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Global Inflation Dynamics and Inflation Expectations

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Abstract

In this paper we investigate dynamics of global inflation and short-run inflation expectations. We estimate a global vector autoregressive (GVAR) model estimated using Bayesian techniques. We then explore the effect of three source of inflationary pressure that could drive up inflation expectations: domestic aggregate demand and supply shocks as well as a global increase in oil price inflation. Our results indicate that inflation expectations tend to increase as inflation accelerates. However, the effects of the demand and supply shock are for most countries only short-lived. If domestic inflation accelerates due to a global acceleration of oil price inflation, however, effects are generally more pronounced and long-lasting. This implies that to assess the link between actual inflation and inflation expectations appropriately, it is important to disentangle the underlying sources of inflationary pressure. We also examine whether the relationship between actual inflation and inflation expectations has changed since the global financial crisis. We find that the transmission between inflation and inflation expectations was largely unaffected in response to domestic demand and supply shocks, while effects of an oil price shock on inflation expectations are smaller post-crisis.

Keywords

inflation, inflation expectations, GVAR modelling, anchoring of inflation expectations

JEL Classification

E31, E52, E58, C32

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ABSTRACT

In this paper we investigate dynamics of global inflation and short-run inflation expectations. We estimate a global vector autoregressive (GVAR) model estimated using Bayesian techniques. We then explore the effect of three source of inflationary pressure that could drive up inflation expectations: domestic aggregate demand and supply shocks as well as a global increase in oil price inflation. Our results indicate that inflation expectations tend to increase as inflation accelerates. However, the effects of the demand and supply shock are for most countries only short-lived. If domestic inflation accelerates due to a global acceleration of oil price inflation, however, effects are generally more pronounced and long-lasting. This implies that to assess the link between actual inflation and inflation expectations appropriately, it is important to disentangle the underlying sources of inflationary pressure. We also examine whether the relationship between actual inflation and inflation expectations has changed since the global financial crisis. We find that the transmission between inflation and inflation expectations was largely unaffected in response to domestic demand and supply shocks, while effects of an oil price shock on inflation expectations are smaller post-crisis.

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1 Introduction

Inflation expectations are considered to be the pivotal variable in providing insights about likely future economic conditions. While the decades long debate about the degree to which monetary policy is forward looking has not abated (e.g., Friedman 1968, Woodford 2003a) there is little doubt that policy makers devote considerable attention to the economic outlook. Hence, the dynamics of the relationship between inflation and inflation expectations continues to pre-occupy the monetary authorities and central bankers. Even before the full impact of the global financial crisis (GFC) of 2008-9 was felt in the US, and in many other parts of the globe, central bankers such as Bernanke (2007) highlighted the importance of inflation expectations since "…the state of inflation expectations greatly influences actual inflation…". More recently, Yellen (2016) also underscores the crucial role played by expectations while bemoaning the fact that the profession must confront gaps in our knowledge about the relationship between observed inflation and the short-run inflation expectations that lies at the heart of many theoretical macroeconomic models. Needless to say, it is not difficult to come across speeches by central bankers who, on a regular basis, touch upon the subject of the formation and implications of inflation expectations.[1]

A main driver of inflation expectations is past inflation. At the risk of some over-simplification, inflation can be thought of as being driven by two sets of determinants, namely local or domestic factors versus international or global forces.[2] The local determinants would include technical progress and changes in productivity, demographic factors, institutional considerations such as the adoption of inflation targeting and central bank independence and, since 2008, the adoption and maintenance of unconventional monetary policies in systemically important economies. More generally, however, economists tend to make the distinction between aggregate demand and supply sources of changes in inflation pressure. In what follows, we retain this distinction to allow for greater comparability with the extant literature as well as because it provides us with a

[1] A good place to look for speeches by central bankers on all topics is https://www.bis.org/cbspeeches/index.htm?m=7%7C123 where they are collected by the Bank for International Settlements (BIS).

[2] This sub-division is distinct from the question of how expectations are formed which is outside the scope of this paper.

vehicle to present new insights into the underlying drivers of inflation and ultimately about the likelihood inflation expectations can be anchored.

Globalization in both the trading of good and services and in finance is often also touted as a critical driver of the international component that influences domestic inflation rates. As a result, the extant literature has diverged wherein some argue that models of inflation are too nation centric (e.g., Borio and Filardo, 2007, Auer, Borio and Filardo, 2017) while others place greater emphasis on the various local factors mentioned above.[3]

The current literature generally focuses on a homogeneous set of countries (e.g., advanced or emerging market economies; see the following section). We depart from this norm to consider 42 economies that span a wide range in terms of their size, success at controlling inflation, monetary strategies in place, and the extent to which they were directly implicated or not in the GFC. To fully exploit the potential for cross-border spillovers in inflation, we use the Global VARs (GVAR) methodology (Pesaran and Chudik, 2016). This methodology is well suited to address the domestic impact of changing inflation on expectations dynamics controlling for international spillovers through cross-border inter-linkages.

Next, we propose a novel set of weights in estimating the GVAR obtained from the forecast error variance decompositions estimated via the methodology of Diebold and Yilmaz (DY; 2008) developed to measure the degree of connectedness. Since the debate about local versus global determinants of inflation partly centers on the extent to which countries are linked to each other the DY technique is a natural one to use in the present circumstances. Indeed, the foregoing combination of methodologies permits us to highlight another neglected aspect of the debate, namely that the relative importance of local versus global factors is likely a function of the policy horizon. In particular, while the GVAR methodology provides a very rich set of potential shocks that may be analyzed, we focus on two. They are: the impact of aggregate demand and supply

[3] There is insufficient space here to go into the details of the large literature dealing with the various domestic determinants of inflation. The role of technical progress was given impetus by Greenspan (2005), while Juselius and Takats (2015) is a good source on demographic factors and inflation. Murray (2017) outlines the impact of inflation targeting and provides some key references. Boneva, Cloyne, Weale, and Wieladek (2016) is an example of a study that explores the links between quantitative easing and inflation.

shocks on inflation and inflation expectations and the impact of a global oil price supply shock on these same two variables.

The rest of the paper is organized as follows. In the next section, we provide a brief literature review that concentrates primarily on empirical links between inflation and inflation expectations. In section 3 we provide details about the data set employed and a few stylized facts before proceeding to outline the econometric methodology in sections 4. Section 5 discusses the main empirical results while section 6 concludes.

Briefly, we find that inflation expectations respond positively to either domestic aggregate demand or supply shocks, but effects are generally temporary. This finding holds equally true for the post-crisis period. By contrast, if inflation accelerates due to a pick-up in global oil price inflation, the effects on inflation expectations are longer lasting. Hence, oil price shocks drive a wedge between inflation and inflation expectations even among professional forecasters. In that case, also, actual inflation and inflation expectations tend to co-move closely and the pass-through has diminished in the aftermath of the crisis. Therefore, in an era where energy prices are volatile and are subject to large swings, this has implications for when and how aggressively monetary authorities ought to respond to oil price shocks. An additional important implication is that identifying the aggregate supply from aggregate demand components of shocks is critical to understanding the dynamics of both observed and expected inflation.

2 Literature Review

Inflation expectations lie at the core of all macroeconomic models, whether or not they are of the New Keynesian variety (e.g., Woodford, 2003a). Moreover, to the extent that policy is able to influence these expectations, understanding the connection with observed inflation remains an essential ingredient in evaluating the impact of monetary policy.

Especially following the GFC, the debate surrounding the mechanism that best describes how expectations adjust in response to shocks, as well as what are the fundamental drivers of inflation expectations, has been rekindled. The same is true of the companion literature that explores the dynamics and determinants of observed inflation. An era of ultra-low interest rates, combined with low inflation, has also contributed to reviving the study and debate about links between inflation and inflation expectations.[4]

Rational expectations serve as a convenient benchmark, in part because theoretical models are readily solvable and closed form solutions are typically feasible. However, when confronted with the empirical evidence, considerable differences of opinion emerge about how best to describe the evolution of expectations. For example, an early assessment by the Bank of Japan of its Quantitative and Qualitative Easing program (QQE; Bank of Japan, 2016), for example, finds that the Japanese are prone to adjusting inflation expectations more gradually than in other advanced economies (e.g., the USA or the euro area). This also resonates with recent evidence from the US (e.g., Trehan, 2015) and other economies both large and systemically important as well as ones that are small and open (e.g., Bhatnagar et. al., 2017).

Of course, there may be several explanations for the sluggish adjustment in inflation expectations. Japan, after two decades or more of very low inflation to low deflation, sets this country apart from the remaining advanced economies which, over the same period, experienced only passing bouts of deflation (early 2000s and in the aftermath of the 2007-8 global financial crisis).[5] Since that time, below 'normal' inflation rates have spread across much of the advanced world. Unsurprisingly, this has attracted the attention and the concern of policy makers. This represents a relatively new element in the story of the dynamics of inflation.[6] It is

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[4] Paralleling this development has been the apparent breakdown of the relationship that defines the Phillips curve. It remains unclear what the source of the breakdown is and whether this is a temporary phenomenon or representative of some fundamental structural shifts in the economy (e.g., see Mavroeidis et. al., 2014, and references therein). Not everyone agrees that the Phillips curve deserves to be discarded (e.g., Fischer, 2016, Coibion and Gorodnichenko, 2015). Indeed, those who maintain that the Phillips curve remains a valuable part of the macroeconomist's toolkit focus precisely on the role and behavior or inflation expectations. Others point out that one need to take seriously the amount of economic slack and that the Phillips curve is indeed alive and well (Gordon, 2013) even if its slope may well have changed over time (e.g., Blanchard et. al., 2015).

[5] Barnerjee and Mehrotra (2018) present some recent international evidence about the determinants of expectations in deflationary environment.

[6] Also, in this connection, see Stock and Watson (2018) who attempt to measure components of inflation that are more cyclically sensitive than others. One strand of the relevant literature considers more carefully the distinction between short and long-run expectations of inflation. The former are considered more volatile, the latter are thought to be more representative of the credibility of the monetary policy regime in place. As Clark and Davig (2016) note, using US data, most studies rely on one or the other type of proxy for expectations but rarely both. Part of the problem is the absence of adequate survey type data beyond a selection of advanced economies. This state of affairs

also notable that, prior to the recent drop in inflation, the main concern was the role of commodity prices, notably oil prices, in generating higher inflation and the extent to which these shocks were seen to have permanent effects or not.[7]

Even if domestic economic slack retains its power to influence inflation, the globalization of trade and finance has introduced a new element into the inflation story, namely the potential role of global slack. Rogoff (2003, 2006) early on drew attention to the link between the phenomenon of globalization and inflation. Alternatively, at almost the high point of the globalization era, studies began to appear that provided empirical support either in favor of a significant global component in inflation, in some of its critical components (e.g., Ciccarelli and Mojon, 2010, Parker, 2017), or via the global influence of China's rapid economic growth (e.g., Pang and Siklos 2016, and references therein).

Economists, central bankers and policy makers have waxed and waned in their views about the significance of global slack as a source of inflationary pressure but it is a consideration that needs to be taken seriously and the question remains understudied (e.g., see Borio and Filardo ,2007, Ihrig et. al., 2010 and Yellen, 2016). More recently, Bianchi and Civelli (2015) conclude that while global slack is a significant determinant of inflation, whose effects are facilitated by the degree of trade and financial openness, the impact has not been strong enough to generate a structural break in domestic inflation dynamics. More broadly, the notion that a global component is an important driver of domestic inflation rates continues to find empirical support in spite of the proliferation of new econometric techniques used to address the question (e.g., Carriero et. al., 2018).[8]

is slowly changing (e.g., see Chan et. al., 2017). In any case the link between many theoretical models and short-run inflation expectations is inescapable as noted earlier (also see Yellen, 2016).

[7] The precise transmission mechanism between commodity price changes and headline inflation is also one that remains inadequately understood (e.g., Gospodinov and Ng, 2013, De Gregorio, 2012, Bernanke, 2008).

[8] An important related issue is whether the globalization of inflation phenomenon survives an analysis done using core inflation. Generally, the answer seems to be in the negative (e.g., Béreau et al., 2018, Carney, 2017, Carriero et. al., 2018). Data limitations (see below) prevent us from conducting the analysis below relying on core inflation data. Moreover, other than for some professional forecasts, headline inflation forecast are, by far, the most commonly published forecasts.

Recalling the words of central bankers cited in the introduction there remains much to be learned about the dynamic relationship between observed and expected inflation.[9] The two are inextricably linked, for example, in theory because the anchoring of expectations is thought to be the core requirement of a successful monetary policy strategy that prevents prices (and wages) from drifting away either from a stated objective, as in inflation targeting economies, or an implicit one where the central bank is committed to some form of price stability.[10]

There is, of course, also an ever-expanding literature that examines how well expectations are anchored. This literature focuses mostly on long-run inflation expectations (e.g., see Buono and Formai, 2018, Chan et. al., 2017, Mehrotra and Yetman, 2017, Lyziak and Paloviita, 2016, Strohsal and Winkelmann, 2015, and references therein). A few authors have focused on episodes when inflation is below target (e.g., Ehrmann, 2015), or during mild deflations (Banerjee and Mehrotra, 2018), while IMF (2016), Blanchard (2016), and Blanchard et. al. (2015), are more general investigations of the issues.[11] We contribute to this literature indirectly in the sense that we quantify the effects of inflationary shocks on short-run inflation expectations, which has a bearing on the ability of central banks to anchor inflation in the medium-term.

Beyond the foregoing issues there is also another question that has resonance in central banks especially, namely which expectation to examine? While central banks and academics often generate model-based forecasts that are guided by theoretical beliefs and considerations (e.g., as in models with a New Keynesian flavor; see Mavroeidis et.al. 2014 for a recent survey) central bankers and professional economists, not to mention academics, prefer survey-based forecasts. While many survey-type forecasts exist (i.e., households, professional forecasters, firms or

[9] Part of the challenge is what to assume about how expectations are formed, a topic outside the scope of this paper. Theories range from rational expectations (Muth, 1961; Lucas, 1982), rational inattention (Sims, 2006), sticky versus noisy information (Mankiw and Reis, 2002, Woodford, 2003b), to adaptive learning (Sargent, 1999).

[10] The possibility of a persistent gap between observed and expected inflation raises another thorny question, namely the observation that many empirical studies ignore a slowly changing trend in inflation. Cecchetti et. al. (2017) claim the so-called 'local trend' in inflation creates the "illusion" that inflation expectations contain information about future inflation. Taking first differences in inflation expectations (or inflation) destroys potentially useful information. Indeed, Strohsal and Winkelmann (2015) exploit this implication to model expectations using an exponential smooth transition model in the levels. Also, see the survey of Ascari and Sbordone (2014).

[11] There exists no formal definition of anchoring. Bernanke (2007) suggested a definition that relied on deviations from long-run inflation expectations. However, Levin, Natalucci and Piger (2004) show that too much sensitivity in short-term inflation expectations is also a sign that expectations are not well anchored.

enterprises; see Siklos 2019 for an illustration) very few can be used in a cross-country setting that includes emerging market economies. The reasons have to do with coverage, the manner in which the surveys are carried out, the timing and design of these surveys.

One survey that is generally comparable across countries is the one carried out by Consensus Economics (http://www.consensuseconomics.com/). We mainly rely on these data not only because they are appropriate in a global setting but also because of their global coverage and reliability over time (e.g., see Batchelor, 2001, Loungani, 2001). Nevertheless, at least one more issue stems from reliance on these forecasts: the choice of fixed event versus fixed horizon forecasts. Many forecasts, including ones published by several central banks, are fixed event forecasts as when the inflation or real GDP growth outlooks are evaluated on a calendar year basis. As new information comes in the horizon for such forecasts shrinks over time. In contrast, fixed horizon forecasts come closer to the manner in which models economists used are specified, namely an expectation formed at time t for some future horizon h (i.e., a year or longer). In this case it is the horizon that remains constant.

Ad hoc methods exist to convert fixed event into fixed horizon forecasts (e.g., see Buono and Formai 2018, Siklos 2013). Winkelried (2017) adapts the Kozicki and Tinsley (2012) shifting endpoint model to exploit the information content of fixed event forecasts. Of course, we do not know whether or how much new information is absorbed into subsequent forecasts in an environment where the horizon shrinks whether it is because information is sticky or there is sufficient rational inattention that mitigates the effective differences between fixed horizon and fixed event forecasts. Although constructed fixed horizon forecasts are imperfect they have the advantage that several papers in the extant literature employ this proxy.

