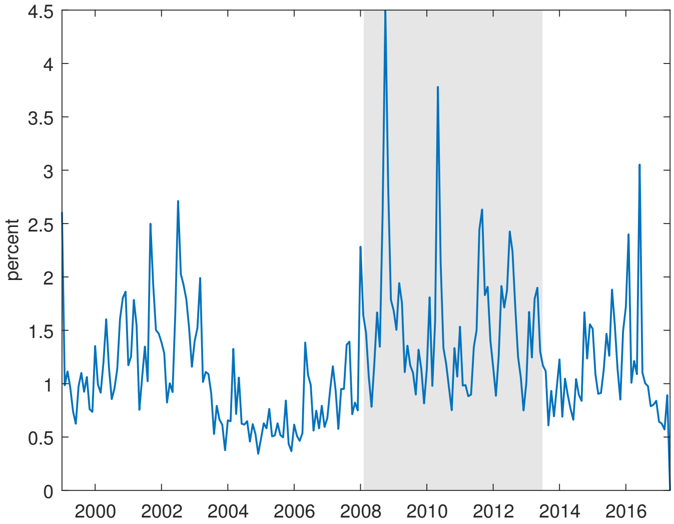


Figure 1: Realized monthly stock market volatility in Spain 1999–2016.
Notes: Based on the monthly standard deviation of daily returns of the Madrid Stock Exchange General Index (IGBN) performance index. Shaded area denotes recessions as dated by the Economic Cycle Research Institute.

on the effects of uncertainty shocks. For this purpose we estimate a Bayesian vector autoregression (BVAR) model on quarterly data for Spain. Our sample spans the period since the inception of the euro in 1999 and runs until 2016. Our baseline indicator for uncertainty is realized stock market volatility (Bloom, 2009). We isolate country-specific uncertainty on the basis of a principal component analysis. In terms of identification we first choose a (Cholesky) identification consistent with our theoretical model, i.e. all variables can react contemporaneously to uncertainty shocks, and then show the robustness of our results with respect to different orderings.

We find that uncertainty shocks have a strong and persistent effect on economic activity. An increase of uncertainty by one standard deviation lowers output by about 0.15 percent. The peak effect obtains after about 1.5 years. Economic activity recovers quickly thereafter, even overshooting its pre-shock level somewhat. As in Jurado et al. (2015) for US data, we also find a strong co-movement of macroeconomic aggregates in response to uncertainty shocks. We find that the Euro area policy rate did not respond to the country-specific uncertainty shocks.

In a second step, we investigate the counterfactual: what would the effect of uncertainty shocks have been, if Spain had a floating exchange rate.[2] Unfortunately, we cannot conduct

[2] In doing so, we abstract from the possibility that a different exchange rate regime may potentially

such a counterfactual analysis using time series techniques as Spain last had floating exchange rates in the 1950s (Ilzetzki et al., 2017). Thus, we put forward an open economy version of the dynamic, stochastic general equilibrium model developed by Basu and Bundick (2017). This model is able to account for the time-series evidence on the effects of an uncertainty shock in US data. The model features supply and demand shocks as well as uncertainty shocks which widen the distribution of demand shocks. The volatility of equity returns provides a measure of uncertainty which conforms well with our empirical analysis. We adapt the basic structure of their model to allow for international trade in goods and assets. In particular, we assume that the economy operates within a currency union and is small enough so that domestic developments have negligible effects on the rest of union.

In comparing the model predictions to the vector autoregression (VAR) evidence, we find that the model performs well. In particular it captures key aspects in the transmission of uncertainty shocks, not only from a qualitative point of view, but also quantitatively. Uncertainty shocks induce a protracted recession, as all macroeconomic aggregates decline in sync. There is also a sizeable overshooting in the medium run as the economy converges back to the pre-shock level.

Given the empirical performance of the model, we run a counterfactual experiment: we study the adjustment to an uncertainty shock under flexible exchange rates. In this case monetary policy is autonomous to adjust domestic interest rates. Specifically, we assume that it follows a conventional Taylor-type inflation targeting feedback rule and lets the exchange rate adjust freely to clear the foreign exchange market. We find that the effects of uncertainty shocks are about twice as strong in the counterfactual.

To understand this finding note that precautionary price setting by firms is key for the transmission of uncertainty shocks in models with incomplete nominal flexibility (Basu and Bundick, 2017). Specifically, as firms are assumed to satisfy the demand they face at posted prices, the risk of charging too low a price increases with the uncertainty of actual demand. Higher uncertainty thus induces firms to charge higher markups and, hence,

have prevented the occurrence of the European sovereign debt crisis in the first place.

economic activity to contract.

For a small open economy which operates within a currency union, however, the foreign price level serves as a nominal anchor for domestic prices because purchasing power parity holds in the long run.[3] Contrast this with an inflation targeting regime, which is typically assumed to be in place if the exchange rate is allowed to float freely. In this case, inflation expectations, i.e. price level *changes*, are well anchored but the price *level* features a unit root. It may thus wander off arbitrarily far away from its initial position. As this possibility is ruled out for a small member country of a currency union, the markup-channel looses much of its force: in equilibrium there is less need for precautionary pricing.

Our paper relates to a number of recent studies investigating the effects of uncertainty shocks.[4] Fernández-Villaverde, Guerrón-Quintana, Rubio-Ramírez, et al. (2011) and Born and Pfeifer (2014b) analyze the effect of interest rate risk in a flex-price small open economy model for emerging markets. Their model relies on very high investment adjustment costs to generate comovement and does not consider the effect of different exchange rate regimes. Başkaya et al. (2013) investigate the effect of oil price volatility shocks in a small open economy model with flexible exchange rates. Kollmann (2016) studies the effect of uncertainty shocks in an open production economy with recursive preferences. Meinen and Roehe (2017) investigate the effect of uncertainty shocks, proxied by various indicators, on different countries of the euro zone. In their analysis, they do not account for the change in exchange rate regime occurring with the the introduction of the euro. Our paper is also related to papers like Basu and Bundick (2017), Fernández-Villaverde, Guerrón-Quintana, Kuester, et al. (2015), and Johannsen (2014) who investigate the amplification of uncertainty shocks in the presence of the zero lower bound on interest rates.

The remainder paper of the paper is organised as follows. Section 2 provides time-series evidence on the effects of uncertainty shocks on economic activity in a country

[3]Rogoff (1996) reviews the empirical evidence on the PPP and documents that PPP tends to hold in the long-run.

[4]See Bloom (2014) for a review.

that operates in a currency union. Section 3 then presents a Dynamic Stochastic General Equilibrium (DSGE) model of a small open economy with fixed exchange rate regime that is subject to demand uncertainty shocks. Section 4 concludes.

2 Time series evidence

In this section, we provide evidence on the effects of uncertainty shocks in a country which operates in a currency union. We focus on Spain as it is one of the crisis countries in the euro area. Our sample covers the period from the start of the EMU in 1999Q1 to 2016Q4. We estimate a VAR model with the following 7 variables in the vector of endogenous variables Y_t: the quarterly realized return volatility[5] of the Datastream Spanish stock market performance index, computed as the average standard deviation of daily returns, real per capita GDP, real per capita consumption, real per capita private investment, employment, inflation, and the Wu and Xia (2016) shadow rate for the Euro Area.[6] We use a Bayesian approach to estimate the VAR model because our sample is rather short.

Formally, we estimate the following BVAR model

$$Y_t = \mu + \alpha t + A(L)Y_{t-1} + \nu_t \ , \tag{2.1}$$

where and μ and αt are a constant and time trend, respectively, $A(L)$ is a lag polynomial of degree $p = 4$, and $\nu_t \overset{iid}{\sim} \mathcal{N}(0, \Sigma)$. In terms of identification, we follow Bloom (2009) and Jurado et al. (2015) and employ a Cholesky-ordering, that is, we assume a lower-triangular matrix B, which maps reduced-form innovations ν_t into structural shocks $\varepsilon_t = B\nu_t$. Following Basu and Bundick (2017) and Baker et al. (2016), we order the uncertainty proxy first.

We use a shrinking prior of the Independent Normal-Inverse Wishart type (Kadiyala

[5]Ideally, we would like to use the implied equity return volatility instead of realized one as it more closely maps into the macroeconomic concept of uncertainty/risk shocks. Unfortunately, such an index is not consistently available for the individual member countries of the euro area. Our experience is that this theoretical distinction matters less in practice. In Born and Pfeifer (2017), we report a correlation between realized and implied volatility of 0.88 for the US. That is also the reason why Bloom (2009) concatenated realized and implied volatility measures.

[6]We use this measure to alleviate concerns about the effective zero lower bound introducing a nonlinearity the VAR is not being able to capture. The data sources are detailed in Appendix D.

and Karlsson, 1997), where the mean and precision are derived from from a Minnesota-type prior (Doan et al., 1984; Litterman, 1986). Denote the vector of stacked coefficients with $\beta = vec([\mu\ \alpha\ A_1\ \ldots\ A_p]')$. It is assumed to follow a normal prior

$$\beta \sim N(\underline{\beta}, \underline{V}) . \tag{2.2}$$

For the prior mean $\underline{\beta}$, we assume the variables to follow a univariate AR(1)-model with mean of 0.9 for levels and mean 0 for growth rates (like inflation), while all other coefficients are 0. The prior precision $\underline{V}$ is assumed to be a diagonal matrix with the highest precision for the first lag and exponential decay for the other lags. The weighting of cross-terms is conducted according to the relative size of the error terms in the respective equations, while a rather diffuse prior is used for deterministic and exogenous terms. The diagonal element corresponding to the jth variable in equation i, $\underline{V}_{i,jj}$ is:

$$\underline{V}_{i,jj} = \begin{cases} \frac{\underline{a}_1}{r^2}, & \text{for coefficients on own lag } r \in \{1, \ldots, p\} , \\ \frac{\underline{a}_2 s_i^2}{r^2 s_j^2}, & \text{for coefficients on lag } r \in \{1, \ldots, p\} \text{ of variable } j \neq i , \\ \underline{a}_3 s_i^2, & \text{for coefficients on exogenous or deterministic variables} , \end{cases} \tag{2.3}$$

where s_i^2 is the OLS estimate of the error variance of an $AR(p)$ model with constant and trend estimated for the ith variable (see Litterman, 1986). We set $\underline{a}_1 = 0.1, \underline{a}_2 = 0.1$ and $\underline{a}_3 = 10^4$. The prior error covariance is assumed to follow

$$\underline{\Sigma} \sim IW\left(\underline{S}, \underline{\nu}\right) \tag{2.4}$$

with $\underline{\nu} = 10$ "pseudo-observations", corresponding to $\approx 14\%$ of the observations, and $\underline{S}$ being the OLS covariance matrix.

