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Missing disinflation and missing inflation: the puzzles that aren't

Task force on low inflation (LIFT)

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This paper presents research conducted within the Task Force on Low Inflation (LIFT). The task force is composed of economists from the European System of Central Banks (ESCB) - i.e. the 29 national central banks of the European Union (EU) and the European Central Bank. The objective of the expert team is to study issues raised by persistently low inflation from both empirical and theoretical modelling perspectives.

The research is carried out in three workstreams:

1) Drivers of Low Inflation;

2) Inflation Expectations;

3) Macroeconomic Effects of Low Inflation.

LIFT is chaired by Matteo Ciccarelli and Chiara Osbat (ECB). Workstream 1 is headed by Elena Bobeica and Marek Jarocinski (ECB) ; workstream 2 by Catherine Jardet (Banque de France) and Arnoud Stevens (National Bank of Belgium); workstream 3 by Caterina Mendicino (ECB), Sergio Santoro (Banca d'Italia) and Alessandro Notarpietro (Banca d'Italia).

The selection and refereeing process for this paper was carried out by the Chairs of the Task Force. Papers were selected based on their quality and on the relevance of the research subject to the aim of the Task Force. The authors of the selected papers were invited to revise their paper to take into consideration feedback received during the preparatory work and the referee's and Editors' comments.

The paper is released to make the research of LIFT generally available, in preliminary form, to encourage comments and suggestions prior to final publication. The views expressed in the paper are the ones of the author(s) and do not necessarily reflect those of the ECB, the ESCB, or any of the ESCB National Central Banks.

Abstract

In the immediate wake of the Great Recession we didn't see the disinflation that most models predicted and, subsequently, we didn't see the inflation they predicted. We show that these puzzles disappear in a Vector Autoregressive model that properly accounts for domestic and global factors. Such a model reveals, among others, that domestic factors explain much of the inflation dynamics in the 2012-2014 euro area missing inflation episode. Consequently, economists and models that excessively focused on the global nature of inflation were liable to miss the contribution of deflationary domestic shocks during this episode.

JEL Classification: E31, E32, F44

Keywords: Inflation Dynamics, International Transmission of Shocks, Phillips curve, Bayesian Vector Autoregression, Conditional Forecast, Shock Identification

Non-technical summary

This paper answers two questions related to inflation developments since the start of the Great Recession. First, was inflation unusual during this time, given domestic and global developments? Second, what was the relative importance of global and domestic shocks? The period is particularly interesting as inflation in advanced economies has systematically surprised economists, raising questions about the reliability of existing models used for understanding inflation. In the US, in the aftermath of the financial crisis, inflation was expected to fall by more than it did, judging by the predictions of standard models such as reduced-form Phillips curves (see e.g. Ball and Mazumder, 2011). This so-called 'missing disinflation' puzzle also characterizes other advanced economies where inflation proved to be rather resilient given the weakness in economic activity (see Friedrich, 2016). Since 2012, particularly in the euro area, inflation has surprised in the opposite direction, falling to very low levels and giving birth to what we call the 'missing inflation' puzzle (see Constâncio, 2015). We analyze these two episodes, missing disinflation and missing inflation, and compare the case of the US with that of the euro area.

We employ a suite of Bayesian Vector Autoregressive (VAR) models flexible enough to properly account for domestic and global factors, and capture their changing relative importance over time. We illustrate the roles of global and domestic factors in two complementary ways. First, in a medium-scale VAR, we compare forecasts conditional on either domestic or external variables with actual inflation outcomes. Second, in smaller structural VARs, we identify global and domestic shocks.

Looking first at the conditional forecasts of inflation in a medium-scale VAR, we find that this flexible and data-rich model is able to account for inflation dynamics both in the US and in the euro area. Based on this model, one can conclude that no missing disinflation puzzle exists. In fact, the observed fall in inflation in the first phase of the Great Recession appears to be large, not small, judging by the link between inflation and real activity prevailing over the past two decades. Global variables have a high explanatory power for the inflation swings recorded in this period. In the same econometric set-up, zooming in on the post-2012 period for the euro area, we find again that the VAR is able to match inflation developments and we do not find a missing inflation puzzle in the data. This time, the forecast based on domestic real variables matches the inflation path quite well, whereas global variables have a lower explanatory power.

