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Novi indeks optimalnog valutnog područja za europodručje

Sažetak

U radu konstruiramo novi indeks optimalnog valutnog područja (eng. optimum currency area, OCA) za europodručje. Indeks se temelji na relativnoj važnosti simetričnih šokova za poslovne cikluse zemalja članica koja je izračunata na temelju rezultata strukturnog VAR modela za malu otvorenu ekonomiju. U radu argumentiramo kako je europodručje usklađenije s definicijom optimalnog valutnog područja kadgod je relativna važnost simetričnih šokova u prosjeku visoka, ali istovremeno nije previše raspršena među članicama monetarne unije. Naši rezultati sugeriraju kako su simetrični šokovi bili dominantni generatori dinamike poslovnih ciklusa zemalja članica. No, također pokazujemo kako ciklička konvergencija nije kontinuirana i posebno je ometana (lokalnim) krizama u europodručju. Ipak, po okončanju kriza, konstruirani OCA indeksi se oporavljaju i polako sustižu svoje predkrizne razine.

Ključne riječi: ekonomska konvergencija, optimalno valutno područje, simetrični i nesimetrični šokovi

JEL: F33, F44, E42

A new optimum currency area index for the euro area[*]

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Abstract

We propose a new and time-varying optimum currency area (OCA) index for the euro area in assessing the evolution of the OCA properties of the monetary union from an international business cycle perspective. It is derived from the relative importance of symmetric vs. asymmetric shocks that result from a sign and zero restricted open-economy structural vector autoregression (VAR) model. We argue that the euro area is more appropriate through the lens of empirical OCA properties when the relative importance of common symmetric shocks is high, but, at the same time, is not overly dispersed across euro area member countries. We find that symmetric shocks have been the dominant drivers of business cycles across euro area countries. Our OCA index, nevertheless, shows that cyclical convergence among euro area members is not a steady process as it tends to be disrupted by crises, especially those not primarily triggered by common external shocks. In the aftermath of a crisis the OCA index embarks on a recovery trajectory catching up with its pre-crisis level. Our OCA index is slow-moving and a good reflection of changing underlying economic structures across the euro area and, therefore, informative about the ability of monetary policy to stabilise the euro area economy in the medium run.

JEL codes: F33, F44, E42

Keywords: Economic convergence, optimum currency area, symmetric and asymmetric shocks

Contents

Non-technical summary

It was well known at inception that the euro area did not satisfy all the theoretical preconditions of an optimum currency area (OCA) as stated, for example, in Mundell (1961). Such OCA prerequisites are rather difficult to measure. Now, with more than 20 years of euro area macroeconomic data, we show that it has become feasible to empirically evaluate the OCA properties of the euro area. In this paper we propose some new OCA indicators for the euro area, which are time-varying and model-based, derived from a sign and zero restricted open economy structural VAR model with block exogeneity.

Our aim is to measure the ability of the common monetary policy to stabilise the euro area economy depending on the underlying OCA conditions that change over time. We evaluate the relative importance of symmetric vs. asymmetric shocks across the euro area and its member countries. We define symmetric shocks as those that affect the individual country and the rest of the euro area in the same way (i.e. same sign). By contrast, asymmetric shocks include country-specific shocks with no impact on the rest of the euro area or the rest of the world as well as a particular type of common shock that affects different parts of the euro area asymmetrically. Our shock identification strategy opens up an empirical strategy for measuring a *catch-all* OCA property, that sheds light on the economic cohesion of the currency union.

Using the concept of a *signal-to-noise* ratio, we summarise our findings on the behavior of relative importance of symmetric compared to asymmetric shocks and their dispersion among the euro area countries in an indicator we label as an *OCA index for the euro area*. The average contributions of symmetric shocks to individual countries' economic growth are generally high, found to peak around the Global Financial Crisis (GFC) before declining afterward and picking up only in recent years. The cross-country dispersion is less dynamic but rose rapidly around the sovereign debt crisis before re-converging fast, while rising again in recent years. The resulting OCA features are time-varying, exposed to risks that threaten a trend improvement and thus the ability of common monetary policy in stabilising the euro area economy. Even though improving prospects of the OCA index tend to be disrupted by crises, it is also noteworthy that it recovers subsequently in the post-crisis period, catching up towards its pre-crisis level.

1 Introduction

Optimum Currency Area (OCA) theory provides a widely accepted, but rather an illustrative framework to assess under what conditions it makes sense for a group of economies to form a currency union. The euro area at inception was not the ideal real-world example for an optimum currency area à la Mundell (1961) and therefore gave rise to doubts about its survival. In the over twenty years in place it has plowed its way through complex processes of economic, financial and political integration and stemmed a number of perilous crises, while expanding further in the number of participating countries, but not muted the skepticism about a (yet) possible breakup. Any perception that the European Central Bank (ECB) stabilizing effectiveness may be impaired tends to translate into destabilising political signals, not least due to the absence of an appropriate measure of 'optimality' for the euro area as a currency union. To counter the risks of a solely sentiment-driven (mis)trust in the euro, we propose a quantitative measure of the OCA properties of the euro area to help anchor perceptions about the ability of common monetary policy to stabilise the aggregate economy, underpinned by the degree of economic cohesion among its constituent member states varying across time.

There is so far no consensus on a single way of measuring the *optimality* of a currency union. Early OCA literature in the 1960s, most notably Mundell (1961), McKinnon (1963) and Kenen (1969), stipulated nominal adjustment flexibility, factor mobility, diversification of production and fiscal integration among other factors as most important prerequisites for forming a currency union. During *the second phase* of the theory, the key considerations moved towards the costs of fixing the exchange rate or adopting the common currency (i.e. the loss of monetary policy autonomy and nominal exchange rate as a macroeconomic stabilization instrument) and the role of financial integration, see for example Corden (1972), Ishiyama (1975) and Mundel (1975). While many of these criteria and costs are difficult to measure, various empirical OCA properties were put forward only long time later, mostly in the 1990s, when debating the onset of EMU. Several contributors, including Bayoumi and Eichengreen (1992), Masson and Taylor (1993), Mongelli (2002) and Alesina and Barro (2002), suggested that *similarity of shocks* driving euro area member countries would qualify as a *catch-all* OCA property capturing the interaction between several of these properties at once. Indeed, when business cycles across union members are mainly driven by symmetric shocks and, therefore, likely correlated, the single monetary policy can more successfully stabilise all countries in the union simultaneously (see, for example, Belke et al. (2017) or Alesina et al. (2002)).

Similarity of shocks among countries is most often measured by correlations between identified shocks, as proposed in a highly influential work by Bayoumi and Eichengreen (1992). We argue that correlation of shocks as a measure, even though intuitive and easy to calculate, would prove insufficient to capture complex shock propagation mechanisms across different economies. In addition to similarity of shocks, OCA properties of country groups may also be evaluated more directly using specific OCA indices, as proposed by Bayoumi and Eichengreen (1997) and Bayoumi and Eichengreen (1998) and subsequently used in numerous applications. Existing methods, however, are focused on the relationship between a country's nominal exchange rate volatility and various OCA criteria. For that reason, they seem to be well-suited to evaluate the costs of abandoning monetary and exchange rate policies for countries *outside* the monetary union, but less so to monitor OCA features of an existing monetary union such as the euro area which is in the focus of our work.

In this paper, we address these gaps in existing methods that rely on simple correlation between shocks or nominal exchange rate volatility in proposing a set of time-varying OCA indices that are capable of capturing the way the OCA properties of the euro area have evolved since its formation. To this end, for each euro area member country under analysis, we first estimate the relative importance of symmetric and asymmetric shocks in explaining the overall business cycle fluctuations in an open economy BVAR using sign and zero restrictions.

Using the concept of a *signal-to-noise ratio*, we then summarise our findings on the behavior of both cross-country average and dispersion of relative importance of symmetric shocks hitting the euro area countries in an indicator we label as an *OCA index for the euro area*. Our indicator explicitly penalizes a lack of cyclical coherence among euro area members by emphasizing that high relative importance of symmetric shocks across countries alone may not be sufficient to improve OCA features of a currency union, whenever there are important differences between countries. For example, a monetary union with a high cross-country average importance of symmetric shocks may, nevertheless, be characterized as *poor* in terms of its OCA features, in case when relative importance of symmetric shocks is *overly dispersed* across countries. Our OCA indices for euro area thus reflect the view that cross-country heterogeneity in business cycle fluctuations makes the common currency not equally desirable for all which could create tensions between countries (De Grauwe, 1996) and eventually even threaten the political viability of EMU (Orphanides, 2020).

Our OCA index is slow-moving and a good reflection of changing underlying economic structures across the euro area and, therefore, informative about the ability of monetary policy to stabilise the euro area economy in the medium run. Our results show that the degree of synchronisation in economic cycles across euro area countries exhibit important variations over time as they are driven by the changing share of symmetric shocks relative to non-symmetric shocks. Through the lens of our OCA indicators, we show that cyclical economic convergence occurs at a measured pace and is not a smooth process as any trend of improving OCA properties can be disrupted by crises, especially those not primarily triggered by common external shocks. Another notable feature of our OCA indicators is that, while macroeconomic crises have a major adverse impact on OCA conditions, they are followed by a trend recovery that pulls them towards the pre-crisis level.

The rest of the paper is organised as follows: Section 2 provides a literature review on existing OCA indices. Section 3 proceeds to presenting the baseline modelling framework. Then, section 4 explains the rationale underlying the computation of alternative OCA indicators. The results and robustness are discussed in section 5 and final section 6 concludes on the findings and policy insights.

2 Relation to the literature

The focus of this paper is, first, on the estimation of symmetric and asymmetric shocks among countries constituting a monetary union and, secondly, on summarizing that information in a form of an index that may be used to track stabilizing potential of a common monetary policy over time. It, therefore, directly builds on the two related literature strands: one dealing with the separation between symmetric vs. asymmetric shocks and, the other dealing with the construction of OCA indices.[1]

The methodology we use to separate symmetric from asymmetric shocks builds on related VAR literature, most importantly on Bayoumi and Eichengreen (1993), Peersman (2011) and Deskar-Škrbić et al. (2020). Similarity of shocks was first conceptualised within a structural VAR framework as part of OCA theory in a seminal contribution from Bayoumi and Eichengreen (1993), later used frequently in related literature, for example by Campos and Macchiarelli (2016) and Fidrmuc and Korhonen (2003). They start by identifying demand and supply shocks for a number of European countries using Blanchard-Quah methodology (Blanchard and Quah, 1989) and then evaluate the costs of abandoning autonomous monetary policy by looking at the cross-country correlation of the shocks identified. However, simple correlations between shocks may not be sufficient to evaluate the costs of having a common monetary policy. For example, the correlation between shocks may be high, but their *overall importance* may be very different across countries. Consequently, a common, one-size-fits-all monetary policy cannot be equally suitable for all countries in a monetary union and the costs of having a common currency are unevenly distributed across constituent countries. For this reason, we construct a time-varying measure of the relative importance of symmetric and asym-

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[1] More generally, our paper is also naturally related to the literature on international business cycles and, more specifically, to business cycle synchronization among euro area countries, see for example Camacho et al. (2006), Belke et al. (2017) or Klaus and Ferroni (2015).

metric shocks by means of *historical shock decomposition*. In contrast to simple correlation between shocks, a measure based on this approach is dynamic in that it takes into account how the shocks identified spread through the economy and contribute to overall macroeconomic variability. Relative importance of symmetric shocks has already been evaluated using historical or variance decomposition in related VAR literature, but usually to investigate the similarity of shocks between the euro area and non-euro area countries. This literature typically includes studies that investigate the importance of (a-)symmetric shocks to various *candidate* countries relative to the euro area (*bilateral links*). Prominent examples are Peersman (2011) for the UK and, more recently, Deskar-Škrbić et al. (2020) for three candidate countries (Croatia, Bulgaria and Romania) *willing* to join and Deskar-Škrbić and Kunovac (2020) for EU members (Sweden, Czech Republic, Hungary and Poland) currently *reluctant* to join the euro area. In this paper, in contrast to existing literature, we propose a straightforward analytical framework to jointly evaluate OCA features of the euro area countries that exemplify a group of countries within a currency union.

Our identification strategy closely relates to Peersman (2011), who identifies symmetric and asymmetric shocks for the UK and euro area by directly imposing cross-country sign restrictions. In contrast to Peersman (2011), who define asymmetric shocks as those impacting different economies with the opposing sign, we follow a different strategy and argue that asymmetric shocks are more appropriately represented by two different types of shocks. The first type refers to local (country) shocks that cannot possibly affect other regions and the second consists in a narrower subset of common shocks that affect a country and the rest of the euro area asymmetrically [2]. Identifying country-specific shocks requires to impose block exogeneity restrictions, as explained in Comunale and Kunovac (2017) or Deskar-Škrbić et al. (2020), whereas asymmetric common shocks are identified based on the reaction of output in a member country and the rest of the euro area to that shock evaluated from historical shock decomposition.