In the Gibbs sampler, we use 25,000 draws, of which we discard the first 5,000 draws as a burn-in.[7] Given the shortness of our sample with 71 observations, we prefer the 68% highest posterior density intervals (HPDIs), but also report 90% HPDIs. Posterior computations are based on 1000 random posterior draws after burn-in. As a practical matter, we z-scored the data (including the trend) to avoid numerical problems arising

[7] The Raftery and Lewis (1992) convergence diagnostics suggests that this is sufficient for convergence.

from under-/overflow during the posterior computations that involve sum of squares. We also impose a stability condition on our VAR by drawing from the conditional distribution for β until all eigenvalues of the companion form matrix are smaller than 1.

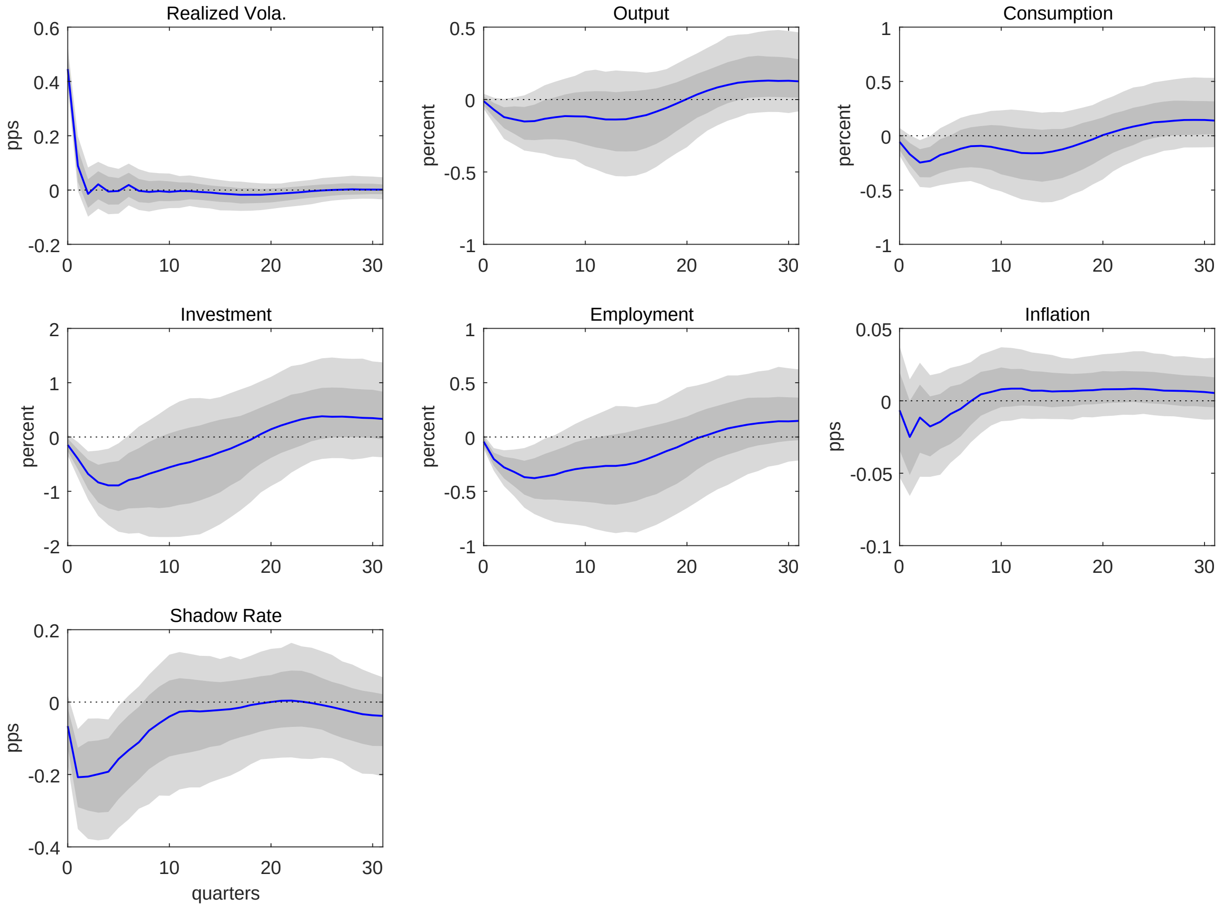


Figure 2: IRFs to one-standard-deviation overall uncertainty shock.
Notes: Uncertainty ordered first. Shaded bands are pointwise 68% (dark) and 90% (light) HPDIs, respectively.

Figure 2 presents the VAR impulse responses of the aggregate variables following a one-standard deviation uncertainty shock. Macroeconomic aggregates show a strong co-movement, with output, employment, consumption, and investment falling by between 0.15 and 1.0 percent. Peak effects obtain after about 1-1.5 years. Economic activity recovers slowly thereafter, even overshooting its pre-shock level somewhat. Inflation also falls for two years and recovers thereafter.

Interestingly, the negative response of the shadow rate displayed in the last panel shows that the European Central Bank (ECB) stabilizes the effects of the uncertainty shock. This is due to the fact that there is a large *common* euro area-component contained in

Spanish stock market volatility. What we identify might be a correlated shock across euro area members to which the ECB reacts. To isolate the *idiosyncratic* Spanish uncertainty shock component, we purge the Spanish stock market volatility from the first principal component across euro area stock market volatilities.[8] The resulting idiosyncratic Spanish volatility series is plotted in Figure 3. It can clearly be seen, that especially the volatility

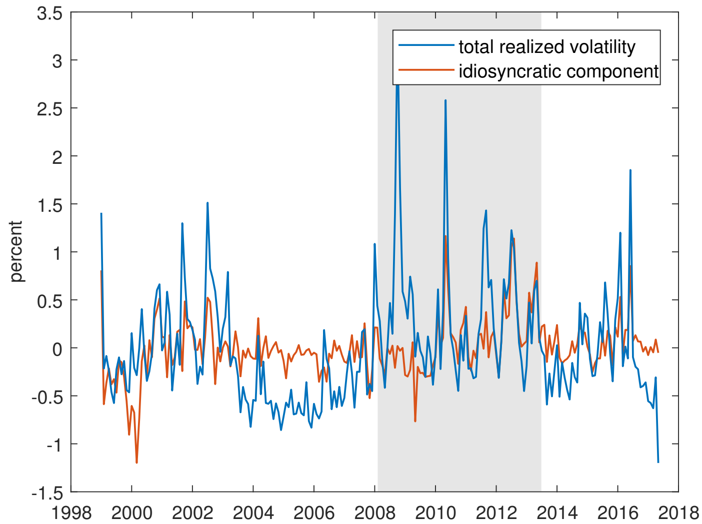


Figure 3: Total and idiosyncratic component of realized monthly stock market volatility in Spain 1999–2016.
Notes: Based on the monthly standard deviation of daily returns of Datastream market indices. Both series are demeaned. Shaded area denotes Spanish recessions as dated by the Economic Cycle Research Institute (ECRI).

increase during the financial crisis of 2008/09 was a euro area-wide phenomenon, while the 2011/12 spike in volatility was to a larger degree Spain-specific.

We then re-estimate our VAR replacing the stock market volatility series by its idiosyncratic component. The resulting impulse response functions (IRFs) are shown in Figure 4. Overall, the responses are somewhat more muted. Importantly, the ECB does not stabilize the uncertainty shock when it is Spain-specific.

Appendix E shows that our results are somewhat more muted when uncertainty is ordered last, but are qualitatively the same. Identifying uncertainty shocks via stock market volatility may be problematic, because stock market returns are inherently endogenous.[9]

[8]See Appendix D for details. Results are similar when taking the first principal component of 52 advanced and emerging economies from the Datastream universe of indices.