These results are consistent with the conclusions obtained in the second step, using smaller-scale structural VAR models, which disentangle the various shocks behind inflation dynamics since the Great Recession. In order to ensure robustness of results we employ three different identification schemes that use either restrictions on the timing of effects, or on the co-movement between global and domestic variables. Historical decompositions of the inflation rate show that the relative importance of global and domestic shocks was changing over time, especially in the euro area. Global shocks played an important role in explaining inflation dynamics during the euro area missing disinflation episode. Domestic shocks played an important role in explaining the low inflation in the euro area missing inflation episode.

The inflation 'puzzles' seem to be an artefact of models that are too small or too restricted. The economic research that highlights the puzzling nature of inflation uses either simple Phillips curve-type regressions, or tightly restricted versions of the workhorse New Keynesian DSGE model. In these restricted set-ups conditional forecasts are indeed far from actual inflation, suggesting its puzzling nature.

Our results have important implications for modelling and policy analysis. We show that a sufficiently flexible and data-rich model properly accounting for the changing relative importance of global and domestic factors matches well inflation developments since the Great Recession. We confirm the importance of the global factors driving inflation (see e.g. Ciccarelli and Mojon, 2010), but we also isolate an episode, the euro area missing inflation period, where the link between domestic real activity and inflation appears crucial for explaining inflation. We find that the strength of this link (i.e. the implicit slope of the Phillips curve) does not seem to have changed after the Great Recession. Finally, we document a remarkable similarity between the inflation forecast errors and the contribution of domestic shocks to inflation. This suggests that, attuned to the global nature of inflation, professional forecasters may have missed the importance of domestic economic developments for euro area inflation.

1 Introduction

The dynamics of inflation since the start of the Great Recession has puzzled economists. First, a 'missing disinflation' puzzle emerged when inflation in advanced economies failed to fall as much as expected given the depth of the recession (see e.g. Hall, 2011 on the US and Friedrich, 2016 on the rest of the advanced economies). Then came the 'missing inflation' puzzle, particularly manifest in the euro area, where inflation was unexpectedly low after 2012 (see e.g. Constâncio, 2015; IMF, 2016). These puzzles have led economists to question and reassess the relation between real activity and inflation, and reconsider the global nature of inflation. These studies used small reduced-form models (e.g. Ball and Mazumder, 2011; Coibion and Gorodnichenko, 2015) or structural Dynamic Stochastic General Equilibrium (DSGE) models (e.g. Del Negro et al., 2015; Christiano et al., 2015; Gilchrist et al., 2015). In this paper we investigate the puzzles using reduced-form and structural Bayesian vector autoregressions (VARs) as the tools to interpret the data. This investigation sheds new light on the puzzles.

We show that the puzzles disappear in a VAR with multiple domestic and global variables. That is, the forecasts conditional on the actual path of domestic real activity do not underpredict inflation during the missing disinflation period in the euro area and the US. Furthermore, analogous forecasts do not overpredict inflation during the euro area missing inflation. In fact, during each episode some conditional forecasts match inflation quite well, so it is interesting to ask what this econometric framework says about the interpretation of the two episodes.

The VARs reveal that the relative importance of global and domestic factors has varied strongly over time. In the first euro area disinflation (2008-2011) the forecast conditional on global variables matches inflation much better than the forecast conditional on domestic real activity. But in the second disinflation (2011-2014) this ranking is reversed. Identifying economically interpretable domestic and global shocks in a smaller VAR leads to similar conclusions. The first episode is driven more by global shocks, and the second one more by domestic shocks. In the US, global shocks contribute positively to inflation in the second part of the missing disinflation episode. These lessons follow consistently from three alternative identification schemes, using either restrictions on the timing or on the comovement of global and domestic variables to separate global from domestic shocks.

