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Estimating uncertainty spillover effects across euro area using a regime dependent VAR model

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Abstract: This paper investigates macroeconomic uncertainty spillover effects across countries and their impact on real economic activity in different economic periods, i.e. pre-crisis and during the recent financial crisis. The analysis is initially carried out using Monte Carlo simulations and, subsequently, real data for four euro zone economies, namely Italy, France, Germany, and Spain. The Monte Carlo findings clearly indicate a need to account for spillover effects across countries when investigating the impact of aggregate uncertainty on economic variables. The empirical results provide clear-cut evidence of the existence of macroeconomic spillovers between the four euro countries, with some feedback from periphery economies, notably Italy, to the core economies during the financial crisis period. Further, the impact of uncertainty on real economic activity is dampened for the four euro countries when spillover effects are accounted for. Spillover effects among the four countries are also observed when US uncertainty is taken into account. Further, US macroeconomic uncertainty impacts negatively on the real economic activity of the four euro countries.

Keywords: Euro area; real economic activity; spillover effects; uncertainty.

JEL classification: C32; C50; E32.

1 Introduction

In recent years there has been a considerable debate on the effect of macroeconomic and financial uncertainty on economic fluctuations [see, for example, Angelini et al. 2019; Bachmann and Sims 2013; Bloom 2009; Bloom, Bond, and Van Reenen 2007; Caldara et al. 2016; Carriero, Clark, and Marcellino 2018; Cesa-Bianchi, Pesaran, and Rebucci 2020; Girardi and Reuter 2016; Jurado, Ludvigson, and Ng 2015; Ludvigson, Ma, and Ng 2021; Meinen and Roehe 2017; Mumtaz and Theodoridis 2015; Rossi and Sekhposyan 2015]. A number of empirical studies have used a variety of measures for macroeconomic uncertainty, such as implied volatility of stock market or cross-sectional dispersion of stock returns.

Jurado, Ludvigson, and Ng (2015) argue that, while some measures may be preferable to others because of their observability, their effectiveness largely relies on the degree of correlation with the latent processes. Consequently Jurado, Ludvigson, and Ng (2015), proposed a new measure of uncertainty that is related to the potential unpredictability of the state of the economy rather than its variability. In their empirical analysis, based on a macro VAR Jurado, Ludvigson, and Ng (2015), show that uncertainty is counter-cyclical and far

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more persistent than common uncertainty proxies. In a related paper Meinen and Roehe (2017), use different measures of uncertainty to investigate their impact on the dynamic of investment for four euro countries, namely France, Germany, Italy, and Spain. While they use a variety of uncertainty measures, the measure proposed by Jurado, Ludvigson, and Ng (2015) "generates remarkably robust investment dynamics across model specifications and countries" [Meinen and Roehe 2017, page 162].

The purpose of the present paper is to investigate spillover effects among macroeconomic uncertainty across four euro countries, notably Germany, France, Italy and Spain, which belong to the same currency area with strong economic links [see, for example Caporale and Girardi 2013; Costantini, Fragetta, and Melina 2014; Costantini and Sousa 2022; Potjagailo 2017]. The empirical analysis is carried out over the period 1996:M7-2015:M12 using the macroeconomic uncertainty measure proposed by Jurado, Ludvigson, and Ng (2015), and compiled by Meinen and Roehe (2017) for these economies.

The approach by Bacchiocchi and Fanelli (2015), Bacchiocchi (2017) and Bacchiocchi, Castelnuovo, and Fanelli (2018) is used to account for the effects of the financial crisis, so to deal with volatility regimes and spillover effects.[1] Moreover, the different volatility regimes found in the data allow us to take into account reverse causality (or feedback) between core and periphery countries during the financial crisis period by identifying the structural shocks through a full on-impact matrix in the second regime. This implies that in the first regime spillover effects propagate from core to periphery countries, while in the second regime (financial crisis) spillover effects move also from periphery to core countries.

The paper also looks at the impact that uncertainty may have on real economic activity, namely industrial production [see also Jurado, Ludvigson, and Ng 2015; Ludvigson, Ma, and Ng 2021; Meinen and Roehe 2017; Moore 2017] and unemployment rate (Caggiano, Castelnuovo, and Figueres 2017; Caggiano, Castelnuovo, and Groshenny 2014) taking into account spillover effects. The literature has largely debated on whether uncertainty is a source of business cycles fluctuations or a consequence of them. Several approaches based on a VAR model have been used to investigate the impact of uncertainty on the real economy [for a review, see Ludvigson, Ma, and Ng 2021]. This paper examines the impact of (macro and financial) uncertainty on the real activity while dealing with spillover effects and related identification scheme by assuming exogeneity of uncertainty shocks with respect to business cycle Angelini and Fanelli (2019).

Along with the empirical analysis, this paper offers a Monte Carlo study and a set of robustness checks for the empirical application. The Monte Carlo study considers three different data generating processes. For the robustness checks, we first use an alternative measure of uncertainty, namely the stock market volatility [see Bloom 2009; Meinen and Roehe 2017] for the four euro countries within the SVAR framework by Bacchiocchi and Fanelli (2015), Bacchiocchi (2017) and Bacchiocchi, Castelnuovo, and Fanelli (2018). Second, with the same SVAR framework, we investigate the role of US uncertainty for the spillover effects using the macroeconomic and financial indicators by Jurado, Ludvigson, and Ng (2015) and Ludvigson, Ma, and Ng (2021), respectively. Third, we evaluate the impact of the US macroeconomic uncertainty on the real economic activity (industrial production) of the four euro countries. Lastly, a different approach for the identification of the SVAR based on the contribution by Lanne and Lütkepohl (2008) is applied to delve into spillover effects across the four euro countries with the macroeconomic uncertainty indicator by Jurado, Ludvigson, and Ng (2015).

The main results of the paper are as follows. First, the Monte Carlo exercise documents the importance of accounting for spillover effects when investigating the impact of uncertainty on economic variables. Second, the empirical results clearly indicate that there are macroeconomic spillovers between the four euro countries, with some feedback from periphery economies, notably Italy, to the core economies during the financial crisis

1 The empirical literature has used different models to deal with spillover effects. For example Rossi and Sekhposyan (2017), study spillover effects for both output growth- and inflation-based uncertainty in the euro Area using a VAR model [see Klößner and Wagner 2013], Caggiano, Castelnuovo, and Figueres (2020) use a nonlinear Smooth Transition VAR (STVAR) model to capture economic policy uncertainty spillovers from the US to Canada, and Cipollini and Mikaliunaite (2020) apply a global VAR, based on the approach by Greenwood-Nimmo, Nguyen, and Shin (2021), to macroeconomic and financial data in the euro Area Greenwood-Nimmo, Nguyen, and Shin (2021) extend the approach by (Diebold and Yilmaz 2012; Diebold and Yilmaz 2014).

period. Third, the impact of uncertainty on real economic activity is dampened when the spillover effects are accounted for. Lastly, the additional findings in the robustness checks are qualitatively similar to those displayed in the main empirical analysis. In particular, spillover effects are observed even when US (macro and financial) uncertainty is taken into account. Further, US macroeconomic uncertainty impacts negatively on the real economic activity (industrial production) of the four euro countries.

The rest of the paper is organized as follows. Section 2 describes data and methodology. Section 3 presents the Monte Carlo exercise. Section 4 presents the empirical analysis. Section 5 concludes.

2 Data and methodology

This paper uses the measure of uncertainty proposed by Jurado, Ludvigson, and Ng (2015), as computed by Meinen and Roehe (2017) in their analysis, as to investigate uncertainty in France, Germany, Italy, and Spain. It also uses the stock market volatility index by Meinen and Roehe (2017) (see Section 4.3.1) as a proxy for financial uncertainty and we use the US macroeconomic and financial uncertainty measures by Ludvigson, Ma, and Ng (2021) as control variables in the VAR (see Section 4.3.2).

Jurado, Ludvigson, and Ng (2015) aim to construct a measure of uncertainty that is "as free as possible both from the structure of specific theoretical models, and from dependencies on any single (or small number) of observable economic indicators" [Jurado, Ludvigson, and Ng 2015 page 1178]. More formally, denote by $\mathcal{U}^y_{jt}(h)$ the h-period head uncertainty in the series $y_{jt} \in Y_t = (y_{1t}, \ldots, y_{N_y t})'$. The uncertainty is the conditional volatility of the purely unforecastable component of the future values of the series considered. More specifically,

$$\mathcal{U}^y_{jt}(h) \equiv \sqrt{E\left[(y_{jt+h} - E[y_{jt+h} \mid I_t])^2 \mid I_t\right]}. \tag{1}$$

In (1), if the expectation today of the squared error in forecasting y_{jt+h} rises, then the uncertainty in the series will also rise. In order to construct a macroeconomic uncertainty measure Jurado, Ludvigson, and Ng (2015), propose to aggregate individual uncertainty at each date by weights w_j

$$\mathcal{U}^y_t(h) \equiv \text{plim}_{N_y \to \infty} \sum_{j=1}^{N_y} \text{w}_j \mathcal{U}^y_{jt}(h) \equiv E_w\left[\mathcal{U}^y_{jt}(h)\right]. \tag{2}$$

In order to yield estimates of (2), Jurado, Ludvigson, and Ng (2015) propose the following three-step procedure. First, factors are extracted from a large set of economic and financial indicators. These indicators accurately represents the information set I_t. These factors are then used to approximate $E[y_{jt+h}|I_t]$, the forecastable component, by using a diffusion index. Second, given the h-step-ahead forecast error, V^y_{jt+h}, Jurado, Ludvigson, and Ng (2015) proceed to estimate the conditional volatility of this error, $E\left[\left(V^y_{jt+h}\right)^2 |I_t\right]$. To this end, a parametric stochastic volatility model for both the one-step-ahead prediction errors in y_{jt} and the analogous forecast errors for the factors is applied. The volatility estimates are then used to compute the values of $E\left[\left(V^y_{t+h}\right)^2 |I_t\right]$ for $h > 1$, recursively. In the last step, the macroeconomic uncertainty in (2), $\mathcal{U}^y_t(h)$, is constructed from the individual uncertainty measures, $\mathcal{U}^y_{jt}(h)$.[2]

Meinen and Roehe (2017) follow the approach by Jurado, Ludvigson, and Ng (2015) to estimate (2) for four euro countries, France, Germany, Italy, and Spain. They collect a large data set comprising between 137 and 143 macroeconomic and financial time series. The uncertainty series are constructed in such a way that nine broad fields of macroeconomic time series data are taken into account. More specifically, the macroeconomic categories considered are: (i) real output and income; (ii) employment and compensation; (iii) housing; (iv) consumption, orders, and inventory; (v) money and credit; (vi) bond and exchange rates; (vii) price indexes;

2 Equally-weighted average of individual uncertainties is considered.

(viii) stock market indexes; and (ix) international trade.[3] For the financial data Meinen and Roehe (2017), follow Jurado, Ludvigson, and Ng (2015), and construct a financial data set based on data obtained from Kenneth French's website at Dartmouth College. In particular, they use aggregate series for Europe for each country under investigation,[4] that is Fama and French risk factors for Europe, 25 portfolios formed on size and book-to-market (5×5) for Europe, and the series termed $R15 - R11$, which is a spread computed from these portfolios [for details, see Appendix in Meinen and Roehe 2017]. The number of financial series used in their analysis amounts to 29. In our empirical analysis, we use one-step-ahead macroeconomic uncertainty, $\mathcal{U}_t^y(1)$.