In separating symmetric from asymmetric shocks, we consider a simple VAR with only three variables as our baseline model, in contrast to the literature that usually relies on a larger number of well defined shocks, such as in aggregate demand, aggregate supply, monetary or fiscal policy, by assuming they affect a large number of variables in a theoretically coherent manner, see, for example, Forbes et al. (2018) or Bobeica and Jarociński (2019). To test the robustness of our conclusions derived from the baseline VAR, we also specify an extended version of the model that additionally identifies demand-side and supply-side shocks by including an inflation measure for all three geographic blocks. Both the baseline and extended specifications reach similar conclusions, suggesting

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[2] See (EC, 1990) for discussion about various types of shocks

that our very compact baseline model is both sufficient and efficient at disentangling the symmetric and asymmetric shocks driving the business cycles in the euro area. The extended specification may, however, be of special interest for studying inflation differentials or the relative importance of demand vs. supply shocks.

The existing literature on formal OCA indices largely rests on the work pioneered by Bayoumi and Eichengreen (1997) and Bayoumi and Eichengreen (1998). This framework was widely used to evaluate the costs of adopting the euro ahead of its launch as well as later in the case of candidate countries as mentioned in Horváth et al. (2003), Skorepa (2013), Vieira and Vieira (2012) and Frydrych and Burian (2017). The methodology proposed by Bayoumi and Eichengreen (1998) simply relates nominal exchange rate volatility to various characteristics implied in OCA theory such as similarity of business cycles or the strength of trade linkages. Their OCA index is then constructed based on the observation that countries where the nominal exchange rate volatility implied by certain proxies for the OCA criteria is sufficiently low are supposedly more willing to abandon autonomous monetary and exchange rate policy. Clearly, the OCA criteria and the notion of importance of symmetric shocks are not less important for countries *already in a currency union*. The significance of common shocks and business cycle coherence in that situation are in the focus of our paper as they determine the potential of a common monetary to stabilise all member countries simultaneously over the cycle. As already mentioned, indices developed by Bayoumi and Eichengreen (1997) and Bayoumi and Eichengreen (1998) are not fully suitable to keep track of OCA properties of an existing currency union. The absence of formal OCA indices for the euro area is a gap we aim to fill this paper.

3 Estimating the relative importance of symmetric shocks

3.1 A small open-economy BVAR

We start by specifying an open-economy Bayesian VAR (BVAR) for fifteen euro area countries that includes three variables: GDP growth of one euro area country i, the rest of the euro area (REA, that is the euro area excluding country i) and the rest of the world (RoW). We then show that this *minimalist* model is sufficient to separate country-specific from common euro area shocks and well-suited to evaluate the relative importance of symmetric vs. asymmetric shocks across the constituent countries.

A generic structural VAR with k lags is represented by:

$$A_0 y_t = \mu + A_1 y_{t-1} + \ldots + A_k y_{t-k} + \varepsilon_t, \qquad t = 1, \ldots, T. \tag{3.1}$$

where y_t is a $n \times 1$ vector of observed variables, the A_j are fixed $n \times n$ coefficient matrices with invertible A_0, μ is $n \times 1$ fixed vector and ε_t are structural economic shocks with a zero mean and covariance matrix I_n. The reduced-form VAR model is obtained from (3.1) by pre-multiplying the equation by $(A_0)^{-1}$:

$$y_t = c + B_1 y_{t-1} + \ldots + B_k y_{t-k} + u_t, \qquad t = 1, \ldots, T, \tag{3.2}$$

where $B_j = A_0^{-1} A_j$, $c = A_0^{-1}\mu$, $u_t = A_0^{-1}\varepsilon_t$ and $E(u_t u_t') = \Omega = (A_0' A_0)^{-1}$. To identify the structural model (3.1) additional restrictions are required. It is important to note that for any $n \times n$ orthogonal matrix Q (i.e., $QQ^T = Q^T Q = I$), pre-multiplying (3.1) by Q results in an observationally equivalent structural model, i.e., whose reduced-form representation is also (3.2). Identification methods relying on *sign restrictions* are generally based on this principle (see e.g., Canova and De Nicolo (2002), Rubio-Ramírez et al. (2010), Arias et al. (2014), and Arias et al. (2018)).

To separate country-specific shocks from common ones, it is necessary to impose two types of restrictions. First, to ensure that country-specific shocks cannot affect foreign (REA and RoW) variables, restrictions on the impulse response function at $t = 0$ have to be imposed. In practice, zero restrictions on matrix A_0^{-1}. in addition to sign restrictions can be implemented as suggested by Arias et al. (2014). However, they do not prevent country-specific shocks from impacting foreign variables at longer horizons (beyond $t = 0$). To achieve this, *block-exogeneity* restrictions, i.e., zero restrictions on some regression parameters, are also required. In other words, in the reduced-form model (3.2), domestic GDP depends on its own lags as well as lags of foreign variables. By contrast, foreign variables depend on own lags only.[3] To impose zero restrictions on the regression parameters, we rewrite (3.2) in a more compact form:

$$y_t = X_t' \beta + u_t, \tag{3.3}$$

where $X_t' = I_n \otimes [1, y_{t-1}', \ldots, y_{t-k}']$ and $\beta = vec([c, B_1 \ldots B_k]')$. Within the Bayesian estima-

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[3] Kadiyala and Karlsson (1997) and Miranda-Agrippino and Ricco (2018) provide another example where asymmetric treatment of the endogenous variables in a VAR is appropriate and in line with *prior beliefs*: theory suggests that *money neutrality* implies that the money supply does not Granger-cause real output.

tion framework, β can be restricted by setting an appropriate prior distribution. The usual choice of the natural conjugate (Normal inverse Wishart) prior, although beneficial in terms of tractability of the posterior probability density function and computational speed, is not suitable for this purpose because it assumes a Kronecker-type structure of the prior covariance of VAR coefficients, which is rather inflexible. In this case, the prior covariances are proportional to each other across equations so that it is not possible to independently set the prior for a subset of parameters in selected equations as would be needed to impose block-exogeneity. Sims and Zha (1998), Kadiyala and Karlsson (1997), Koop and Korobilis (2010) or Carriero et al. (2019) explain why standard conjugate priors may appear as an overly restrictive choice for some applications of BVAR models.[4] Instead, *independent* Normal inverse Wishart prior is more appropriate in our case as the prior beliefs for the VAR coefficients and error covariance matrix are set independently:

$$\beta \sim N(\underline{\beta}, \underline{V}_\beta), \qquad \Omega \sim IW(\underline{M}, \underline{\gamma}).$$

Conditional posterior distributions $p(\beta|y,\Omega)$ and $p(\Omega|y,\beta)$ for this prior have the following form

$$\beta|y,\Omega \sim N(\overline{\beta}, \overline{V}_\beta), \qquad \Omega|y,\beta \sim IW(\overline{M}, \overline{\gamma}),$$

where

$$\overline{V}_\beta = \left(\underline{V}_\beta^{-1} + \sum_{t=1}^{T} X_t \Omega^{-1} X_t'\right)^{-1}, \qquad \overline{\beta} = \overline{V}_\beta \left(\underline{V}_\beta^{-1}\underline{\beta} + \sum_{t=1}^{T} X_t \Omega^{-1} y_t\right)$$

and

$$\overline{\gamma} = T + \underline{\gamma}, \qquad \overline{M} = \underline{M} + \sum_{t=1}^{T} \left(y_t - X_t'\beta\right)\left(y_t - X_t'\beta\right)'.$$

While the posterior distribution is no longer available in the closed-form, conditional posterior distributions are readily available and a Gibbs sampler is therefore used to draw an approximate sample from the posterior of the reduced form parameters, β and residual covariance matrix Ω. To evaluate the properties of a simulated sample from the posterior, we resort to MCMC convergence diagnostics methods, see Geweke (1992) or Chib (2001) for example.

To impose zero restrictions on some regression parameters using an independent Normal inverse Wishart prior, we assume zero mean priors with very small variance for all small country parameters in the REA and the RoW equations. For example, to restrict the j-th element of β, we can set

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[4] There are, however, alternative approaches proposed in the recent literature to circumvent this forced symmetry imposed by standard Normal inverse Wishart prior. For instance, Chan (2019) proposes ”asymmetric conjugate priors” that do not preserve the VAR Kronecker structure in the forecasting context using large Bayesian VARs and alternative strategy to implement asymmetric priors can be found in Carriero et al. (2019).

$\left(\underline{\beta}\right)_j = 0$ and $\left(\underline{V}_\beta\right)_{jj} = \varepsilon$, ε being some small positive number. This attaches a large weight to the (zero mean) prior parameters when calculating posteriors. Thus, sample information is largely ignored as the posteriors of these coefficients will be predominantly influenced by the prior. Other elements of $\underline{\beta}$ and $\underline{V}_\beta$ are set to shrink posterior parameters in the spirit of the Minnesota prior. Hyperparameters are set to $\lambda_1 = 100$, $\lambda_2 = 100$, $\lambda_3 = 2$ and $\lambda_4 = 10^4$, which reflects our choice to use non-informative priors.

To account for the COVID-19 pandemic, we rely on Lenza and Primiceri (2020) when estimating the VAR parameters. Consequently, we use data up to the fourth quarter of 2019 for the model estimation and keep the estimate values fixed when evaluating historical shock decomposition and the relative importance of symmetric shocks also in later periods. The structural BVAR models used in our analysis are all specified in log differences and estimated at a quarterly frequency using two lags. Experimenting with different lag numbers did not change our results significantly.

3.2 Identification of country-specific vs. common shocks

We identify in each of the country BVARs three shocks to real economic activity using the sign and zero restrictions as summarized in Table 1. In order to separate between country-specific and common shocks we set restrictions directly on the impulse response functions on impact using the algorithm by Arias et al. (2014) and impose additional zero restrictions on autoregressive parameters in the same way as in Deskar-Škrbić et al. (2020).

Table 1: Sign and zero restrictions at $t = 0$

type of shocks/variables	Y_{Home}	Y_{REA}	Y_{RoW}
Country-specific (local)	+	0	0
Common (euro area)	+	+	0
Common (global)	+	+	+

Notes: (+) = positive response; (-) = negative response; (0) = no response; (?) = unrestricted response. Y_{Home} denotes GDP growth in an euro area country, Y_{REA} in the rest of the euro area and Y_{RoW} in the rest of the world. Details of the definitions of the variables can be found in Table A.1 of the Appendix.

A country-specific shock affects domestic real GDP growth but cannot affect real activity in the rest of the euro area or the rest of the world. This is clearly an asymmetric shock that potentially reflects the costs for a member state of adopting a common currency. To identify this shock, we impose sign and zero restrictions on the impulse response function at $t = 0$, together with zero restrictions on the VAR regression coefficients of domestic variables in the equations with foreign variables as the dependent variables (block-exogeneity restrictions).

An euro area common shock affects GDP growth in the domestic country and the rest of the euro area symmetrically, i.e., with the same sign on impact. It cannot affect the rest of the world contemporaneously but only with a lag. To identify this shock, we impose sign restrictions on the impulse response function at $t = 0$, ensuring a symmetrical response in real GDP growth to this shock across the euro area. To prevent the rest of the world GDP from reacting to the shock, we impose a zero restriction on impact.

A global common shock affects the domestic economy, the rest of the euro area and the rest of the world in the same way at time $t = 0$. It is identified by imposing the same sign on the real GDP responses in all three geographical regions to this shock on impact.

Following these restrictions the relative importance of country-specific and common shocks in each euro area country can be evaluated. Should a stricter separation of euro area common shocks from global common shocks be desired, additional zero restrictions could be imposed on the VAR coefficients. Occasionally, the focus may be on the euro area common shocks that are not allowed to affect the rest of the world, neither on impact nor over a longer time horizon. In such a case, in addition to the restrictions imposed at $t = 0$, we may also restrict the VAR regression parameters in the RoW equation. However, this is not crucial for our analysis. We are primarily interested in evaluating the relative importance of common symmetric shocks to euro area countries, irrespective of where they originate. Both types of common shocks are relevant for the ECB monetary policy to address.

3.3 Relative importance of shocks: historical shock decomposition

The relative importance of the identified country-specific and common shocks in individual euro area countries can be gauged from the historical shock decomposition of the estimated country BVARs.[5] The *relative importance* of shock k to variable j at period t can be calculated from:

$$\widetilde{y_{jt}^k} = \frac{|y_{jt}^k|}{\sum_{l=1}^n |y_{jt}^l|}. \tag{3.4}$$

where y_{jt}^k represents contribution of shock k to the historical shock decomposition of variable j at period t and n denotes the total number of shocks.

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[5] Static variance decomposition, in contrast to historical shock decomposition, is not suitable for tracking different shock combinations hitting the economy *over time*.