A striking picture emerges when we compare the contributions of different shocks to inflation in the euro area with the inflation forecast errors made by professional forecasters: in the missing inflation period the forecast errors and the contributions of domestic shocks follow the same pattern. A plausible story of the 'missing inflation' is that economists, attuned to the global nature of inflation, overlooked the effect of domestic deflationary shocks.

Our results suggest that, as is often the case in economics, the puzzles seem to be an artefact of models that are too small or too restrictive. The economic research that highlights the puzzling nature of inflation uses either simple Phillips curve-type regressions (see e.g. Ball and Mazumder, 2011; Coibion and Gorodnichenko, 2015) or tightly restricted versions of the workhorse New Keynesian DSGE model. In such restricted set-ups conditional forecasts are indeed far from actual inflation. Two key modeling differences explain why our VARs are better at explaining the actual path of inflation. First, our VARs include multiple variables representing real activity and global influences in a flexible way, instead of relying on a single indicator of each. Second, our VARs include multiple lags of all variables, which allows them to capture the dynamics of the economy.

Our paper is related to a number of other works. A growing literature argues that inflation is largely a global phenomenon, as the globalisation process has rendered domestic inflation more sensitive to economic developments abroad (see e.g. Borio and Filardo, 2007; Ciccarelli and Mojon, 2010; Mumtaz and Surico, 2012; Ferroni and Mojon, 2015). Another line of research argues that the Phillips curve has flattened over the recent decades and hence downplays the connection between inflation and domestic real activity (see e.g. IMF, 2013; Blanchard et al., 2015). While we do not question these findings in general, we put them in a perspective by isolating a recent episode, the missing inflation period in the euro area, when domestic real activity was crucial for explaining inflation dynamics.

A sequence of DSGE papers argues that the missing disinflation puzzle disappears in models that realistically account for the dynamics of a richer set of variables. In Christiano et al. (2015) interest rate spreads increase costs via the working capital channel, and, in addition, productivity falls. In Gilchrist et al. (2015) firms raise prices when facing liquidity problems. In Del Negro et al. (2015) forward looking agents expect the central bank to prevent future marginal cost declines. In Bianchi and Melosi (2016) agents factor in an increasing probability of a switch to the fiscally led policy mix. All these complementary mechanisms imply that inflation does not fall in the Great Recession as much as a simple Phillips curve would suggest. We also find it important to incorporate a richer set of variables, but, unlike most of these papers, we fail to detect a prominent role of financial variables.

Our results are also related to the explanation of the missing disinflation proposed by Coibion and Gorodnichenko (2015). They argue that the growth of the price of oil between 2009 and 2011 affected household inflation expectations and, through them, inflation itself. We find that global shocks were behind the increase in inflation inflation in this period, and that conditional forecasts of inflation in this period are very good when conditioning on global variables, although the price of oil is not the most important of them.

Conditional forecasts imply that the relation between real activity and inflation in our medium-sized VAR has been essentially unchanged in the wake of the Great Recession. This alleviates concerns about the short-run time variation in the slope of the Phillips curve. Aastveit et al. (2014) reach the opposite conclusion. They find that conditional forecasts are disturbingly far from actual outcomes in this period and advocate the use of time-varying models. The difference between our results lies in the model size. We also find that conditional forecasts in small VARs are poor, but we show that these forecasts become very good when the VAR is sufficiently large. This finding is about out-of-sample conditional forecasts, which could in principle become more affected by estimation error in larger models, so it is not a forgone conclusion. Giannone et al. (2014) and Bańbura et al. (2015) also find that the conditional forecasts of the main euro area macroeconomic variables in a large VAR match actual outcomes well in the Great Recession, with the exception of financial variables. Laseen and Sanjani (2016) report the same finding for the US, particularly when conditioning on external developments (but financial and monetary policy related factors also play a role).

Historical decompositions of inflation in the Great Recession into domestic and global shocks appear in two recent papers. Conti et al. (2015) and Ferroni and Mojon (2015) show the importance of global shocks throughout the crisis, and of domestic shocks in the missing inflation period. We confirm the robustness of these conclusions in a structural VAR similar to Conti et al. (2015), with three identification schemes that use a similar logic but different specific assumptions (our sign and zero restrictions follow Corsetti et al., 2014 and Baumeister and Benati, 2013).