Meinen and Roehe (2017) also consider the implied or realized volatility of stock market returns (SVOL) for the four euro countries as a measure of uncertainty. In particular Meinen and Roehe (2017), use the VDAX, which measures the implied volatility of the DAX, for Germany, concatenate the series of the actual volatility of the CAC40 and of the implied volatility measured by the VCAC for France, and compute the index based on the volatility of actual returns for the FTSE MIB and IGBM for Italy and Spain, respectively.

In order to evaluate the spillover effect of uncertainty shocks across the four countries under investigation, and the interactions between the real economic activity and the uncertainty measures, we use a SVAR model. Let Y_t be an $n \times 1$ vector of time series of interest. The SVAR model has the following representation

$$Y_t = C + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + Be_t, \qquad e_t \sim \mathrm{WN}(0_{n\times 1}, I_n), \qquad t = 1, \ldots, T \tag{3}$$

where T is the sample length, p is the system lag order, C is a $n \times 1$ constant, A_i, $i = 1, \ldots, p$ are $n \times n$ matrices of parameters, $\eta_t = Be_t$, e_t is the vector of mean zero, unit variance and uncorrelated structural shocks, and η_t is a $n \times 1$ vector of reduced form innovations with covariance matrix $\Sigma_\eta = BB'$. It is straightforward to derive the Vector Moving Average (VMA) representation from (3)

$$Y_t = \mu + \Psi(L)Be_t, \tag{4}$$

where $\Psi(L)I_n + \Psi_1 L + \Psi_2 L^2 + \cdots$ is a polynomial in the lag operator L of infinite order. In this setup the Impulse Response Functions (IRF) can be easily computed as follows

$$\frac{\partial Y_{t+h}}{\partial e_{jt}} = \Psi_h b_j = J(A)^h J' b_j, \qquad h = 0, 1, 2, \ldots, \qquad j = 1, \ldots, n \tag{5}$$

where Ψ_h is the matrix associated with the h-lag of $\Psi(L)$, $J = (I_n, 0_{n\times n}, \ldots, 0_{n\times n})$ is a selection matrix, A is the companion matrix associated with (3), and b_j is the jth column of the matrix B. A necessary condition for the calculation of the IRF is that b_j (and the matrix B) is identified, that is it can not be expressed as a linear combination of the other columns of B. The identification of the matrix B in (3) can be achieved using a different technique. In this paper we follow the idea proposed by Bacchiocchi and Fanelli (2015), who make the identification possible using potential heteroscedasticity in the data, as an additional information [see also Angelini et al. 2019]. This approach has two merits. First, it allows us to compute regime dependent IRFs. Therefore, it makes possible to evaluate IRFs during the pre-crisis period and the crisis period (see Section 4), which is the focus of this paper. Second, there is no need to impose strong 0 restrictions on the structural matrix.

As for the reduced covariance matrix, the following is required: $\Sigma_{\eta,\mathrm{pre}} \neq \Sigma_{\eta,\mathrm{crisis}}$ [see Assumption 1 in Bacchiocchi and Fanelli 2015]. In particular, we specify $\Sigma_{\eta,\mathrm{pre}} = B_{\mathrm{pre}} B'_{\mathrm{pre}}$ and $\Sigma_{\eta,\mathrm{crisis}} = (B_{\mathrm{pre}} + B_{\mathrm{crisis}})(B_{\mathrm{pre}} + B_{\mathrm{crisis}})'$. In our notation, the subscripts "pre" and "crisis" indicate the matrices related to the pre-crisis period and the period of crisis, respectively. The SVAR model in (3) can then be generalized as follows

$$Y_t = A(t)W_t + \eta_t, \quad \Sigma_\eta(t) = E\left(\eta_t \eta_t'\right), \quad t = 1, \ldots, T \tag{6}$$

3 Meinen and Roehe (2017) arranged their final data set with 113, 114, 108, and 110 time series for Germany, France, Italy, and Spain, respectively.

4 This is due to the unavailability of timely country-specific series for European countries.

where W_t contains lagged regressors and a constant. In this formulation, both the slope autoregressive matrix $A(t)$ and the covariance matrix $\Sigma_\eta(t)$ are regime dependent

$$A(t) = A_{\text{pre}} \times \mathbf{1}(t \le T_B) + A_{\text{crisis}} \times \mathbf{1}(t > T_B), \tag{7}$$

$$\Sigma_\eta(t) = \Sigma_{\eta,\text{pre}} \times \mathbf{1}(t \le T_B) + \Sigma_{\eta,\text{crisis}} \times \mathbf{1}(t > T_B). \tag{8}$$

The regime-dependent SVAR described in (6) has different IRFs for each regime. In particular, we have

$$\text{IRF}_{\text{pre}}(h) = J\left(A_{\text{pre}}\right)^h J' b_{\text{pre},j}, \tag{9}$$

$$\text{IRF}_{\text{crisis}}(h) = J(A_{\text{crisis}})^h J'(b_{\text{pre},j} + b_{\text{crisis},\text{j}}), \tag{10}$$

where $b_{\text{pre},j}$ is the jth column of the matrix B_{pre} and $b_{\text{pre},j} + b_{\text{crisis},j}$ is the jth column of the matrix $B_{\text{pre}} + B_{\text{crisis}}$. For details about the estimation of the SVAR described in (6)–(8), see Bacchiocchi and Fanelli (2015) and Angelini et al. (2019). For the analysis in the paper, we consider only exactly identified specifications in line with the sufficient conditions proposed by Rubio-Ramirez, Waggoner, and Zha (2010).

3 Monte Carlo analysis

In this section we conduct a set of Monte Carlo experiments to evaluate the consequences of the omission of spillover effects in the analysis. The Monte Carlo analysis looks at different scenarios, depending on the absence/presence of spillover effects. In particular, we proposed three different scenarios (different B_{pre} and B_{crisis} matrices). For simplicity, an economy with only two countries, say i and j, is considered. Further, the true Data Generating Process (DGP) is based on a trivariate SVAR with $Y_t = \left(U_{i,t}, U_{j,t}, E_{j,t}\right)$, where $U_{i,t}$ and $U_{j,t}$ denote the measures of uncertainty for country i and j, respectively, and $E_{j,t}$ is a measure of real economic activity of country j, and a bivariate miss-specified SVAR with $\tilde{Y}_t = \left(U_{j,t}, E_{j,t}\right)$ is estimated for the evaluation of the omission of the spillover effects. In the Monte Carlo simulations, miss-specification is due to the assumption of uncorrelated uncertainty measures. The analysis is conducted for two different sample sizes, $T_1 = T_2 = 100$ and $T_1 = T_2 = 500$, where T_1 and T_2 denote the sample size of the trivariate and bivariate SVAR, respectively (see Tables 1–3), and for 10,000 replications. The identification scheme relies on the SVAR in (6)–(8) and the matrices B_{pre} and B_{crisis} are defined as follows

$$B_{\text{pre}} = \begin{pmatrix} \times & 0 & 0 \\ \times & \times & 0 \\ \times & \times & \times \end{pmatrix}, \quad B_{\text{crisis}} = \begin{pmatrix} \times & \times & 0 \\ 0 & \times & 0 \\ \times & \times & \times \end{pmatrix}, \quad B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \times & \times & 0 \\ \times & \times & 0 \\ \times & \times & \times \end{pmatrix},$$

where $\times$ indicates potential non-zero element.

For DGP 1 (see Table 1), we consider an economy where the uncertainty measure of country j has no effects on the real economic activity in country j (the 0 element in the third row, second column of the matrices B_{pre} and $B_{\text{pre}} + B_{\text{crisis}}$ in Table 1), the uncertainty measure of country i has a negative effect on real economic activity in country j, and the uncertainty measures of the two countries are positively related.

We estimate a true trivariate SVAR model for Y_t, and a misspecified bivariate SVAR model with $\tilde{Y}_t$ (in the true DGP there are no direct effects from $U_{j,t}$ and $E_{j,t}$). The estimation results clearly show that the omission of spillover effects in the analysis point to misleading findings. More specifically, looking at the right part of Table 1, it emerges that, when the spillover effects between U_i and U_j are not accounted for, the impact of U_j on E_j tend to be different from 0 (even when the sample size T increases).

This result may imply that when spillover effects are omitted, a direct effect of U_j on E_j is observed. Therefore, potential spillover effects due to the characteristics of the economy should be taken into account.

Table 1: Monte Carlo results: DGP 1.