3.4 Mapping to symmetric vs. asymmetric shocks

In this section we build on the identified common and local shocks and map them into symmetric vs. asymmetric shocks, which are the focus of our analysis.

Asymmetric shocks are not only all country-specific shocks but also those common shocks that affect a country and the REA asymmetrically despite being initially symmetric by definition (see Table 1). In fact, some shocks, common to the entire euro area, may have asymmetric impact on different euro area member states depending on differences in the cyclical initial states, economic structures, economic behavior or preferences across the countries (see e.g., EC (1990)). Consequently, asymmetric shocks include both country-specific (local) shocks and the aforementioned particular type of common shocks. Such a definition of (a)symmetric shocks spells out the idea that whenever a country's economy is predominantly driven by country-specific or common shocks with an asymmetric impact, the membership to the monetary union is more costly. Equation 3.4 yields directly the relative importance of country-specific shocks. To separate asymmetric from symmetric common shocks it is necessary to compare whether the effect of both euro area and global common shocks on the individual country under consideration and REA is asymmetric in terms of historical shock decomposition of GDP in each period.[6] Formally, let $home$ and REA index any euro area country and the REA respectively and let k denote an identified common shock (euro area or global). Then, a common shock k is said to be *asymmetric* in period t whenever $y^k_{home,t} y^k_{REA,t} < 0$.

Symmetric shocks are those common shocks k for which $y^k_{home,t} y^k_{REA,t} > 0$ in period t.

Regarding the interpretation of our shock decomposition, the identified common shocks are not the same for all countries as the rest of the euro area real activity is different each time when excluding a different home country. Therefore, the symmetry, as defined in our model, is to be seen from the individual country's point of view and reflects to what extent the costs of abandoning national monetary policy are outweighed by the benefits of the common currency, in line with the central idea of the OCA theory. Relative importance of symmetric shocks for each country is a country-specific measure of net benefits or *happiness* to share the monetary policy with the rest of euro area. For example, a shock that affects a country and the rest of the euro area with the same sign is according to our definition symmetric for that country, irrespective of a possible mixed response among other

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[6] There are alternative definitions of asymmetric reactions to common shocks to restricting the reaction to these shocks with signs (*the phase synchronicity* between business cycles measured by GDP growth). For example, we may be interested in those asymmetric shocks that affect various countries with the same sign but with very different amplitudes, see for example Mink et al. (2012) for a concept of *similarity* between cycles. The COVID-19 shock for instance, while affecting all the countries negatively, has increased the heterogeneity among euro area members in terms of the severity of recession (Muggenthaler et al., 2021). Alternative variants of asymmetric shocks are not crucial for our results as the majority of asymmetric shocks is related to country-specific shocks and not to asymmetric reactions to common shocks.

currency union members. Those countries that react, at the same time, very differently from the rest of the euro area are consequently *unhappy* with such a shock because they are hit asymmetrically and policy stance of one-size-fits all policy is most likely unsuitable. In that sense our definition of symmetric shocks departs from a definition where symmetric shock is assumed to affect all the members of a currency union in the same way.

3.5 Data

We consider real GDP growth, which is the most frequently used macro economic aggregate variable to study business cycle convergence. Our sample includes 15 euro area countries, excluding Malta, Cyprus and Luxembourg (due to shorter data series) and Ireland (due to exceptionally volatile GDP series) and is at quarterly frequency from 2000Q1 to 2020Q2. The world demand is captured by rest of the world GDP and rest of the euro area data is calculated by excluding one country at a time from the euro area aggregate. When carrying out robustness checks (shown in Appendix 5.3), we extend the model by including also consumer price inflation and a crude oil price index. All details of the data used in this paper are described in Table A.1 of the Appendix.

4 Constructing a new optimum currency area index for the euro area

4.1 Signal-to-noise ratio: A definition

In this section we summarize the results from the country BVAR estimation in the form of a time-varying OCA index for the euro area. We construct our OCA measure for the euro area starting from the observation that the common monetary policy will be more successful in stabilizing the euro area economy if the percentage of symmetric shocks is sufficiently high across member countries. Only in that case will the union-wide monetary policy be well-tailored for all member countries. Through the lens of our empirical framework we argue that the euro area may be *closer to optimal* as a currency area if two conditions are met jointly:

1. **The cross-country average of the relative importance of symmetric shocks, denoted μ, is high**. A high value of μ reflects that business cycles across member states are predominantly driven by symmetric shocks, ensuring higher chances for common monetary policy to stabilise all euro area members simultaneously.

2. **The cross-country standard deviation of the relative importance of symmetric shocks,**

denoted σ, is low. In addition, it is desirable that symmetric shocks be of similar importance for all euro area countries such that the value of σ is low. This implies that for a given value of μ, the summarising index should penalise high dispersion of the relative importance of common shocks across countries.

The concept of a simple *signal-to-noise* ratio[7] intuitively embeds these two requirements simultaneously:

$$SNR(t) = \frac{\mu(t)}{\sigma(t)},$$

where $\mu(t)$ and $\sigma(t)$ denote the cross-country sample mean and standard deviation of estimated relative contributions of symmetric shocks, denoted $y_1(t), \ldots, y_n(t)$, calculated for a group of n euro area members:

$$\mu(t) = \frac{1}{n} \sum\nolimits_{i=1}^{n} y_i(t) \tag{4.1}$$

$$\sigma(t) = \sqrt{\frac{1}{n-1} \sum\nolimits_{i=1}^{n} (y_i(t) - \mu(t))^2}. \tag{4.2}$$

In this version of the index, equal weights are attached to each country by definition so we call it the *unweighted OCA index*. We also compute a *weighted OCA index*:

$$SNR^w(t) = \frac{\mu^w(t)}{\sigma^w(t)},$$

where each country enters the formula for the mean and standard deviation first weighted by its GDP:

$$\mu^w(t) = \sum_{i=1}^{n} w_i y_i(t) \tag{4.3}$$

$$\sigma^w(t) = \sqrt{\frac{\sum_{i=1}^{n} w_i (y_i(t) - \mu^w(t))^2}{1 - \sum w_i^2}}, \tag{4.4}$$

where $w_i \in [0, 1]$, $\sum w_i = 1$ denote the relative weight of the GDP of country i in the aggregate euro area GDP.

An increase in the ratio $SNR(t)$ implies strengthening OCA conditions in the euro area. It is important to consider both the mean and dispersion criteria at the same time as it may not be sufficient to consider only one of them in isolation. For example, the average importance of symmetric shocks may be high, but heterogeneity across members may have also increased as well. Then, our OCA

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[7] In electronics, the ratio of desired electronic signals to unwanted noise, often expressed in decibels (dB) is routinely analysed to evaluate the signal quality. Here, some analogy can be drawn with our application where high average importance of symmetric shocks cannot provide *clear signal* of favorable OCA properties whenever surrounded by a lot of ”noise” (many under/over performers).

indicators would signal stagnating or even decreasing OCA properties in spite of high cross country average importance of symmetric shocks. Indeed, if, for example, high average relative importance of symmetric shocks of, say, 70% is attained within highly heterogeneous environment - say the share of symmetric shocks amounts to 90% in come countries and in others only 20% - common policy will not be optimal for all, with risks of causing political tensions or even possible break up.

The two measures, $SNR(t)$ and $SNR^w(t)$, have a somewhat different interpretation. When calculating the weighted index $SNR^w(t)$, which accounts for the country sizes, both moments, $\mu^w(t)$ and $\sigma^w(t)$, and the resulting signal-to-noise ratios are by construction dominated by large countries. $SNR^w(t)$ is therefore better at measuring the potential for the common monetary policy to stabilize the overall euro area economy. On the other hand, economic homogeneity across *all* euro area members is better reflected in high values for unweighted $\mu(t)$ and low values for $\sigma(t)$. A high $SNR(t)$ implying greater heterogeneity across member states represents a challenge for the ECB as the single monetary authority and may threaten the political viability of EMU, see Orphanides (2020) for a further discussion on political risks.

4.2 Some properties of the OCA index

Signal-to-noise or mean-to-standard deviation ratios are generally non-negative numbers and unbounded from above. In our specific case, the relative contributions of symmetric shocks $y_1(t), \ldots, y_n(t)$ are all within the interval $[0, 1]$ implying that the sample means $\mu(t)$ and $\mu^w(t)$ also lie within the same interval. $\sigma(t)$ is bounded by zero from below and if it assumes a very small value, signal-to-noise ratios may end up being exceptionally large. For example, for a small value of $\mu(t)$, say 10%, the signal-to-noise ratio goes to infinity if the relative importance of symmetric shocks is sufficiently similar across countries. Our methodology in this case points to *full optimality* of the euro area in the OCA sense, which would be misleading as on average only 10% of the overall growth dynamics is driven by common symmetric shocks. This outcome is possible but very unlikely. Estimated standard deviations are relatively stable over time and have a mean value of around 10%, never dropping below 4%. Nevertheless, to remove noisy high frequency movements from both $\mu(t)$ and $\sigma(t)$ and focus on medium term developments, we look at the four-year-moving average of both statistics.

Finally, the cross-country standard deviation is always bounded from above according to Bhatia-Davis inequality (see Bhatia and Davis (2000)) for a given average importance of symmetric shocks, irrespective of how $y_1(t), \ldots, y_n(t)$ are distributed:

$$\sigma(t) \leq \sqrt{\mu(t)(1 - \mu(t))}.$$

Bhatia-Davis inequality provides an upper bound for the standard deviation $\sigma(t)$ and a lower bound for signal-to-noise ratio $SNR(t)$ for a given estimated $\mu(t)$ and, thus, may help to compare estimated values of OCA indices to some known boundary values. For example, for $\mu(t) = 0.6$, similar to the estimates from our baseline specification, standard deviation $\sigma(t)$ must be smaller than 0.49, in fact, much larger than the dispersion among euro area countries we observe. Therefore, the constraint provided by Bhatia and Davis (2000) is never binding in our study such that our signal-to-noise ratios are always far above the boundary implied by the Bhatia-Davis inequality.

5 Empirical results

Our OCA indicators rely on country BVARs[8] so it is crucial to verify whether estimated impulse responses and relative importance of symmetric vs. asymmetric shocks may indeed capture the main features of some characteristic recent episodes such as the global financial crisis (GFC) and the euro area debt crisis. We first evaluate the relative importance of symmetric vs. asymmetric shocks, as elaborated in section 3.3, and, thereafter, we focus on the OCA indices for the euro area. Finally, as country BVARs are all estimated using MCMC methods, we evaluate the properties of a simulated sample from the posterior in Appendix A.2.

5.1 Relative importance of symmetric vs. asymmetric shocks

First, we verify that the zero and sign restrictions in our baseline model are fulfilled to separate local from common shocks according to Table 1, with Germany as an example. Indeed, the sign and zero restrictions, together with additional zero restrictions on autoregressive parameters, are sufficient to separate local and the two common shocks to real activity as can be seen from Figure 1. The local shocks in the top row cannot influence the rest of the euro area or the rest of the world over any time horizon. The common global shocks in the bottom row affect real activity in all *regions* similarly. Also, common euro area shocks are clearly separated from global shocks in all countries. Although reported impulse responses illustrate how our identification strategy is indeed able to separate local from common shocks, for our analysis it is crucial to map out symmetric shocks hitting euro area members (see section 3.4).

To illustrate the difference between the two types of shock mapping, Figure 2 compares cross-country average relative importance of common shocks with that of symmetric shocks, based on

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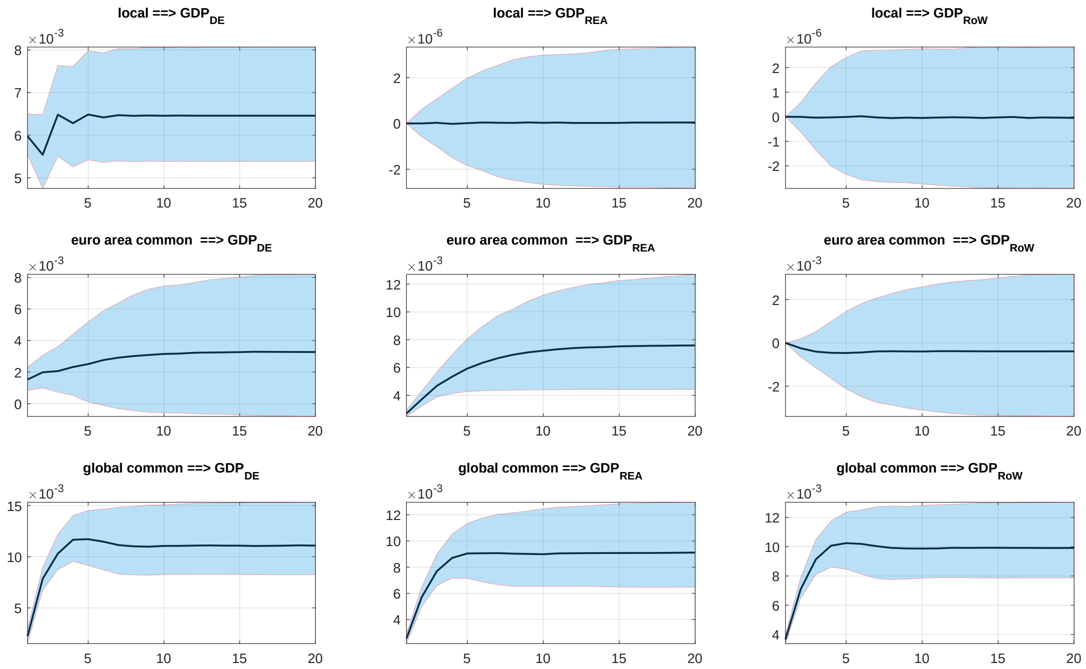
[8] We specify separate country VARs for Belgium (BE), Germany (DE), Estonia (EE), Greece (EL), Spain (ES), France (FR), Italy (IT), Latvia (LV), Lithuania (LT), the Netherlands (NL), Austria (AT), Portugal (PT), Slovenia (SI), Slovakia (SK), and Finland (FI).