Until the recent period of sluggish inflation the focus of much research fell on accounts that sought to evaluate the success, or lack thereof, of inflation targeting (IT) regimes. The fact that this kind of monetary policy strategy was designed in an era where the challenge was to reduce inflation is not lost on those who ask whether IT regimes are up to the task of maintaining inflation close to the target (e.g., see Ehrmann 2015 and references therein).[12]

Fuhrer (2017) considers the extent to which expectations of inflation are informative about the dynamics of observed inflation based on empirical work that covers a period of 25 years for the U.S. and Japan. Fuhrer's study is also interested in the extent to which long-term inflation objectives can be modelled via a sequence of short-term forecasts. The answer seems to be in the affirmative but significant departures from the long-term are present in the data. In contrast, our study is not able to determine the strength of any such links due to data limitations, as we shall see. Nevertheless, as suggested above, the degree to which inflation is anchored need not be solely evaluated according to long-term expectations. Short-term deviations can also serve as warning signals.

To our knowledge then, a dynamic model that attempts to evaluate the link between inflation and inflation expectations across a large number of economies not primarily restricted to the advanced group of economies alone, and the role of global factors as well as cross-country interactions, is still missing. The following sections begin to fill the gap.

3 Data and some stylized facts

In this section we describe the data and provide some stylized facts about inflation expectations, actual inflation and the cross-country links of inflation data.

3.1 Data description

We constructed a data set consisting of monthly data since all economies in our data set publish monthly CPI figures while Consensus Economics forecasts are also published at the monthly frequency. Given the heterogeneity of the countries in our data set we restrict the sample to the 2001m01 to 2016m12 period. Although longer samples are clearly feasible for several advanced economies the same is not true of most emerging markets and constraints on obtaining useful

[12] The literature that considers the extent to which inflation expectations are anchored also considers the problem from a couple of other angles not directly considered in this paper. They are: the degree to which inflation and expectations are persistent over time (e.g., see Jain 2017, and references therein), and whether forecasters disagree about the outlook (e.g., see Siklos 2019, and references therein).

expectations data are even more severe again for most of the emerging market economies in our dataset. The data we collect are described in Table 1 below.

Table 1: Data description

Variable	Description
Dp^e	Inflation expectations (fixed horizon) based on Projections from Consensus Economics for the current and the next year. Updated from Siklos (2013).
gdp	Monthly real GDP estimate using the Chow Lin time disaggregation method and industrial production as a monthly time series.
Dp	Consumer price inflation in y-o-y terms.
ur	Unemployment rate, in %.
stir	Short-term interest rates, 3-months money market rates, in %.
sp	Long-term interest rates, 10-year government bond yields, in %.
eq	Stock price index, in logarithmic transform.
reer	Real effective exchange rate from the BIS data base.
Dp^{oil}	Oil price inflation (in y-o-y terms).
q^{oil}	Global oil production, in logarithmic transform.

Region	*ISO-2 Code*
Advanced	US, CA*, NO*, SE*, GB*
Euro area (EA)	AT, BE, DE, SK (2008), SI (2007), PT, GR (2001), IE, IT, ES, FI, FR,NL
CESEE	EE (2011), LT (2015), LV (2014), BG, CZ*, HR, HU*, PL*, RO*, RU*, TR*
Asia	CN, JP*, KR*, MY, PH*, SG, ID*, IN*
Latin America (LATAM) and South Africa	BR*, CL*, MX*, PE*, ZA*

Notes: * indicates countries that formally target inflation. All countries target inflation since the beginning of the sample, except the following: RO (2005), RU (2014), TR (2006), JP (2013), PH (2002), ID (2005), IN (2016), NO (2001). The years in parenthesis indicate when the countries in question joined the euro area.

Our focal variable is inflation expectations (Dp^e) which we measure as fixed horizon inflation forecasts from Consensus Economics. Occasionally, we had to fill some missing values (see the appendix). We did this by relying on data from the World Economic Outlook (http://www.imf.org/en/publications/weo) which also publishes semi-annual current and one calendar year ahead forecasts. Since the current and one year ahead forecasts are calendar year based these were converted to fixed horizon forecasts via a linear transformation employed frequently in the literature as noted previously. Effectively, the transformation combines forecast information over a two year period. Hence, this comes close to the two year horizon central banks consider it takes for a change in the stance of monetary policy to take effect.

The remaining data comprise real GDP (*gdp*) and the unemployment rate (*ur*), short-term interest rates (*stir*), the term spread (*sp*), equity prices (*eq*) and the real effective exchange rate (*reer*). These data should capture the most important determinants of price factors and macroeconomic and financial conditions that could shape inflation expectations. Instead of using industrial production as a measure of output, we converted real GDP into monthly data using the Chow-Lin interpolation procedure (Chow and Lin, 1971). When data were missing we relied on monthly industrial production indices. Consumer prices and oil prices were transformed in year-over-year changes (y-o-y), the remaining data are in levels. Data are collected for the 42 countries listed in the bottom panel of Table 2. For the sake of illustration and brevity we grouped them into four regional aggregates, namely advanced economies and the euro area on the one hand and emerging economies from Central East- and South-Eastern Europe (CESEE), Asia and Latin America on the other hand. Note that some CESEE countries adopted the euro during our sample period (Slovenia and Slovakia and the Baltics). We assign Slovenia and Slovakia to the group of euro area countries and the Baltics to the CESEE economies mainly since the latter are comparably more volatile and adopted the euro at a later stage. Also, we assign South Africa to the Latin American countries. This choice does not affect the estimation in the empirical part of the paper – it only affects the arrangement and display of figures and the presentation of the overall results.

These data were mostly obtained from the International Monetary Fund's International Financial Statistics and national central banks of the economies in our data set. These are easily accessed from the BIS's Central Bank Hub (https://www.bis.org/cbanks.htm?m=2%7C9).

3.2 Stylized facts

We next present some stylized facts for the inflation data. A brief data description is provided in Table 2 below.

Table 2: Descriptive statistics

	Dp^e				*Dp*				*Correlation (Dp^e, Dp)*
	Min.	*Median*	*Max.*	*SD*	*Min.*	*Median*	*Max.*	*SD*	
Advanced	0.25	1.91	3.34	0.59	-1.1	1.83	4.89	1.09	0.76
EA	0.09	2.02	3.99	0.95	-1.3	2.12	5.43	1.53	0.90
CESEE	0.80	4.20	16.76	3.58	-1.1	4.29	17.88	4.10	0.93
Asia	0.84	2.91	6.35	1.20	-0.4	2.89	9.39	1.99	0.74
LATAM	2.54	4.14	8.29	1.05	-2.4	3.52	11.87	2.77	0.66

Notes: Simple regional averages over country-specific statistics.

A first glance at the data reveals that the level of inflation expectations is highest in CESEE and Latin American countries. In advanced economies and the euro area inflation expectations are on average anchored close to the 2% inflation target pursued in most of the countries from these regions. Inflation expectations are on average 3% in Asia and thus lie between those of advanced and euro are countries on the one hand and CESEE and Latin American countries on the other hand. In CESEE economies the standard deviation of inflation expectations is rather high, whereas in Latin American countries the small standard deviation indicates that inflation expectations are constantly elevated. A similar picture arises when considering actual inflation provided in the middle panel of Table 3. This is not surprising, given the strong positive correlation of inflation expectations and actual inflation (right panel). Correlations are strongest in European countries (euro area and CESEE above 0.90) and weakest in Latin America (0.66).

Figure 1 displays the relationship between inflation and inflation expectations on a country-by-country basis.

[Figure 1 to be included here]

The horizontal axis plots observed inflation while the vertical axis shows our measure of inflation expectations. If the two series were perfectly coincident then a 45 degree line would describe their relationship. Clearly, this is not the case although a strong positive relationship is visible in several cases, including notably 10 euro area member economies that have been in the single currency area since the beginning of the sample. Also notable is that, in at least 34 economies, there have been instances of deflation albeit of the mild variety.[13] In contrast, there are far fewer instances where inflation expectations are deflationary with only 13 countries recording some temporary evidence of expected deflation.[14] Possibly most striking of all is the sheer heterogeneity in the relationship between these two series. Thus, for example, in several cases (i.e., KR, MX, PE, SI, SK) there is much greater variation in observed inflation than in inflation expectations while Malaysia (MY) is the only noticeable case of variation in expectations exceeding greatly fluctuations in observed inflation. In a few other important instances, the scatter plot suggests a change in the relationship between the two series at low inflation rates (i.e., US, JP). Although non-linearity in inflation performance over time have been noted in the literature visual inspection of Figure 1 does not suggest that a linear approximation would do much injustice in a model that seeks to examine the dynamic relationship between inflation and inflation expectations.

Lastly, we want to examine cross-country links among inflation expectations and actual inflation. To answer this question, we follow Diebold and Yilmaz (2009) and calculate a spillover index. The Diebold and Yilmaz (2009) spillover index is based on a forecast error variance decomposition and an underlying vector autoregressive (VAR) representation of the data. Hence we estimate two VAR models, one for inflation expectations and one for actual inflation, each featuring 42 endogenous variables, a constant term and 4 lags.[15] We calculate the spillover index following the approach of Chan-Lau (2017), utilizing generalized forecast error variances (GFEVD), normalized as in Lanne and Nyberg (2016) such that the shares sum up to unity.[16] More details are provided in Appendix A.1.

[13] Usually these have not exceeded 2% with the highest recorded one time deflation (annualized rate) reaching only 3%.

[14] Japan is the one exception to this rule where deflationary expectations are relatively more common.

[15] Since the model is highly parametrized, we use Normal-Gamma shrinkage priors and Bayesian estimation techniques as in Huber and Feldkircher (2018). The results are based on 500 retained MCMC draws.

[16] A prerequisite to calculate the spillover index is that the shares of forecast error variance sum up to unity. This is the case whenever the (structural) residuals in the VAR are orthogonal. Since we cannot orthogonalize the residuals

The spillover index can be constructed for different horizons (*h*) of the underlying GFEVD. The index for inflation expectations is about 40% on impact (*h=0*) and then steadily increases. At six months it is already above 80%. This implies that there exist cross-country dependencies for inflation expectation data. Put differently, inflation expectations of other countries matter for the expectation formation process of inflation in a particular country. The corresponding figures for actual inflation are a bit smaller in the short-run (30% at *h=0*) but show a similar degree of connectivity in the medium term (above 80% at *h=6*).

In Figures 2 and 3 we provide a regional breakdown of the spillover index. More specifically we show the normalized GFEVD on impact (*h=0*), after 6 (*h=6*) and 12 (*h=12*) months. The colors refer to own contributions (in red), regional contributions (in green) and international contributions (in light gray).

[Figure 2 to be included here]

[Figure 3 to be included here]

We define regional spillovers as contributions from countries within the same region as shown in Table 1 and international spillovers as those coming from all other economies. A few stylized facts emerge from the analysis. First, and as indicated by the overall spillover index, on impact the domestic component of inflation expectations emerge as an important determinant. For most economies an equal share of forecast error variance can be explained by domestic and global inflation expectation dynamics, whereas at longer forecast horizons the importance of spillovers becomes evident. Investigating cross-country differences reveals that inflation expectations in CESEE economies are to a large extent driven by inflation expectation dynamics

without the use of further assumptions (such as the timing of shocks as in a Cholesky type of orthogonalization) we have to rely on the generalized version of the forecast error variance decomposition. The Lanne and Nyberg corrected GFEVD offers the useful property that the shares sum up to unity and has been recently applied in the context of Diebold Yilmaz connectivity in Chan-Lau (2017).

from the same regions as indicated by the large share of forecast error variance explained by the regional factor. For other economies the international factor is much more important. This can be partially explained by the importance of some particular countries. For example, it turns out that Turkish inflation expectations account for much forecast error variance which explains the emergence of the regional factor for CESEE and the international factor for the remaining economies. The same applies to a lesser extent to India, Indonesia and Brazil, all of which explain a large amount of forecast error variance for the remaining countries while their own inflation dynamics are more shaped by domestic factors. These results are very similar when looking at forecast error variance decompositions of actual inflation provided in Figure 4.

Summing up, we find that inflation expectations are close to 2% on average in advanced and euro area countries, while they are about 4% for emerging economies from CESEE and Latin America. There also tend to be less deflationary instances than actual inflation data would suggest. The smaller cross-country in Latin America suggests that inflation expectations are generally high for that region, whereas in CESEE for some countries expectations might be as low as in advanced economies. Asian economies stand somewhat between these two groups regional groups. Actual inflation and inflation expectations are generally positively correlated. However, for some countries, this relationship might change when inflation rates are low. Investigating the cross-country dimension further reveals strong connectivity in global inflation expectations. This implies that the expectation formation process in a particular country is not determined by domestic considerations alone. Rather international expectation formations play an important role. Taken at face value this suggests that international linkages have to be taken into account when analyzing inflation expectations at the global level.

4 Econometric framework

In this section we investigate how domestic aggregate demand and supply shocks that drive up actual inflation impact inflation expectations. We complement these two domestic shocks by looking at the effect of a global oil price supply shock. This question is closely related to the literature that examines the anchoring of inflation expectations which frequently employs a regression of inflation expectations on lags of actual inflation (see e.g., Ehrmann, 2015). However, inflation expectations and actual inflation are intrinsically related (Lyziak and Paloviita, 2016) - a fact that is neglected by the simple linear regression approach.

Consequently, we use a global vector autoregressive (GVAR) model to examine the relationship of inflation expectations and inflation. This approach models inflation expectations and inflation jointly and controls for the cross-country linkages evidenced in the previous section. In what follows, we will borrow the GVAR mechanics proposed in Pesaran et al. (2004) and estimate the country models using shrinkage priors and Bayesian estimation techniques. For each country *i*, we estimate the following vector autoregression:

$$y_{i,t} = a_{io} + \sum_{j=1}^{p=2} A_{ij} y_{i,t-j} + \sum_{j=0}^{q=2} B_{ij} y^{*}_{i,t-j} + \varepsilon_{i,t} \tag{1}$$

with $\varepsilon_{i,t}$ being a Gaussian vector white noise process with time-varying variance covariance matrix $\Sigma_{i,t}$, $\mathbf{a_{io}}$ a k_i-dimensional vector of intercept terms, A_{ij} for j=1,…,2 a k_i x k_i matrix of autoregressive coefficients associated to the j^{th} lag of the endogenous variable and B_{ij} for j=0,…,2 a k_i^* x k_i^* coefficient matrices on the k_i^* so-called foreign variables. These are calculated as weighted cross-country averages using weights that account for the interconnectedness between the countries: $y^{*}_{i,t} = \sum_{z \neq i} w^{o}_{zj} y_{z,t}$, with $w^{o}_{zj} \geq 0$; $w^{o}_{ii} = 0$; $\sum_{i=1}^{N} w^{o}_{zj} = 1$, for o=1, 2, 3 different weight matrices. Since the focus of our study is inflation and inflation expectations we draw particular attention to the calculation of *Dp** and *Dp^e**. For that purpose we utilize the bilateral connectivity indices, calculated in the previous section. More specifically, we use the re-scaled off-diagonal elements of the generalized forecast error variance decompositions (h=12) of inflation expectations ($w^{Dp^e}_{ij}$) to calculate foreign inflation expectations and the one of actual inflation (w^{Dp}_{ij}) to compute foreign inflation. For all other variables we follow the bulk of the GVAR literature and use bilateral trade weights (w^{trade}_{ij})[17]. The use of different weight matrices

[17] More precisely, we use annual bilateral trade flows from the IMF's DOTS data base, averaged over the period from 2000 to 2012.

to compute $y^*_{i,t}$ is not uncommon in the GVAR literature (see e.g., Eickmeier and Ng, 2015) but often prohibited by lack of suitable bilateral data. Utilizing the Diebold and Yilmaz (2009) connectivity index offers a valuable and novel alternative to reflect connectivity within the GVAR framework.

The model given in equation (1) features stochastic volatility. We allow the residual variances to vary over time since first, our sample covers a very volatile time period and secondly, to accommodate criticism that the assumption of a homoscedastic variance is at odds with the data for most macroeconomic applications (see e.g., Sims and Zha, 2006, Clark, 2011).

More specifically, we decompose $\Sigma_{i,t}$ into

$$\Sigma_{i,t} = U_i H_{i,t} U'_i, \tag{2}$$

with U_i a k_i-dimensional lower triangular matrix with unit diagonal and off-diagonal elements denoted by $u_{ij,n}(j = 2, \cdots k_i; n = 1, \cdots j-1)$ and $H_{i,t}$ a diagonal matrix with $H_{i,t} = diag(e^{h_{i1,t}}, \cdots, e^{h_{ik_i,t}})$. We then assume that the log-volatilities $h_{ij,t}$ follow an AR(1) process:

$$h_{ij,t} = \mu_{ij} + \rho_{ij}(h_{ij,t-1} - \mu_{ij}) + \xi_{ij,t}, \tag{3}$$

with μ_{ij} denoting the (unconditional) mean of the log-volatility, ρ_{ij} the persistence parameter and $\xi_{ij,t}$ a white noise error with variance ϱ^2_{ij}. In the empirical application, impulse responses will be calculated based on the mean volatility over time.