[9]In a model with sufficient nonlinearity, any homoskedastic shock temporarily moving the distribution along the nonlinear policy function for equity returns will alter the variance of the prediction error. Thus, Total Factor Productivity (TFP) level shocks for example can potentially significantly move the implied

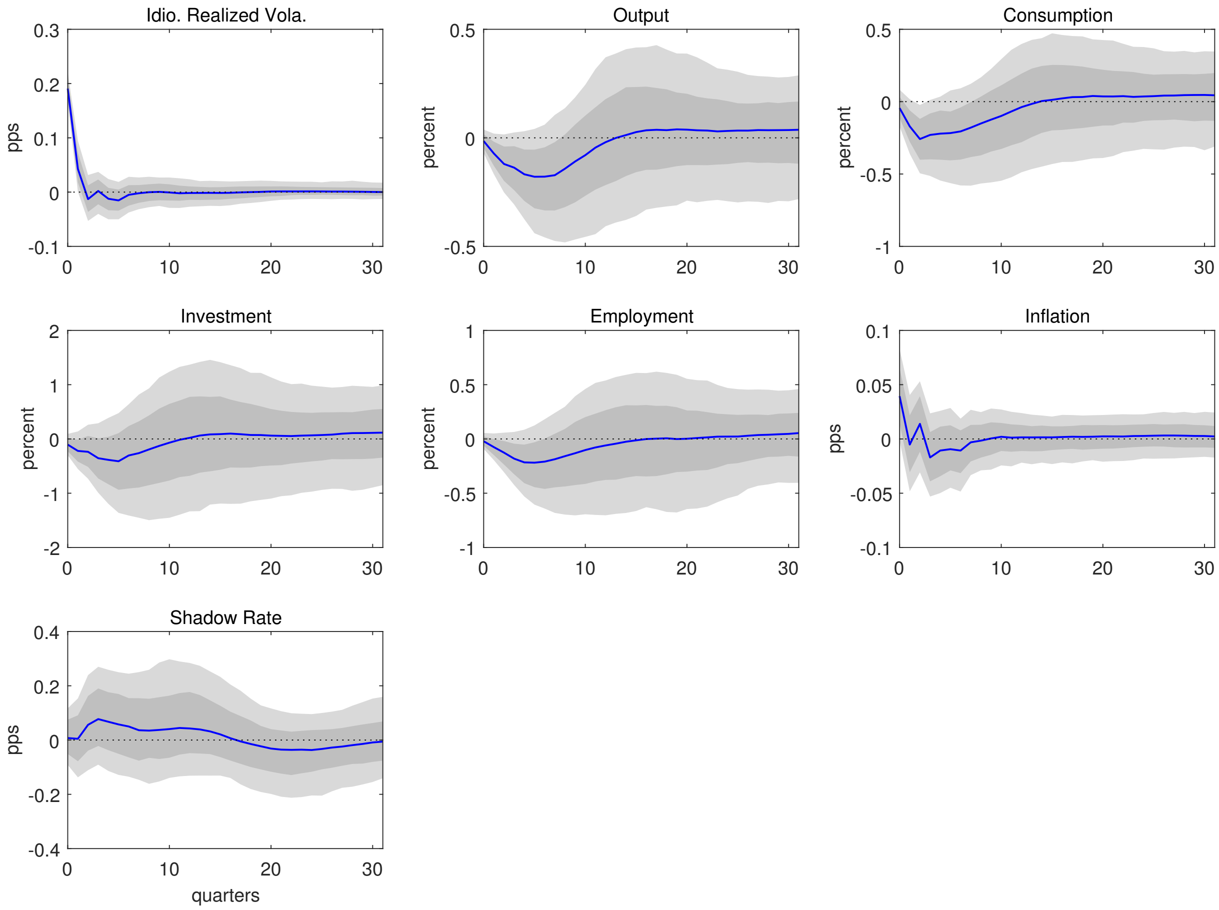


Figure 4: IRFs to one-standard-deviation idiosyncratic uncertainty shock.
Notes: Uncertainty ordered first. Shaded bands are pointwise 68% (dark) and 90% (light) HPDIs, respectively.

Figure E.3 in the Appendix shows that results are similar if, instead of the total realized volatility, one uses the macroeconomic uncertainty index for Spain that Meinen and Roehe (2017) computed based on the approach by Jurado et al. (2015). Unfortunately, we can cannot conduct the same check for the idiosyncratic component as we lack the same measure for most of the euro area countries.

As we are missing the empirical counterfactual to Spain in a monetary union, we will move to a DSGE model to further analyze the effects monetary union membership has on the effects of uncertainty shocks. To this end, we will use the VAR evidence to bring our model to the data.

volatility index. We are currently investigating the quantitative relevance of this channel and how it affects the identification of uncertainty shocks via a stock market volatility index.

3 Model

We consider a (semi-)small open economy in the spirit of Galí and Monacelli (2005, 2008). Because of home bias domestically produced goods have non-zero weight so that final goods have an import content in addition to domestically produced goods. International financial markets incomplete.

3.1 The final good

The final good F_t is assembled from domestic goods Y_t^H and imported goods Y_t^F using a Constant Elasticity of Substitution (CES) production function

$$F_t = \left((1-\upsilon)^{\frac{1}{\eta_g}} \left(Y_t^H\right)^{\frac{\eta_g - 1}{\eta_g}} + \upsilon^{\frac{1}{\eta_g}} \left(Y_t^F\right)^{\frac{\eta_g - 1}{\eta_g}} \right)^{\frac{\eta_g}{\eta_g - 1}} , \tag{3.1}$$

where η_g is the trade elasticity and $0 \leq \upsilon \leq 1$ measures the import content. The Consumer Price Index (CPI) price index P_t^{CPI} is then given by

$$P_t^{CPI} = \left[(1-\upsilon)(P_t^H)^{1-\eta_g} + \upsilon(P_t^F)^{1-\eta_g} \right]^{\frac{1}{1-\eta_g}} . \tag{3.2}$$

Here, P_t^H is the price of the domestic input in terms of domestic currency and $P_{F,t} = \mathcal{E}_t P_t^*$ the price of imports, where P_t^* is the foreign CPI and $\mathcal{E}_t$ is the nominal exchange rate.[10] Thus, we assume the law of one price holds at the individual goods level at all times (see e.g. Galí, 2015, Ch. 8).

Defining the real exchange[11] as

$$\mathcal{Q}_t \equiv \frac{\mathcal{E}_t P_t^*}{P_t^{CPI}} = \frac{P_t^F}{P_t^{CPI}} , \tag{3.3}$$

it is linked to the terms of trade $\mathcal{S}_t = P_{F,t}/P_{H,t}$ as follows

$$\mathcal{Q}_t = \frac{1}{\left[(1-\upsilon)\mathcal{S}_t^{\eta_g - 1} + \upsilon \right]^{\frac{1}{1-\eta_g}}} . \tag{3.4}$$

Defining CPI inflation Π_t^{CPI} as P_t^{CPI}/P_{t-1}^{CPI} and PPI inflation as $\Pi_t^H = P_t^H/P_{t-1}^H$, equation

[10] As the foreign economy operates like a closed economy, the foreign CPI coincides with the foreign Producer Price Index (PPI).

[11] Given this definition, a decrease in Q_t corresponds to an appreciation as the price of a foreign goods bundle decreases relative to the price of a domestic bundle.

(3.2) implies that PPI and CPI are linked via

$$\left(\Pi_t^{CPI}\right)^{1-\eta_g} = (1-\upsilon)\left(\Pi_{H,t} S_{t-1}^{-1} Q_{t-1}\right)^{1-\eta_g} + \upsilon\left(Q_t \Pi_t^{CPI}\right)^{1-\eta_g} . \tag{3.5}$$

3.2 Firms

The domestic good Y_t^H is assembled from a continuum of differentiated intermediate inputs $Y_t(i)$, $i \in [0,1]$, using the constant returns to scale Dixit-Stiglitz-technology

$$Y_t^H = \left[\int_0^1 Y_t(i)^{\frac{\theta_p - 1}{\theta_p}}\, di\right]^{\frac{\theta_p}{\theta_p - 1}} , \tag{3.6}$$

where $\theta_p > 0$ is the elasticity of substitution between intermediate goods. It is sold in a competitive market at cost P_t^H

$$P_t^H = \left[\int_0^1 P_t(i)^{1-\theta_p}\, di\right]^{\frac{1}{1-\theta_p}} , \tag{3.7}$$

where $P_t(i)$ is the price of intermediate good i. Profits

$$P_t^H Y_t^H - \int_0^1 P_t(i) Y_t(i)\, di \tag{3.8}$$

are then maximized subject to the production technology by choosing the optimal bundle of input goods, giving rise to the cost-minimizing price (3.7). Cost minimization implies that demand for good i is given by:

$$Y_t(i) = \left[\frac{P_t(i)}{P_t^H}\right]^{-\theta_p} Y_t^H . \tag{3.9}$$

There is a continuum of monopolistically competitive intermediate goods firms i, $i \in [0,1]$, which produce differentiated intermediate goods $Y_t(i)$ using the predetermined capital stock $K_{t-1}(i)$ with utilization rate $u_t(i)$, and a hired composite labor bundle $N_t(i)$, defined in the next subsection, according to a Cobb-Douglas production function

$$Y_t(i) = \left(u_t(i) K_{t-1}(i)\right)^{\alpha} \left(Z_t N_t(i)\right)^{1-\alpha} - \Phi . \tag{3.10}$$

Here, $0 \leq \alpha \leq 1$ parameterizes the labor share. The fixed cost of production Φ is set to reduce economic profits to zero in steady state, thereby ruling out entry or exit (Christiano et al., 2005). Z_t denotes a stationary, labor-augmenting technology process specified below. Each intermediate goods firm owns its own capital stock, whose law of motion is given by

$$K_t(i) = (1 - \delta_t(u_t))\, K_{t-1}(i) + \left(1 - \frac{\phi_K}{2}\left(\frac{I_t(i)}{I_{t-1}(i)} - \delta\right)^2\right) I_t(i)\ ,\ \phi_K \geq 0\ . \qquad (3.11)$$

The depreciation rate depends on the rate of capital utilization

$$\delta_t(u_t) = \delta_0 + \delta_1\,(u_t - 1) + \frac{\delta_2}{2}\,(u_t - 1)^2 \qquad (3.12)$$

where $\delta_i \geq 0$ are parameters. Equation (3.11) includes investment adjustment costs at the firm level of the form introduced by Christiano et al. (2005).

Intermediate goods producers are owned by domestic households. They maximize the present discounted value of per period profits subject to the law of motion for capital, (3.11), the production function, (3.10), and the demand from the final goods producer, (3.9). Cash flows $D_t(i)/P_t^{CPI}$, measured in terms of the final good, are then given by

$$\frac{D_t(i)}{P_t^{CPI}} = \frac{P_t(i)}{P_t^{CPI}} Y_t(i) - \frac{W_t}{P_t^{CPI}} N_t(i) - I_t(i) - \frac{\phi_p}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - \Pi^H\right)^2 Y_t\ , \qquad (3.13)$$

where the whole equation is expressed in terms of the final good, $N_t(i)$ is hired in a competitive rental market at the given nominal wage rate W_t, and the last term denotes price adjustment costs as in Rotemberg (1982) that are measured in terms of the domestic good.[12] For discounting, firms use the households' stochastic discount factor.