True data generating process

$$B_{\text{pre}} = \begin{pmatrix} 0.8 & 0 & 0 \\ 0.4 & 0.3 & 0 \\ -0.2 & 0 & 0.3 \end{pmatrix}$$

$$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} 1 & 0.2 & 0 \\ 0.4 & 0.4 & 0 \\ -0.5 & 0 & 0.9 \end{pmatrix}$$

Trivariate VAR (Correctly specified model)		Bivariate VAR (Mis−specified model)
	$T_1 = T_2 = 100$	
$B_{\text{pre}} = \begin{pmatrix} \underset{(0.057)}{0.778} & 0 & 0 \\ \underset{(0.041)}{0.389} & \underset{(0.021)}{0.290} & 0 \\ \underset{(0.033)}{-0.194} & \underset{(0.030)}{0.000} & \underset{(0.021)}{0.289} \end{pmatrix}$		$B_{\text{pre}} = \begin{pmatrix} \underset{(0.064)}{0.531} & 0 \\ \underset{(0.049)}{-0.159} & \underset{(0.023)}{0.314} \end{pmatrix}$
$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.063)}{0.960} & \underset{(0.169)}{0.182} & 0 \\ \underset{(0.041)}{0.389} & \underset{(0.076)}{0.381} & 0 \\ \underset{(0.098)}{-0.478} & \underset{(0.123)}{0.005} & \underset{(0.064)}{0.865} \end{pmatrix}$		$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.066)}{0.618} & 0 \\ \underset{(0.121)}{-0.324} & \underset{(0.042)}{0.602} \end{pmatrix}$
	$T_1 = T_2 = 500$	
$B_{\text{pre}} = \begin{pmatrix} \underset{(0.026)}{0.796} & 0 & 0 \\ \underset{(0.018)}{0.398} & \underset{(0.009)}{0.298} & 0 \\ \underset{(0.015)}{-0.199} & \underset{(0.013)}{0.000} & \underset{(0.009)}{0.298} \end{pmatrix}$		$B_{\text{pre}} = \begin{pmatrix} \underset{(0.044)}{0.545} & 0 \\ \underset{(0.031)}{-0.165} & \underset{(0.011)}{0.321} \end{pmatrix}$
$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.027)}{0.992} & \underset{(0.072)}{0.196} & 0 \\ \underset{(0.018)}{0.398} & \underset{(0.031)}{0.396} & 0 \\ \underset{(0.044)}{-0.496} & \underset{(0.054)}{0.001} & \underset{(0.029)}{0.893} \end{pmatrix}$		$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.043)}{0.634} & 0 \\ \underset{(0.071)}{-0.337} & \underset{(0.019)}{0.619} \end{pmatrix}$

(1) T_1 and T_2 refer to the sample size of trivariate and bivariate SVARs, respectively; (2) Standard errors are in brackets.

The second Monte Carlo exercise is based on the DGP illustrated in Table 2. It differs from DGP 1, as the uncertainty measure of country j has now a low effect on the real economic activity in country j, −0.05 in pre-crisis period (see second element in the third row of B_{pre}), and −0.06 during the period of the crisis (see second element in the third row of $B_{\text{pre}} + B_{\text{pre}}$).

The results are similar to those obtained with DGP 1: the omission of spillover effects in the analysis point to misleading results. Indeed, the impact of U_j on E_j tends to be higher (in absolute value) than true one. In particular, the true on-impact effect of U_j on E_j is −0.05 and −0.06 for the pre-crisis period and during the period of the crisis, respectively, while the estimated values in the mis-specified model for $T_1 = T_2 = 500$ are −0.19 and −0.37.

The last simulation exercises (DGP 3) is based on an economy in which the uncertainty measures are not related across the two countries (no spillover effects). The matrices B_{pre} and B_{crisis} are described in Table 3.

Unlike previous DGPs, the impact of U_j on E_j in the mis-specified model is no longer statistically significant indicating that, when no spillover effects are present, the omission of one of the uncertainty measure in the system does not affect the relationship between the other uncertainty measure and the real economic activity.

The Monte Carlo simulations based on the three different DGP produce a clear set of results. When no spillovers are present or accounted for, the results are statistically insignificant. This implies that, when assessing the impact of macroeconomic uncertainty on real economic activity, the effects of uncertainty spillovers from other integrated economies must be taken into account.

Table 2: Monte Carlo results: DGP 2.

True data generating process

$$B_{\text{pre}} = \begin{pmatrix} 0.8 & 0 & 0 \\ 0.4 & 0.3 & 0 \\ -0.2 & -0.05 & 0.3 \end{pmatrix}$$

$$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} 1 & 0.2 & 0 \\ 0.4 & 0.4 & 0 \\ -0.5 & -0.06 & 0.9 \end{pmatrix}$$

	Trivariate VAR (Correctly specified model)	Bivariate VAR (Mis–specified model)
$T_1 = T_2 = 100$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.057)}{0.778} & 0 & 0 \\ \underset{(0.041)}{0.389} & \underset{(0.021)}{0.290} & 0 \\ \underset{(0.034)}{-0.194} & \underset{(0.030)}{-0.049} & \underset{(0.021)}{0.289} \end{pmatrix}$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.063)}{0.534} & 0 \\ \underset{(0.044)}{-0.188} & \underset{(0.022)}{0.303} \end{pmatrix}$
	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.063)}{0.960} & \underset{(0.169)}{0.182} & 0 \\ \underset{(0.041)}{0.389} & \underset{(0.076)}{0.381} & 0 \\ \underset{(0.097)}{-0.478} & \underset{(0.123)}{-0.053} & \underset{(0.064)}{0.865} \end{pmatrix}$	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.065)}{0.620} & 0 \\ \underset{(0.116)}{-0.363} & \underset{(0.042)}{0.591} \end{pmatrix}$
$T_1 = T_2 = 500$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.026)}{0.796} & 0 & 0 \\ \underset{(0.018)}{0.398} & \underset{(0.009)}{0.298} & 0 \\ \underset{(0.015)}{-0.199} & \underset{(0.014)}{-0.050} & \underset{(0.009)}{0.298} \end{pmatrix}$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.045)}{0.547} & 0 \\ \underset{(0.028)}{-0.193} & \underset{(0.010)}{0.310} \end{pmatrix}$
	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.027)}{0.992} & \underset{(0.072)}{0.196} & 0 \\ \underset{(0.018)}{0.398} & \underset{(0.031)}{0.396} & 0 \\ \underset{(0.043)}{-0.496} & \underset{(0.054)}{-0.059} & \underset{(0.029)}{0.893} \end{pmatrix}$	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.044)}{0.634} & 0 \\ \underset{(0.069)}{-0.374} & \underset{(0.019)}{0.607} \end{pmatrix}$

See note in Table 1.

4 Empirical analysis

This section focuses on the empirical analysis and is divided into three parts. In Section 4.1, we evaluate the spillover effects amongst one-step-ahead macroeconomic uncertainty (see Section 2) for the four euro countries using the SVAR framework by Bacchiocchi and Fanelli (2015), Bacchiocchi (2017) and Bacchiocchi, Castelnuovo, and Fanelli (2018). Section 4.2 investigates the impact uncertainty measures on real economic activity, namely industrial production and unemployment rate [see, for example, Caggiano, Castelnuovo, and Figueres 2017; Caggiano, Castelnuovo, and Groshenny 2014; Jurado, Ludvigson, and Ng 2015; Ludvigson, Ma, and Ng 2021; Meinen and Roehe 2017; Moore 2017], using the same SVAR model of Section 4.1, and the role of spillover effects. Section 4.3 reports a set of robustness checks.

4.1 Macroeconomic uncertainty spillovers

Figure 1 illustrates the dynamics of the uncertainty measures across the four euro countries. Overall, uncertainty levels in Spain appear to be higher than the uncertainty in the other countries over the period under investigation. Furthermore, there are periods where uncertainties seem to co-move (for example during the financial crisis). Cross correlations among the uncertainty measures are also computed (see Table 4). The results indicate that the highest correlations are documented for the pair of Germany and France, and Italy

Table 3: Monte Carlo results: DGP 3.

True data generating process

$$B_{\text{pre}} = \begin{pmatrix} 0.8 & 0 & 0 \\ 0 & 0.3 & 0 \\ -0.2 & 0 & 0.3 \end{pmatrix}$$

$$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0.4 & 0 \\ -0.5 & 0 & 0.9 \end{pmatrix}$$

Trivariate VAR (Correctly specified model)	Bivariate VAR (Mis−specified model)
$T_1 = T_2 = 100$	
$B_{\text{pre}} = \begin{pmatrix} \underset{(0.057)}{0.778} & 0 & 0 \\ \underset{(0.030)}{0.000} & \underset{(0.021)}{0.290} & 0 \\ \underset{(0.033)}{-0.194} & \underset{(0.030)}{0.000} & \underset{(0.021)}{0.289} \end{pmatrix}$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.036)}{0.398} & 0 \\ \underset{(0.037)}{-0.046} & \underset{(0.028)}{0.352} \end{pmatrix}$
$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.070)}{0.964} & \underset{(0.126)}{0.000} & 0 \\ \underset{(0.030)}{0.000} & \underset{(0.028)}{0.388} & 0 \\ \underset{(0.097)}{-0.481} & \underset{(0.110)}{0.000} & \underset{(0.064)}{0.865} \end{pmatrix}$	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.048)}{0.527} & 0 \\ \underset{(0.102)}{-0.057} & \underset{(0.044)}{0.640} \end{pmatrix}$
$T_1 = T_2 = 500$	
$B_{\text{pre}} = \begin{pmatrix} \underset{(0.025)}{0.796} & 0 & 0 \\ \underset{(0.013)}{0.000} & \underset{(0.009)}{0.298} & 0 \\ \underset{(0.015)}{-0.199} & \underset{(0.013)}{0.000} & \underset{(0.009)}{0.298} \end{pmatrix}$	$B_{\text{pre}} = \begin{pmatrix} \underset{(0.022)}{0.405} & 0 \\ \underset{(0.018)}{-0.046} & \underset{(0.015)}{0.360} \end{pmatrix}$
$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.031)}{0.993} & \underset{(0.055)}{0.000} & 0 \\ \underset{(0.013)}{0.000} & \underset{(0.013)}{0.398} & 0 \\ \underset{(0.043)}{-0.496} & \underset{(0.049)}{0.000} & \underset{(0.029)}{0.893} \end{pmatrix}$	$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} \underset{(0.030)}{0.541} & 0 \\ \underset{(0.047)}{-0.061} & \underset{(0.022)}{0.658} \end{pmatrix}$

See note in Table 1.

and Spain, respectively. Further, there is clear-cut evidence of larger cross-correlations over the second sample period.