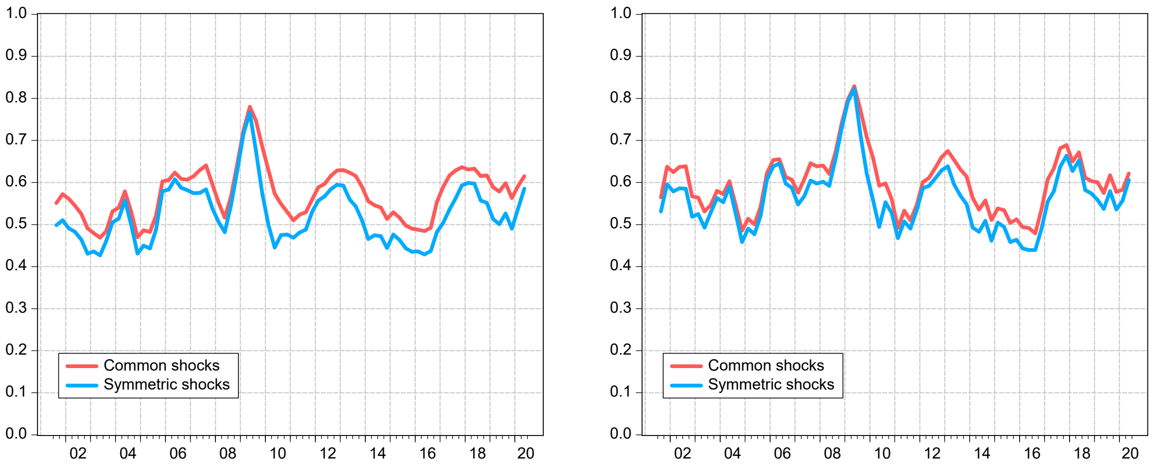
Figure 1: Impulse response functions for Germany (median and 68% posterior bands)



calculations as laid out in Equations 3.3 and 3.4. Overall, the two series are very similar and highly correlated, reflecting that a vast majority of common shocks are, in fact, symmetric. Occasionally, there are some more pronounced differences between them, for example, following the GFC and the sovereign debt crisis. In those periods, some of the shocks related to the crises initially affected all members symmetrically but afterwards turned out to affect various countries with the opposite sign so that they ended up being asymmetric. Differences are more pronounced for unweighted statistics reflecting the fact that they occur only very rarely for large countries.

Figure 3 shows the median relative importance of shocks identified for selected countries calculated from estimated BVAR historical shock decomposition (see Equation 3.4). In Germany (panel (a)), symmetric shocks are the most significant drivers of growth but asymmetric shocks may surge to dominate very occasionally. One such episode was the period immediately following the GFC, when German GDP, in contrast to the rest of the euro area, recovered exceptionally fast. A detailed explanation of a fast recovery in Germany can be found, for example, in an IMF report (IMF, 2011). Historical shock decomposition of GDP growth in Italy (panel (b)) suggests that common symmetric shocks dominate throughout the sample period even more. In fact, according to the results from our BVARs, the relative importance of symmetric shocks here mostly exceeds those of all other countries in our sample (see Appendix A). This is in line with Belke et al. (2017) and Klaus and Ferroni (2015) who, *somewhat to their own surprise*, also find very strong cyclical coherence between Italy and

Figure 2: Comparison of relative importance of common vs. symmetric shocks

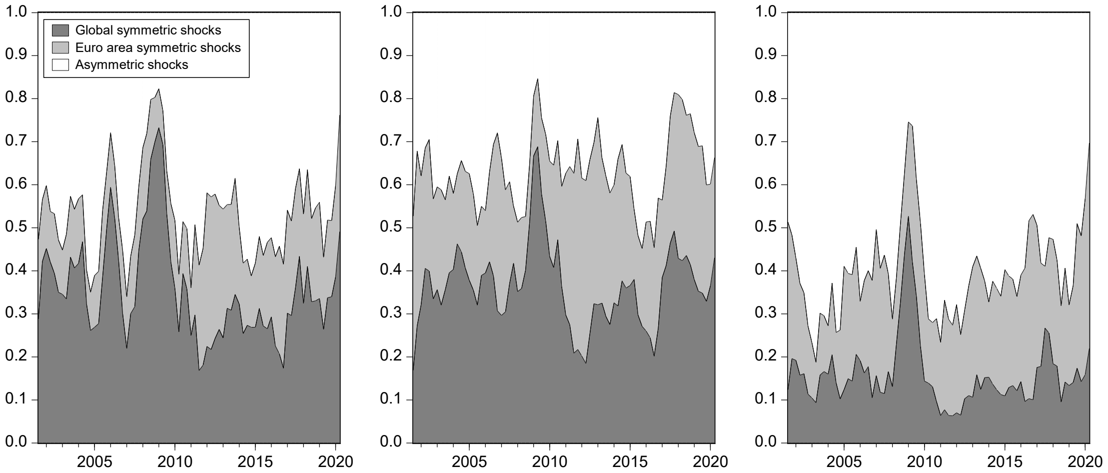


(a) Unweighted

(b) Weighted

other euro area countries. Local shocks have gained importance in driving GDP growth only very sporadically. In the case of Greece, unlike in Germany and Italy, episodes where local shocks prevail are more and longer - both before and after the GFC. During the more recent period, however, symmetric shocks have mounted to become the dominant drivers of Greek GDP growth. Overall, the decomposition for the three countries illustrates how combination of shocks hitting euro area members is varying over time and across countries.

Figure 3: Shock contribution to growth for selected countries

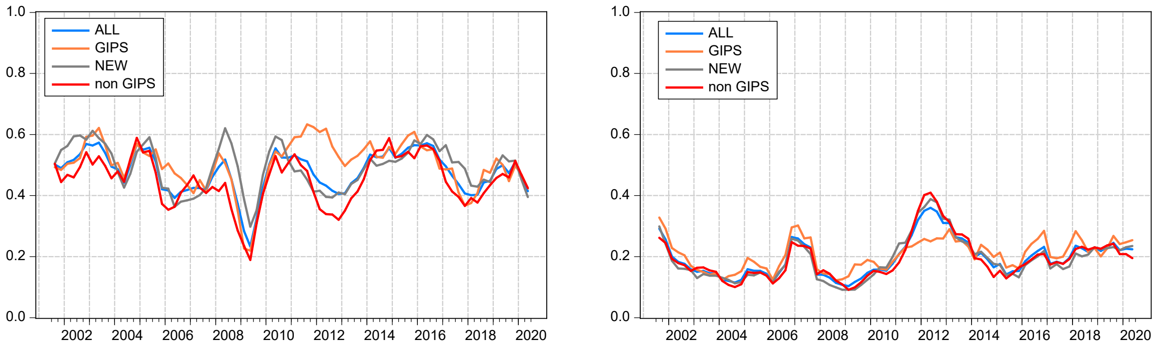


(a) Germany

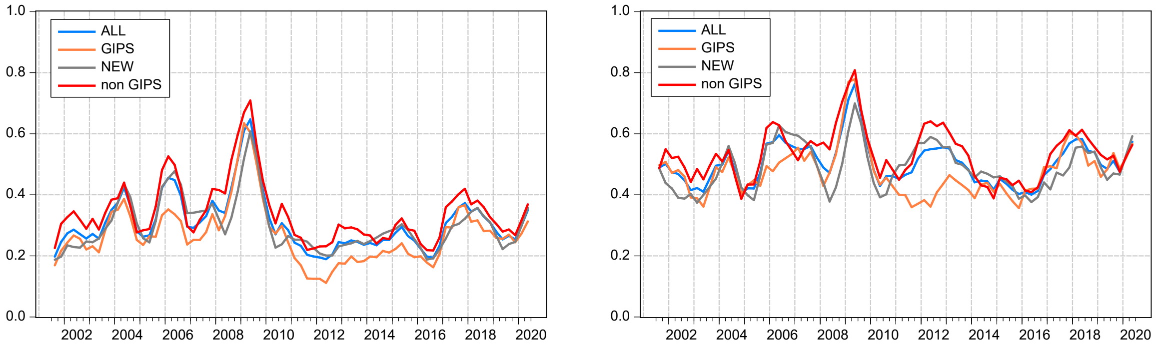
(b) Italy

(c) Greece

Figure 4: Shock contributions by country group


(a) Asymmetric shocks

(b) Euro area symmetric shocks


(c) Global symmetric shocks

(d) All symmetric shocks

In order to see whether our simple identification strategy is able to reflect the key business cycle events in all euro area countries as well, Figure 4 compares the relative importance of asymmetric, symmetric euro area (but non-global) and global shocks for three characteristic sub-groups of euro area countries. The first group consists of Greece, Italy, Portugal and Spain (labelled GIPS), which were the countries most heavily stressed during the debt crisis. The second group is made up of longstanding non-GIPS (or *non-stressed*) member countries: Belgium, Germany, France, the Netherlands, Austria and Finland. The third group comprises the new member countries: Estonia, Latvia, Lithuania, Slovenia and Slovakia. Overall, the relative importance of common symmetric shocks for all euro area countries is large. During the most recent period, symmetric shocks have been the dominant business cycle driver across euro area countries and account for around 60% of overall GDP movement. Their contribution, however, is not constant over time - it has been increasing throughout our sample, but at a rather slow pace. The relative importance of symmetric shocks was at its peak during the GFC, when it accounted for up to 80% of the overall variation in GDP growth. Our results also suggest that most symmetric shocks which hit euro area countries are, in fact, global shocks. The European sovereign debt crisis is an exception. In that episode, negative symmetric euro area shocks were important drivers for the business cycle in all member countries. Despite the preponderance of symmetric euro area shocks during the European debt crisis, and in contrast to other member countries, business cycles in the GIPS countries were still strongly affected by negative local shocks, especially in the early phase of the crisis. According to our results, this was the major source of heterogeneity in the relative importance of symmetric shocks across euro area countries over the last 20 years. Other than this single - albeit very important exception, the relative importance of symmetric shocks has been similar across the country groups over time.

5.2 An optimum currency area index for the euro area

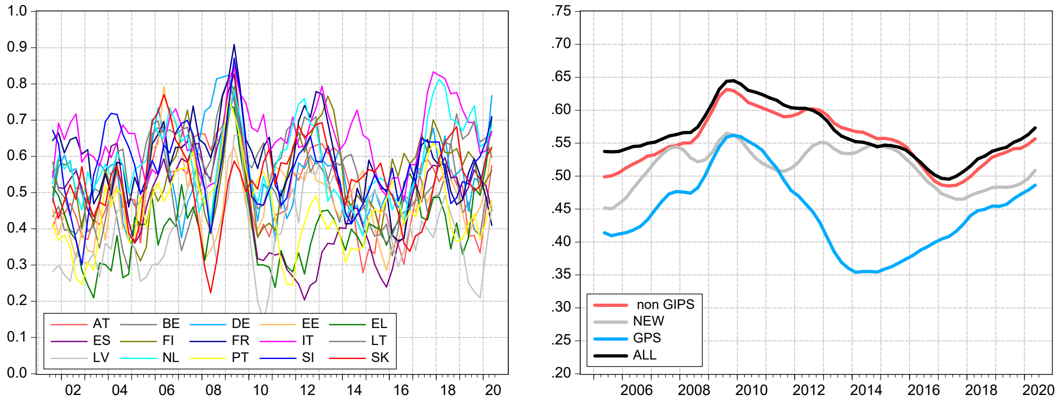
As argued in section 4.1, a simple cross-country *signal-to-noise* or *mean-to-standard deviation* ratio of relative importance of symmetric shocks is proposed for constructing an OCA indicator, which should adequately reflect the potential of the common monetary policy to stabilize output fluctuations across euro area member countries. To be able to understand the dynamics of constructed OCA indicators, it is important first to analyse cross-country distribution of relative importance of symmetric shocks and their first two moments $\mu(t)$ and $\sigma(t)$.