In order to have our model speak to the movement of stock market volatility, we employ the financial structure used in Basu and Bundick (2017). Firms finance themselves by issuing stocks S_t at price nominal price P_t^E and real risk-free discount bonds B_t^{rf}, paying the real rate R_t^R. For convenience, we normalize the number of stocks to $S_t = 1$. As the Modigliani-Miller theorem holds in our model, the financing structure will neither affect the firm value nor the real allocations. Rather, the risk-return tradeoff in equilibrium assures that households and firms are indifferent between bond and equity financing. We assume the amount of risk-free bonds to be νK_t, where ν corresponds to the leverage.

[12] Rotemberg adjustment costs give rise to a true representative firm, which makes aggregation in the context of a nonlinear model easier. Recently, Richter and Throckmorton (2016) have also argued that the Rotemberg pricing may allow nonlinear model to fit the data better.

This exogenously imposed leverage allows increasing the riskiness of equity returns and therefore the empirical VIX index. Given the bond financing, shareholders receive the residual cash flows as dividends:

$$\frac{D_t^E(i)}{P_t^{CPI}} = \frac{D_t(i)}{P_t^{CPI}} - \nu \left(K_{t-1}(i) - \frac{1}{R^R{}_t} K_t(i) \right) \ . \tag{3.14}$$

3.3 Household

There is a representative households with Epstein and Zin (1989)/Weil (1989) preferences

$$V_t = \max \left[\xi_t^{pref} V^{norm} \left(C_t^{\eta} (1-N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} + \beta_t \left(\mathbb{E}_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{1-\sigma}} \ , \tag{3.15}$$

which allow separately specifying the risk aversion and the intertemporal substitution. The parameter $\sigma \geq 0$ measures the risk aversion, while χ is the intertemporal elasticity of substitution with $\theta_V \equiv \frac{1-\sigma}{1-\chi^{-1}}$. $0 \leq \eta \leq 1$ denotes the share of the consumption good in the consumption-leisure Cobb-Douglas bundle, and ξ_t^{pref} denotes a shock to the discount factor which can be interpreted as a demand shock and is specified in the next section. V^{norm} is a normalizing constant used to scale discounted lifetime utility in the deterministic steady state to 1.[13] To close the model and prevent a unit root in the net foreign asset position, we assume an endogenous discount factor that decreases in the consumption output ratio:[14]

$$\beta_t = \bar{\beta} \left[1 - \phi_B \left(\frac{C_t}{Y_t} - \frac{C}{Y} \right) \right] \tag{3.16}$$

where $0 \leq \bar{\beta} \leq 1$ is the pure discount factor and ϕ_B measures the slope of the discount factor.[15]

The household faces the nominal per period budget constraint

$$\begin{aligned} & B_t + \mathcal{E}_t B_t^* + P_t^E S_t + P_t^{CPI} \left(\frac{1}{R_t^R} B_t^{rf} + C_t \right) \\ & \leq W_t N_t + \left(P_t^E + D_t^E \right) S_{t-1} + P_t^{CPI} B_{t-1}^{rf} + R_{t-1} B_{t-1} + \mathcal{E}_t R_{t-1}^* B_{t-1}^* \ . \end{aligned} \tag{3.17}$$

[13]While inconsequential for the results, this improves the numerical behavior of the model solution. See e.g. Rudebusch and Swanson (2012).

[14]Kollmann (2016) uses a similar version.

[15]The linear function we use in principle allows for $\beta_t < 0$. However, for realistic parameterizations of the model, this is extremely unlikely to ever happen. Moreover, the often used exponential functional form would be approximated with a polynomial as in our solution step and would also imply an asymptote.

The household spends its income on consumption C_t, buying domestic bonds B_t, paying the nominal interest rate R_t in units of the domestic currency, and on buying foreign bonds B_t^*, denominated in foreign currency and paying the foreign nominal interest rate R_t^*. In addition, the household can buy stocks S_t at price P_t^E, paying dividends D_{t+1}^E next period and a real risk-free discount bond B_t^{rf}, providing the risk-free real return R_t^R. The household earns income from supplying labor N_t at the nominal wage rate W_t and from the corresponding gross asset returns.

The optimization problem of the household involves maximizing (3.15), subject to the budget constraint (3.17) and the endogenous discount factor (3.16).

The Euler equations for domestic and foreign bonds, respectively, are

$$1 = E_t \left[M_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right] \tag{3.18}$$

$$1 = E_t \left[M_{t,t+1} \frac{R_t^* \mathcal{E}_{t+1}}{\mathcal{E}_t \Pi_{t+1}} \right] , \tag{3.19}$$

where $M_{t,t+1}$ denotes the stochastic discount factor for nominal payoffs.[16] Thus, the uncovered interest parity holds in our model.

The domestic bond is assumed to be in zero net supply, i.e. $B_t = 0$. Using our assumptions that $B_t^{rf} = \nu K_t$ and $S_t = 1$, the real budget constraint is then given by

$$\begin{aligned} & C_t + \frac{\mathcal{E}_t P_t^*}{P_t^{CPI}} \frac{B_t^*}{P_t^*} + \frac{P_t^E}{P_t^{CPI}} + \frac{1}{R_t^R} \nu K_t \\ & = \frac{W_t}{P_t^{CPI}} N_t + \left(\frac{P_t^E}{P_t^{CPI}} + \frac{D_t^E}{P_t^{CPI}} \right) + \nu K_{t-1} + \frac{\mathcal{E}_t P_t^*}{P_t^{CPI}} \frac{R_{t-1}^*}{\Pi_t^*} \frac{B_{t-1}^*}{P_{t-1}^*} \ . \end{aligned} \tag{3.20}$$

3.4 The foreign country

The foreign country faces a symmetric setup, except for the domestic country having negligible weight, giving rise to foreign demand for home output of

$$\upsilon \mathcal{S}_t^{\eta_g} Y_t^* \ . \tag{3.21}$$

We assume throughout our analysis that the foreign output Y_t^* and foreign inflation $\Pi_t^* = P_t^* / P_{t-1}^*$ are constant, with foreign trend inflation in the float case being equal to

[16] See Appendix C for details.

the domestic one.

3.5 Monetary Policy

We consider two monetary policy regimes: a monetary union and floating exchange rates with an inflation targeting central bank. In case of a monetary union, we model it as a credible exchange rate peg, i.e. the gross growth rate of the nominal exchange rate needs to be one for all periods:

$$\Delta\mathcal{E}_t = \frac{\Pi_t^{CPI}\frac{\mathcal{Q}_t}{\mathcal{Q}_{t-1}}}{\Pi^*{}_t} = 1\,\forall\, t. \tag{3.22}$$

In case of a floating exchange rate, the model is closed by assuming that the central bank follows a Taylor rule that reacts to CPI inflation and output:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R}\left(\left(\frac{\Pi_t^{CPI}}{\Pi^{CPI}}\right)^{\phi_{R\pi}}\left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_{Ry}}\right)^{1-\rho_R}. \tag{3.23}$$

Here, ρ_R is a smoothing parameter introduced to capture the empirical evidence of gradual movements in interest rates, Π^{CPI} is the target inflation rate set by the central bank, and the parameters $\phi_{R\pi}$ and ϕ_{Ry} capture the responsiveness of the nominal interest rate to deviations of inflation from its steady-state value and output growth.

3.6 Shock Processes

The exogenous process for TFP is assumed tobe an AR(1)

$$Z_t = (1-\rho_z)Z^* + \rho_z Z_{t-1} + \varepsilon_t^z\,, \tag{3.24}$$

with Z^* chosen to get a steady-state output of 1. The preference shock follows an AR(1)-process with stochastic volatility:[17]

$$\xi_t^{pref} = (1-\rho_{pref}) + \rho_{pref}\xi_{t-1}^{pref} + \sigma_t^{pref}\varepsilon_t^{pref} \tag{3.25}$$

$$\sigma_t^{pref} = (1-\rho_{\sigma^{pref}})\bar{\sigma}^{pref} + \rho_{\sigma^{pref}}\sigma_{t-1}^{pref} + \sigma^{\sigma^{pref}}\varepsilon_t^{\sigma^{pref}}\,, \tag{3.26}$$

where the $\varepsilon_t^i, i \in \{z, pref, \sigma^{pref}\}$ are standard normally distributed i.i.d. shock processes.

[17] We use a level specification in both the level and volatility equation instead of a log-log specification to avoid the problem of non-existing moments implied by the latter as documented in Andreasen (2010).

3.7 Equilibrium

The use of Rotemberg price adjustment costs implies the existence of a representative firm. We consider a symmetric equilibrium in which all intermediate goods firms charge the same price and use the same labor input, capital stock, and capital utilization.

The resource constraint then implies that domestic output is used for consumption, investment, to pay for price adjustment costs, and for exports:

$$Y_t = (1 - \upsilon) \left(\frac{\mathcal{Q}_t}{\mathcal{S}_t}\right)^{-\eta_g} \left(C_t + I_t + + \frac{\phi_p}{2} \left(\Pi_t^H - \Pi^{CPI}\right)^2 Y_t\right) + \upsilon \mathcal{S}_t^{\eta_g} Y_t^*$$

where our assumptions assure that in steady state $\Pi^H = \Pi^{CPI}$

3.8 Parametrization

Our calibration currently quite closely follows the work of Basu and Bundick (2017), adapted for an open economy framework, and Burriel et al. (2010), who estimated a large-scale New Keynesian DSGE model for Spain. We are currently in the process of estimating some of the parameters and the exogenous processes via impulse response function matching.