In order to evaluate the spillover effects between uncertainty measures across the four countries under investigation, we estimate the regime-dependent SVAR model in (6) with:

$$Y_t = \begin{pmatrix} U_{\text{Ger},t} \\ U_{\text{Fra},t} \\ U_{\text{Ita},t} \\ U_{\text{Spa},t} \end{pmatrix}, \tag{11}$$

where $U_{j,t}$, $j =$ Ger, Fra, Ita and Spa, denotes the uncertainty measures taken from Meinen and Roehe (2017) for Germany, France, Italy and Spain, respectively. Using the standard information criteria,[5] the number of lags p in (3) is set to 2. The two volatility regimes that have been identified provide us with 20 moment conditions (the parameters in the matrices η_{pre} and η_{crisis}, see Section 2).[6] Since 32 parameters in the matrices B_{pre} and

5 The AIC (Akaike information criterion), the BIC (Bayesian information criterion) and the HQC (Hannan-Quinn information criterion) criteria are used in the analysis.

6 In line with Angelini et al. (2019), the structural beak is assumed to be at $T_B =$ 2007:M12, so the first regime is 1996:M7-2007:M12, while the second one is 2008:M1-2015:M12. A likelihood ratio test for the null hypothesis $\mathcal{H}_0 \colon \Sigma_{\eta,\text{pre}} = \Sigma_{\eta,\text{crisis}} = \Sigma_\eta$ is performed for the SVAR used in this section and in Section 4.2). The results show that the null hypothesis $\mathcal{H}_0$ can be rejected in all the cases

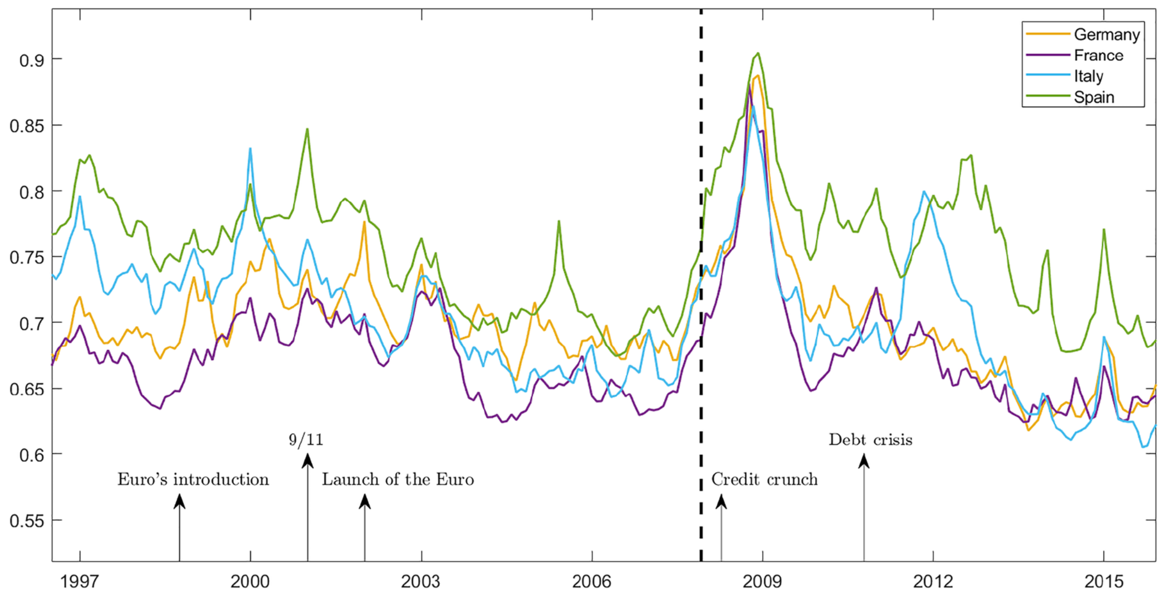

Figure 1: Macroeconomic uncertainty measures for the four euro countries, 1996:M7-2015:M12. The dashed black line indicates $T_B = 2007$:M12.

Table 4: Cross-correlations of macroeconomic uncertainty measures across Germany, France, Italy and Spain.

	U_{Ger}	U_{Fra}	U_{Ita}	U_{Spa}
		Full sample period: 1996:M7-2015:M12		
U_{Ger}	1.000			
U_{Fra}	0.858***	1.000		
U_{Ita}	0.737***	0.750***	1.000	
U_{Spa}	0.716***	0.762***	0.802***	1.000
		First sample period: 1996:M7–2007:M12		
U_{Ger}	1.000			
U_{Fra}	0.676***	1.000		
U_{Ita}	0.557***	0.661***	1.000	
U_{Spa}	0.540***	0.674***	0.836***	1.000
		Second sample period: 2008:M1–2015:M12		
U_{Ger}	1.000			
U_{Fra}	0.936***	1.000		
U_{Ita}	0.825***	0.834***	1.000	
U_{Spa}	0.874***	0.823***	0.866***	1.000

***Denote significance at 1% level.

B_{crisis} should be estimated, at least 12 restrictions should be placed so to achieve identification. To do so, we impose a triangular (Cholesky) structure in the first sub-sample (pre-financial crisis period), which implies a more exogenous role of the core countries (Germany and France), but a complete non-recursive structure during the financial crisis period. On the other hand, during the crisis period, the impact matrix $B_{pre} + B_{crisis}$ is full, and there are no restrictions on the causality direction between countries. Therefore, feedbacks can

since the p-values are close to zero. Therefore, two different covariance matrices are set for the pre-crisis and the period of crisis, respectively. The results of the likelihood ratio test are not reported here and are available upon request from the authors.

be observed from core economies (Germany and France) to the periphery countries (Italy and Spain), and viceversa. The matrices B_{pre} and B_{crisis} are as follows

$$B_{\text{pre}} = \begin{pmatrix} b_{\text{pre},11} & 0 & 0 & 0 \\ b_{\text{pre},21} & b_{\text{pre},22} & 0 & 0 \\ b_{\text{pre},31} & b_{\text{pre},32} & b_{\text{pre},33} & 0 \\ b_{\text{pre},41} & b_{\text{pre},42} & b_{\text{pre},43} & b_{\text{pre},44} \end{pmatrix} \tag{12}$$

$$B_{\text{crisis}} = \begin{pmatrix} b_{\text{crisis},11} & b_{\text{crisis},12} & b_{\text{crisis},13} & b_{\text{crisis},14} \\ 0 & b_{\text{crisis},22} & b_{\text{crisis},23} & b_{\text{crisis},24} \\ 0 & 0 & b_{\text{crisis},33} & b_{\text{crisis},34} \\ 0 & 0 & 0 & b_{\text{crisis},44} \end{pmatrix} \tag{13}$$

$$B_{\text{pre}} + B_{\text{crisis}} = \begin{pmatrix} b_{\text{pre},11} + b_{\text{crisis},11} & b_{\text{crisis},12} & b_{\text{crisis},13} & b_{\text{crisis},14} \\ b_{\text{pre},21} & b_{\text{pre},22} + b_{\text{crisis},22} & b_{\text{crisis},23} & b_{\text{crisis},24} \\ b_{\text{pre},31} & b_{\text{pre},32} & b_{\text{pre},33} + b_{\text{crisis},33} & b_{\text{crisis},34} \\ b_{\text{pre},41} & b_{\text{pre},42} & b_{\text{pre},43} & b_{\text{pre},44} + b_{\text{crisis},44} \end{pmatrix}. \tag{14}$$

The on-impact matrices B_{pre} and B_{crisis} capture the instantaneous (structural) relationships between uncertainties. As pointed out earlier (see Section 2), the matrix B_{pre} contains the pre-crisis on-impact effects, while the matrix $B_{\text{pre}} + B_{\text{crisis}}$ in (14) reports the instantaneous effects during and after the financial crisis. The estimates of the structural parameters are reported in Table 5. Interestingly, the structural parameters $b_{\text{crisis},12}$, $b_{\text{crisis},13}$ and $b_{\text{crisis},14}$ are not statistically different from 0, indicating that Germany plays an exogenous role even during the financial crisis, that is uncertainty in Germany does not respond instantaneously to shocks to uncertainty in other countries. As such, Germany plays a dominant role among the four euro countries, in the sense that any external shock to the Eurozone, such as that resulting from the US sub-prime mortgage markets, affects the German economy directly and not via the other Eurozone countries, while the other euro countries may also be affected by the German economy. Moreover, looking at the elements on the main diagonal of the two matrices, the magnitude of the coefficients is higher during the financial crisis for all the countries except for Germany, denoting that, differently from the other countries, the variance of the shock related to the German uncertainty does not augment during the financial crisis. It would appear that Germany was not unduly affected by the financial crisis, that is effects on German uncertainty appear to be the same in the crisis period as they are in the pre-crisis period.

The IRFs are reported in Figure 2, where 90% confidence bands are computed following the bootstrap approach proposed in Kilian (1998). As previously highlighted, the analysis distinguishes between pre-financial crisis period (1996:M7–2007:M12) and crisis period (2008:M1–2015:M12) [see also

Table 5: B_{pre} and B_{crisis} estimates for uncertainty measures.

$$\hat{B}_{\text{pre}} = \begin{pmatrix} \underset{(0.001)}{0.011^{***}} & 0 & 0 & 0 \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.000)}{0.007^{***}} & 0 & 0 \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.001)}{0.002^{**}} & \underset{(0.001)}{0.010^{***}} & 0 \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.001)}{0.002^{**}} & \underset{(0.001)}{0.004^{***}} & \underset{(0.001)}{0.009^{***}} \end{pmatrix}$$

$$\hat{B}_{\text{pre}} + \hat{B}_{\text{crisis}} = \begin{pmatrix} \underset{(0.001)}{0.010^{***}} & \underset{(0.002)}{0.002} & \underset{(0.005)}{0.001} & \underset{(0.002)}{0.002} \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.001)}{0.012^{***}} & \underset{(0.001)}{0.003^{***}} & \underset{(0.001)}{0.003^{***}} \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.001)}{0.002^{**}} & \underset{(0.001)}{0.010^{***}} & \underset{(0.002)}{0.002} \\ \underset{(0.001)}{0.005^{***}} & \underset{(0.001)}{0.002^{**}} & \underset{(0.001)}{0.004^{***}} & \underset{(0.001)}{0.013^{***}} \end{pmatrix}$$

(1) Standard errors in brackets; (2) *** and ** denote statistical. Significance at 1 and 5% level, respectively.