The general model outlined in equation (2) is completed by including oil price inflation, the quantity of oil and euro area interest rates as additional weakly exogenous variables. The set of variables featured in a typical country model *i* thus consists of:

$$y_{i,t} = (\mathrm{Dp}^{e}{}_{i,t}, \mathrm{gdp}_{i,t}, \mathrm{ur}_{i,t}, \mathrm{Dp}_{i,t}, \mathrm{stir}_{i,t}, \mathrm{sp}_{i,t}, \mathrm{reer}_{i,t}, \mathrm{eq}_{i,t})',$$
$$\mathrm{y}^{*}{}_{i,t} = (\mathrm{Dp}^{e*}{}_{i,t}, \mathrm{gdp}^{*}{}_{i,t}, \mathrm{ur}^{*}{}_{i,t}, \mathrm{Dp}^{*}{}_{i,t}, \mathrm{stir}^{*}{}_{i,t}, \mathrm{sp}^{*}{}_{i,t}, \mathrm{reer}^{*}{}_{i,t}, \mathrm{eq}^{*}{}_{i,t}, \mathrm{Dp}^{oil*}{}_{t}, \mathrm{q}^{oil*}{}_{t}, stir^{*}_{EA,t})'. \quad (4)$$

Oil price inflation and the quantity of global oil supply are jointly modeled in a separate country model. The weights to calculate $\mathrm{Dp}^{oil*}, \mathrm{q}^{oil*}{}_{t}$ are thus 1 when *i* equals the index of the oil price model and zero elsewhere. In the oil price model itself, only world GDP, constructed using purchasing power parities, is included as a foreign variable.

Second, for euro area countries we have to account for the existence of a single monetary policy. We do this by adding a further country model that determines euro area interest rates. In line with Feldkircher et al. (2017), and Georgiadis (2015), we assume that euro area interest rates follow a Taylor rule. That is, euro area short-term interest rates are set according to euro area actual inflation and output, where we use purchasing power parity weights to aggregate the respective euro area single countries' figures. The euro area short-term interest rate ($stir^{*}_{EA}$) is then fed as a foreign variable into the other countries' models.[18] Consequently, the euro area countries do not feature own domestic interest rates thereby rendering this region distinct from the other countries as outlined in equation (4).

Note that the specification regarding the domestic variables given in equation (4) comprises a lot of models that have been previously estimated in the literature. There are none, to our knowledge, that model the role of the global components in the manner described above.[19] As noted previously, our interest in the empirical work is motivated primarily by the belief in some quarters that a global component in domestic inflation behavior has become important in recent years.

Using the algebra outlined in appendix A.2., and put forth by Pesaran et al. (2004), we can rewrite the country models in terms of a global model:

[18] We include euro area short-term interest rates as foreign variable in all countries considered in this study, similar to oil price inflation and oil quantities. A more parsimonious way would be to include them only in euro area country models but we abstain from this a priori assumption and, via the shrinkage priors, to let the data decide about inclusion / exclusion of this variable. Analogous to the oil price model, the weights to calculate $stir^{*}_{EA}$ are 1 when *i* equals the index of the euro area monetary policy model and zero elsewhere.

[19] As surveyed in section 2 above, global slack is, by far, the global component of choice that enters equation (1).

$$y_t = \sum_{j=1}^{\max(p,q)=2} \boldsymbol{F}_j y_{t-j} + \mathrm{e}_\mathrm{t}. \tag{5}$$

with $\mathrm{y_t} = \left(\mathrm{y}'_{0,\mathrm{t}}, \cdots, \mathrm{y}'_{\mathrm{N,t}}\right)'$ denoting the global vector that stacks the data of all countries and $\boldsymbol{F_j}$ stacked coefficient matrices.

To estimate the county models, we use a Normal-Gamma prior on the coefficients and the off-diagonal elements of the variance covariance matrix. This prior has been put forth in Huber and Feldkircher (2018) and applied to the GVAR framework in Huber and Punzi (2017). The exact prior specification is provided in appendix A.2. The country model is then estimated using 30,000 posterior draws after a burn-in phase of 30,000 draws. Due to storage constraints, we use a thinning interval and retain every tenth draw from the 30,000 posterior draws. From these, we reject draws that lead to an instable GVAR system leaving us with 2,620 final draws upon which inference and diagnostic checks are based for the baseline specification.

4.1 Identification

We identify two domestic shocks and examine the effects on inflation expectations, namely a domestic aggregate demand and aggregate supply shock. The shocks are identified locally and using sign restrictions (Eickmeier and Ng, 2015). The sign restrictions are summarized in Table 3 below:

Table 3: Sign restrictions AD and AS shock

Shock	*gdp*	*Dp*	*ur*	*stir*	*reer*	*Dp^e^*
Aggregate demand (AD):	+	+	-	+	+	?
Aggregate supply (AS)	-	+	+	+	+	?

Notes: The restrictions are imposed only on impact, + (-) refers to a positive (negative) impact response of the respective variable.

The restrictions outlined in Table 3 comply with standard economic theory. As aggregate demand (AD) increases, inflation rises. As in Blanchard and Galí (2010), we assume a negative relationship between output and unemployment, so that the unemployment rate decreases in the face of an AD shock. In line with Peersman (2005) and Feldkircher and Huber (2016) we assume that the central bank will aim at containing the rise in inflation by increasing interest rates[20], which in turn causes an appreciation of the real effective exchange rate. The restrictions for an aggregate supply (AS) shock follow a similar reason. The only exception and distinguishing feature is the fall in output caused by the inward shift of the supply curve. Note that we leave the sign of the variable of interest, inflation expectations, unrestricted. All restrictions are imposed only on impact to ensure that our results are not driven by our assumptions.

We complement the domestic supply and demand shocks by a global oil supply shock. Commodity price shocks are an important determinant of inflation and their impact on inflation expectations could be potentially different from the domestic demand and supply shocks. While the literature on identifying oil price shocks is large (see e.g., Kilian, 2008, 2009, Hamilton, 2009), the GVAR framework offers a further convenient way to pin down an oil price shock, namely the cross-section. In what follows we will look at a positive innovation to oil price inflation and facilitate identification further by assuming cross-country output restrictions. More specifically, we follow Cashin et al. (2014) and use the subsequent set of restrictions to identify the oil supply shock.

Table 4: Global oil supply shock

Shock	Dp^{oil}	q^{oil}	$gdp^{importers}$
Oil supply shock:	+	-	-

Notes: The restrictions are imposed only on impact, + (-) refers to a positive (negative) impact response of the respective variable. The restriction on GDP for the oil importing countries ($gdp^{importers}$) has to hold for the majority of oil importing countries.

As with the AS shock, the oil supply shock is characterized by an opposite movement of oil prices and quantities. The cross-sectional restrictions on GDP of oil importers ($gdp^{importers}$)[21] further

[20] For the euro area countries, the rise in short-term rates corresponds to a positive innovation in the ECB taylor rule model.

[21] These are the euro area countries, China, Japan, the USA, Brazil, Chile, Peru, Korea, Malaysia, Philippines, Singapore, India, South Africa, Sweden, Turkey, Bulgaria, Czech Republic, Croatia, Hungary, Poland and Romania.

enhance identification of the shock since no other shock moves oil prices, oil production and real output of oil importing countries in opposite directions (Cashin et al., 2014). In contrast to Cashin et al. (2014) we impose the restrictions again only on impact. We do this to be consistent with identification of the domestic demand and supply shocks. We also do not impose that the sum of GDP of oil importing countries has to decline – as in Cashin et al. (2014) but rather the majority of oil importing countries has to witness a fall in output. This is to ensure that the restriction is not driven by one particularly large country but identification holds on a more general scale.

5 Empirical results

To get a first impression of the results we provided estimates of impact and peak responses for the three shocks in Figure 4. The domestic aggregate demand and supply shocks are normalized to a +1 percentage point increase in actual inflation on impact. The global oil supply shock is calibrated as a +1 percentage point increase in oil price inflation.

[INSERT FIGURE 4 HERE]

Comparing impact responses to the three shocks, we see that an aggregate demand shock that drives up domestic inflation has a positive immediate effect on inflation expectations in most of the countries. Impact effects are strongest in Russia and Romania, two countries that witnessed periods of high inflation in the past, and Great Britain. In contrast, the impact effects triggered by an AS shock are mixed, with half of the countries showing positive and the other half negative effects. This might be driven by the contraction in output as the supply curve shifts inward. In emerging economies such as Brazil, Chile, Philippines and Mexico the supply shock triggers an immediate downward revision of inflation expectations. The oil supply shock triggers positive immediate effects in all countries, underscoring the importance of oil price shocks for inflation expectations. Note that the comparably smaller size of the effects is related to the calibration of the shock. With a few exceptions, peak effects on inflation expectations are for all countries positive and in the range of -0.7 to 1.8 percentage points. The number of countries with a strong and positive response (above 0.5 percentage points) is largest for the oil price shock corroborating the findings from above.

To investigate the shape and the significance in more detail, we provide the full impulse response functions of inflation expectations and actual inflation in Figures 5 to 10. We show the posterior mean (blue solid line) along with 50% and 68% credible intervals. The use of less stringent credible intervals, such as the 50% set, is not uncommon in highly parametrized models, such as the GVAR model (see e.g., Chudik and Fratzscher, 2012 or Almansour et al., 2015). For completeness, we provide output responses in the appendix.

[INSERT FIGURE 5 HERE]

[INSERT FIGURE 6 HERE]

[INSERT FIGURE 7 HERE]

[INSERT FIGURE 8 HERE]

We begin by investigating the responses of inflation expectations and actual inflation to a domestic AD shock. We see that for most economies the response of inflation expectations is either flat and hovers around zero or is hump shaped, petering out in the longer term. This finding implies a high degree of anchoring of short-term inflation expectations, which might directly translate into anchoring of long-run inflation expectations. Countries for which inflation expectations converge more slowly comprise advanced and euro area economies (Italy, Ireland, Norway, Portugal and Slovenia), CESEE economies (Bulgaria, Croatia, Russia), Asian economies (China, India and Indonesia) as well as South Africa. In Italy, Norway, South Africa and Slovenia the cooling off phase of inflation expectations takes particularly long. Inflation expectations decrease in India, Indonesia and Chile.

Do inflation expectations and actual inflation always move in the same direction? In Figure 6 we see, that actual inflation responses are not hump shaped – rather in most countries actual inflation gradually declines and dies out after 8 to 16 months. In countries that show a longer adjustment phase, also actual inflation responses take longer to cool off, though. Also in countries with negative inflation expectation responses also actual inflation tends to be negative over the impulse response horizon such as in the cases of India and Chile. In Indonesia, by contrast, actual inflation is positive up until 20 months which indicates a negative relationship between inflation expectations and inflation.[22]

Next, we investigate the impact of domestic AS shocks on inflation expectations. Here, we also find that inflation expectations tend to adjust rather quickly for almost all countries. Actual inflation responses tend to differ from those of inflation expectations indicating that there is no direct one-to-one relationship between the two series. Exceptions to this are countries that either show a positive and significant response of inflation expectations in the long-run (Bulgaria and Croatia) or a negative response (India, Brazil and Chile). In these countries, inflation expectations tend to follow closely actual inflation responses.

Finally, we look at the effects of a supply side driven acceleration of oil price inflation. Here, we see that most of the effects are positive and long-lasting. Also, the effects are sometimes rather sizable even in the long-run. More precisely, in 23 of 42 countries, long run-effects on inflation expectations are above 0.4. This implies that nearly half of the acceleration in oil prices directly translates into upward movements of inflation expectations. In some countries the pass-through

[22] Indonesia has adopted an inflation targeting regime. One way of rationalizing the result reported above is by arguing that, in the presence of a positive inflation shock, the central bank will tighten policy to maintain its credibility. Assuming this is the case inflation expectations should subsequently fall. Inflation targeting, however, may be a necessary but not sufficient condition. All that is needed is a credible central bank which is expected to control inflation.

is even greater than 1 (Romania and Philippines). In contrast to the domestic demand and supply shocks, there are no significantly negative responses for the countries covered in this study. Also, we find a strong relationship between actual inflation and inflation expectation responses while comparably larger, actual inflation responses show a similar shape as inflation expectations responses.

Summing up, inflation expectations increase in the short-run if inflationary pressure stems from either domestic supply or demand shocks. However, no permanent effects are found. This result changes when considering a global acceleration of oil price inflation. Here we find positive long-run effects on inflation expectations for a range of countries. Also, there is a close link between actual inflation and inflation expectations indicating that there is a direct pass-through from oil prices, to domestic inflation to inflation expectations.

5.1 Did the global financial crisis affect the pass-through from inflation to inflation expectations?

In this section we examine whether the link between inflation and inflation expectations has been affected by the period after the global financial crisis. The aftermath of the global financial crisis was characterized by low inflation rates in advanced economies (Ehrmann, 2015) as well as ultra-low interest rates and unconventional monetary policy. Doh and Oksol (2018) argue that the launch of large scale asset purchase programs helped stabilizing inflation expectations in the USA. Whether this claim can be supported on a global scale has not been examined so far.

For that purpose we, first run a sub-sample analysis to broadly examine parameter changes over time and second, draw particular attention to one facet of the aftermath of the crisis, namely monetary policy and the zero lower bound. For the sub-sample analysis we re-estimate the GVAR model for the post-crisis period, which we define from 2009m12 to 2016m12. We use a later cut-off date that marks the aftermath of the GFC since we use a global sample and some countries (e.g., in CESEE) have been affected with a delay (see e.g., the discussion in Feldkircher, 2014).[23]

[23] We have also re-estimated the GVAR model over the pre-crisis period, but the model was less stable, which prohibits a direct comparison of the pre- and post-crisis periods.

To gauge whether the effects are different in a more systematic way, we have calculated the differences in impulse responses from the full and post-crisis period. Using Monte Carlo integration we have computed the median difference along with its 68% credible interval.[24] In case both responses are similar, the median should be close to zero or – if estimation / structural uncertainty precludes any precise statement -- the bounds large. The results are reported in Table 6, which shows the median of the difference in cumulative impulses responses as well as for its peak value. Significant values according to the 68% bounds are in bold. Looking at the table reveals that the differences in cumulative inflation expectation responses to an inflationary AD or AS shock are in general rather small. This indicates that the link between inflation and inflation expectations tends not to be different in the post-crisis period for most of the countries. However, in some countries, we find significant deviations post-crisis. For example, for France, Indonesia and Canada we find stronger (positive) responses of inflation expectations in the post-crisis period. The opposite is found in the case of Peru, with inflation expectations reacting less in the post-crisis period compared to the full sample period. The differences in inflation expectation responses to the oil price shock are positive for most countries and significantly so for nearly a third of them. This implies that inflation expectations in the aftermath of the crisis would react less strongly to an oil price shock that drives up inflation.[25] Poland is an exception since it exhibits a comparably higher sensitivity of inflation expectations to an increase in oil prices in the aftermath of the crisis. Looking at peak effects tells a similar story.

We then proceed to investigate whether the transmission of the shocks is altered by the zero lower bound constraint. We do this by using so-called shadow interest rates, which are derived from term structure models. The shadow rate mirrors actual rates during normal times, and becomes negative during periods when the zero lower bound is binding. We substitute the shadow rates for short-term interest rates in the countries that witnessed periods of zero short-

[24] More precisely, we have a different number of MCMC draws for which a rotation matrix has been found for the two sample periods. We hence have randomly matched the number of MCMC draws for both periods 500 times and calculated the statistic of interest (the difference in responses).

[25] Also notable are large variations in oil prices since the GFC. Of course, there continues to be a lively debate about whether the pass-through effects in oil prices has changed over time. See, for example, Clark and Terry (2010) and Baumeister and Kilian (2016) for the US and Holm-Hadulla and Hubrich (2017) for the euro area.

term interest rates, namely the country model for the ECB, Japan, the UK and the USA. The shadow rates we use are from Krippner (2013) and are publicly available from the webpage of the Reserve Bank of New Zealand. We then re-estimate the model and calculate impulse responses to the three shocks as above. The correlation of inflation expectations posterior median impact responses with and without shadow rates is above 0.9 for both the local demand and local supply shocks. For the oil supply shock, the correlation is close to 1. This indicates that accounting for monetary policy during the zero lower bound period more properly does not alter our baseline results. To investigate this further we carry out the same exercise as with the sub-sample analysis above, namely calculating differences of impulse responses for the two settings and gauging their statistical significance. The results are provided in Table A.[26]

Summing up, for most countries, we do not find a systematically different effect of domestic demand and supply shocks on inflation expectations in the aftermath of the crisis. This holds also true for advanced countries that used unconventional monetary policy to drive up inflation during that period and when using shadow rates instead of actual short-term interest rates for countries that hit the zero lower bound. When inflation picks up due to a shortage in oil supply, however, inflation expectations in a range of countries respond less in the aftermath of the crisis.