Table 1 displays the parametrization of our model. The capital share α is set to 0.3621, the discount factor $\beta = 0.99$, and the quarterly steady-state depreciation rate δ_0 to 0.0175, following the calibration of Burriel et al. (2010). δ_1 is set to imply a capital utilization of 1 in steady state. The parameter δ_2 is set to 0.687, the estimate of Burriel et al. (2010) for their exogenous monetary policy sample. We set the risk aversion parameter $\sigma = 80$, following Binsbergen et al. (2012) and Rudebusch and Swanson (2012). The intertemporal elasticity of substitution is set to a value slightly smaller than 1, following Hall (1988) as in Basu and Bundick (2017). The leisure share in the Cobb-Douglas utility bundle η is set to imply a Frisch elasticity of 2.[18] We set the elasticity of substitution $\theta_\mu = 9$ to imply a 12.5% markup, which roughly corresponds to the average substitution elasticity across sectors in Burriel et al. (2010). We consider a zero annual inflation steady state, i.e. $\Pi^{CPI} = 1$. The Taylor rule parameters are taken from the euro area estimates in

[18]See Appendix A.2.1 of Born and Pfeifer (2017) for details.

Table 1: Model parametrization

Parameter	Description	Value	Target
α	capital share parameter	0.362	Burriel et al. (2010)
β	discount factor	0.99	Burriel et al. (2010)
δ_0	SS depreciation rate	0.0175	Burriel et al. (2010)
δ_1	linear utilization cost	0.031	$u = 1$
δ_2	quadratic utilization cost	0.687	Burriel et al. (2010)
σ	risk aversion	80.000	Binsbergen et al. (2012)
ψ	intertemporal elasticity of substitution	0.950	Basu and Bundick (2017)
θ_μ	intermed. goods substitution elasticity	8	Burriel et al. (2010)
η	leisure share	0.347	Frisch elasticity of 2
Π^{CPI}/Π^*	steady state gross inflation	1	zero inflation steady-state
ρ_r	interest rate smoothing	0.8	Christoffel et al. (2008)
$\phi_{R\pi}$	inflation feedback	1.7	Christoffel et al. (2008)
ϕ_{Ry}	output feedback	0.125	Christoffel et al. (2008)
υ	import share	0.300	30% Import share
η_g	trade price elasticity	0.900	
ϕ_k	capital adjustment costs	29	Burriel et al. (2010)
ϕ_p	price adjustment costs	153.846	Duration of 5 quarters
ϕ_B	slope endogenous discount factor	0.0001	small positive number
ν	leverage	0.9	Basu and Bundick (2017)
Φ	fixed costs	0.2	0 steady-state profits
V^{norm}	util. normalization	0.006	Steady state output of 1
Y^*	foreign output	1	symmetric per capita steady state
Z^*	steady-state technology	1.094	unit output
	Exogenous processes		
ρ_{pref}	pref. shock autocorrelation	0.936	Basu and Bundick (2017)
$\rho_{\sigma^{pref}}$	pref. shock volatility autocorrelation	0.742	Basu and Bundick (2017)
$\bar{\sigma}_{pref}$	pref. shock volatility	0.003	Basu and Bundick (2017)
$\sigma_{\sigma^{pref}}$	pref. volatility shock volatility	0.003	Basu and Bundick (2017)
ρ_z	TFP shock autocorrelation	0.988	Basu and Bundick (2017)
$\bar{\sigma}_z$	TFP shock volatility	0.001	Basu and Bundick (2017)

Christoffel et al. (2008). The price adjustment costs are set to $\phi_p = 153.846$, which implies the same slope of the linear New Keynesian Phillips Curve as a Calvo model with a price duration of 5 quarters. The investment adjustment costs parameter is taken from Burriel et al. (2010), while the slope of the endogenous discount factor, ϕ_d is set to a small positive number. The leverage is set to 90% of assets, following Basu and Bundick (2017). For the openness parameter υ we chose a value of 0.3, corresponding to a 30% import share. We use a value of 0.9 for the trade price elasticity η_g. Finally, the exogenous processes are taken from Basu and Bundick (2017). Foreign per capita output Y^* and steady-state technology Z^* are chosen to obtain a symmetric steady state with unit output.

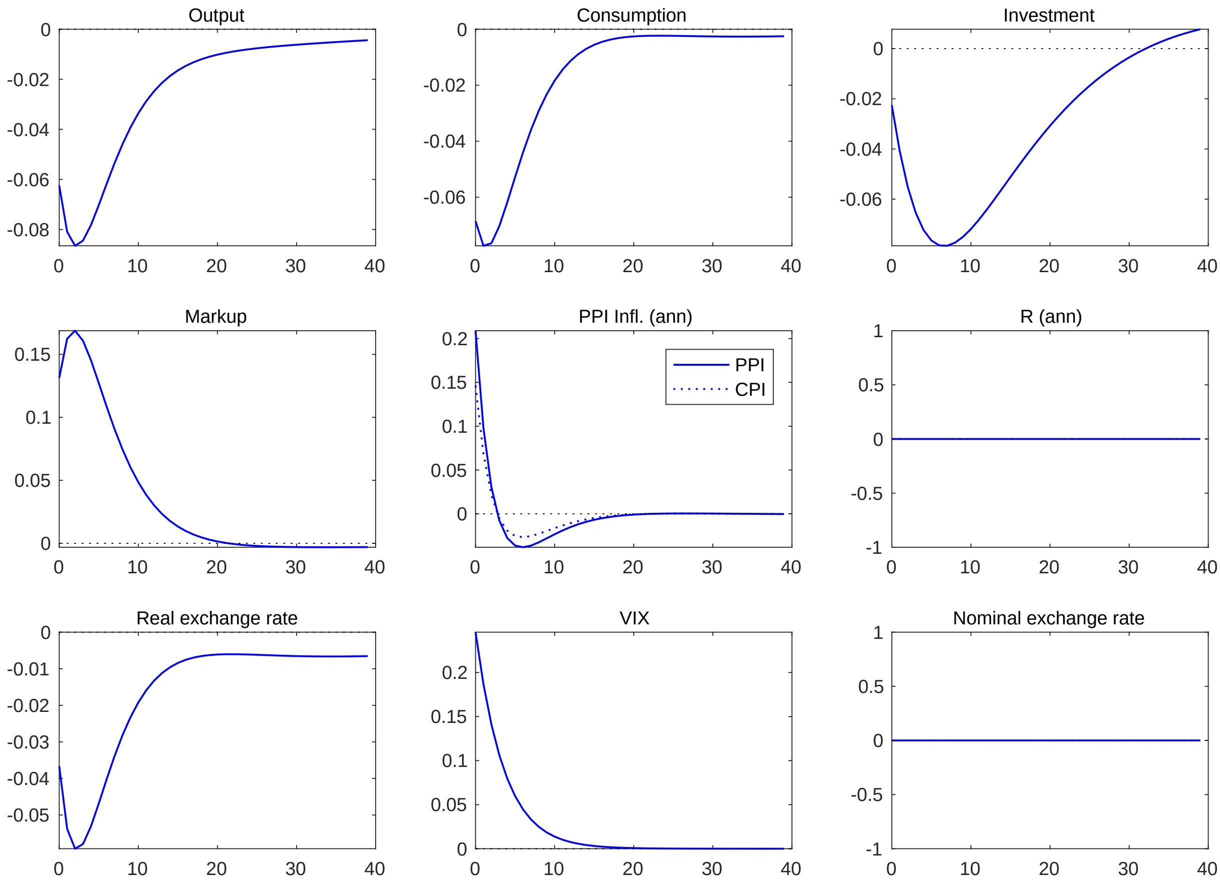
3.9 Model Responses

Figure 5 displays the impulse responses to a one-standard deviation preference uncertainty shock $\varepsilon_t^{\sigma^{pref}}$ for the monetary union case.[19] As predicted by theory, an increase in uncertainty leads to an increase in the price markup. As output is demand-determined in the short run, output drops. All other macroeconomic aggregates decline in sync. The negative impact on output is amplified by an appreciation of the real exchange rate. There is also a sizeable overshooting in the medium run as the economy converges back to the pre-shock level.

Figure 6 displays the counterfactual case if Spain had an independent inflation targeting central bank that allows the nominal exchange rate to adjust. In this case, the recessionary effects of the uncertainty shock more than double, driven by a bigger increase in markups and a stronger appreciation of the real exchange rate. Thus, having an independent monetary policy aimed at stabilizing inflation and output deviations from steady state is not sufficient to stabilize output - to the contrary.

To understand this finding, it is important to consider that precautionary price setting is key for the transmission of uncertainty shocks in models with incomplete nominal flexibility (Basu and Bundick, 2017; Fernández-Villaverde, Guerrón-Quintana, Kuester,

[19]IRFs are Generalized Impulse Response Functions (GIRFs), shown as percentage deviations from the ergodic mean, computed using third-order perturbation techniques of Dynare (Adjemian et al., 2011) with the pruning algorithm of Andreasen et al. (2013).



(a) Preference Volatility

Figure 5: Model IRFs to a to a one-standard deviation preference uncertainty shock in a monetary union. Notes: Quarterly responses are in percentage deviations from the ergodic mean, except for inflation, interest rate, and the VIX, which are in percentage points.

et al., 2015). Specifically, as firms are assumed to satisfy the demand they face at posted prices. This demand depends on the price firm i sets relative to the aggregate, as shown in equation (3.9), but of course without internalizing that in equilibrium all firms will be the same. Given this demand function, firms face a convex marginal revenue product. Hence, they prefer to charge too high a price to charging too low a price. The reason is that for too high a price, the high price is going to partially offset the loss in quantity sold. In contrast, a low price will be associated with simultaneously having to sell more, potentially at a loss.[20] With Rotemberg (1982) price adjustment costs, firms try to smooth price adjustments over time. If uncertainty increases today, keeping the level shocks constant, this signals high uncertainty in the future as well, due to the process for volatility, equation (3.26), being persistent. As the future expected optimal price has

[20]See Born and Pfeifer (2017, Section 2) for a partial equilibrium illustration of this mechanism.