5.2.1 Cross-country distribution of relative importance of symmetric shocks

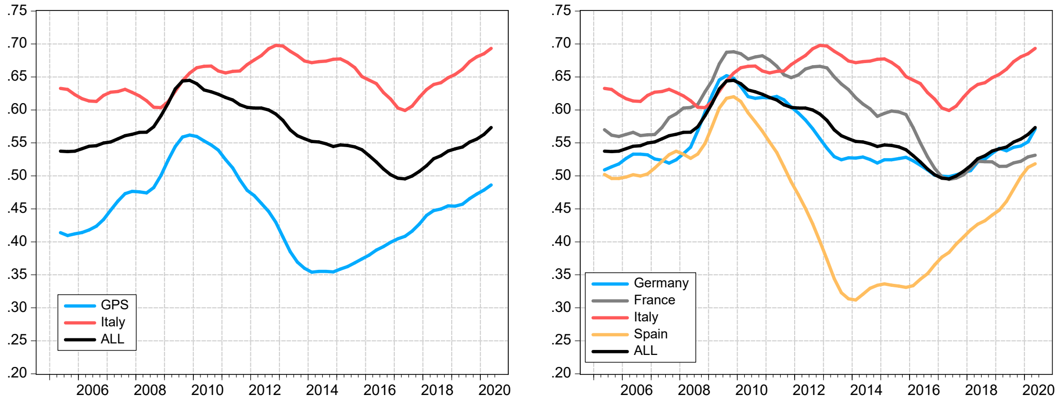
Panel (a) of Figure 5 plots the estimated relative importance of symmetric shocks of all 15 countries. Despite a crowded illustration, it is still possible to recognise some regularities in the business cycle dynamics of euro area members as elaborated in detail in section 5.1. With highly volatile short term dynamics smoothed out, panel (b) shows four-year moving average of estimated relative importance of symmetric shocks for different country groups: stressed euro area countries (GPS; GIPS minus Italy), non-stressed (non-GIPS) and new member states. Overall, smoothed (weighted) average relative importance of symmetric shocks, $\mu^w(t)$, clearly displays variations over time. It increases during the GFC and decreases during euro debt crisis. Non-stressed euro area members, partly by definition, are, on average, highly correlated with average euro area relative importance of symmetric shocks. For new members, symmetric shocks have gained importance during the more recent period and their share is now relatively close to average euro area statistics. Stressed countries in our sample, in contrast, have relatively low share of symmetric shocks throughout the sample. Italy is not included in the group of *stressed* countries here, despite being characterized by elevated country-specific risk during the recent debt crisis. As already elaborated, GDP growth in Italy has been highly synchro-

Figure 5: Relative importance of symmetric shocks

(a) All countries (b) Some interesting country groups



(c) Italy vs. other stressed countries (d) The Big Four



nized with rest of the euro area throughout the sample and, in that regard, very different from other countries in this group of stressed countries. Figure 5 panel (c) illustrates that GPS countries have had below-average importance of symmetric shocks throughout the sample while Italy is constantly above average. Finally, panel (d) comparing smoothed statistics of relative importance of symmetric shocks for the big four euro area members - Germany, France, Italy and Spain - illustrates how Italy is not only above the average relative importance statistics, but is also almost constantly characterized by highest share of symmetric shocks of all big members of the euro area. Spain, on the other hand, has on average been much less driven by symmetric shocks, whereas Germany and France are usually well aligned with euro area average $\mu^w(t)$.

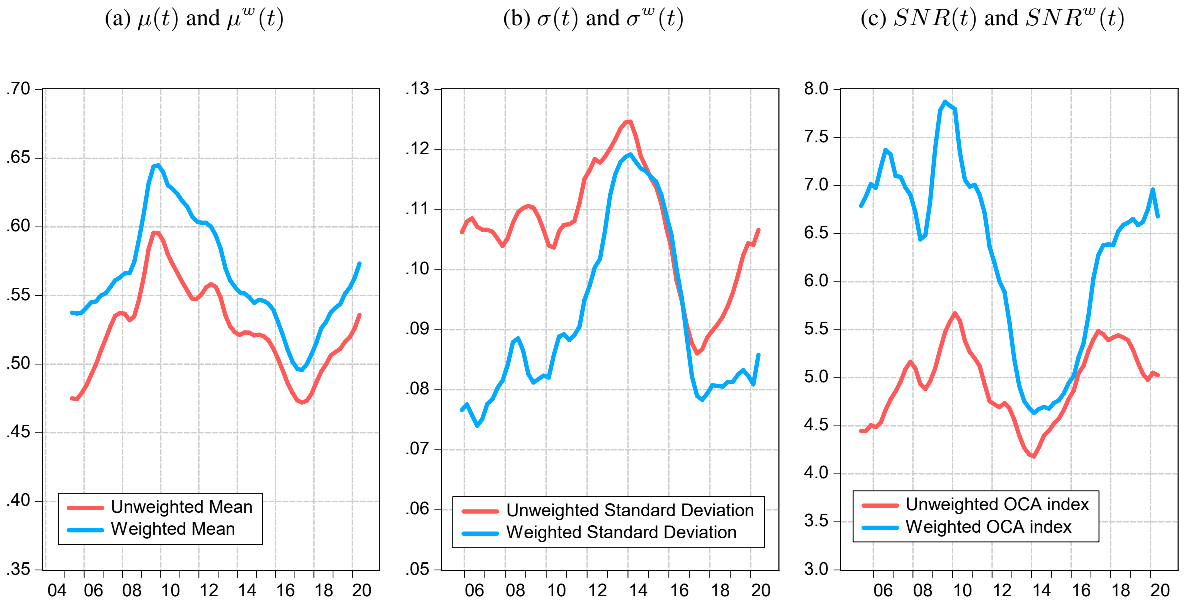
5.2.2 Cross-country statistics - $\mu(t)$, $\mu^w(t)$, $\sigma(t)$ and $\sigma^w(t)$

Figure 6 compares cross-country means and standard deviations, both weighted and unweighted. The weighted average importance of symmetric shocks $\mu^w(t)$ is always greater than the unweighted figure $\mu(t)$, reflecting the fact that the large euro area members have, on average, had more coherent business cycles with the rest of the euro area than the other countries. The dynamics of the two mean statistics has been elaborated in the previous section - they peak around the GF and decrease in debt crisis. The weighted standard deviation of the relative importance of symmetric shocks $\sigma^w(t)$, on the other hand, is always smaller than the unweighted version $\sigma(t)$, suggesting that larger member states deviate less from cross-country average relative importance. Both measures of dispersion peak during the debt crisis when the gap between weighted and unweighted dispersion almost disappeared, mostly because importance of symmetric shocks for some large euro area member - Spain and Italy - diverged from euro area average in that period. More recently, in the period after the European debt crisis, the gap between weighted and unweighted dispersion has been much smaller compared to pre-crisis period. In addition to already mentioned divergence of some large members from euro area average importance of symmetric shocks, this trend also reflects increased synchronisation of small and new members with the rest of the euro area. Previously more idiosyncratic business cycles in these countries were important drivers of the relatively high unweighted dispersion throughout the period before the crisis.

5.2.3 OCA indices $SNR(t)$ and $SNR^w(t)$

OCA indices $SNR(t)$ and $SNR^w(t)$, shown in Figure 6, are then constructed directly as ratios of $\mu(t)$ and $\sigma(t)$ and $\mu^w(t)$ and $\sigma^w(t)$, respectively. For our proposed indicators, it is the *signal* with respect to surrounding *noise*, $\mu(t)/\sigma(t)$, and not necessarily the signal $\mu(t)$ itself, that is crucial

Figure 6: Signal, noise and signal-to noise ratio


(a) $\mu(t)$ and $\mu^w(t)$ (b) $\sigma(t)$ and $\sigma^w(t)$ (c) $SNR(t)$ and $SNR^w(t)$

for stabilizing potential of a common monetary policy. The large values for both the weighted and unweighted versions of the proposed indices provide a clear signal of the average importance of symmetric shocks across countries between four and five times larger than cross-country dispersion.

The optimality of the euro area as a currency union as measured by the proposed indices varies over time and, by the nature of their construction, depends on the types of shocks hitting member countries. Most importantly, constructed indices signal that the OCA features of the euro area are stagnating in the longer run. The two indices differ in that the weighted index is always above the unweighted version, mostly reflecting relations between weighted and unweighted moments ($\mu^w(t) > \mu(t)$ and $\sigma^w(t) < \sigma(t)$), as described in 5.2.2. .

Figure 6 clearly demonstrates how relative importance $\mu(t)$ alone occasionally points to different dynamics in OCA properties, compared to ratio $\mu(t)/\sigma(t)$ confirming that both $\mu(t)$ and $\sigma(t)$ are useful for tracking coherence between business cycles. Most notably, this is the case during the period after the debt crisis - starting from 2014. In that period, decreasing $\mu(t)$ (panel (a)), that would normally signal moderately decreasing OCA properties of euro area, is accompanied by decreased heterogeneity between countries (panel (b)) which all together resulted in increased OCA indices $SNR(t)$ and $SNR^w(t)$ (panel (c)). Conversely, rising $\mu(t)$ during the last years of our sample, starting from 2017, does not provide clear signal of increased synchronization within euro area, all because elevated dispersion $\sigma(t)$.

Overall, when analysed jointly the two indicators can provide useful information on how the OCA properties of the euro area are evolving over time and how the values for the unweighted and weighted groups may converge in the longer run. The overall trend in the indices, however, is disrupted by major events. In times of global crises OCA features strengthen, while situations such as the sovereign debt crisis, period of increased fragmentation within the euro area, cause them to weaken.

5.3 Robustness

Our baseline VAR is sufficient to separate symmetric from asymmetric drivers of GDP growth across euro area members. It is compact, easy and efficient to estimate and provides timely information on drivers of business cycle coherence among euro area members over time, which is particularly valuable for a common *one-size-fits-all* monetary policy. By construction, such an index is suitable to track the potential of ECB to stabilize each member country successfully.

Nevertheless, to check the robustness of our results, in this section we extend the baseline BVAR described in section 3.4 by including data on consumer inflation and oil prices so to additionally identify domestic and foreign supply-side and demand-side shocks.[9] We argue that relying on a smaller model setup is a trade-off often worth making. In order to accommodate a large number of country specificities, it is indeed desirable to keep our model as simple as possible. Relying on an simplified specification, however, is beneficial if the main conclusions of a larger model can be replicated by the simpler model. We now test this hypothesis in this section. The extended specification, although more costly in terms of computational time and complexity, may also be of interest for other purposes, e.g., to decompose inflation into symmetric and asymmetric drivers or distinguishing between demand and supply side shocks.

5.3.1 Model

In order to specify our alternative 6-variable model, we include three additional variables in our model: inflation in the country under investigation, inflation in the rest of the euro area and oil prices. The extended model is in the spirit of the literature and allows us to identify demand and supply shocks for the three regions separately. For each euro area country under analysis we therefore specify a six-variable VAR and identify the following six shocks:

Country-specific aggregate demand and supply shocks shocks affect domestic GDP growth and

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[9] See Forbes et al. (2018), Peersman (2011), Bobeica and Jarociński (2019) or Comunale and Kunovac (2017) for similar applications.

inflation, but cannot affect real activity and prices in REA or RoW. A demand shock is associated with positive correlation between GDP growth and inflation, supply shocks with negative correlation between the two. In addition, only supply shocks can have a long-run impact on GDP growth, whereas the cumulative response of growth to demand-side shocks is restricted to zero in the long run, see for example Blanchard and Quah (1989) and Forbes et al. (2018). Finally, by appropriately restricting the VAR autoregressive parameters, we also impose that REA and RoW variables must not depend on lagged values of home-country variables. This assumption, together with restrictions imposed on the IRF at $t = 0$, is sufficient to fully separate local shocks from other shocks at all horizons.

Common euro area aggregate demand and supply shocks affect macroeconomic indicators (GDP growth and inflation) in the home country and the rest of the euro area. Initially at $t = 0$, that impact is symmetric, but may become asymmetric afterwards. Demand-side and supply-side shocks are respectively characterised by a positive and negative correlation between GDP growth and inflation. Besides that, only supply shocks can impact GDP growth in the long run. We assume that the two common shocks cannot affect GDP growth in the rest of the world contemporaneously, but only with a lag. We also assume that common euro area supply shocks cannot affect oil prices, while the impact of a common demand shock on the same variable is left unrestricted.