5.2 Which factors drive inflation expectations?

We assess the drivers of inflation expectations by looking at a forecast error variance decomposition. Since we are interested more generally in the drivers of inflation expectations, we use the Lanne-Nyberg corrected generalized forecast error variance decomposition as in section 4.[27] The posterior mean of the variance decompositions after 12 months are provided in Table 7.

[26] in the appendix and corroborate our first impression based on simple correlations for all countries but the USA in the case of an aggregate supply shock. Here, there is a modest indication that our baseline results overestimate effects on inflation expectations.

[27] An alternative would be to assess error variances based on the structural model. This would allow us to quantify the shares of variance explained by either demand or supply shocks. This, however, is computationally demanding for shocks which are identified via sign restrictions.

[INSERT TABLE 7 HERE]

The first column shows the variables that explain more than 50% of the total forecast error variance of inflation expectations of a particular country for the model estimated over the full sample period. For example, more of half of the total forecast error variance of inflation expectations in the USA can be accounted for by shocks to oil price inflation. More generally, oil price inflation turns out to be a major determinant of inflation expectations in advanced and euro area countries corroborating the results of Galesi and Lombardi (2013). By contrast in emerging economies, domestic inflation expectations account for the bulk of the forecast error variance. For some countries, additional foreign macro variables account for a significant share of forecast error variance. These mostly stem from Turkey and India, two large emerging markets. Shocks to actual inflation dynamics appear less frequently. The right column of Table 6 provides the forecast error variance decompositions for the post-crisis period. In general, oil inflation shocks appear less frequently as determinants of forecast error variance. Also, for most countries forecast error variance is accounted for by more factors compared to considering the full sample. In some countries other, domestic variables show up as important determinants (e.g., in Hungary or Spain), while in others further international factors account for forecast error variance (e.g., Russia in Croatia and Poland). There is surprisingly little change in the composition of forecast error variance explanatory factors regarding Latin American countries.

Overall, we conclude that domestic inflation expectations and oil price inflation are important determinants of inflation expectations. To a lesser extent this holds true for domestic actual inflation an indication that energy prices drive a wedge between observed and expected inflation. International variables from important emerging markets such as India and Turkey or Russia for some CESEE economies also explain a significant share of forecast error variance in inflation expectations.

5.3 Diagnostic checks

In Figure 11 we show several diagnostic checks based on the residuals of the country models. From the upper left panel we see that the residuals are generally not serially autocorrelated. In the upper right panel, we show that cross-sectional dependence of the country residuals is generally weak. The cumulative density function of the pairwise correlations across the country residuals show that 90% of the mass lies below a correlation of 0.3 and indicating weak cross-sectional dependence (Burriel and Galesi, 2018). Thus the two main assumptions that apply when using the GVAR framework are satisfied. In the bottom panel of Figure 11 we show the percentage of rotation matrices that fulfill the sign restrictions for the domestic aggregate supply and demand shocks outlined in the previous section. These show that for both the full sample and the post-crisis period, the median acceptance ratio of rotation matrices is above 80%. For some countries, however, this ratio is significantly lower. This mostly applies to Russia, Turkey and India. The small number of valid rotation matrices implies that the results for these economies should be interpreted cautiously which is also mirrored in wider confidence intervals. The number of successful rotation matrices for the oil supply shock is 1,072 (out of 2,620) for the full sample and 136 (out of 935) for the model estimated over the post-crisis period. Last, we investigate convergence of the MCMC sampler. For that purpose, we calculate Z-scores of Geweke's convergence diagnostic (Geweke, 1992) for all estimated coefficients of the system. This statistic indicates excellent convergence since only for 6% out of all coefficients the (absolute) values of the statistic exceed the 1.96 threshold.

6 Conclusions

In this paper we investigate the dynamics of global inflation and short-run inflation expectations. We first demonstrate the existence of substantial interlinkages in international inflation and inflation data. This implies that inflation expectations are not only driven by changes in domestic macroeconomic conditions but more generally by inflation expectations of other countries. The same holds true for actual inflation data.

We then proceed to investigate the drivers of inflation expectations controlling for global linkages in the data. For that purpose we use a global vector autoregressive (GVAR) model estimated using Bayesian shrinkage priors. Our model nests a broad range of specifications for inflation and inflation expectations including variables that measure global slack. We then identify three shocks that can lead to inflationary pressure, namely a domestic aggregate demand shock, a domestic aggregate supply shock and a global acceleration of oil price inflation. The shocks are identified using sing restrictions and the oil supply shock makes use of the cross-sectional dimension of the data (Cashin et al., 2014).

Our main findings are as follows: First, we find that inflation expectations respond positively to domestic shocks that drive up actual inflation. This applies in particular to aggregate demand shocks that drive up both actual inflation and output. But also for aggregate supply shocks which are characterized by an acceleration of inflation but a contraction in output, peak effects of inflation expectations tend to be positive. The most direct pass-through from actual inflation to inflation expectations, however, is observed when inflation increases due to a global acceleration of (supply-driven) oil price inflation. Here, both actual inflation and inflation expectations respond positively and in a similar fashion. This implies that for a policy maker interested in the anchoring of long-run inflation expectations, oil price shocks should be closely watched since the high pass-through to short-run inflation expectations can limit the room for long-run inflation expectation anchoring. This is not the case for domestic demand and supply shocks that only show short-lived effects on short-run inflation expectations.

Second, we examine whether the pass-through of inflation to short-run inflation expectations has changed during the aftermath of the global financial crisis – a period that was characterized by low inflation in advanced economies and the introduction of unconventional monetary policy by several major central banks to stimulate inflation. We find that the transmission between inflation and inflation expectations was largely unaffected in response to domestic demand and supply shocks. For the oil supply shock, our findings indicate a smaller impact on inflation expectations post-crisis. This implies a greater likelihood of a successful anchoring of long-run inflation expectations in the aftermath of the crisis compared to the full sample period. Lastly, we examine more generally the drivers of inflation expectations. Here we find that domestic inflation expectations, oil prices and variables from large emerging economies such as India and

Turkey are important drivers of inflation expectations. For some CESEE economies, also Russian macroeconomic conditions shape inflation expectations.

Some (e.g., Coibion et al., 2018) have drawn attention to differences between household and the professional forecasts used in the present study as critical to determining whether expectations are anchored. Clearly, this is a potential area where additional work is necessary. However, unlike household expectations, whose availability is episodic and where the manner in which surveys are structured and information about inflation expectations are solicited, our data set consists of comparable data and is on a global scale. Moreover, paralleling some of the results based on household surveys, professional forecasts are potentially just as sensitive to energy prices movements. Policy makers will have to bear this in mind when associating a tightening or loosening of monetary policy to changes in oil prices.

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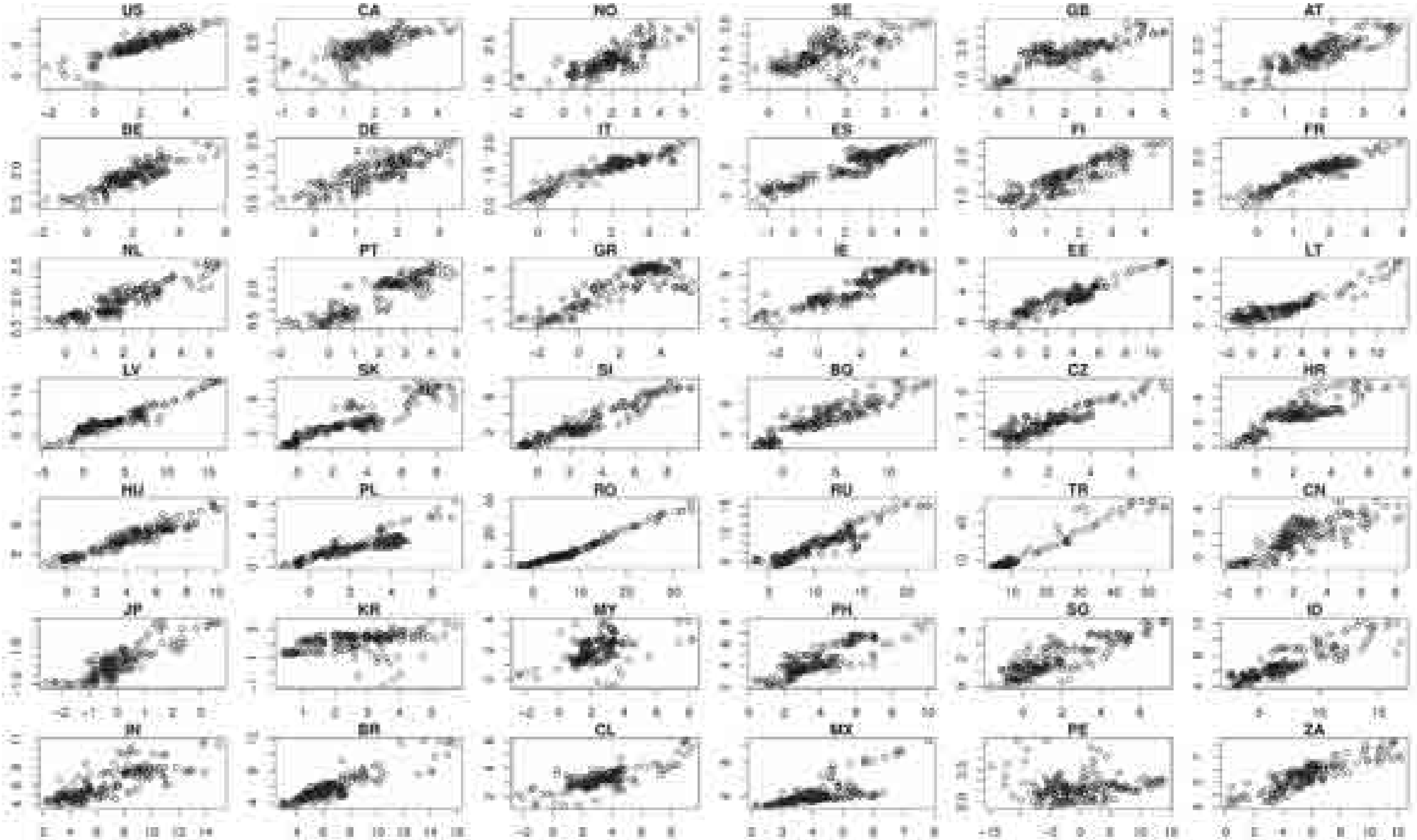
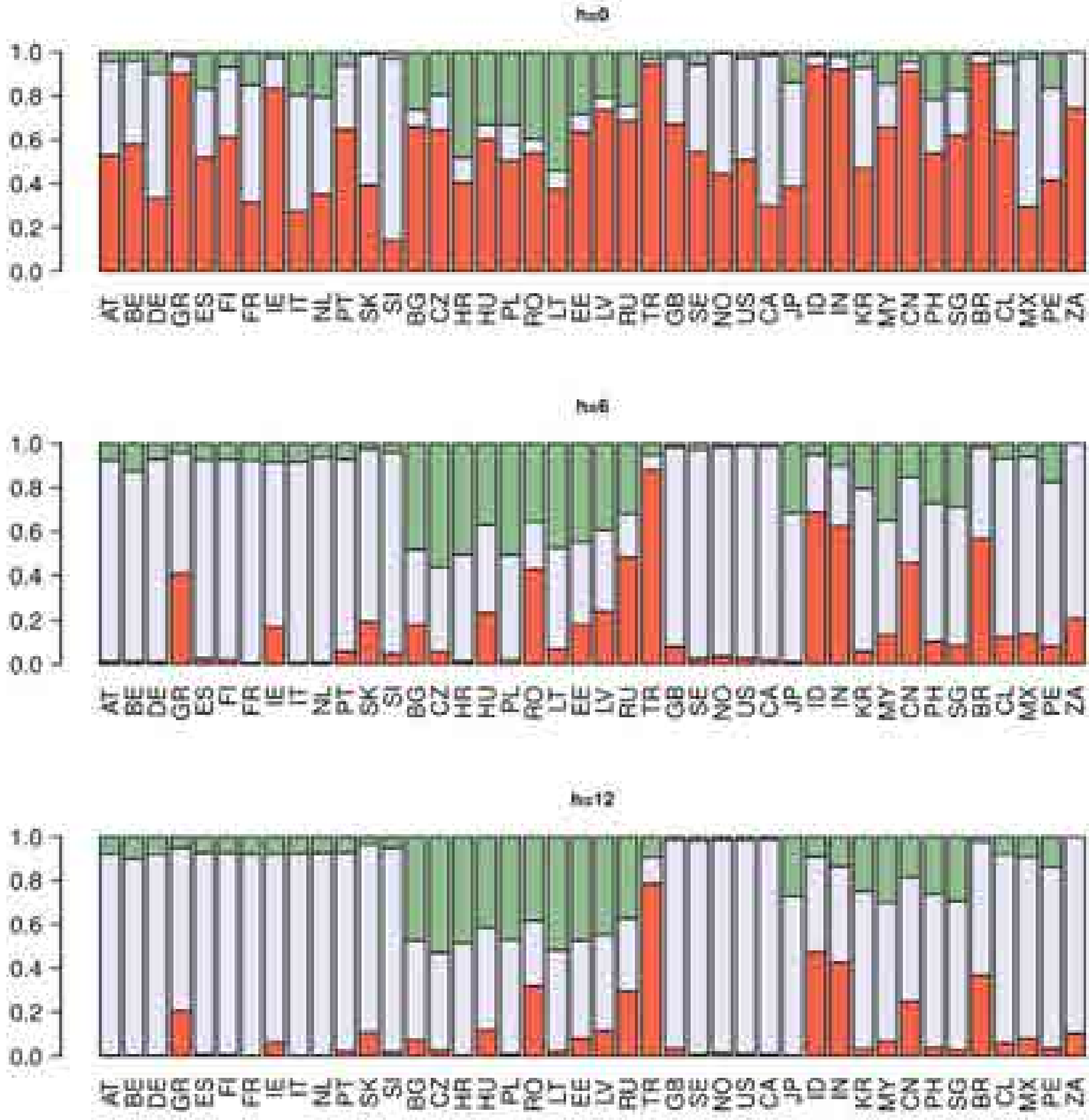
Figure 1 Observed versus expected inflation, monthly 2001-2016



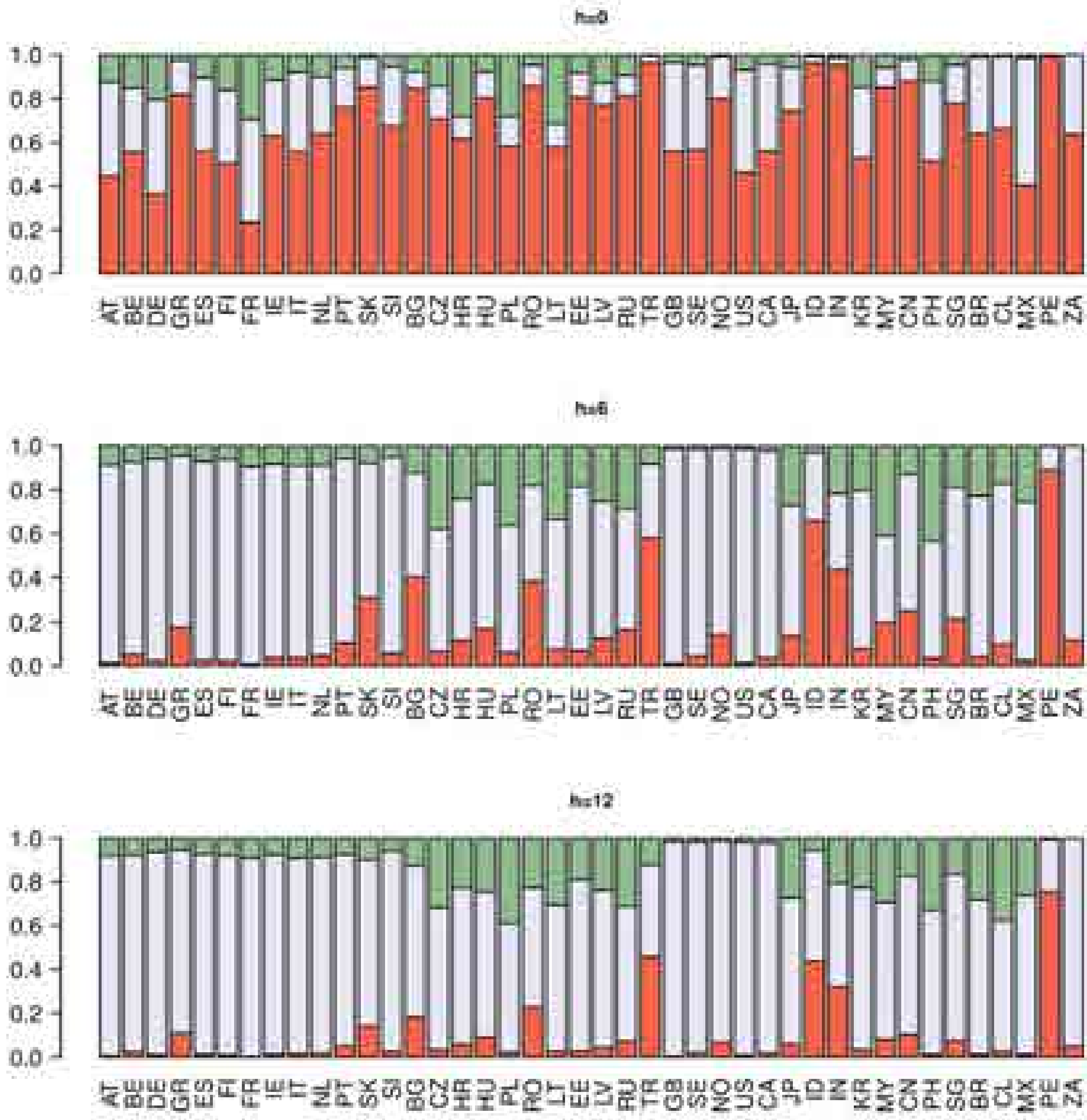
Note: The plot shows on the y-axis inflation expectations (Dp^e) and on the x-axis actual inflation (Dp), country codes are defined in Table 2.