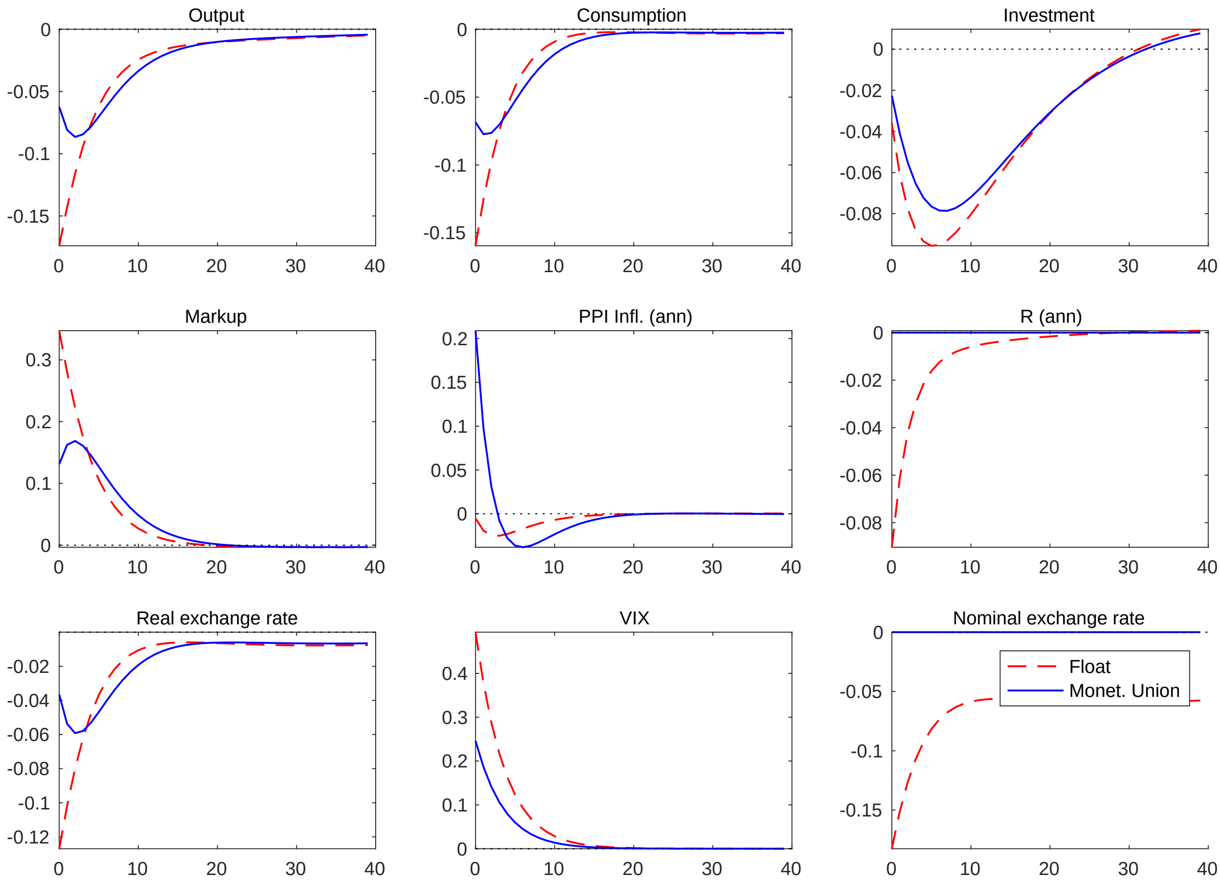


Figure 6: Model IRFs to a to a one-standard deviation preference uncertainty shock: union vs. float. Notes: Quarterly responses are in percentage deviations from the ergodic mean, except for inflation, interest rate, and the VIX, which are in percentage points.

increased due to still unresolved uncertainty, the firm will increase prices over marginal costs already today. If the economy's output is demand-determined as is the case in New Keynesian models, this increase in markups will lead economic activity to contract. Depending on the strength of general equilibrium effects in the model, this contractionary pressure can be associated with either inflation or disinflation. If the central bank follows an inflation target, inflation expectations are well anchored but the price level features a unit root. It may thus wander off arbitrarily far away from its initial position. The new price level after a given shock subsides, and therefore the long-run target price for firms, will be permanently higher/lower than before, giving firms an incentive to adjust into this direction already today.

Things are quite different for a small open economy operating within a currency union. Here the foreign price level serves as a nominal anchor for domestic prices because purchasing power parity holds in the long run. Thus, firms know already today that the price level will return to the long-run level, reducing the incentive for precautionary pricing. As a result, the markup-channel looses much of its force. This mechanism can be easily shown when replacing the Taylor rule reacting to CPI *inflation*, (3.23), with one slowly reacting to deviations of the CPI *level* from its long-run value P^{CPI}:

$$R_t = R\left(\frac{P_t^{CPI}}{P^{CPI}}\right)^{0.001} \tag{3.27}$$

By bringing the CPI price level back to its target level, this rule removes the unit root in the price level. Figure 7 compares the IRFs under the price level targeting Taylor rule to the ones under monetary union membership. They are virtually indistinguishable. The price level targeting cuts the markup increase in half and thereby reduces the output drop by 50% as well.

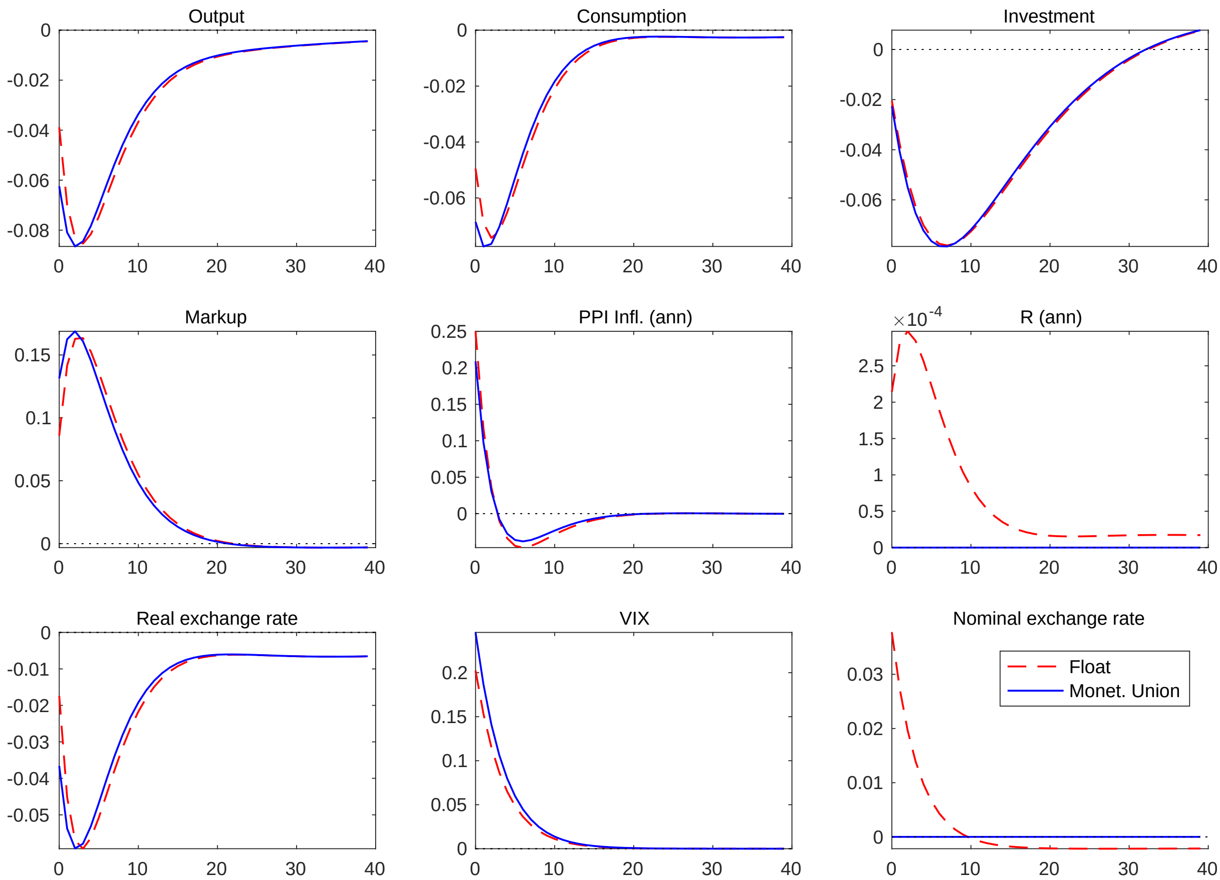


Figure 7: Model IRFs to a to a one-standard deviation preference uncertainty shock: float under price-level targeting. Notes: Quarterly responses are in percentage deviations from the ergodic mean, except for inflation, interest rate, and the VIX, which are in percentage points.

4 Conclusion

In this paper we ask to what extent the effects of uncertainty shocks are amplified by currency-union membership. This question is important in light of the weak performance of the euro area periphery during the last decade. This was, after all, also a period of heightened uncertainty. Our focus is on Spain as an example of a small open economy without monetary independence facing large uncertainty shocks. While all crisis countries of the euro area have been exposed to higher uncertainty, the issue is particularly pertinent in Spain because its economic fundamentals have been relatively sound—at least in comparison to Greece, Italy, or Portugal.

We estimate a BVAR model on time series for the period 1999Q1–2016Q4 and identify uncertainty shocks as innovations to (idiosyncratic) stock market volatility. The shock induces a protracted recession as all macroeconomic aggregates decline. Employment drops as well. We interpret these findings through the lens of a small open economy NK DSGE model in the spirit of Basu and Bundick (2017) and Galí and Monacelli (2005, 2008). Uncertainty shocks in the model widen the distribution of discount-factor (demand) shocks. The predictions of the model of how the economy adjusts to the shock align well with the evidence.