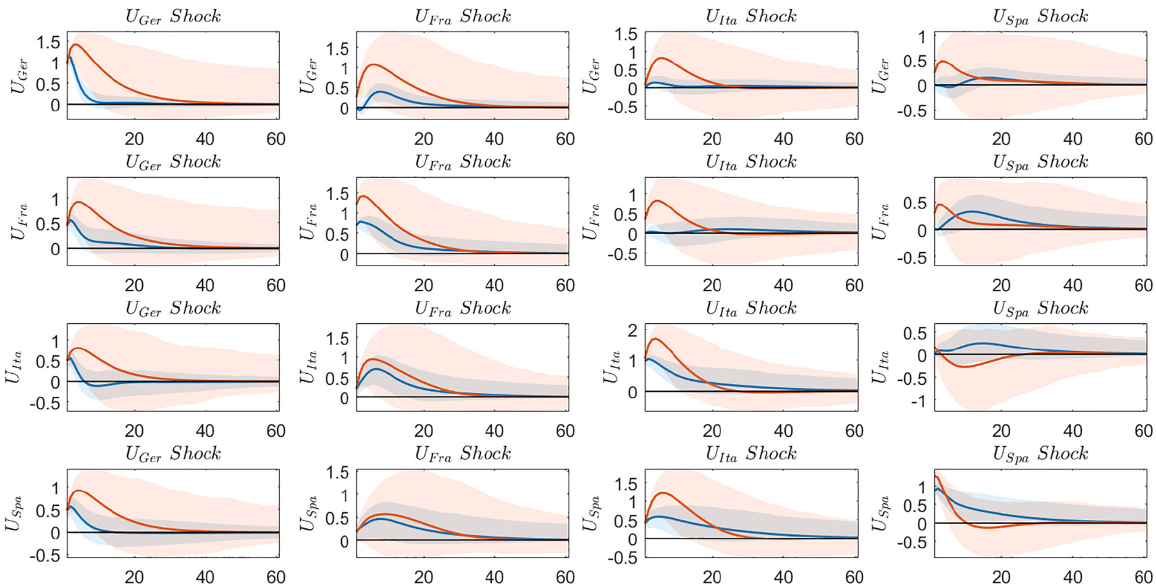

Figure 2: Macroeconomic uncertainty spillovers across Germany, France, Italy and Spain. U_{Ger}, U_{Fra}, U_{Ita}, and U_{Spa} denote the uncertainty measures for Germany, France, Italy and Spain. Blue and red lines indicate the impulse response functions for the period 1996:M7–2007:M12 and 2008:M1–2015:M12, respectively. The VAR in (11) is estimated. 90% confidence bands are computed following the bootstrap approach proposed by Kilian (1998).

Angelini et al. 2019]. The euro countries where affected by the credit crunch originating from the US and the resulting financial crisis. In addition, euro countries are blighted by the deficit crisis, as well as Italian banking crisis. Both have had a prolonged effect on these economies.

There are four noteworthy results. First, during the pre-financial crisis period (first regime), shocks to individual country's uncertainty seem to affect their own uncertainty ("self-effects") (see Figure 2). In particular, a rapid increase in uncertainty is observed across the four countries, with Germany showing the fastest decline thereafter. France, Italy and Spain display more persistence.

Second, also in the pre-crisis period, there is a clear evidence that shocks to core countries uncertainty propagate to periphery countries.[7] Notably, a shock on uncertainty in France propagates to Italy (the effect on Spain is substantially non-existent) and remains significant for more than a year. Similarly, spillover effects from Germany to Italy and Spain are observed, albeit for a shorter period.

Third, in the crisis period (second regime), the self-effects are still present, with a larger magnitude than that in the pre-crisis period. This finding is unsurprising in view of the financial crisis: Figure 1 points to a rise in uncertainty, especially over the period 2008–2012, in contrast to the level of uncertainty right before the period of the financial crisis. Fourth, the spillover effects from the core economies to the periphery countries seem to mimic those in the pre-financial crisis period, though Germany plays now a more relevant role in the transmissions of uncertainty over the two periphery countries. Interestingly, uncertainty in periphery economies now seems to exert some impact on the core countries. In particular, there is clear evidence of spillover effects from Italy to the core countries. The spillover effects last for a few horizons with a similar magnitude. On the other hand, in case of Spain, these effects are significant for a very short horizon.[8] In the Italian case, the prolonged and individual-specific nature of the aftermath of the financial crisis on the

7 The identification scheme previously discussed does not allow for feedbacks from periphery to core countries in the pre-financial crisis.

8 While Germany and France are the two largest Eurozone economies, Italy and Spain are still large economies with significant investments from the core economies, and Italy has a significant industrial base (mainly located in the north).

Italian economy clearly had an effect on the core economies. Indeed, the ensuing banking crisis meant that the idiosyncratic shock has prolonged the recovery of the Italian economy and its effects were felt by other Eurozone economies.

4.2 Macroeconomic uncertainty shocks and their effects on the real economic activity

This section considers the effect of uncertainty shocks on the real economic activity, namely industrial production (IP) and unemployment rate (UR). Data for these variables are taken taken from Federal Reserve Economic Data (FRED). We consider the impact of uncertainty shocks on these macroeconomic variables one after another.

We investigate the potential transmission channels of macro uncertainty on real economic activity. Specifically, we empirically assess the transmission in two scenarios: with and without spillover effects. First, we consider all the four uncertainties (with spillover effects) when studying the impact of these on the real economic activity of the country in question (see (15)), and then the macroeconomic uncertainty in this country only (without spillover effects) is considered for the impact on real economic activity (see (18)).

In the case with spillover effects, the SVAR model in (6) is expanded by adding one measure of economic activity

$$Y_t = \begin{pmatrix} U_{\text{Ger},t} \\ U_{\text{Fra},t} \\ U_{\text{Ita},t} \\ U_{\text{Spa},t} \\ E_t \end{pmatrix}, \tag{15}$$

where the variable E_t is the measure of economic activity. For the analysis, the SVAR model in (15) is estimated 8 times, i.e. replacing E_t with $\Delta\text{IP}_{j,t}$ and $\Delta\text{UR}_{j,t}$, respectively, where $j = \text{Ger, Fra, Ita and Spa}$. To this end, let the structural matrices B_{pre} and B_{crisis} be as follows:

$$B_{\text{pre}} = \begin{pmatrix} b_{\text{pre},11} & 0 & 0 & 0 & 0 \\ b_{\text{pre},21} & b_{\text{pre},22} & 0 & 0 & 0 \\ b_{\text{pre},31} & b_{\text{pre},32} & b_{\text{pre},33} & 0 & 0 \\ b_{\text{pre},41} & b_{\text{pre},42} & b_{\text{pre},43} & b_{\text{pre},44} & 0 \\ b_{\text{pre},51} & b_{\text{pre},52} & b_{\text{pre},53} & b_{\text{pre},54} & b_{\text{pre},55} \end{pmatrix} \tag{16}$$

$$B_{\text{crisis}} = \begin{pmatrix} b_{\text{crisis},11} & b_{\text{crisis},12} & b_{\text{crisis},13} & b_{\text{crisis},14} & 0 \\ 0 & b_{\text{crisis},22} & b_{\text{crisis},23} & b_{\text{crisis},24} & 0 \\ 0 & 0 & b_{\text{crisis},33} & b_{\text{crisis},34} & 0 \\ 0 & 0 & 0 & b_{\text{crisis},44} & 0 \\ b_{\text{crisis},51} & b_{\text{crisis},52} & b_{\text{crisis},53} & b_{\text{crisis},54} & b_{\text{crisis},55} \end{pmatrix}. \tag{17}$$

This specification is consistent with the analysis reported in Section 4.1, where the reverse causality between uncertainties is only allowed for the financial crisis period. Also, in line with Bloom (2009), Ludvigson, Ma, and Ng (2021) and Angelini et al. (2019), the real economic activity has no instantaneous impact on uncertainty measures (see zeros in the last column of B_{pre} and B_{crisis} matrices). This specification is also consistent with the results in Caggiano, Castelnuovo, and Groshenny (2014), in which the effects of uncertainty measures on the real economic activity during normal times are negligible. Indeed, with this specification we can consider a full on-impact matrix (expect for the last column) during the financial crisis, the period in which the effects of uncertainty variables on the economy are stronger. Uncertainty shocks have a pronounced and significant effect on both real economic variables considered in the second period, while there are no effects in the pre-crisis period. The significant effects also take the forms of a feedback from periphery to core economies.

In the case without spillover effects, the SVAR model in (15) is now estimated considering one uncertainty measure and one measure of economic activity at a time

$$Y_t = \begin{pmatrix} U_{j,t} \\ E_t \end{pmatrix}. \tag{18}$$

The bivariate SVAR model in (18) is estimated 32 times, i.e. by replacing E_t with $\Delta \mathrm{IP}_{j,t}$ and $\Delta \mathrm{UR}_{j,t}$, respectively, where $j = \mathrm{Ger}, \mathrm{Fra}, \mathrm{Ita}$ and Spa and $U_{j,t}$, with one uncertainty measures each time.[9] The structural matrices B_{pre} and B_{crisis} are:

$$B_{\mathrm{pre}} = \begin{pmatrix} b_{\mathrm{pre},11} & 0 \\ b_{\mathrm{pre},21} & b_{\mathrm{pre},22} \end{pmatrix}$$

$$B_{\mathrm{crisis}} = \begin{pmatrix} b_{\mathrm{crisis},11} & 0 \\ b_{\mathrm{crisis},21} & b_{\mathrm{crisis},22} \end{pmatrix}.$$

The structure of B_{pre} and B_{crisis} implies that the real economic activity has no instantaneous impact on uncertainty measures.

Figures 3 and 4 illustrate the IRFs for the SVAR model in (15) with ΔIP and ΔUR, respectively during the financial crisis (the second regime).[10] The red lines indicate the IRFs when spillover effects are taken into account while the dashed purple lines represent the IRFs when the spillover effects between uncertainties are omitted. In general, it emerges that uncertainty shocks have a negative (positive) effects on industrial production (unemployment) during the financial crisis. More specifically, macroeconomic uncertainty shocks in France and Italy exert a significant effect on the industrial production of the other economies, indicating that the macroeconomic uncertainties in France and in Italy during the financial crisis propagate across Europe.