Figure 3: Regional break down of spillover index: Inflation expectations



Notes: The bar plot shows the normalized general forecast error variance decomposition for the h=0, h=6 and h=12 forecast horizons. Own contributions are in red, regional contributions in green and international contributions in light gray.

Figure 4: Regional break down of spillover index: Actual inflation

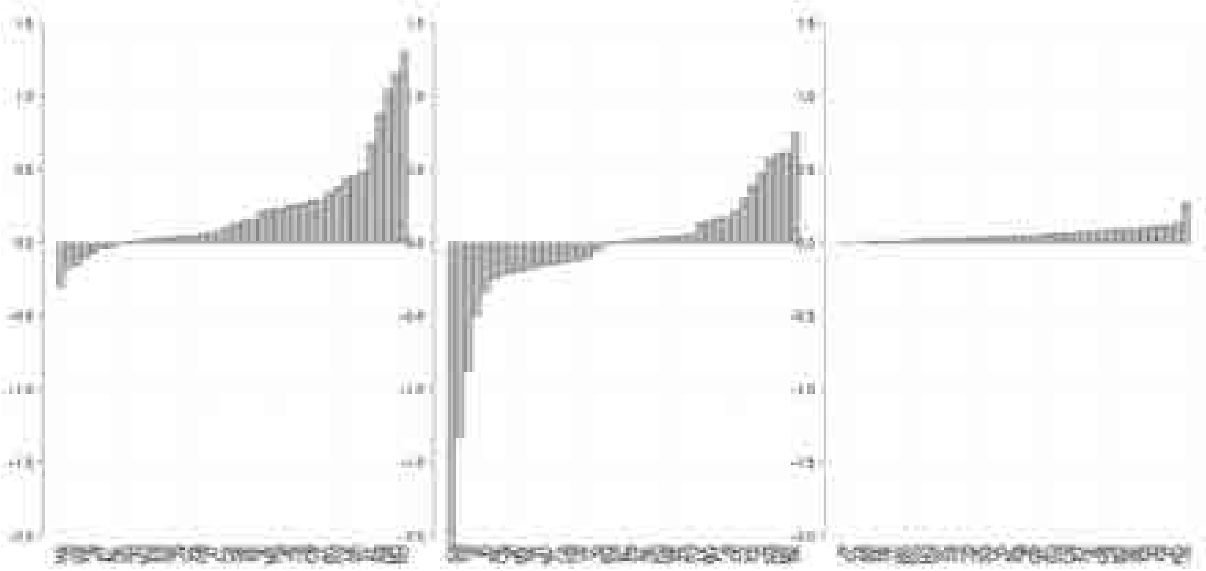


Notes: The bar plot shows the normalized general forecast error variance decomposition for the h=0, h=6 and h=12 forecast horizons. Own contributions are in red, regional contributions in green and international contributions in light gray.

Figure 5: Impact & peak effects of inflation expectations

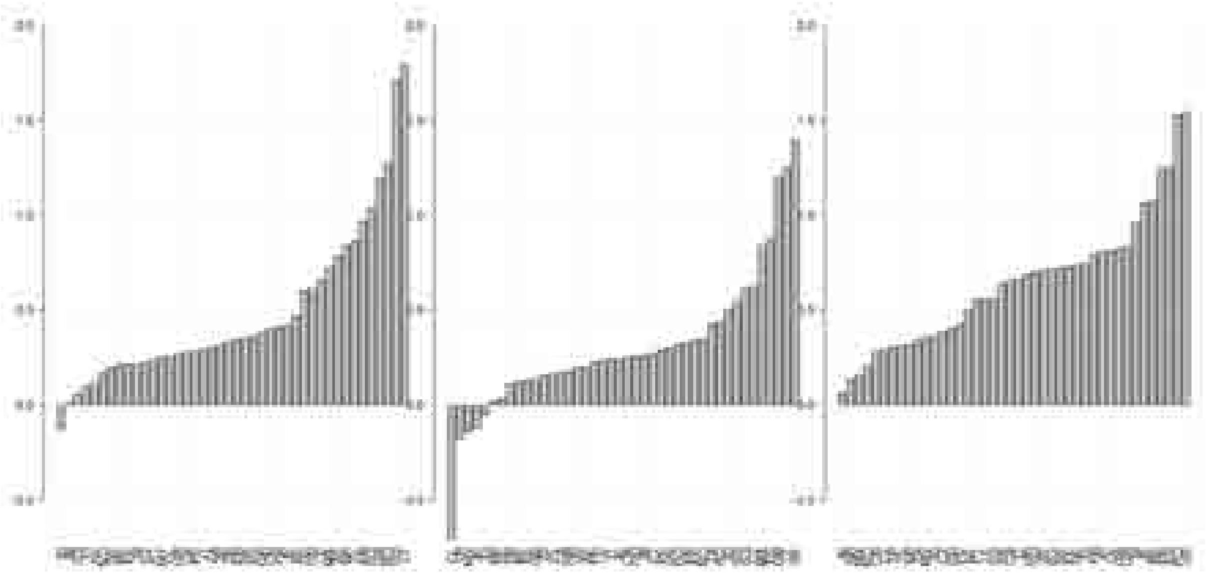
Impact effects

Aggregate demand **Aggregate supply** **Oil supply**



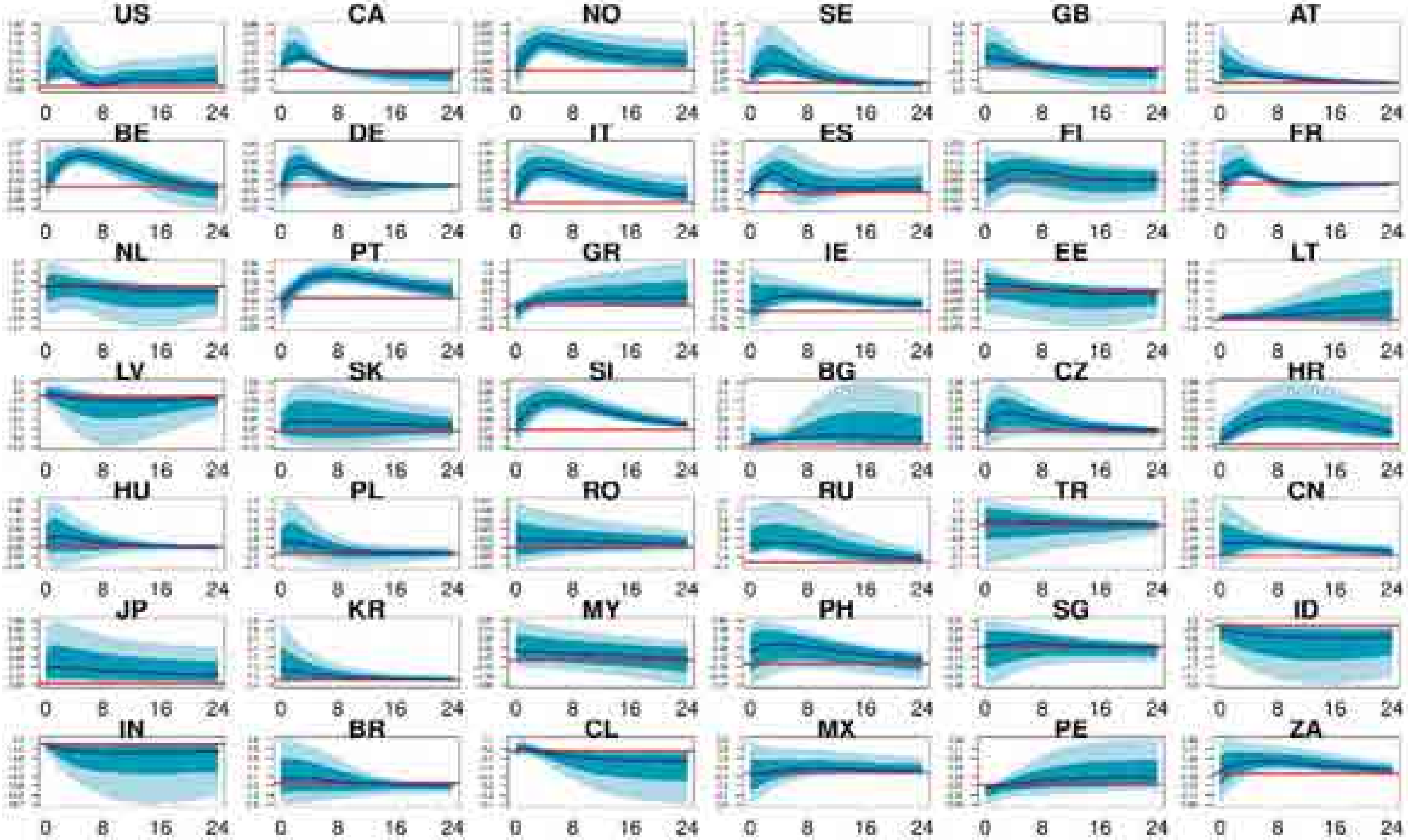
Peak effects

Aggregate demand **Aggregate supply** **Oil supply**



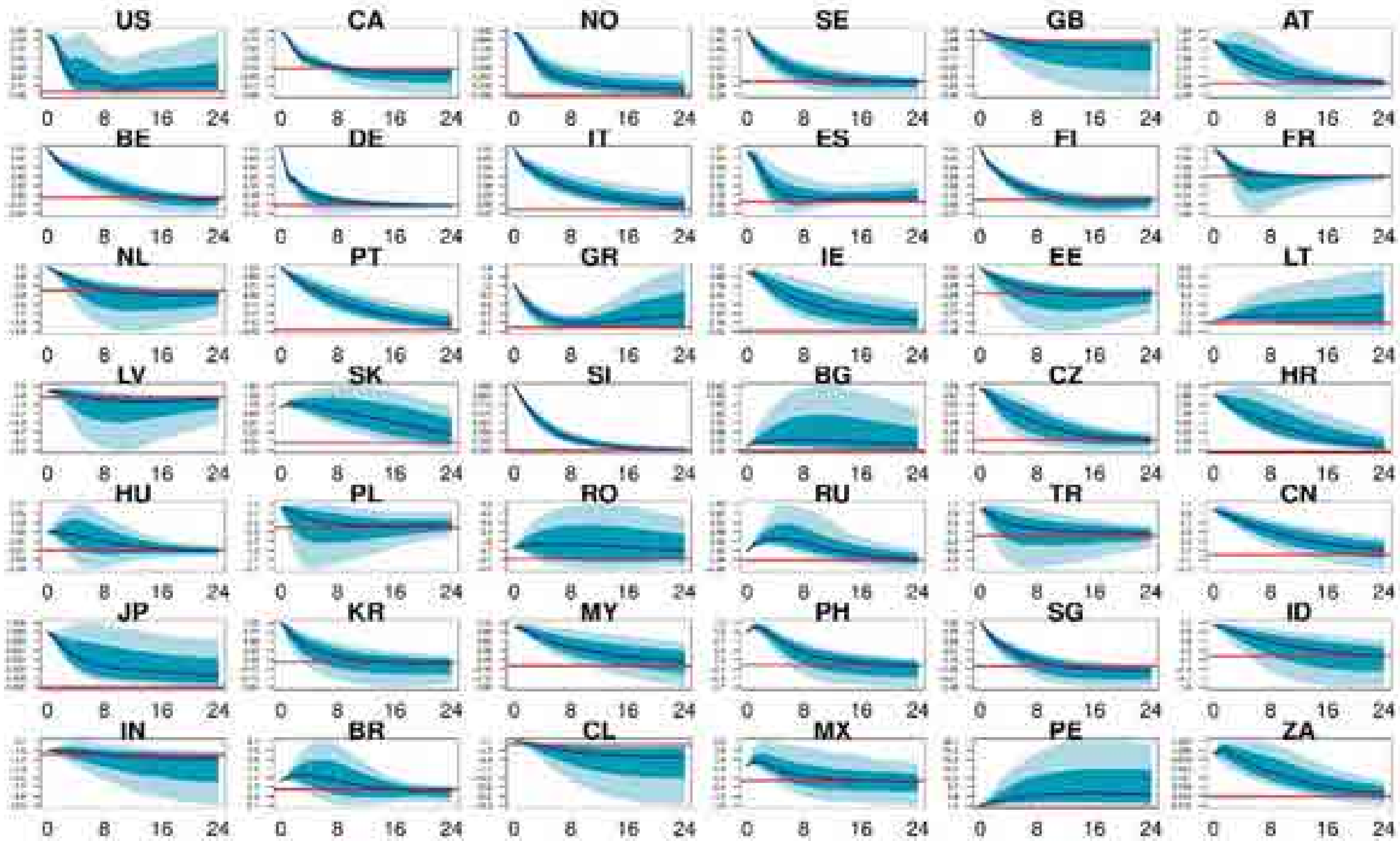
Notes: The left panel shows the impact effect on inflation expectations in response to an aggregate demand shock, the middle panel to an aggregate supply shock and the right panel to a global oil supply shock. In the aggregate supply shock panel, Brazil is left out since its response can be considered an outlier (about -6%).