The model is thus well suited for a counterfactual analysis. Specifically, we consider a scenario where the country experiences the same uncertainty shock but enjoys monetary autonomy as it maintains a fully flexible exchange rate and follows an inflation targeting regime. In this case the effects of the shock turn out to be twice as large as in the currency union case. We show that currency-union membership helps to stabilize small-open economies as it anchors long-run expectations of the price level and dampens firms' precautionary pricing motive, lowering the increase of markups after uncertainty shocks. Using a price level instead of an inflation targeting monetary policy rule allows almost perfectly replicating the outcomes of the fixed exchange rate regime.

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A Variance Decomposition

Table A.1: Variance Decomposition

	Vola.	Output	Cons.	Invest.	Empl.	Infl.	Shadow Rate
Idio. Uncertainty	47.31	10.46	10.76	9.67	9.76	10.11	10.34
Uncertainty	42.27	14.07	14.13	15.14	15.14	11.51	17.43

Notes: Forecast error variance contribution at horizon infinity of the uncertainty shock in the VAR with uncertainty ordered first. First row: idiosyncratic realized uncertainty; second row: total realized volatility.

B VXO

The VXO is given by 100 times the square root of the annualized conditional equity return variance under a risk-neutral measure:

$$VXO = 100\sqrt{4Var_t^{RN}\left(R_{t+1}\right)} = 100\sqrt{4\left[E_t^{RN}\left([R_{t+1}^E]^2\right) - [E_t^{RN}\left(R_{t+1}^E\right)]^2\right]}, \tag{B.1}$$

where the superscript RN denotes the risk-neutral measure as opposed to the physical measure under which the regular expectations are computed. Equity returns are given by

$$R_t^E = \frac{\frac{P_t^E}{P_t^{CPI}} + \frac{D_t^E}{P_t^{CPI}}}{\frac{P_{t-1}^E}{P_{t-1}^{CPI}}}. \tag{B.2}$$

Under a risk neutral measure, every asset returns the risk free rate $R_t^{RF} = 1/E_t M_{t+1}$ in expectations. Therefore, the following identities need to hold:

$$E_t\left(M_{t+1}R_{t+1}^E\right) = E_t\left(M_{t+1}\right)E_t^{RN}\left(R_{t+1}^E\right)$$

and

$$E_t\left(M_{t+1}(R_{t+1}^E)^2\right) = E_t\left(M_{t+1}\right)E_t^{RN}\left((R_{t+1}^E)^2\right)$$

This can be used to rewrite (B.1) as

$$VXO = 100\sqrt{4\left[\frac{E_t\left(M_{t+1}(R_{t+1}^E)^2\right)}{E_t\left(M_{t+1}\right)} - \left(\frac{E_t\left(M_{t+1}R_{t+1}^E\right)}{E_t\left(M_{t+1}\right)}\right)^2\right]}. \tag{B.3}$$

In contrast, the VXO under the physical measure is given by

$$VXO = 100\sqrt{4Var_t\left(R_{t+1}^E\right)} = 100\sqrt{4\left[E_t\left[(R_{t+1}^E)^2\right] - \left(E_t\left(R_{t+1}^E\right)\right)^2\right]} \tag{B.4}$$

Note that at third order, there is no difference between the physical and risk-neutral VXO.

C Deriving the Stochastic Discount Factor

The stochastic discount factor is given by

$$M_{t+1} \equiv \frac{\partial V_t / \partial C_{t+1}}{\partial V_t / \partial C_t} \,, \tag{C.1}$$

where

$$\frac{\partial V}{\partial C_t} = V_t^{1-\frac{1-\sigma}{\theta_V}} \eta \xi_t^{pref} V^{norm} \frac{\left(C_t^{\eta}(1-N_t)^{1-\eta}\right)^{\frac{1-\sigma}{\theta_V}}}{C_t} \tag{C.2}$$

and, using the Benveniste and Scheinkman (1979) envelope theorem,

$$\begin{aligned}
\frac{\partial V_t}{\partial C_{t+1}} =& \frac{\theta_V}{1-\sigma} \left(\xi_t^{pref} V^{norm} \left(C_t^{\eta} \left(1-N_t\right)^{1-\eta}\right)^{\frac{1-\sigma}{\theta_V}} + \beta_t \left(E_t V_{t+1}^{1-\sigma}\right)^{\frac{1}{\theta_V}} \right)^{\frac{\theta_V}{1-\sigma}-1} \beta_t \frac{1}{\theta_V} \left(E_t V_{t+1}^{1-\sigma}\right)^{\frac{1}{\theta_V}-1} \\
& \times E_t \left(\left(1-\sigma\right) V_{t+1}^{-\sigma} \frac{\partial V_{t+1}}{\partial C_{t+1}} \right) \\
\overset{(C.2)}{=}& V_t^{1-\frac{1-\sigma}{\theta_V}} \beta_t \left(E_t V_{t+1}^{1-\sigma}\right)^{\frac{1}{\theta_V}-1} E_t \left(V_{t+1}^{-\sigma} V_{t+1}^{1-\frac{1-\sigma}{\theta_V}} \eta \xi_{t+1}^{pref} V^{norm} \frac{\left(C_{t+1}^{\eta} \left(1-N_{t+1}\right)^{1-\eta}\right)^{\frac{1-\sigma}{\theta_V}}}{C_{t+1}} \right)
\end{aligned} \tag{C.3}$$

Thus,

$$M \equiv \frac{\frac{\partial V_t}{\partial C_{t+1}}}{\frac{\partial V}{\partial C_t}} = \beta_t E_t \frac{\xi_{t+1}^{pref}}{\xi_t^{pref}} \left(\frac{C_{t+1}^{\eta}(1-N_{t+1})^{1-\eta}}{C_t^{\eta}\left(1-N_t\right)^{1-\eta}} \right)^{\frac{1-\sigma}{\theta_V}} \frac{C_t}{C_{t+1}} \left(\frac{V_{t+1}^{1-\sigma}}{E_t V_{t+1}^{1-\sigma}} \right)^{1-\frac{1}{\theta_V}} \,. \tag{C.4}$$

D Data

In our VAR, we use

1. Volatility: the quarterly realized return volatility of the Datastream Spanish Market Index, computed as the average standard deviation of daily returns of the performance index (obtained from Datastream: `TOTMKES(RI)`); for the idiosyncratic realized volatility, we compute the principal compenent over the volatility of the Datastream market indices of the euro area (Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Portugal, Spain, Slovenia, Slovakia) (obtained from Datastream: `TOTMK*(RI)`). To deal with missing values, we us the alternating least squares (ALS) algorithm of the Matlab `pca`-function in the R2017a version.

2. log GDP: real GDP, Seasonally and calendar adjusted data, Million euro, chain-linked volumes, reference year 2010 (Eurostat table `namq_10_gdp`, series `B1GQ`), divided by population

3. log Consumption: real personal consumption expenditures, Seasonally and calendar adjusted data, Million euro, chain-linked volumes, reference year 2010 (Eurostat table `namq_10_gdp`, series `P31_S14_S15`), divided by population

4. log Investment: real private investment, Seasonally and calendar adjusted data, Million euro, chain-linked volumes, reference year 2010 (Eurostat table `namq_10_gdp`, series `P51G`), divided by population

5. log Employment: total employment, Total employment national concept, Seasonally and calendar adjusted data, Thousand persons (Eurostat table `namq_10_gdp`, series `EMP_NC`)

6. Inflation: inflation based on the log difference of the GDP deflator; the GDP deflator is based on the Price index (implicit deflator), 2010=100, euro from Eurostat table `namq_10_gdp`, series `B1GQ`).

7. Shadow rate: the Wu and Xia (2016) shadow rate for the Euro Area whenever it is available and the ECB interest rates for main refinancing operations / End of month (ECB Data Warehouse, `BBK01.SU0202`) for the rest of the sample

To construct per capita values, we use Total population national concept, Seasonally and calendar adjusted data, Thousand persons (Eurostat table `namq_10_gdp`, series `POP_NC`). The introductory Figure 1 displayed the realized volatility of the Madrid Stock Exchange General Index (IGBN)(obtained from Datastream: `MADRIDI(DSRI)`. For the VAR, we rely on the Datastream Market Index to use a consistent index across the euro area countries. During our sample, the correlation of the two quarterly volatility series is 0.988.