When there are no spillover effects (dashed purple line in Figures 3 and 4), the results show that the impact of macroeconomic uncertainty real economic activity is higher in magnitude and more persistent. It is important to notice that these results are in line with those of the empirical literature for the euro area (Meinen and Roehe 2017; Popescu and Smets 2010).[11] The results also show that there is a feedback from periphery to core countries during the crisis period. This may be due to the fact that both Italy and Spain have experienced prolonged downturns during the crisis period, as result of individual-specific aggregate shocks. In particular, in the case of Italy, the banking crisis was severe and prolonged, and this may have had adverse effects on trade and investment flows from the core economies to the periphery, thereby affecting the formers' recovery. However, this was not the case for unemployment. The likelihood is that while the prolonged crisis in the periphery countries has affected the industrial production in the core countries, this has not necessarily translated to the laying off workers by firms. There may be number of reasons for this. For instances, the firms may anticipate a recovery in the foreseeable future and laying off workers in the short-term could be unproductive and costly.

In brief, these findings seem to suggest that uncertainty plays a relevant role in affecting the real economic activity and that the omission of spillover effects in the specification leads to an overestimation, both in magnitude and in persistence, of these effects.

9 In order to avoid non-stationarity issues, we use the first difference of the economic variables.

10 We focus our attention on the financial crisis period because the effects of uncertainty measures during normal times are not statistically significant.

11 Results for different countries can be found in Bloom (2009), Caldara et al. (2016), and Ludvigson, Ma, and Ng (2021).

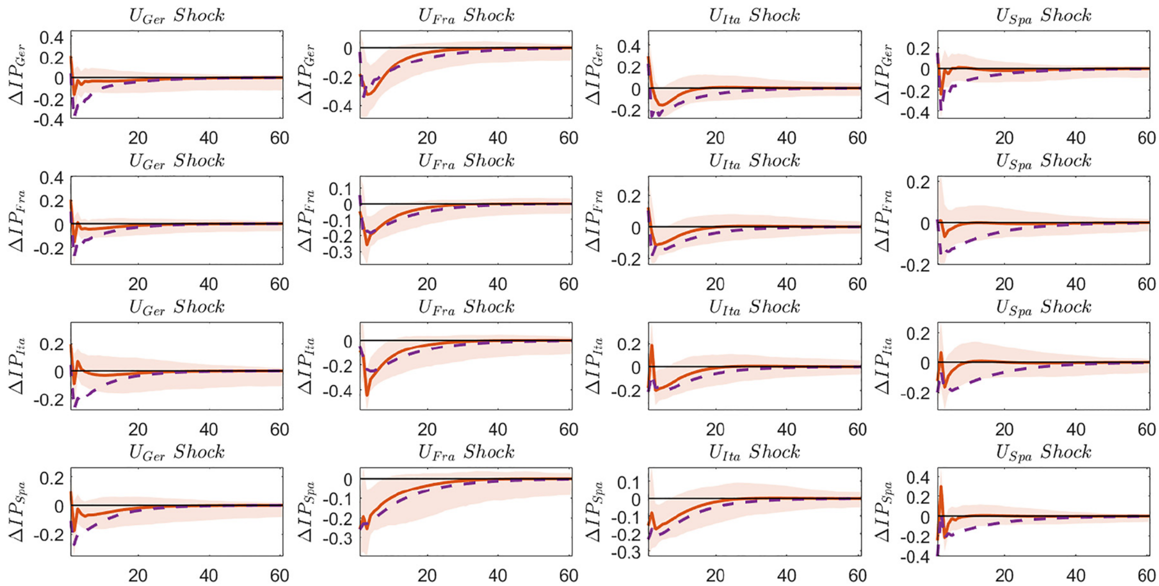

Figure 3: Macroeconomic uncertainty impacts on industrial production. ΔIP_{Ger}, ΔIP_{Fra}, ΔIP_{Ita}, and ΔIP_{Spa} denote the first difference of industrial production series for Germany, France, Italy, and Spain. Red lines indicate the impulse response functions for the second volatility regime (2008:M1–2015:M12) with 90% confidence bands computed following the bootstrap approach proposed by Kilian (1998) in case of spillover effects between uncertainty measures. Dashed purple lines indicate the impulse response functions for the second volatility regime without spillover.

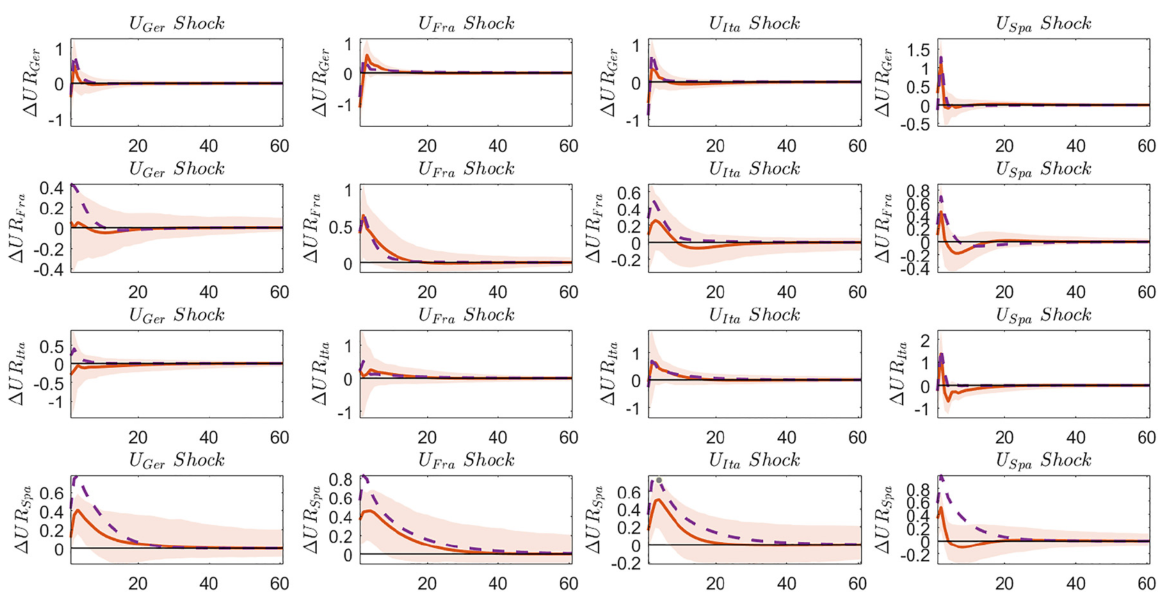

Figure 4: Macroeconomic uncertainty impacts on unemployment rate. ΔUR_{Ger}, ΔUR_{Fra}, ΔUR_{Ita}, and ΔUR_{Spa} denote the first difference of unemployment rate series for Germany, France, Italy, and Spain. Red lines indicate the impulse response functions for the second volatility regime (2008:M1–2015:M12) with 90% confidence bands computed following the bootstrap approach proposed by Kilian (1998) in case of spillover effects between uncertainty measures. Dashed purple lines indicate the impulse response functions for the second volatility regime without spillover effects.

4.3 Robustness checks

In this section we report a set of robustness checks that complement the results in Sections 4.1 and 4.2. First, we repeat the same analysis reported in Sections 4.1 and 4.2 by considering a measure of financial uncertainty. Second, we investigate the spillover effects across countries while controlling for the US macroeconomic and financial uncertainty. Third, we examine the impact of the macroeconomic uncertainty of the four euro countries and of the US on the real economic activity, namely industrial production. Lastly, we use a different approach for the identification of the SVAR based on the contribution by Lanne and Lütkepohl (2008).[12]

4.3.1 Financial uncertainty

This section deals with spillover effects across the four euro countries when we consider a measure of financial uncertainty. In particular, as a proxy of financial uncertainty, we consider the stock market volatility (SVOL) Bloom (2009), and we use the implied volatility of DAX, VCA, FTSE MIB and IGBM for Germany, France, Italy and Spain, respectively (see Section 2).[13] Figure 5 reports the IRFs computed by estimating the SVAR model in (12)–(14) with

$$Y_t = \begin{pmatrix} \mathrm{SVOL}_{\mathrm{Ger},t} \\ \mathrm{SVOL}_{\mathrm{Fra},t} \\ \mathrm{SVOL}_{\mathrm{Ita},t} \\ \mathrm{SVOL}_{\mathrm{Spa},t} \end{pmatrix}, \tag{19}$$

where $\mathrm{SVOL}_{i,t}$, $i = \mathrm{Ger}, \mathrm{Fra}, \mathrm{Ita}, \mathrm{Spa}$ is the measure of stock market volatility for the ith country. The results confirm those reported in Section 4.1. Indeed, spillover effects are stronger in magnitude and persistence during the second regime. Moreover, during the financial crisis significant causal effects from periphery to core countries are observed.

In order to evaluate the effects of SVOL on real economic activity (we conduct the same analysis as in Section 4.2), Figure 6 reports the IRF related to the second volatility regime. The results are similar to those in Figure 3. Indeed, if we do not take into account the presence of spillover effects between SVOL measures, their impact on the real economic activity are overestimated.

4.3.2 The role of US uncertainty as a control variable for spillover effects

This section focuses on spillover effects across the four euro countries using the same structural model in Section 4.1, with the matrices B_{pre} and B_{crisis} described in (12)–(14) and Y_t in (11), and the additional macro and financial uncertainty measures as exogenous variables in the reduced form (6). In particular, for the reduced form we have

$$Y_t = A(t)W_t + B_M(t)U_{\mathrm{USM},t} + B_F(t)U_{\mathrm{USF},t} + \eta_t, \quad t = 1, \dots, T \tag{20}$$

where $U_{\mathrm{USM},t}$ is the US macro uncertainty proposed by Jurado, Ludvigson, and Ng (2015) and $\mathrm{US}_{\mathrm{USF},t}$ is the US financial uncertainty described in Ludvigson, Ma, and Ng (2021). The results illustrated in Figure 7 qualitatively replicate those in Figure 2, with a slightly less persistence of the spillover effects when controlling for the US uncertainty.[14]

12 The section reports only the IRFs. The results of the estimated models are available upon request.

13 From a different point of view Mallick and Sousa (2013), and Bhattarai, Mallick, and Yang (2021) highlight the relevance of spillover effects from financial stress to real sectors

14 We also performed the analysis with industrial production to evaluate the impact of uncertainty on real economic activity using (20). The results replicate those in Figure 3, and are available upon request from the authors.