Figure 5: Response of inflation expectations to an aggregate demand shock (+1 percentage point increase in inflation)



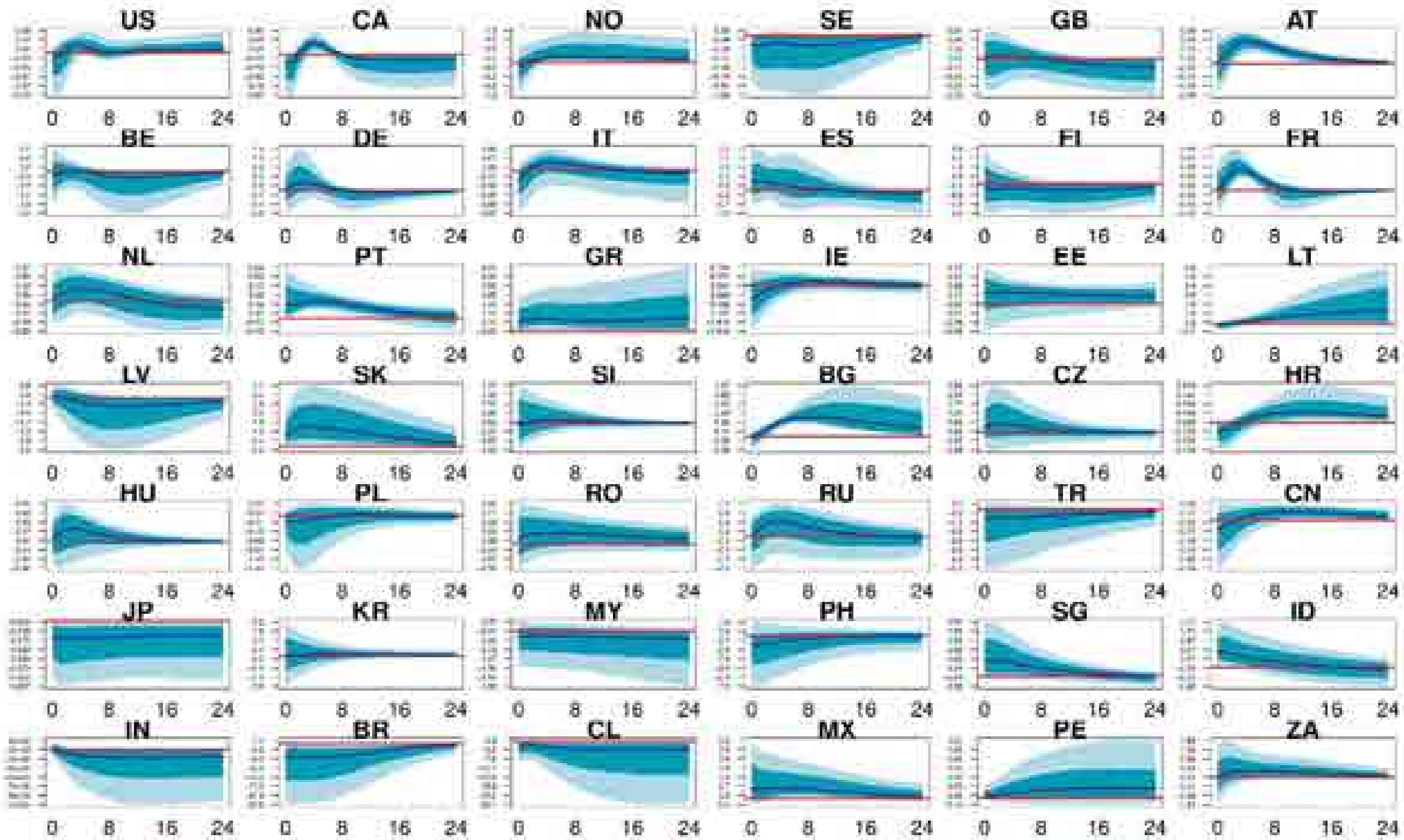
Notes: The upper panel shows the inflation expectation responses to an aggregate demand shock, the middle panel to an aggregate supply and the bottom panel to an oil supply shock. Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure 6: Response of actual inflation to an aggregate demand shock (+1 percentage point increase in inflation)



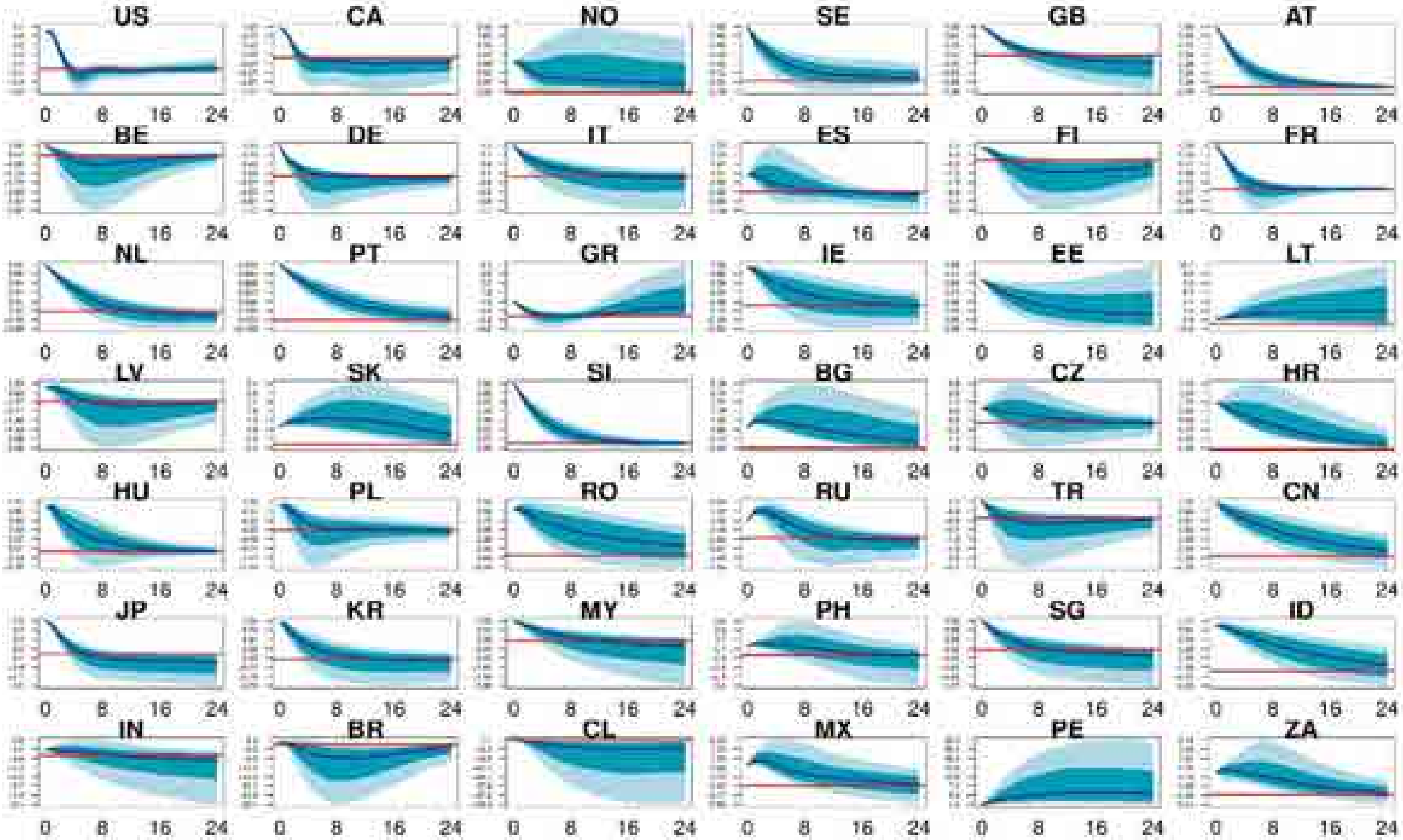
Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure 7: Response of inflation expectations to an aggregate supply shock (+1 percentage point increase in inflation)



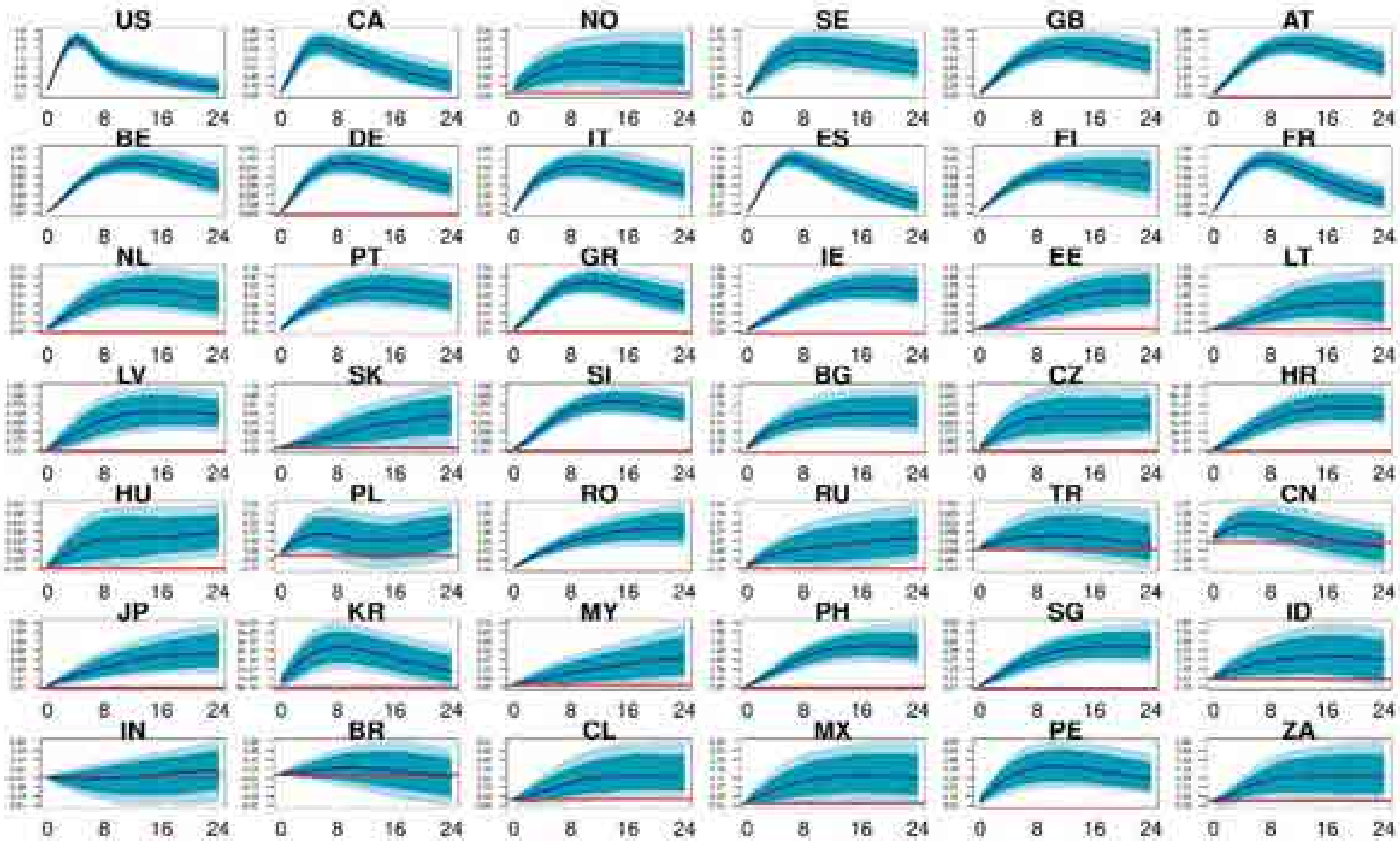
Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure 8: Response of actual inflation to an aggregate supply shock (+1 percentage point increase in inflation)



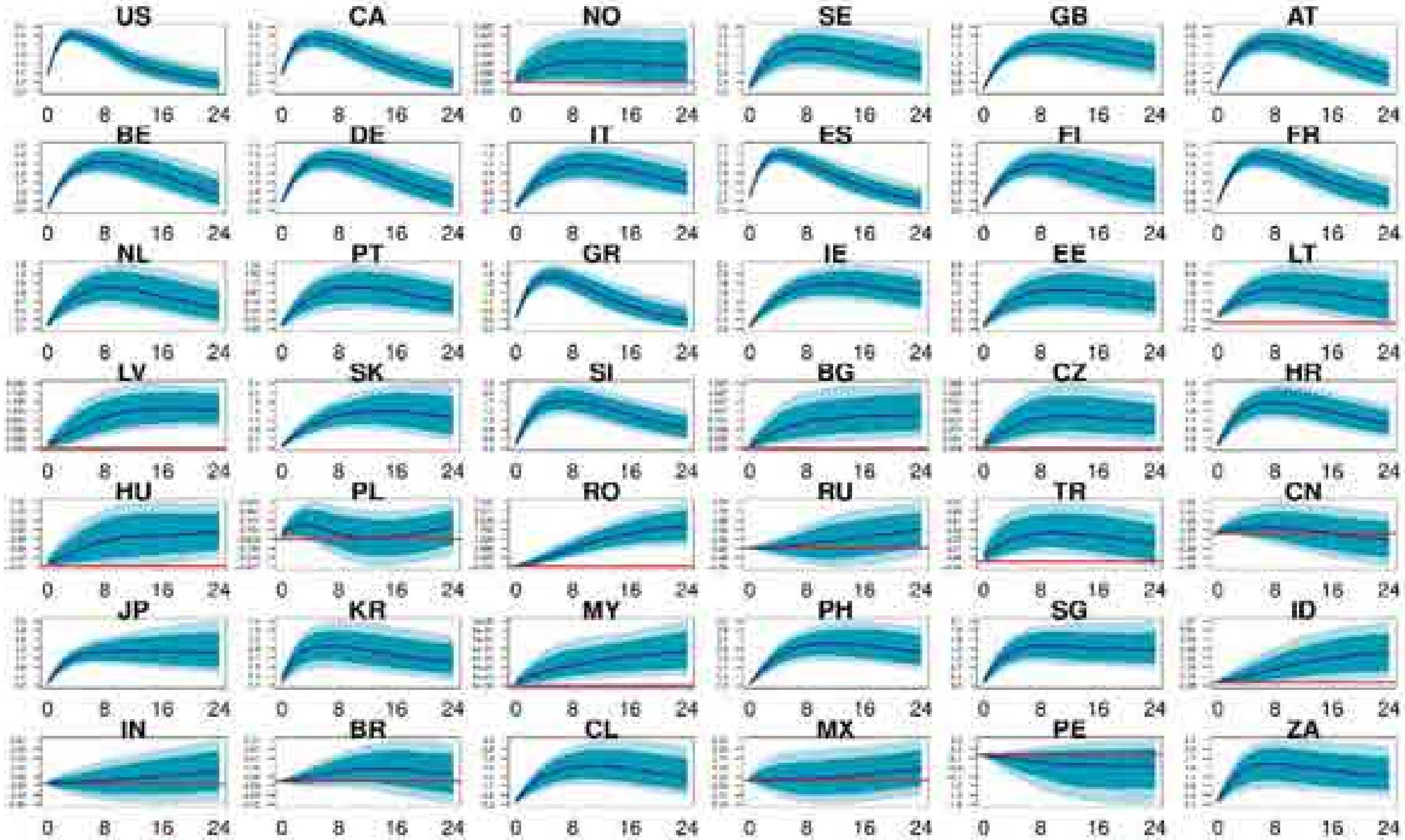
Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure 9: Response of inflation expectations to an oil supply shock (+1 percentage point increase in oil price inflation)



Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure 10: Response of actual inflation to an oil supply shock (+1 percentage point increase in oil price inflation)



Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Table 6: Sub-sample analysis of cumulative and peak effects

	Cumulative			Peak		
	AD	AS	Oil	AD	AS	Oil
US	0.07	0.19	-0.03	-0.17	0.21	**0.55**
CA	-0.07	**-0.08**	0.11	-0.02	0.06	**0.45**
NO	0.06	0.16	**0.31**	0.08	-0.47	**0.17**
SE	-0.08	-0.04	0.26	0.11	-0.18	0.41
GB	-0.46	-0.20	0.12	0.76	-0.15	0.22
AT	0.00	0.00	0.20	0.19	0.02	**0.40**
BE	-0.08	-0.11	**0.54**	-0.20	-0.05	**0.86**
DE	0.01	0.00	0.12	-0.11	-0.09	0.21
IT	-0.18	0.39	**0.39**	-0.17	0.16	**0.43**
ES	0.05	-0.20	0.25	0.06	0.22	**1.02**
FI	0.00	-0.01	0.41	-0.12	-0.41	**0.49**
FR	**-0.30**	-0.02	0.34	-0.32	-0.07	**0.45**
NL	-0.16	0.04	0.05	-0.26	0.00	0.17
PT	0.03	0.15	**0.36**	-0.09	-0.18	**0.40**
GR	0.06	0.31	**0.59**	0.04	-0.36	**0.66**
IE	0.14	-0.02	**0.94**	0.03	-0.24	**0.89**
EE	0.03	-0.06	**0.54**	-0.05	-0.17	0.44
LT	1.54	1.10	0.25	1.24	0.90	0.11
LV	-0.39	-0.34	0.42	0.29	-0.17	0.37
SK	-0.02	0.22	0.05	0.01	0.67	0.03
SI	-0.01	-0.02	**0.55**	0.00	-0.09	**0.64**
BG	0.39	0.13	**0.62**	0.52	0.07	**0.50**
CZ	-0.09	0.10	0.08	-0.18	0.49	-0.09
HR	0.04	0.02	0.36	-0.03	-0.09	0.32
HU	-0.40	-0.10	0.23	-0.16	-0.08	0.13
PL	0.13	0.07	**-0.71**	0.29	-0.01	**-0.68**
RO	0.33	-0.07	**0.97**	-0.74	0.00	0.79
RU	0.02	-0.17	0.44	0.87	0.10	0.38
TR	0.06	-0.20	0.19	-0.13	-0.43	0.03
CN	0.06	0.03	-0.25	-0.20	-0.24	-0.08
JP	0.07	0.05	0.29	0.07	-0.01	0.24
KR	-0.03	0.01	0.04	0.12	0.19	0.11
MY	-0.63	-0.40	-0.31	-0.51	-0.22	-0.30
PH	0.07	-0.04	**0.80**	0.14	-0.21	**0.73**
SG	-0.08	-0.10	0.05	-0.11	0.20	-0.07
ID	**-0.66**	-0.26	0.31	-0.46	0.12	0.22
IN	-1.45	-1.64	0.03	0.24	-0.30	-0.03
BR	0.28	0.34	-0.32	1.16	-0.47	-0.10
CL	-0.71	-1.96	**0.35**	0.12	-0.94	**0.32**
MX	0.09	0.11	0.08	-0.07	0.58	0.03
PE	**0.84**	**0.70**	0.22	0.31	**0.28**	**0.28**
ZA	0.10	0.07	0.32	0.24	-1.40	0.24

Notes: The table shows the differences of inflation expectations impulse responses estimated over the full sample period and the post-crisis sample period (2009m12 to 2016m12). The figures constitute median differences over 500 randomly permutated draws, figures in bold indicate statistically different values according to 68% credible intervals.