Common global shocks are two global shocks that simultaneously affect the country under consideration, the rest of the euro area and the rest of the world. Expansionary common global demand shocks initially affect all six variables under analysis positively. Expansionary oil supply shock affects GDP growth in all regions positively and global oil prices and consumer inflation across the euro area negatively. We also assume that global common demand shocks cannot affect RoW growth in the long run.

The pattern of signs and zeros we impose on impulse responses, most importantly our decision to leave the impact of common demand shocks on oil prices unrestricted, is partly conditioned by the technical requirements of the algorithm we use to draw from constrained posterior distribution, see Arias et al. (2014) or Arias et al. (2018). For example, to identify the first shock we can impose five zero restrictions at most (we apply four in the short run and one in the long run); for the second shock we can impose four zeros overall; in the third row we can impose three zeros and so on. Ideally, we may wish to add three additional zeros to our scheme: how oil prices react to common euro area demand shocks and two long-run restrictions on how local and REA GDP growth react to global common demand shocks. But as already mentioned, strict separation of REA and RoW shocks is not crucial for our paper; our focus is on separating (pooled) symmetric and asymmetric shocks. A slight redistribution of the relative importance of euro area and global common shocks does not affect our conclusions. The sign and zero restrictions we impose are summarised in Table 2.

Table 2: Short run and long run restrictions

Short run restrictions (t=0)						
Shock\Variable	GDP_{Home}	$HICP_{Home}$	GDP_{REA}	$HICP_{REA}$	GDP_{RoW}	Oil
local AD (Country specific)	$+$	$+$	0	0	0	0
local AS (Country specific)	$+$	$-$	0	0	0	0
common AD (Euro area)	$+$	$+$	$+$	$+$	0	?
common AS (Euro area)	$+$	$-$	$+$	$-$	0	0
common AD (Global)	$+$	$+$	$+$	$+$	$+$	$+$
common Oil Supply (Global)	$+$	$-$	$+$	$-$	$+$	$-$
Long run restrictions						
local AD (Country specific)	0	?	?	?	?	?
local AS (Country specific)	?	?	?	?	?	?
common AD (Euro area)	0	?	0	?	?	?
common AS (Euro area)	?	?	?	?	?	?
common AD (Global)	?	?	?	?	0	?
common Oil Supply (Global)	?	?	?	?	?	?

Notes: AD denotes aggregate demand and AS denotes aggregate supply. (+) = positive response; (-) = negative response; (0) = no response; (?) = unrestricted response. GDP_{Home} denotes GDP growth of an euro area country, GDP_{REA} for the rest of the euro area and GDP_{RoW} for the rest of the world; $HICP_{Home}$ denotes GDP growth for an euro area country, $HICP_{REA}$ for the rest of the euro area and $HICP_{RoW}$ for the rest of the world. Details about all variable definitions are listed in Table A.1 of the Appendix.

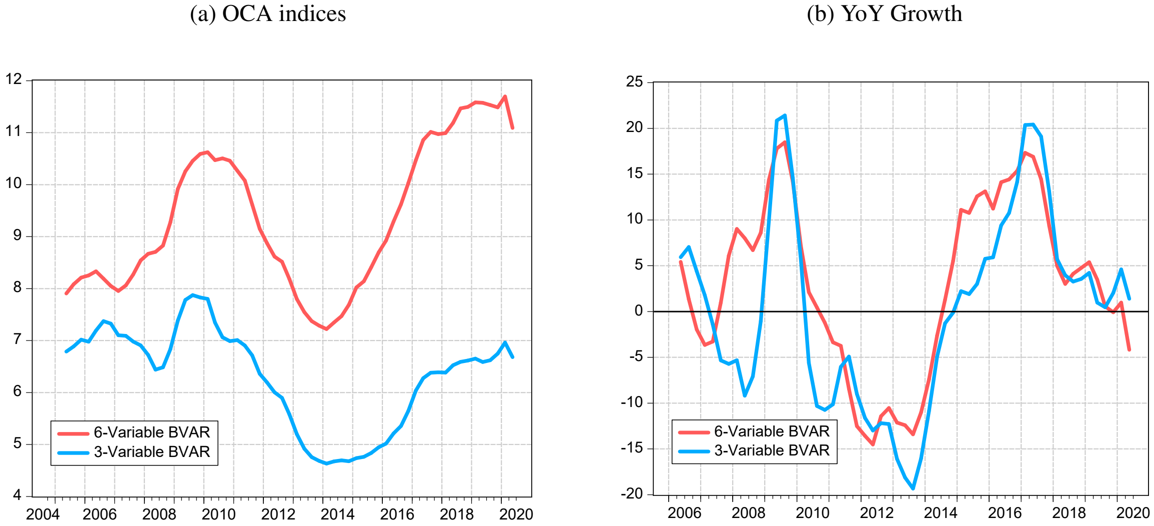
Identified shocks are sufficient to evaluate relative importance of local vs. common shocks, but, similarly as in section 3.3, a comparison of how common shocks affect GDP in a country and the rest of the euro area is needed to separate symmetric from asymmetric common shocks.

5.3.2 Comparison to baseline 3-variable model

Figure 7 (a) compares weighted OCA indices resulting from the three and six-variable specification and points to several main conclusions. First, there is persistent difference in levels between the two indices - six-variable VARs always result in higher levels of the OCA index. This is a consequence of both larger average importance of symmetric shocks $\mu(t)$ and smaller dispersion $\sigma(t)$ produced by that model. This is, however, largely a natural consequence of our definition of relative importance of symmetric shocks in section 3.3 based on absolute values of their contributions to GDP growth over time. Indeed, whenever we allow for both supply and demand shocks to drive GDP in foreign block of a VAR, overall average importance of symmetric shocks is likely to be larger, and dispersion smaller compared to the case when the two shocks are pooled into a single real activity shock as in section 3.2.

Despite the difficulties with reaching a consensus on the overall level of OCA features measured

Figure 7: Comparison of 3- vs. 6- variable models


(a) OCA indices

(b) YoY Growth

by our indices, cyclically, broad pattern of 6-variable model is well in line with the baseline results. Dynamics of constructed indices in the short run are shown in Figure 7(b), which compares the year-on-year growth rates of the two OCA indices. Both models point to the same main conclusions and similar degrees of coherence between euro area countries throughout our sample.

This all provides evidence of robustness of our smaller baseline VAR specification being sufficient to track business cycle coherence among the euro area countries over time, especially at higher business cycle frequencies. Consequently, it provides an efficient model for studying OCA conditions in the euro area, at least in terms of cross-country business cycle coherence. However, some caution is warranted when levels of OCA indices from different models are compared, particularly if the two specifications are of different dimensions.

6 Conclusions

The classic OCA theory prescribes a number of structural conditions for a currency area to be sustainable and likely to perform well. When these conditions are met to a sufficient degree, market adjustment mechanisms come into play so that asymmetric shocks (only affecting some parts of the monetary union) tend to be absorbed and their effects attenuated. By contrast, common symmetric shocks to the monetary union cannot be absorbed through adjustment mechanisms. Consequently, in a well-functioning monetary union the economies involved are predominantly on similar cycles as they are all primarily driven by common shocks. Based on these premises, we investigated in this paper the OCA properties of the euro area by evaluating to what extent asymmetric shocks are balanced out through underlying adjustment mechanisms enabled by OCA conditions within the currency union. This paper then proposes a novel and time-varying index measuring effectiveness of the OCA properties of a monetary union, applied to the euro area.

Our results indicate that OCA conditions in the euro area have not progressed significantly, even though common symmetric shocks have gained prominence as a driver of the business cycle in the euro area countries. The progress has been slow and was most importantly disrupted by the especially the sovereign debt crisis starting in 2011 in addition to other crises.

Our OCA indicators provide policy insights in that they help monitor the trend development of the portion of regional business cycles that are primarily driven by shocks common to monetary union and that maximise the effectiveness of common monetary policy stabilisation. The merits of a common currency are the greatest when common shocks are relatively important and cross-country heterogeneity is low, as reflected in a high value for our OCA indices. Conversely, when the OCA value is low the stabilising role of monetary policy is more constrained. The prevailing OCA conditions vary over time and depend on structural convergence processes in individual economies that shape individual countries' cyclical responses to shocks.

The COVID-19 crisis has led to increased economic divergence in the euro area, with risks undermining the convergence achieved so far. It is especially crucial to address these risks in the aftermath of the crisis with an accurate assessment of the most appropriate policy mix. Whenever the OCA value is high or starts to climb, the ECB can rely on more effective monetary policy transmission in fulfilling its mandate. Against all reservations in some countries in terms of membership, the euro area so far strikes a positive balance as our OCA indicators are above the level at the euro creation. According to Frankel and Rose (1998) the creation of the euro area has been likely in itself a driving force of structural change and business cycle synchronisation across the euro area.

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A Appendix

A.1 Data

Table A.1: Variable descriptions

Variable	definition	source
Real GDP (country)	Chained link volume, million of euros	Eurostat
Real GDP (rest of the euro area)	euro area aggregate excl. one member country	Eurostat
Real GDP (world)	sum of real GDP of Norway, Switzerland, Turke, Russia, USA, Canada, Mexico, Brazil, Australia, New Zealand, Japan, China, Hong Kong, Korea and EU but non-euro area countries	Eurostat, OECD
HICP (country)	Hamonised index of consumer prices, index	Eurostat
HICP (rest of the euro area)	weighted sum of HIPC indices excl. one member country	Eurostat
Oil price	Crude oil price index: Brent Europe	St. Louis Fed

A.2 Convergence of Markov chain Monte Carlo algorithm

Estimated VARs, both three- and six-variable specifications, all converge fast, with posterior statistics all converging already after only 100 or 200 admissible models are found. Our results are all based on overall 1000 admissible draws. We follow Primiceri (2005) to address convergence of the Gibbs sampling algorithm formally and to assess how efficient the algorithm used explores the posterior. Figures A.1 and A.2 in Appendix A.2 plot the 10th order sample autocorrelation of the saved draws from the posterior of the reduced-form parameters (regression parameters β and covariance matrix Ω). Figure A.1 shows autocorrelation of the elements of β and in A.2 are elements of the lower triangular part of the error covariance matrix Ω. Both figures point to weakly autocorrelated MCMC draws - estimated autocorrelation are only rarely outside interval $[-0.05, 0.05]$. Figures A.3 and A.4 plot the inefficiency factors for the posterior estimates of the reduced-form parameters when using 4% tapered window for the estimation of the spectral density at frequency zero. Inefficiency factor (IF)[10] is inverse of Geweke (1992) relative numerical efficiency and it serves to quantify the relative efficiency loss in the computation from correlated versus independent samples (Chib, 2001). Primiceri (2005) suggests that values of IFs below or around 20 are regarded as satisfactory. In our application these values are less than two, showing a strong convergence of Gibbs sampler. Figures A.5 to A.8 correspond to the same set of convergence diagnostics for the extended model as described in section 5.3 leading to the same conclusions.

There are, however, substantial differences in the computational time between our baseline specification and extended model. The total estimation time needed for the baseline model is about 15

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[10] MCMC draws are realizations of a Markov chain and are, by definition, correlated. When the inefficiency factor is equal to m, we need a MCMC sample that is m times larger compared to an uncorrelated sample to have the same information contained in both.

minutes. Compared to this, the extended model with just the double number of variables loses computational efficiency considerably, requiring a multiplied total estimation time of almost 16 hours and a half to run through all 15 country-level VARs. This comparison, although very illustrative, may, among other factors, well depend on how MCMC algorithm is optimized and, without deeper analysis, should be seen as indicative only.