E VAR Robustness

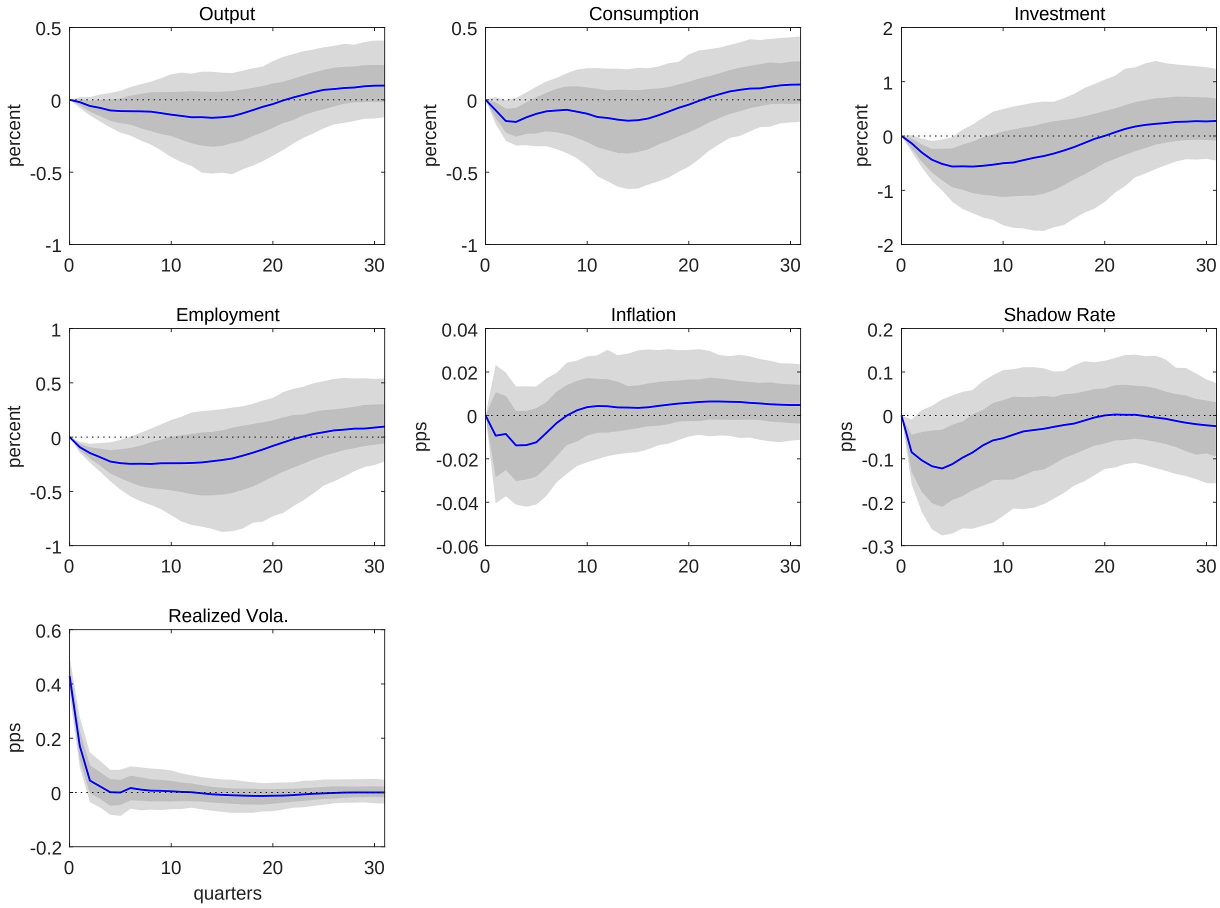

Figure E.1: IRFs to one-standard-deviation overall uncertainty shock with uncertainty ordered last.
Notes: Shaded bands are pointwise 68% (dark) and 90% (light) HPDIs, respectively.

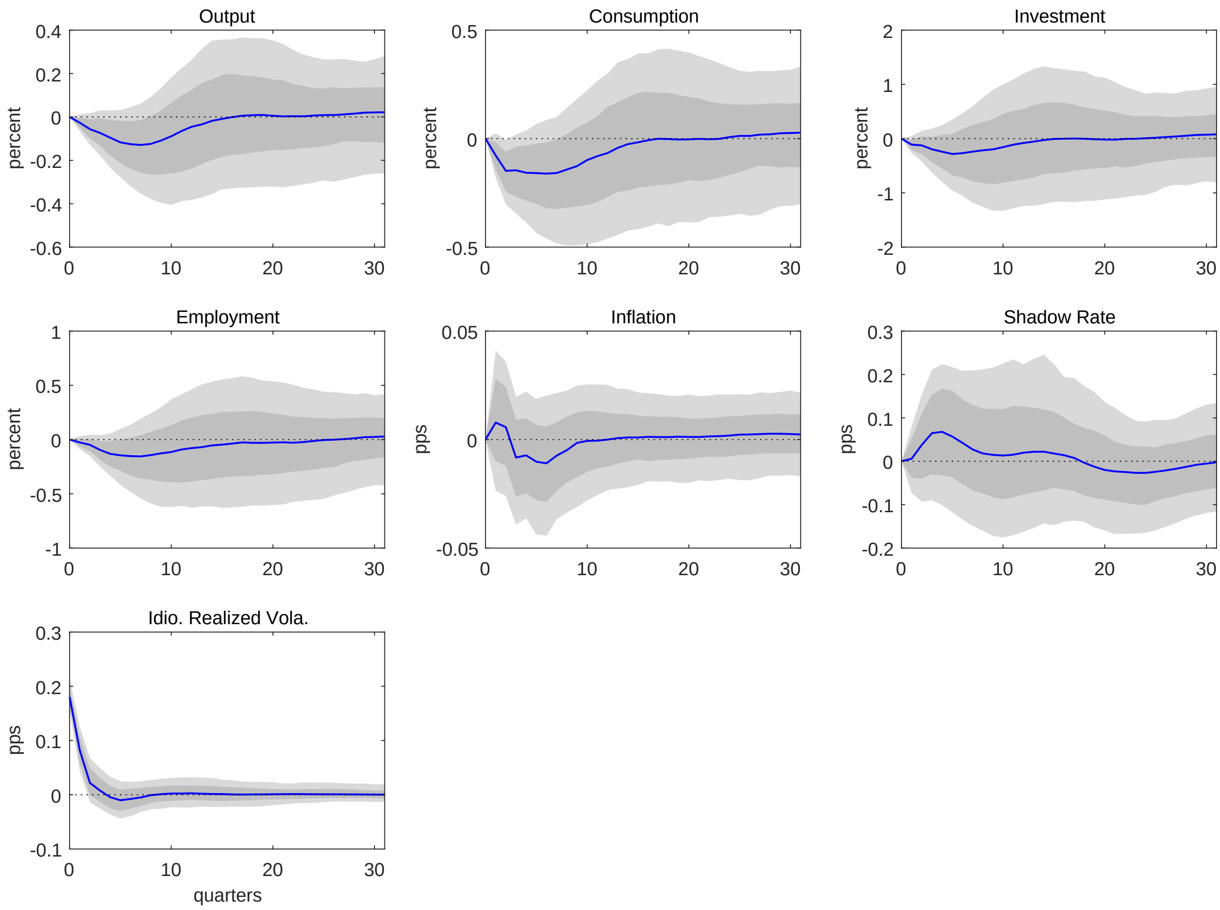

Figure E.2: IRFs to one-standard-deviation idiosyncratic uncertainty shock ordered last. *Notes:* Shaded bands are pointwise 68% (dark) and 90% (light) HPDIs, respectively.

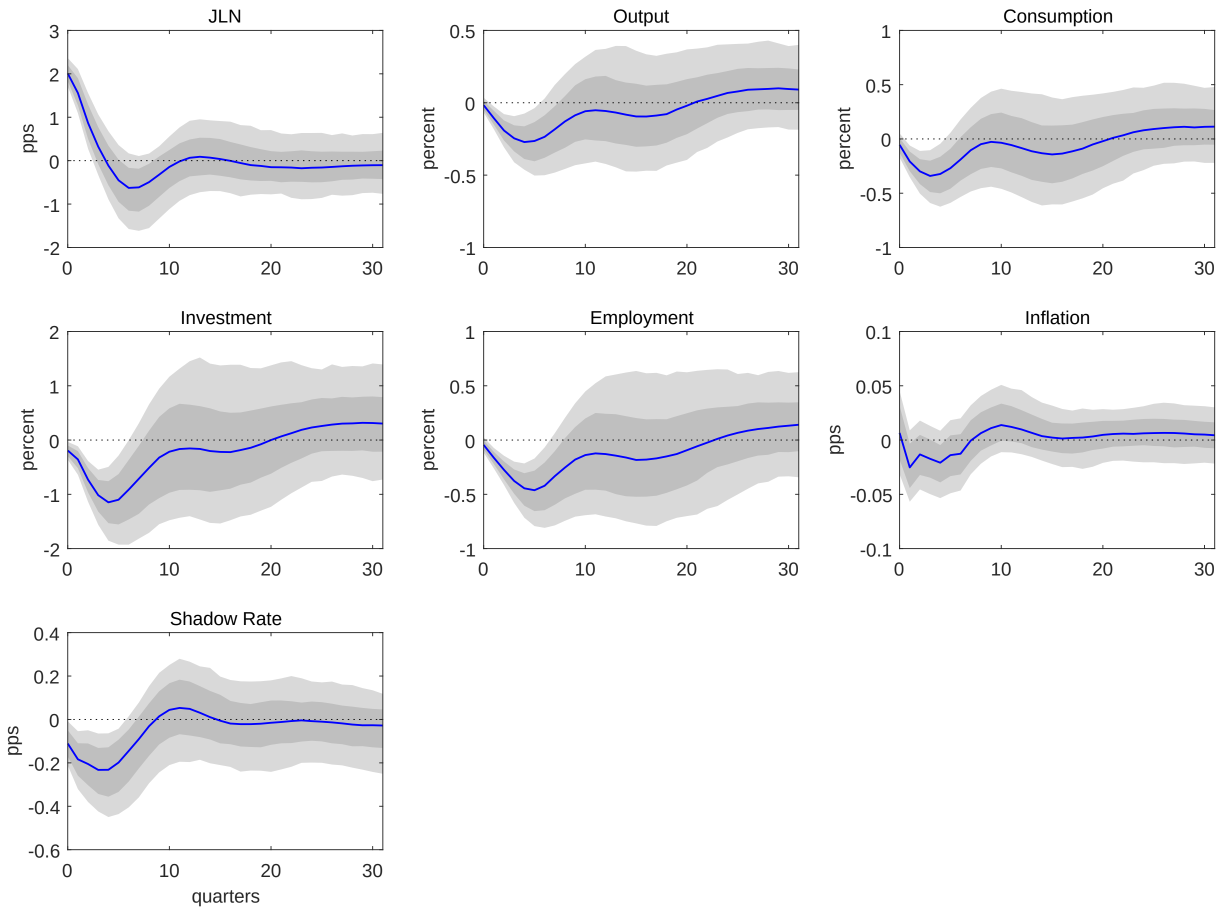

Figure E.3: IRFs to one-standard-deviation uncertainty shock, measured with the Spanish Meinen and Roehe (2017)-Jurado et al. (2015) measure ordered first.
Notes: Shaded bands are pointwise 68% (dark) and 90% (light) HPDIs, respectively.