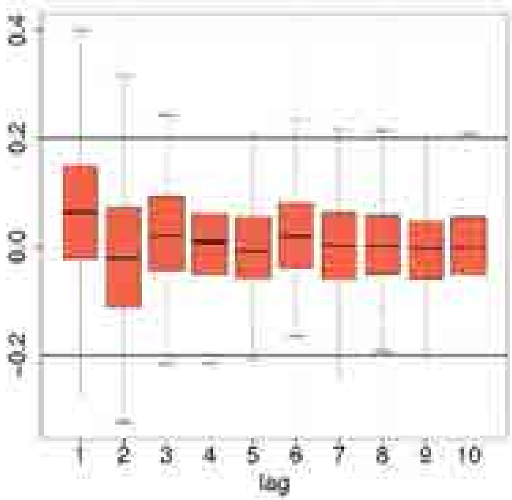
Table 7: Generalized forecast error variance decomposition

Country	*Full sample period*	*Post-crisis period*
US	Dpoil	Dpoil, US.Dpe
CA	TR.stir, Dpoil, CA.Dpe	CA.Dpe, CA.Dp, CA.gdp.m
NO	NO.Dpe, NO.Dp, NO.stir	NO.Dpe, NO.Dp, EA.stir
SE	SE.Dpe, Dpoil, EA.stir	SE.Dpe, SE.Dp
GB	GB.Dpe, Dpoil	GB.Dpe, TR.stir, Dpoil
AT	Dpoil, AT.Dpe	AT.Dpe, AT.Dp
BE	Dpoil	BE.Dp, BE.Dpe
DE	Dpoil, DE.Dpe, IN.sp	Dpoil, DE.Dpe, DE.Dp
IT	Dpoil, IT.Dp, IT.Dpe	IT.Dp, IT.Dpe
ES	Dpoil	ES.Dp, ES.Dpe, ES.sp
FI	Dpoil, FI.Dpe	FI.Dpe, FI.Dp
FR	Dpoil	FR.Dpe, Dpoil, FR.Dp
NL	NL.Dpe, Dpoil	NL.Dpe, NL.Dp
PT	PT.Dpe, PT.Dp	PT.Dp, PT.Dpe
GR	GR.Dpe	GR.Dpe
IE	IE.Dpe, Dpoil	IE.Dpe
SK	SK.Dpe	SK.Dp, SK.Dpe, RU.sp, RU.stir
SI	SI.Dpe, Dpoil	SI.Dp, SI.Dpe
EE	EE.Dpe, EE.Dp	EE.Dp, EE.Dpe
LT	LT.sp, LT.Dpe	LT.Dp, LT.Dpe, EA.stir
LV	LV.Dpe	LV.Dp, LV.stir, LV.sp
BG	BG.Dp, TR.stir, BG.Dpe, BG.sp	BG.Dp
CZ	CZ.Dpe, EA.stir	CZ.Dp, CZ.Dpe, Dpoil, CZ.ur
HR	HR.Dpe, IN.sp, IN.stir	HR.Dp, HR.Dpe, RU.sp, RU.stir
HU	HU.Dpe, IN.sp	HU.Dp, HU.Dpe, HU.stir
PL	PL.Dpe, IN.sp, IN.stir	PL.Dpe, RU.sp, RU.stir, PL.sp, PL.Dp, ID.Dp
RO	RO.Dpe	RO.Dp, RO.Dpe
RU	RU.Dpe	RU.Dpe
TR	TR.Dpe	TR.Dpe, TR.Dp
CN	CN.Dpe	CN.Dpe, CN.Dp
JP	JP.Dpe, TR.stir	JP.Dpe
KR	KR.Dpe	KR.Dpe
MY	MY.Dpe	MY.Dpe
PH	PH.Dpe	PH.Dp, PH.Dpe, Dpoil
SG	SG.Dpe	SG.Dpe, SG.Dp
ID	ID.Dpe	ID.Dp
IN	IN.Dpe	IN.Dpe
BR	BR.Dpe	BR.Dpe
CL	CL.Dpe	CL.Dpe
MX	MX.Dpe	MX.Dpe
PE	PE.Dpe	PE.Dpe, PE.stir
ZA	ZA.Dpe, TR.stir	ZA.Dpe

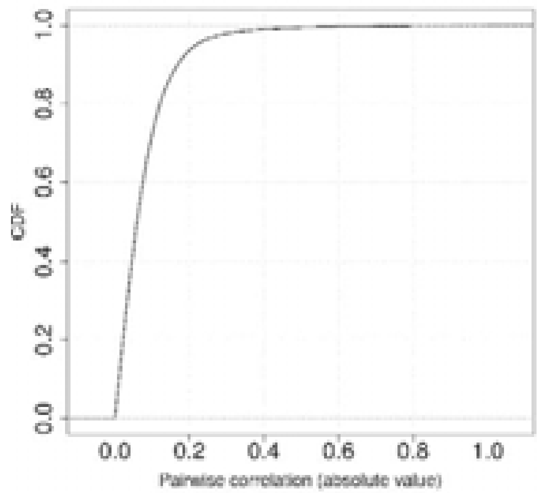
Notes: The table shows the variables that explain more than 50% of variance of inflation expectations in a given country at the *h*=12 months forecast horizon. Posterior mean based on the full set of MCMC draws of the Lanne and Nyberg (2016) corrected generalized forecast error variance decompositions shown.

Figure 11: Diagnostic checks

(a) Residual autocorrelation

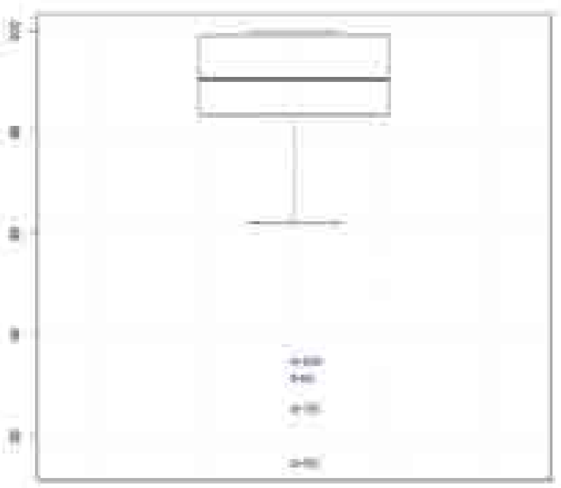


(b) Pairwise residual correlation

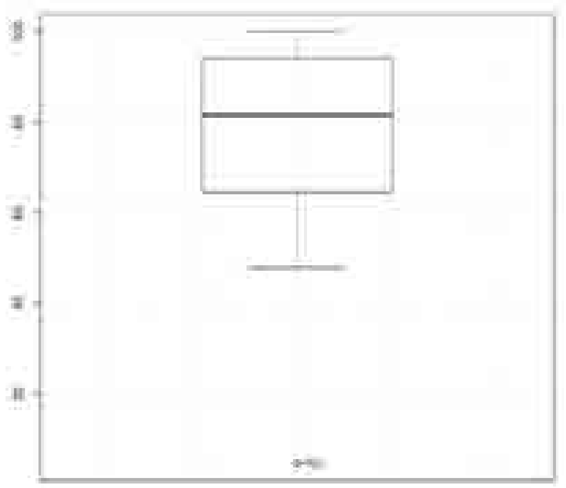


(b) Percentage of accepted rotation matrices (AS & AD shock)

Full sample



Post-crisis



Notes: The top left panel shows the autocorrelation function (ACF) of the cross-country residuals, the right hand side shows the empirical cumulative density function of average pairwise cross-country residual correlations (in absolute values). The bottom panel provides the percentage of accepted rotation matrices for the AS and AD shock for the GVAR estimated over the full period (out of 2,620 draws) and the post-crisis period (out of 935 draws). For the global oil supply shock we collected 1,072 (out of 2,620 draws) for the full sample period and 136 (out of 935 draws) for the post-crisis sample period.

APPENDIX

A.1 Inflation links – calculating the spillover index

The Diebold and Yilmaz (2009) spillover index is based on a forecast error variance decomposition calculated from an underlying vector autoregressive (VAR) model that describes the law of motion of an m- dimensional vector y_t for $t = 1, \cdots, T$,

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t \quad \text{(A.1)}$$

with $A_j (j = 1, \cdots, p)$ denoting a set of m x m coefficient matrices. The errors ε_t are normally distributed with zero mean and variance covariance matrix $\sum$. The VAR can be recast into its infinite moving average representation

$$y_t = \sum_{j=0}^{\infty} C_j \, \varepsilon_{t-j}. \quad \text{(A.2)}$$

Diebold and Yilmaz (2009) use a Cholesky decomposition of $\sum$ to orthogonalize the residuals ε_t in which case the shares of the FEVD sum up to unity. As is well known, this renders the analysis dependent on the ordering of the variables in y_t. Diebold and Yilmaz (2014) overcome this problem by relying on a generalized forecast error variance decomposition (GEFVD) which is based on the generalized impulse response functions (GIRF) of Pesaran and Shin (1998).

For a linear model and assuming a shock to the *j*th element of ε_t denoted as δ_j, the GIRF is defined as follows:

$$GIRF(h, \delta_j) = C_h \Sigma v_j \sigma_{jj}^{-1} \delta_j, \quad \text{(A.4)}$$

with v_j denoting a selection vector with unity as its *j*th element and zeros elsewhere. Considering a positive one standard deviation shock (i.e., setting $\delta_j = \sqrt{\sigma_{jj}}$) leads to the generalized forecast error variance decomposition of Pesaran and Shin (1998):

$$\theta_{ij}(h) = \frac{\sigma_{ii}^{-1} \sum_{l=0}^{h} \left(v_i' C_l \Sigma v_j \right)^2}{\sigma_i^2(h)}, i, j = 1, \ldots, K. \quad \text{(A.5)}$$

Since the shocks are correlated, the GEFVD does not sum up to unity. In a recent contribution Lanne and Nyberg (2016) propose an alternative decomposition based on the partial contribution of variable *j* to the total GIRF of variable *i*:

$$\theta_{ij}(h) = \frac{\sum_{h=0}^{H} GIRF(h,\delta_{jt})^2{}_i}{\sum_{j=1}^{K}\sum_{h=0}^{H} GIRF(h,\delta_{jt})^2{}_i}, i,j = 1,\dots,K. \qquad \text{(A.6)}$$

The Lanne and Nyberg corrected GFEVD sums to unity and has been recently applied in the context of Diebold Yilmaz connectivity in Chan-Lau (2017).

Since we have an international data set and to capture all cross-country linkages the VAR model is going to be highly parametrized. Hence we use shrinkage priors that are particularly useful in estimating large-dimensional VARs. More specifically we rely on the approach proposed in Huber and Feldkircher (2018) imposing a conditionally Gaussian prior for each autoregressive coefficient in the VAR with idiosyncratic and global scaling factors – the latter which are governed by a set of Gamma priors. We collect all coefficient matrices $\mathrm{A_j}(\mathrm{j} = 1, \cdots, \mathrm{p})$ in a matrix B and define $\beta = \mathrm{vec(B)}$ with β_i being the ith element of an K-dimensional vector β ($K = pM^2$). The Normal-Gamma prior set-up is then given by:

$$\beta_i|\tau_i, \lambda^2 \sim N\left(b_o, \frac{2\tau_i}{\lambda^2}\right), \qquad \text{(A.7)}$$

$$\tau_i \sim G(\vartheta_\tau, \vartheta_\tau) \ for \ i = 1, \dots, k_a, \qquad \text{(A.8)}$$

$$\lambda^2 \sim G(\kappa_0, \kappa_1,). \qquad \text{(A.9)}$$

This Normal-Gamma prior provides two sources of shrinkage, a global scaling factor (λ^2) that pushes all elements in β toward the prior mean and a local (coefficient-specific) shrinkage factor (τ_i) that ensures that non-zero signals are not too strongly pulled towards the prior mean. This is achieved by noting that the marginal prior on β, obtained after integrating out the local factors, is heavy tailed. The prior mean b_o is set to one for all elements corresponding to the diagonal of A_1 and zero otherwise.

The posterior distributions of the two shrinkage parameters for β are given by

$$\tau_i|\bullet \sim GIG\left(\vartheta_\tau - \tfrac{1}{2}, (\beta_i - b_0)^2, \lambda^2\vartheta_\tau\right), \tag{A.8}$$

$$\lambda^2|\bullet \sim G\left(\kappa_0 + \vartheta_\tau K, \kappa_1 + \tfrac{\vartheta_\tau}{2}\textstyle\sum_{i=1}^{K}\tau_i\right), \tag{A.9}$$

with *GIG* denoting a generalized inverse Gaussian distribution and *G* a Gamma distribution. We use the same prior distribution for the off-diagonal elements of the variance covariance matrix Σ. Based on a prior sensitivity analysis we set $\vartheta_\tau = 0.3\ (0.6)$ and $\kappa_o = \kappa_1 = 0.01$ (0.01) with the value referring to the prior for the off-diagonal elements of Σ in parentheses. Hence this prior choice implies less shrinkage on the off-diagonal elements of the variance covariance matrix compared to the coefficient matrices.

A.2 Bayesian estimation of the GVAR model

We start with the country models given in equation (1) where we omit the constant term for the sake of brevity. To arrive at the global model one has to re-write the country-specific models in terms of the global vector that stacks the data from all countries, $\boldsymbol{y_t}$. This can be done by invoking a selection matrix $\boldsymbol{S_i}$ that singles out the observations belonging to the *i*th country model. The steps to re-write the country models into the form of a global model are then as follows:

$$\boldsymbol{y_{i,t}} = \sum_{j=1}^{p} \boldsymbol{A_{ij} y_{i,t-j}} + \sum_{j=0}^{q} \boldsymbol{B_{ij} y^*_{i,t-j}} + \boldsymbol{\varepsilon_{i,t}} \tag{A.10}$$

$$\boldsymbol{S_i y_{i,t}} = \sum_{j=1}^{p} \boldsymbol{A_{ij} S_i y_{t-j}} + \sum_{j=0}^{q} \boldsymbol{B_{ij} W_i y_{t-j}} + \boldsymbol{\varepsilon_{i,t}} \tag{A.11}$$

$$(\boldsymbol{S_i} - \boldsymbol{B_{i0} W_i})\boldsymbol{y_t} = \sum_{j=1}^{max(p,q)} \left(\boldsymbol{A_{ij} S_i} + \boldsymbol{B_{ij} W_i}\right) \boldsymbol{y_{t-j}} + \boldsymbol{\varepsilon_{i,t}} \tag{A.12}$$

$$\boldsymbol{G_i y_t} = \textstyle\sum_{j=1}^{max(p,q)} \boldsymbol{H_{ij} y_{t-j}} + \boldsymbol{\varepsilon_{i,t}} \tag{A.13}$$

$$\boldsymbol{G y_t} = \textstyle\sum_{j=1}^{max(p,q)} \boldsymbol{\widetilde{F}_j y_{t-j}} + \boldsymbol{\varepsilon_t} \tag{A.14}$$

$$\boldsymbol{y_t} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{max(p,q)}} \boldsymbol{F_j y_{t-j}} + \boldsymbol{e_t} \tag{A.15}$$

In the second line we invoke a $(k_i + k_i^*) \times \left(\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}} k_i\right)$ dimensional weight matrix $\boldsymbol{W_i}$ that contains the weights to calculate $\boldsymbol{y_t^*}$, which allows us to write the foreign variables in terms of the global vector. This reflects the fact that the weakly exogenous variables are endogenous within the global system and constitutes the core mechanism of the GVAR approach. Note that in accordance with Eickmeier and Ng (2015) and Feldkircher and Huber (2016) we assume a block diagonal variance covariance structure of $\boldsymbol{\varepsilon_t}$ with $\Sigma_{i,t}$ on the diagonal. In principle, this would rule out immediate cross-country spillovers. However, since we pre-multiply in equation (A.15) with $\boldsymbol{G^{-1}}$ from the left, the model also takes contemporaneous spillovers into account.