Figure A.1: Sample autocorrelation (10th order) of the posterior estimates of the reduced-form parameter beta - baseline model

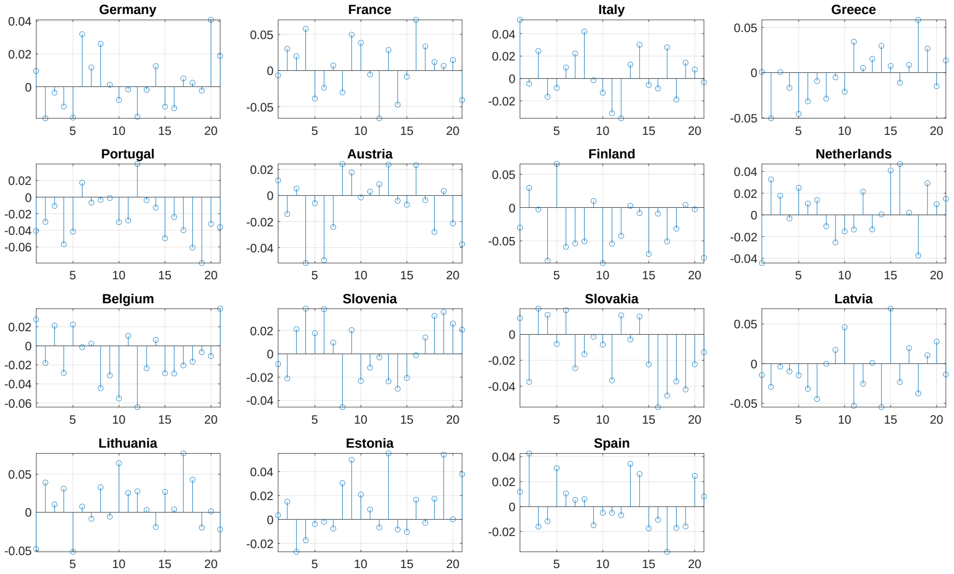


Figure A.2: Sample autocorrelation (10th order) of the posterior estimates of the reduced-form parameter sigma - baseline model

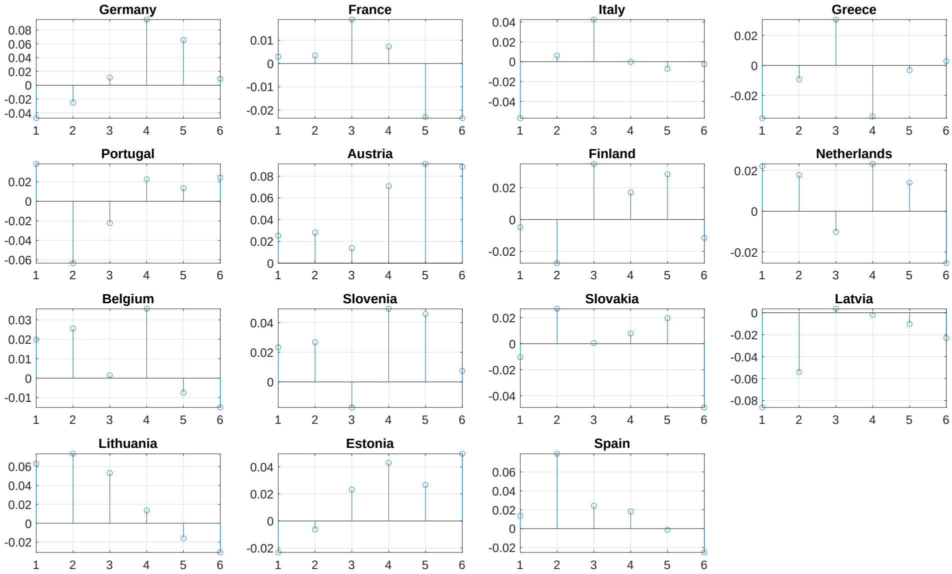


Figure A.3: Inefficiency factors for the posterior estimates of the reduced-form parameter beta - baseline model

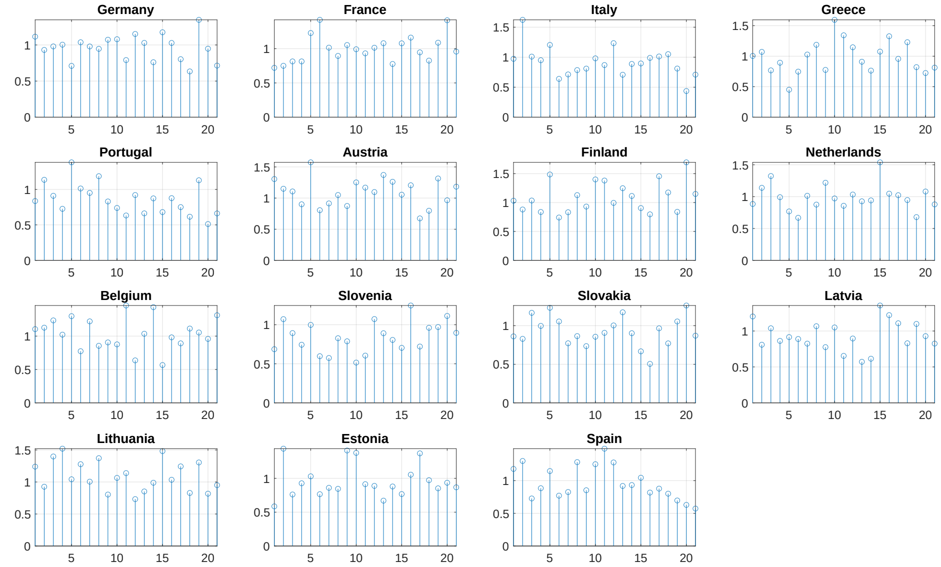


Figure A.4: Inefficiency factors for the posterior estimates of the reduced-form parameter omega - baseline model

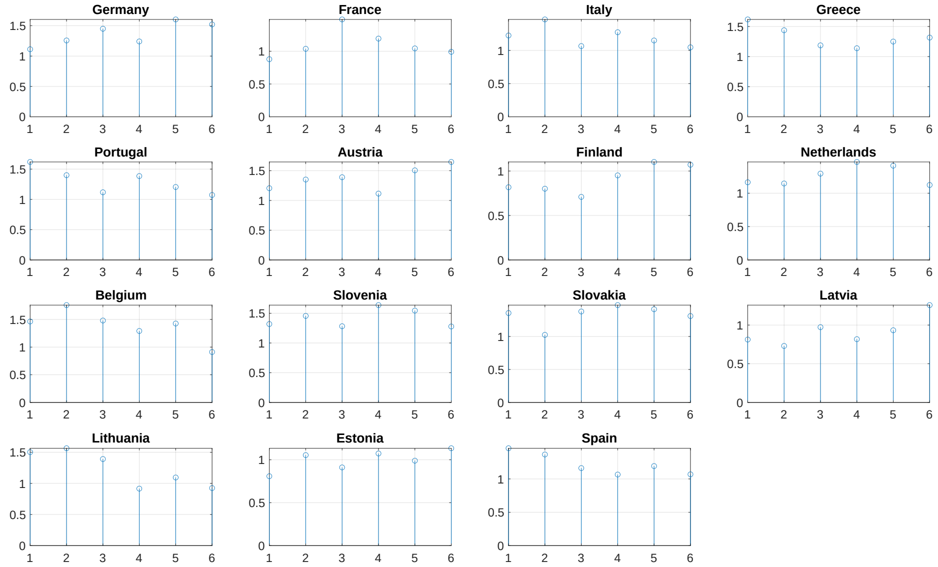


Figure A.5: Sample autocorrelation (10th order) of the posterior estimates of the reduced-form parameter beta - extended model

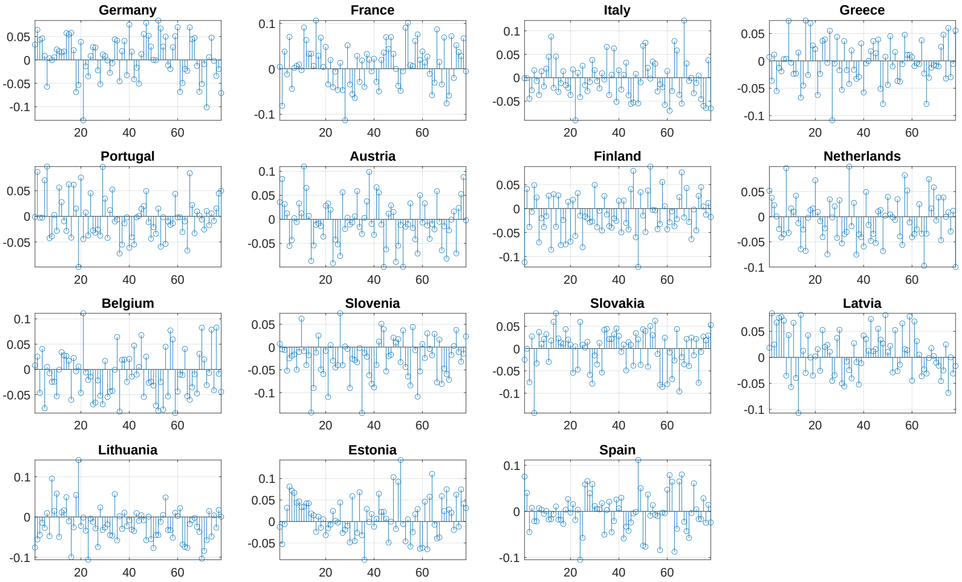


Figure A.6: Sample autocorrelation (10th order) of the posterior estimates of the reduced-form parameter sigma - extended model

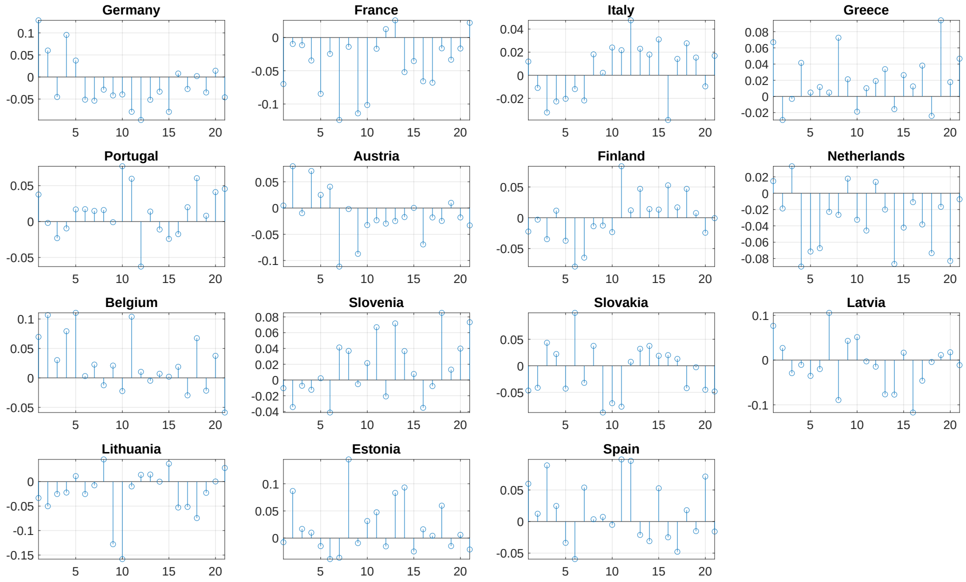


Figure A.7: Inefficiency factors for the posterior estimates of the reduced-form parameter beta - extended model

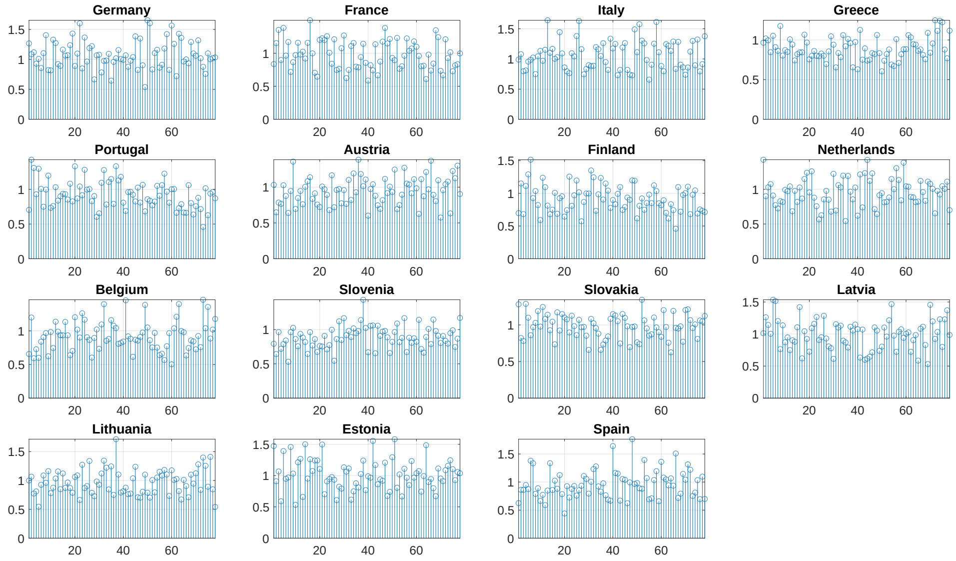
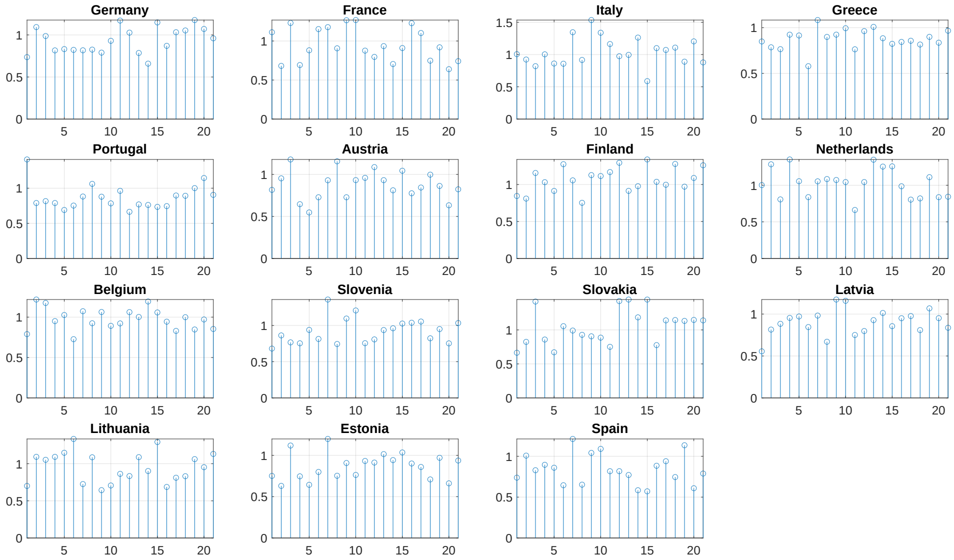
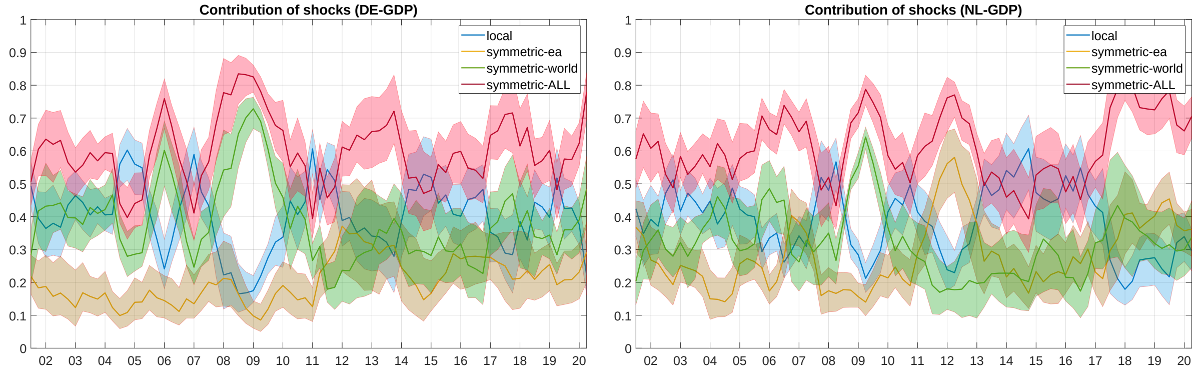