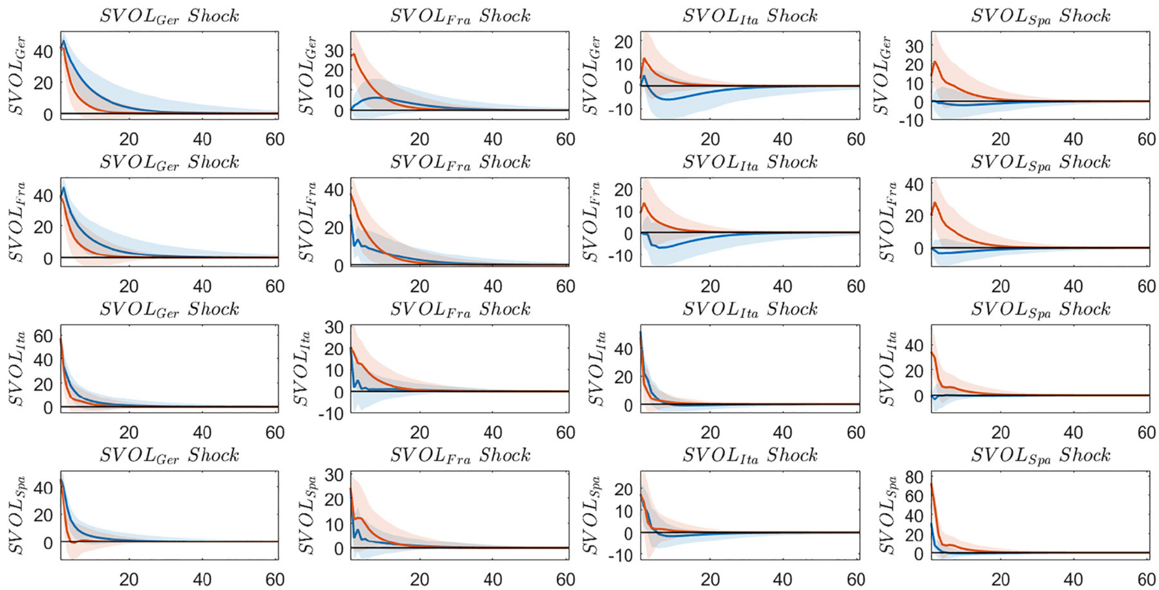

Figure 5: SVOL spillovers across Germany, France, Italy and Spain. $SVOL_{Ger}$, $SVOL_{Fra}$, $SVOL_{Ita}$, and $SVOL_{Spa}$ denote the SVOL measures for Germany, France, Italy and Spain. Blue and red lines indicate the impulse response functions for the period 1996:M7–2007:M12 and 2008:M1–2015:M12, respectively. The VAR in (11) is estimated. 90% confidence bands are computed following the bootstrap approach proposed by Kilian (1998).

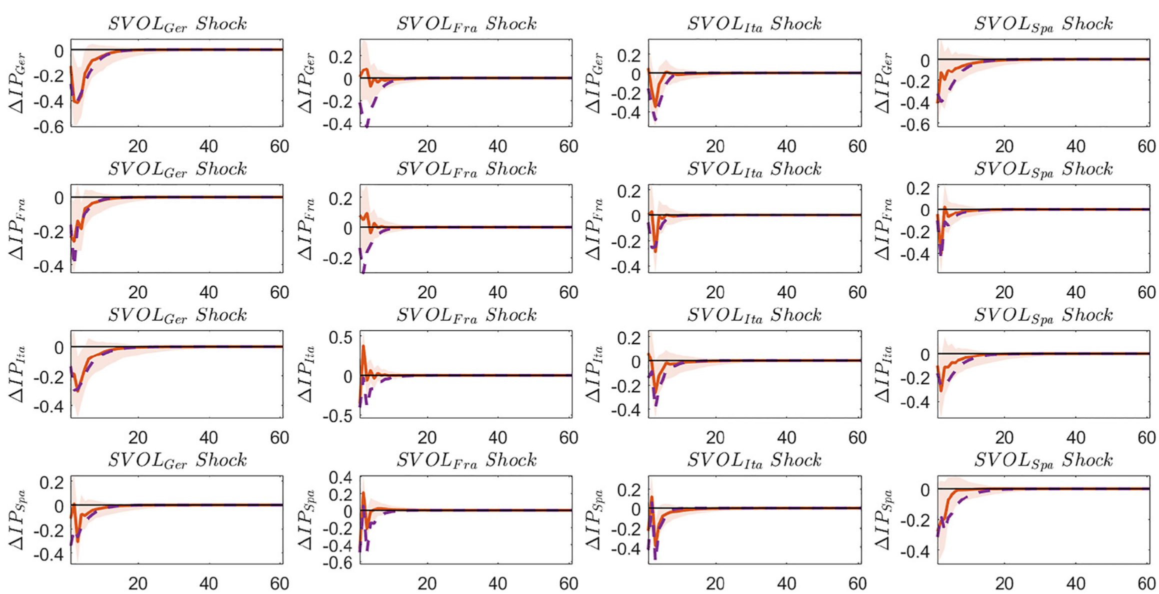

Figure 6: SVOL impacts on industrial production. ΔIP_{Ger}, ΔIP_{Fra}, ΔIP_{Ita}, and ΔIP_{Spa} denote the first difference of industrial production series for Germany, France, Italy, and Spain. Red lines indicate the impulse response functions for the second volatility regime (2008:M1–2015:M12) with 90% confidence bands computed following the bootstrap approach proposed by Kilian (1998) in case of spillover effects between uncertainty measures. Dashed purple lines indicate the impulse response functions for the second volatility regime without spillover effects.

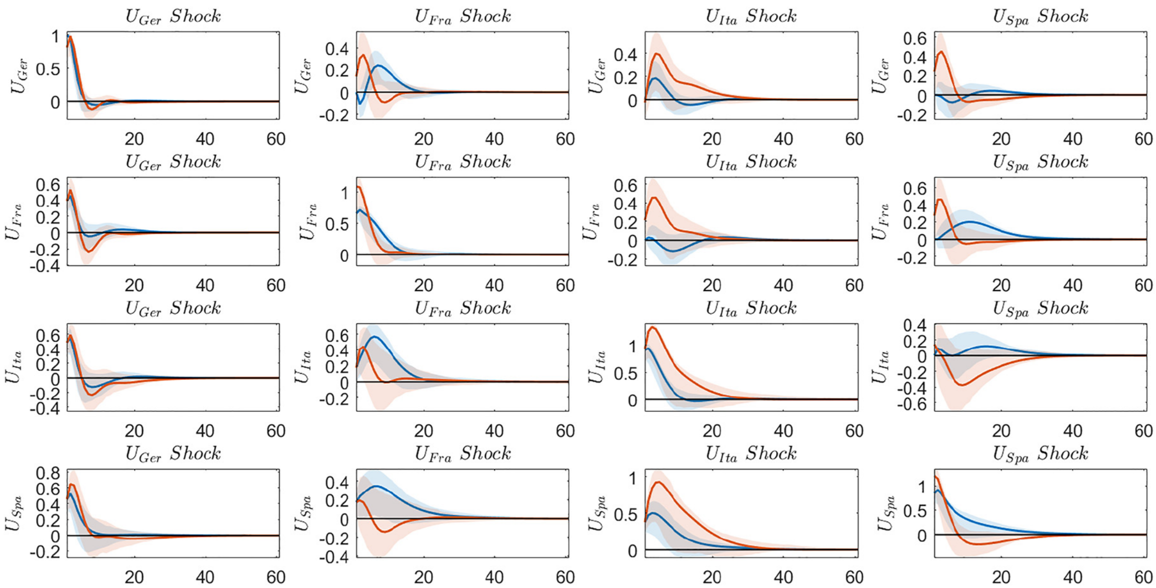

Figure 7: Uncertainty spillovers across Germany, France, Italy and Spain when controlling for *US* macro and financial uncertainty. U_{Ger}, U_{Fra}, U_{Ita}, and U_{Spa} denote the uncertainty measures for Germany, France, Italy and Spain. Blue and red lines indicate the impulse response functions for the period 1996:M7–2007:M12 and 2008:M1–2015:M12, respectively. The VAR in (20) is estimated. 90% confidence bands are computed following the bootstrap approach proposed by Kilian (1998).

4.3.3 The impact of US macroeconomic uncertainty on euro business cycle

This section focuses on the impact of US macro uncertainty on real economic activity (industrial production) of the four euro countries. In this case, the SVAR model in (15) is expanded by including $U_{\text{USM},t}$, that is the US macro uncertainty proposed by Jurado, Ludvigson, and Ng (2015), in Y_t

$$Y_t = \begin{pmatrix} U_{\text{USM},t} \\ U_{\text{Ger},t} \\ U_{\text{Fra},t} \\ U_{\text{Ita},t} \\ U_{\text{Spa},t} \\ E_t \end{pmatrix}. \tag{21}$$

The structural matrices B_{pre} and B_{crisis} become

$$B_{\text{pre}} = \begin{pmatrix} b_{\text{pre},11} & 0 & 0 & 0 & 0 & 0 \\ b_{\text{pre},21} & b_{\text{pre},22} & 0 & 0 & 0 & 0 \\ b_{\text{pre},31} & b_{\text{pre},32} & b_{\text{pre},33} & 0 & 0 & \\ b_{\text{pre},41} & b_{\text{pre},42} & b_{\text{pre},43} & b_{\text{pre},44} & 0 & 0 \\ b_{\text{pre},51} & b_{\text{pre},52} & b_{\text{pre},53} & b_{\text{pre},54} & b_{\text{pre},55} & 0 \\ b_{\text{pre},61} & b_{\text{pre},62} & b_{\text{pre},63} & b_{\text{pre},64} & b_{\text{pre},65} & b_{\text{pre},66} \end{pmatrix} \tag{22}$$

$$B_{\text{crisis}} = \begin{pmatrix} b_{\text{crisis},11} & b_{\text{crisis},12} & b_{\text{crisis},13} & b_{\text{crisis},14} & b_{\text{crisis},15} & 0 \\ 0 & b_{\text{crisis},22} & b_{\text{crisis},23} & b_{\text{crisis},24} & b_{\text{crisis},25} & 0 \\ 0 & 0 & b_{\text{crisis},33} & b_{\text{crisis},34} & b_{\text{crisis},35} & 0 \\ 0 & 0 & 0 & b_{\text{crisis},44} & b_{\text{crisis},45} & 0 \\ 0 & 0 & 0 & 0 & b_{\text{crisis},55} & 0 \\ b_{\text{crisis},61} & b_{\text{crisis},62} & b_{\text{crisis},63} & b_{\text{crisis},64} & b_{\text{crisis},65} & b_{\text{crisis},66} \end{pmatrix}. \tag{23}$$

Figure 8 illustrates the impulse responses. The results show that the effect of US macro uncertainty on the economic activity of the euro countries is statistically significant during the financial crisis (red lines). The largest negative impact on industrial seems to be exerted on Italy, Spain, and Germany. This effect is less pronounced in France. Before the financial crisis, this impact is almost nil.