We use the Normal-Gamma set-up as described in section (A.1) to estimate the country models. Again, it proves convenient to collect all coefficients in a generic matrix $\mathbf{Z}_{\boldsymbol{i}}$ with a typical element $\zeta_{ij}(j = 1, \cdots, K_i)$ where K_i denotes the total number of coefficients in country model **i**. We impose a normally distributed prior on the elements of $\mathbf{Z}_{\boldsymbol{i}}$:

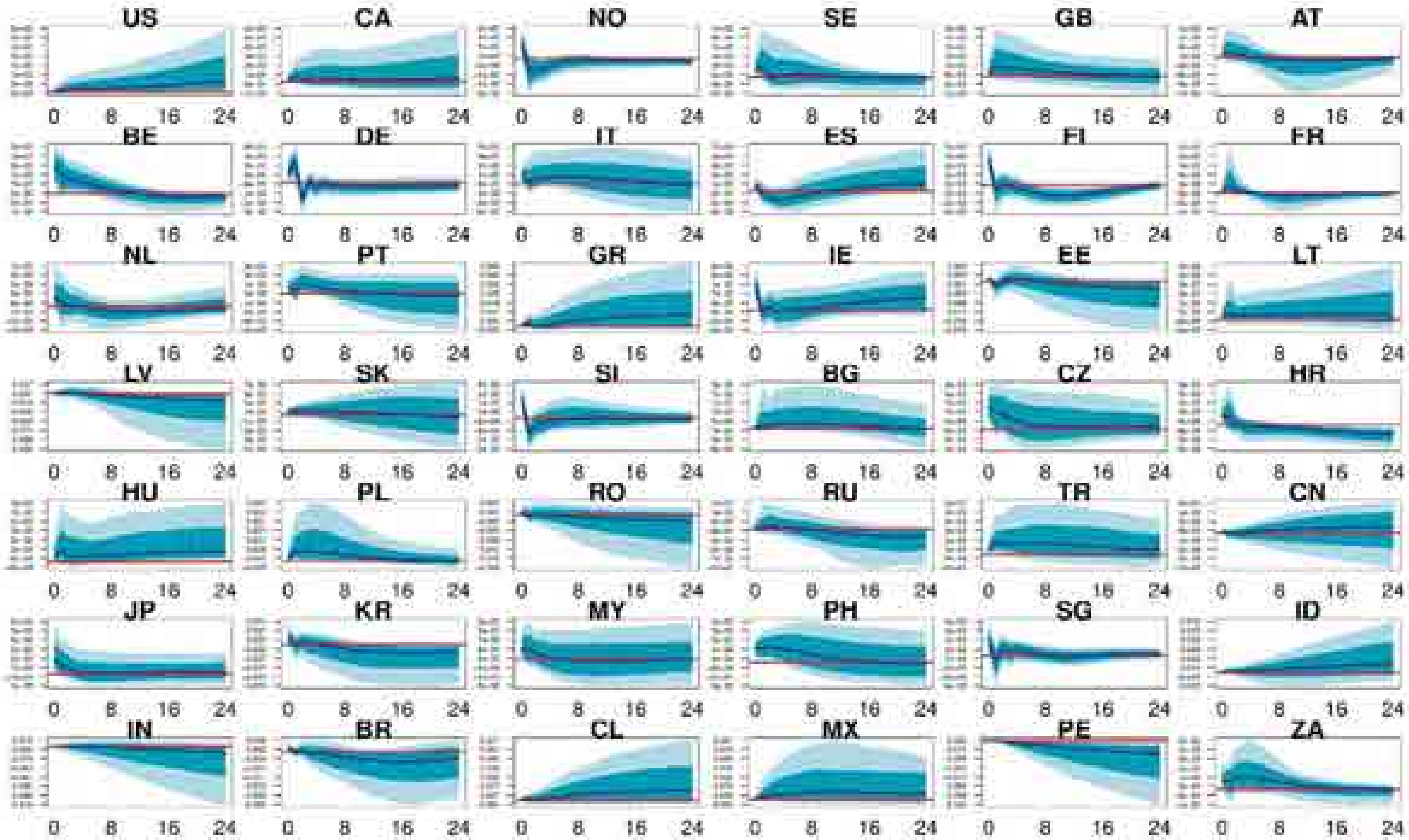
$$\zeta_{ij}|\tau_{ij}^2, \lambda_{\zeta i}^2 \sim N\left(0, \frac{2\tau_{ij}^2}{\lambda_{\zeta i}^2}\right)$$

$$\tau_{ij}^2 \sim G(\vartheta_{\tau i}, \vartheta_{\tau i})$$

$$\lambda_{\zeta i}^2 \sim G(\kappa_{\zeta 0}, \kappa_{\zeta 1})$$

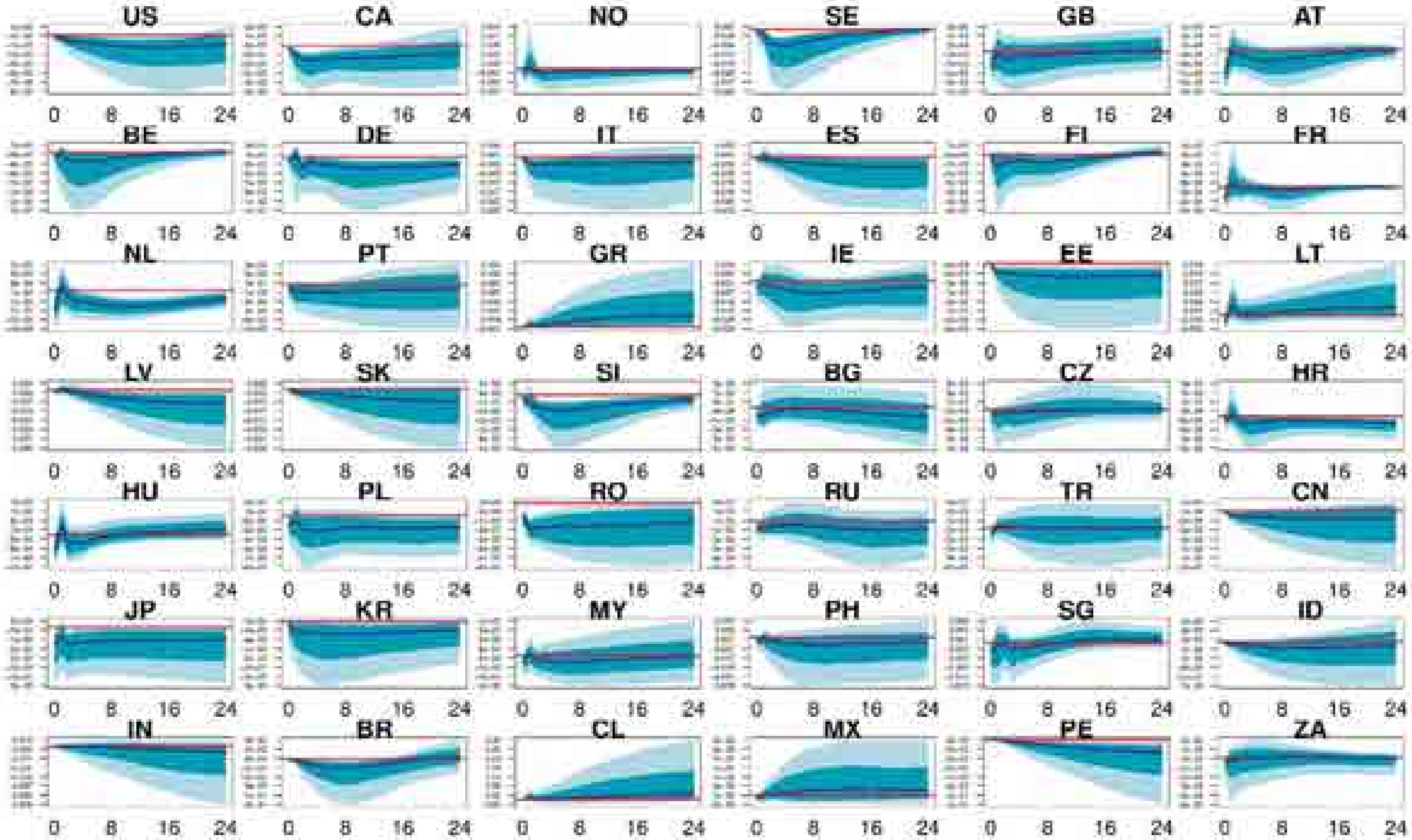
Here, τ_{ij}^2 are local (i.e., coefficient specific) and $\lambda_{\zeta i}^2$ country-specific shrinkage parameters. The latter apply shrinkage on the full matrix $\mathbf{Z}_{\boldsymbol{i}}$. We assume the same prior set-up for the off-diagonals of the variance covariance matrix. The hyperparameters are set as $\vartheta_{\tau i} = 0.6$ (0.6), $\kappa_{\zeta 0} = 3\ (0.01)$, $\kappa_{\zeta 1} = 0.003\ (0.01)$, with the values for the prior on the covariances in parentheses. Note also that we set the prior mean for the first own lag to zero to further enhance stability of the GVAR system.

Figure A.1: Response of output to a positive aggregate demand shock



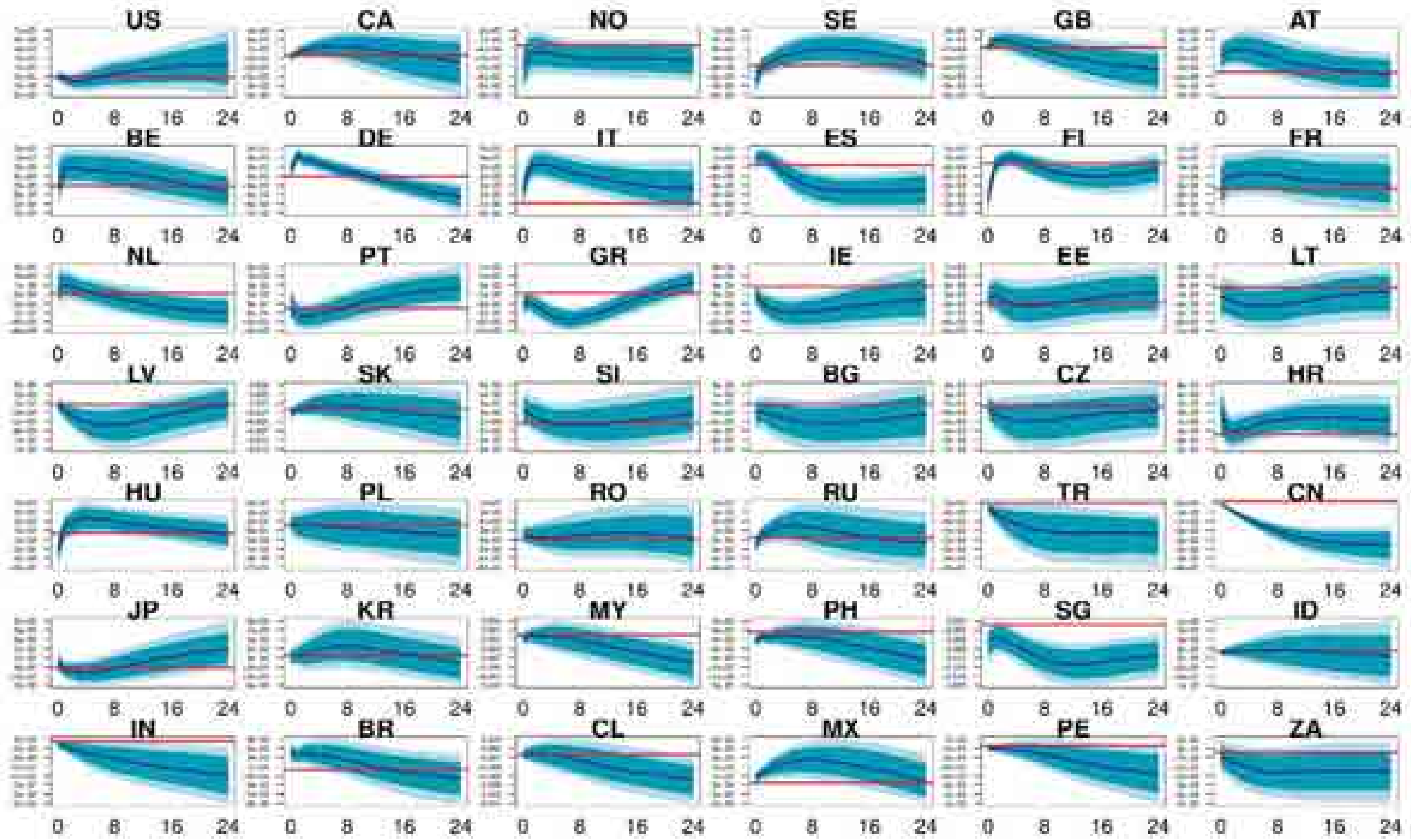
Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure A.2: Response of output to a positive aggregate supply shock



Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Figure A.3: Response of output to a positive oil supply shock



Notes: Posterior median (solid line) along with 50% (light blue) and 68% (dark blue) credible intervals.

Table A.1: Differences of cumulative and peak effects when using shadow rates

	Cumulative			Peak		
	AD	AS	Oil	AD	AS	Oil
US	0.17	**0.33**	0.02	0.18	0.19	0.03
CA	0.03	0.03	-0.07	-0.01	0.03	-0.04
NO	-0.01	-0.02	-0.03	-0.01	-0.02	-0.07
SE	0.04	-0.04	0.01	-0.01	-0.04	-0.17
GB	0.23	0.01	-0.09	0.27	0.06	-0.13
AT	-0.01	0.00	-0.02	0.06	0.01	0.00
BE	-0.01	0.03	-0.04	0.00	0.03	-0.02
DE	0.00	0.00	0.02	0.01	0.09	0.01
IT	-0.01	0.02	-0.02	0.00	0.07	-0.03
ES	0.03	0.14	0.12	0.04	0.04	0.00
FI	0.01	-0.03	-0.02	0.00	0.05	-0.03
FR	0.00	0.01	-0.03	0.02	0.01	-0.03
NL	-0.04	-0.01	-0.06	0.01	0.00	-0.04
PT	0.01	-0.02	-0.02	-0.01	0.00	-0.03
GR	-2.36	-2.12	0.01	-2.37	-2.32	0.01
IE	0.02	0.08	0.02	0.02	0.14	0.01
EE	-0.15	-0.06	-0.05	-0.19	-0.01	-0.11
LT	-1.14	-0.81	0.01	-0.60	-0.59	-0.04
LV	0.02	0.11	-0.16	0.08	-0.01	-0.16
SK	-0.06	-0.26	-0.04	-0.09	-0.63	-0.03
SI	-0.01	0.01	-0.07	-0.01	0.00	-0.05
BG	0.00	-0.06	-0.15	0.06	-0.06	-0.19
CZ	-0.04	-0.11	0.03	-0.01	0.01	-0.04
HR	-0.02	-0.02	-0.12	-0.01	-0.03	-0.11
HU	-0.07	-0.01	-0.10	-0.01	0.00	-0.17
PL	-0.02	0.01	-0.11	-0.06	-0.01	-0.13
RO	-0.36	-0.09	0.05	-0.39	-0.04	0.06
RU	0.00	0.03	-0.22	-0.14	0.04	-0.20
TR	0.00	-0.03	0.06	0.00	-0.05	0.04
CN	0.01	0.04	-0.04	0.00	0.05	-0.04
JP	0.00	0.08	0.12	-0.03	0.01	0.11
KR	0.02	0.02	-0.06	0.10	0.07	-0.02
MY	-0.02	0.21	-0.02	-0.01	0.19	-0.02
PH	-0.04	0.15	-0.08	-0.03	0.30	-0.02
SG	0.01	0.00	-0.10	0.03	0.03	-0.10
ID	-0.04	0.03	0.13	-0.04	-0.05	0.10
IN	-0.25	0.28	-0.03	-0.12	0.05	-0.01
BR	0.05	0.36	0.02	0.14	0.35	0.01
CL	0.16	0.64	-0.06	0.05	0.16	-0.06
MX	-0.03	-0.03	-0.01	0.00	0.02	-0.01
PE	-0.16	-0.07	0.00	-0.14	-0.03	0.02
ZA	-0.03	-0.03	-0.06	-0.01	-0.01	-0.04

Notes: The table shows the differences of inflation expectations impulse responses of the baseline model and a model where we have substituted shadow rates for short-term interest rates in the country models for the ECB, Japan, UK and the USA. The figures constitute median differences over 500 randomly permutated draws, figures in bold indicate statistically different values according to 68% credible intervals.