Figure A.8: Inefficiency factors for the posterior estimates of the reduced-form parameter omega - extended model



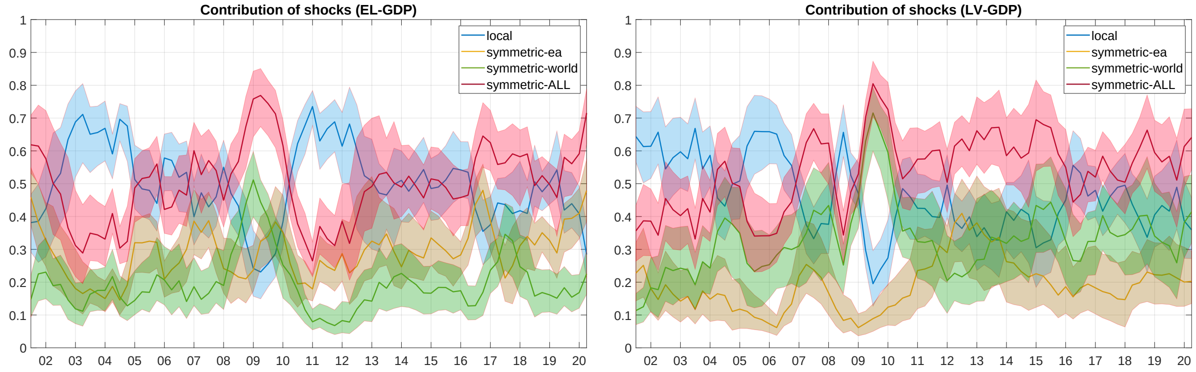
A.3 Relative contributions of symmetric vs. asymmetric shocks

Figure A.9: Contribution of shocks for Germany, Netherlands, Greece and Latvia (median and 68% posterior bands)



(a) Germany

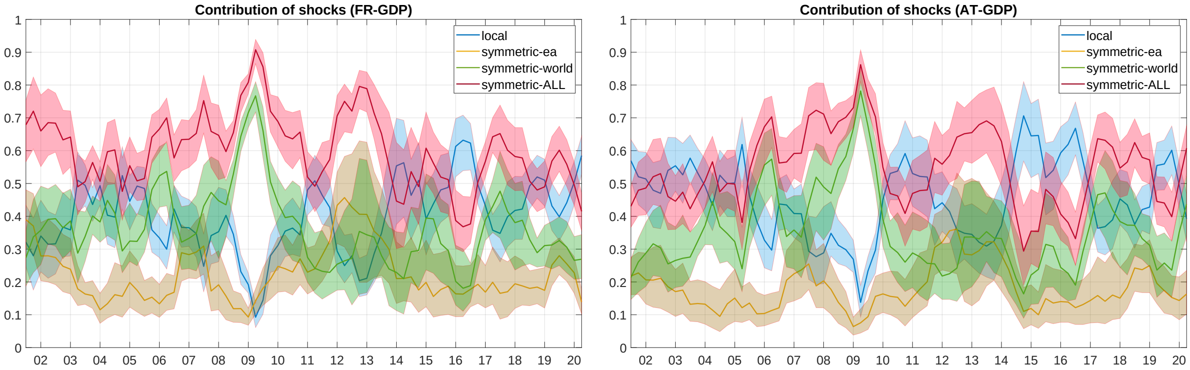
(b) Netherlands



(c) Greece

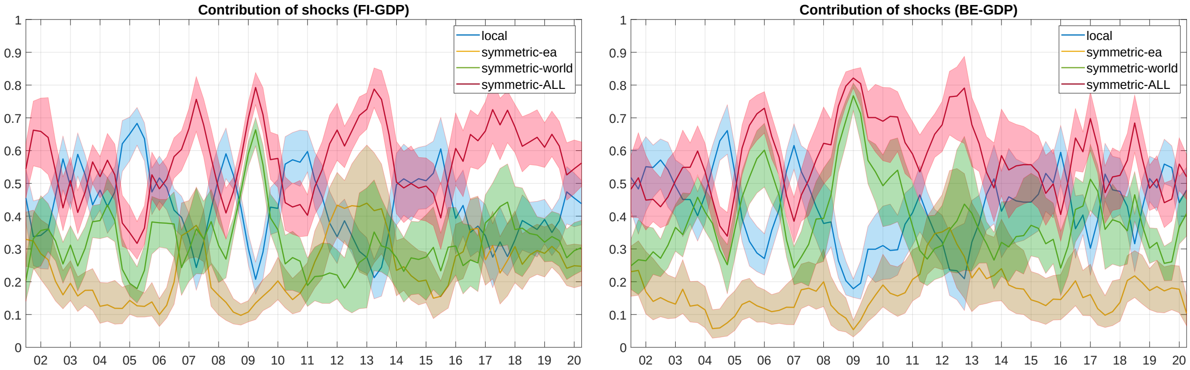
(d) Latvia

Figure A.10: Contributions of shocks for France, Austria, Finland and Belgium



(a) France

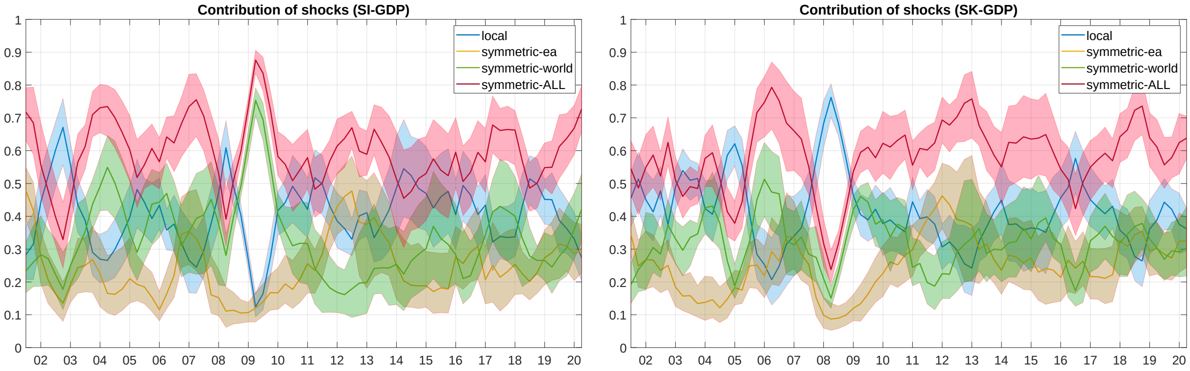
(b) Austria



(c) Finland

(d) Belgium

Figure A.11: Contributions of shocks for Slovenia, Slovakia, Lithuania and Estonia


(a) Slovenia

(b) Slovakia

(c) Lithuania

(d) Estonia

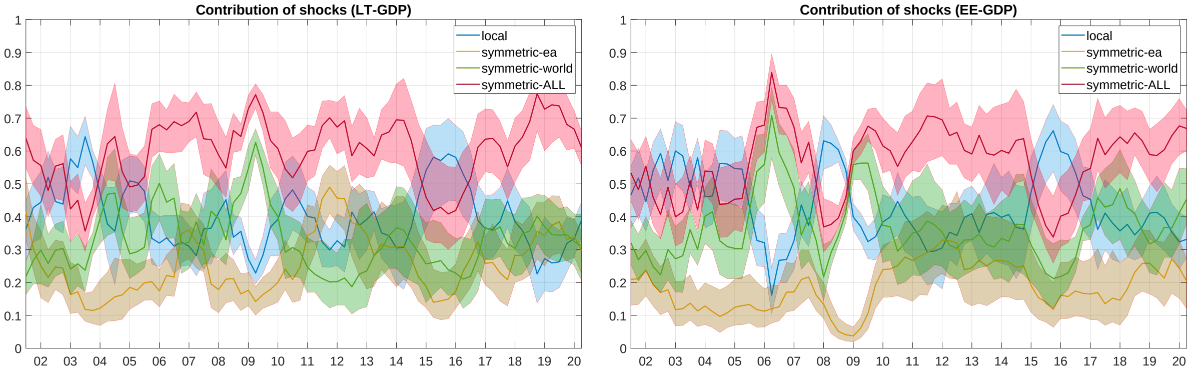
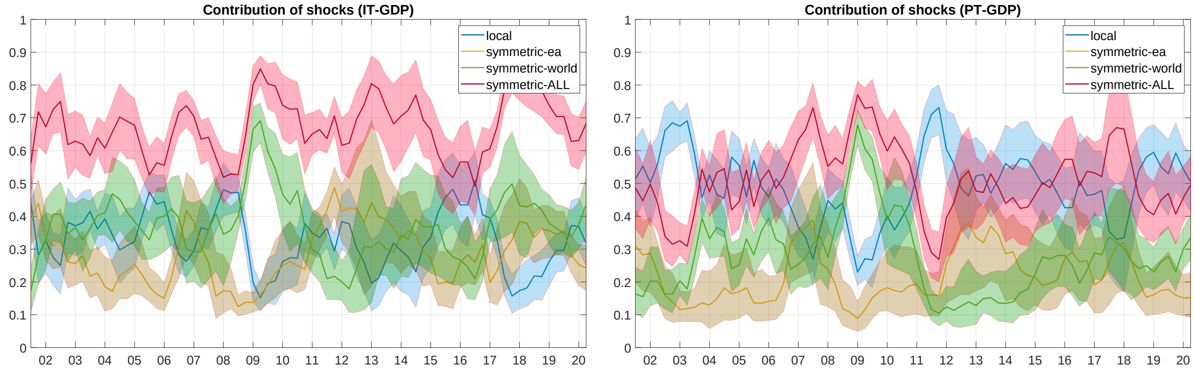


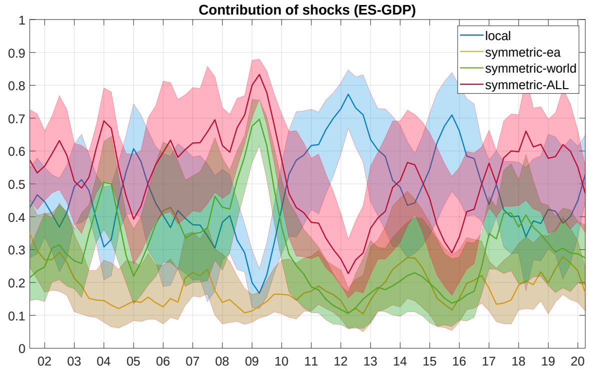
Figure A.12: Contributions of shocks for Italy, Portugal and Spain



(a) Italy

(b) Portugal

(c) Spain



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