4.3.4 Lanne and Lütkepohl's (2008) approach

This section provides a robustness check concerning the identification scheme of the SVAR. We use the approach by Lanne and Lütkepohl (2008), generalized by Lanne, Lütkepohl, and Maciejowska (2010). This approach assumes that the elements of the matrix B do not change across volatility regimes, but changes occur in the variances of structural shocks. Therefore, we have

$$\Sigma_{\eta,\mathrm{pre}} = BB', \tag{24}$$

$$\Sigma_{\eta,\mathrm{post}} = B\Lambda B', \tag{25}$$

where Λ is a diagonal matrix containing the variances of structural shocks in the second regime. In the first regime, the variances are normalized to be the identity matrix I_n. Note that in this case the matrix of on-impact casual effects could be completely full

$$B = \begin{pmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{pmatrix}. \tag{26}$$

In order to be consistent with the analysis in Section 4.1, the autoregressive coefficients in the matrix $A(t)$ are assumed to be regime dependent as in (6).

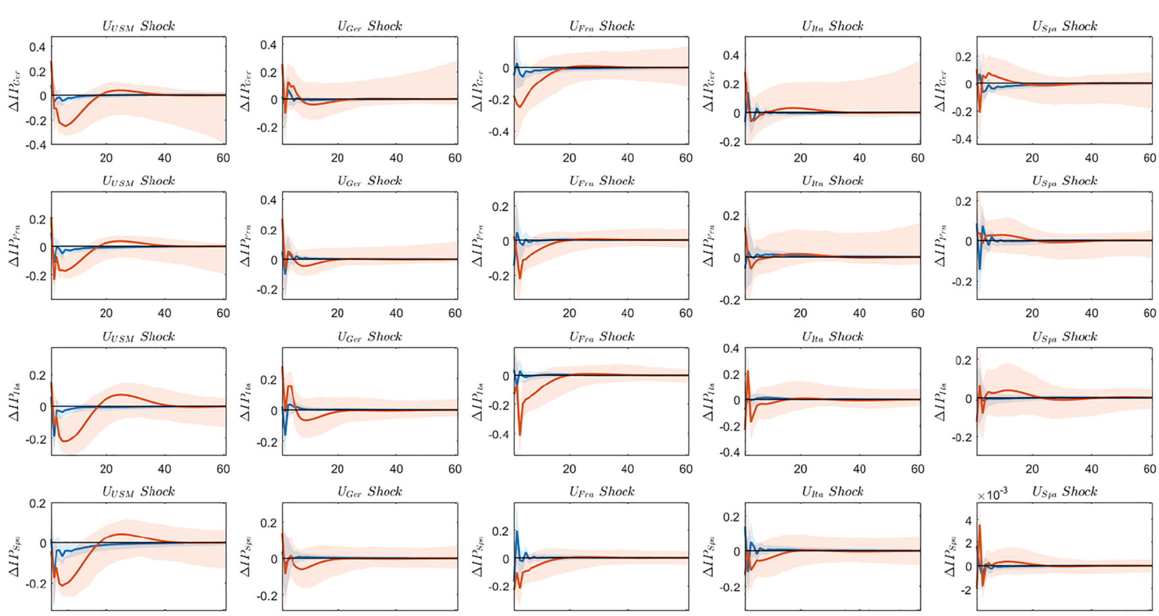

Figure 8: $U_{\mathrm{USM},t}$ impacts on industrial production. $\Delta\mathrm{IP}_{\mathrm{Ger}}$, $\Delta\mathrm{IP}_{\mathrm{Fra}}$, $\Delta\mathrm{IP}_{\mathrm{Ita}}$, and $\Delta\mathrm{IP}_{\mathrm{Spa}}$ denote the first difference of industrial production series for Germany, France, Italy, and Spain. Blue lines indicate the impulse response functions for the first regime (1996:M7–2007:M12) and red lines indicate the impulse response functions for the second regime (2008:M1–2015:M12). 90% confidence bands are computed following the bootstrap approach proposed by Kilian (1998).

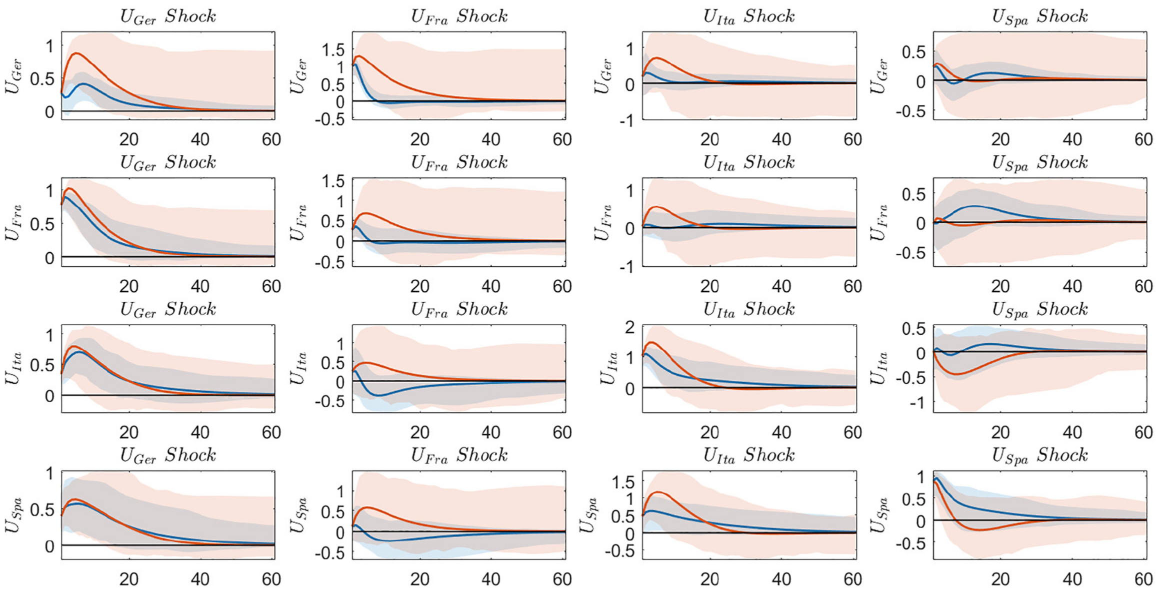

Figure 9: Uncertainty spillovers across Germany, France, Italy and Spain. U_{Ger}, U_{Fra}, U_{Ita}, and U_{Spa} denote the uncertainty measures for Germany, France, Italy and Spain. Blue and red lines indicate the impulse response functions for the period 1996:M7–2007:M12 and 2008:M1–2015:M12, respectively. The VAR in (11) is estimated. 90% confidence bands are computed following the bootstrap approach proposed by Kilian (1998). The IRFs are estimated using the Lanne and Lütkepohl's (2008) identification approach.

Figure 9 reports the IRFs computed using the Lanne and Lütkepohl (2008)'s approach, slightly modified in our analysis in order to account for regime dependent autoregressive parameters, and the macroeconomic uncertainties measures used in Section 4.1. The IRFs replicates those in the main analysis, as spillover effects propagate from core to periphery countries.

5 Conclusions

Following the sub-prime financial crisis, there has been a heightened interest on the impact of aggregate uncertainty on economic fluctuations. The recent literature has proposed several measures of uncertainty so to analyze the impact of those on economic activity [see, for example, Angelini et al. 2019; Bloom 2009; Caldara et al. 2016; Jurado, Ludvigson, and Ng 2015; Ludvigson, Ma, and Ng 2021]. The purpose of this paper is to investigate macroeconomic uncertainty spillovers across the main four euro countries, notably Germany, France, Italy and Spain. It uses the uncertainty measure proposed by Jurado, Ludvigson, and Ng (2015) and complied by Meinen and Roehe (2017) for the four economies. The paper also evaluates the impact of the uncertainty measures on economic activities, namely industrial production and unemployment rate.

The paper contributes to the literature in a number of ways. First, this paper shed valuable insight into the consequences of omitting potential spillover effects when investigating the impact of uncertainty on macroeconomic variables. This is first done by performing a preliminary Monte Carlos study on artificial data and then using data for the four euro countries.

Second, the empirical analysis is carried out over two periods: the pre-crisis period (1996:M7–2007:M12) and the crisis period (2008:M1–2015:M12).

Third, the paper uses a Structural Vector Autoregressive (SVAR) model recently proposed by Bacchiocchi and Fanelli (2015), Bacchiocchi (2017) and Bacchiocchi, Castelnuovo, and Fanelli (2018) that is suitable to deal with regime changes.

Lastly, the paper also performs a robustness check for the empirical analysis. First, it uses alternative measures of uncertainty within the SVAR framework by Bacchiocchi and Fanelli (2015), Bacchiocchi (2017) and Bacchiocchi, Castelnuovo, and Fanelli (2018), namely stock market volatility. Second, it examines the role of US uncertainty for the spillover effects using the macroeconomic and financial indicators by Jurado, Ludvigson, and Ng (2015) and Ludvigson, Ma, and Ng (2021) and the same SVAR framework. Third, it evaluates the impact of the US macroeconomic uncertainty on the real economic activity of the four euro countries. Lastly, it applies a different approach for the identification of the SVAR based on the contribution by Lanne and Lütkepohl (2008) to study spillover effects across the four euro countries while using the macroeconomic uncertainty indicator by Jurado, Ludvigson, and Ng (2015).

The main results of the paper show that spillover effects must be taken into account when investigating the impact of uncertainty on macro economic variables. Also, the empirical results clearly indicate that there are macroeconomic spillovers between the four euro countries and the impact of uncertainty on real economic activity is overestimated when the spillover effects are omitted. Lastly, the additional findings in the robustness checks are qualitatively similar to those displayed in the main empirical analysis. In particular, spillover effects are observed even when US (macro and financial) uncertainty is taken into account. Further, US macroeconomic uncertainty impacts negatively on the real economic activity of the four euro countries.

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