In the rest of this paper, section 2 investigates the presence of the missing disinflation and missing inflation puzzles in the data using conditional forecasts, section 3 identifies structural shocks and studies their contributions to inflation in the two episodes, and section 4 concludes.

2 Conditional forecasts of inflation

In this section we ask whether inflation dynamics was indeed unusual during the missing disinflation and missing inflation episodes, from the point of view of a Bayesian VAR estimated on the data preceding these episodes. We condition on the actual realizations of either domestic or global variables and compare the resulting conditional forecasts of inflation with the actual outcomes.

We use a medium-sized VAR, with 23 variables: a consumer price index, eight indicators of domestic real activity, eight global variables and six financial variables. When choosing the variables we try to focus on the most relevant ones according to the ranking derived in Jarociński and Maćkowiak (2017), but with a few constraints: we use the same specification for the euro area and the US, we want to separate domestic from global variables (so we omit exports and imports which are difficult to classify), and for a-priori reasons we want the number of global variables to be equal to the number of domestic real activity variables, so we end up including some global variables that do not appear relevant in Jarociński and Maćkowiak (2017). The variables are listed in Table 1. The variables are observed at the quarterly frequency over the sample starting in 1990Q1 and the real variables, as well as the price indexes are seasonally adjusted (Appendix A contains details on the construction of some of the series and the data sources). As is the common practice in quarterly VARs, we include four lags of the endogenous variables. All the VARs include an intercept.

We estimate the VARs using the Bayesian approach in the tradition of Sims. More precisely, we include all variables in (log) levels and we use Bayesian priors of Litterman (1979) and Sims and Zha (1998). Since the VAR is relatively large, we follow the advice of Bańbura et al. (2010) and Giannone et al. (2015), and use tighter priors than is standard in smaller VARs. When setting the priors, we start with the prior hyperparameters of Sims and Zha (1998) and scale them by a factor of 4 (see Table 1). When the prior is too loose, the unconditional forecast implies exploding rate of inflation in the long run, so we tighten the prior until the unconditional forecast shows that inflation stabilizes in the long run. It turns out that we need a factor of 4 to achieve this. When computing the conditional forecasts we use the Gibbs sampler of Waggoner and Zha (1999) (see also Jarociński, 2010 for some details on the implementation).

We start with attempts to replicate with a VAR the missing disinflation puzzle in the US. We estimate the VAR using the data up to the peak before the Great Recession, dated by the

Table 1: VAR specification

	Variable	Transformation
Price index	€:Harmonized Index of Consumer Prices (HICP) /	log
	$:Consumer Price Index (CPI)	log
Domestic real activity variables	Real GDP	log
	Real consumption	log
	Real investment	log
	Total employment	log
	Unemployment rate	none
	Capacity utilization	none
	Consumer confidence	none
	Purchasing Managers' Index (PMI)	none
Global variables	Rest-of-the-world real GDP	log
	Price of oil	log
	Commodity prices	log
	Nominal Effective Exchange Rate (NEER)	log
	USD/EUR exchange rate	log
	Foreign* real GDP	log
	Foreign* consumer price index	log
	Foreign* short-term interest rate	none
Financial variables	Short-term interest rate (€:EONIA / $:Fed Funds rate)	none
	2-year government bond spread	none
	10-year government bond spread	none
	Mortgage bank lending spread	none
	Non-financial corporations bank lending spread	none
	Corporate bond spread	none
Prior hyper-parameters Sims and Zha (1998) notation	overall tightness $\lambda_1 = 0.05$	
	decay $\lambda_2 = 1$	
	'other weight' $\lambda_3 = 1$	
	standard deviation of the constant term $\lambda_4 = 2.5 \times 10^3$	
	weight on the no-cointegration (sum of coefficients) dummy observations $\mu_5 = 4$	
	weight on the one unit root dummy observation (initial dummy observation) $\mu_6 = 4$	

Notes: € denotes the euro area VAR, $ denotes the US VAR. *'Foreign' means 'US' in the euro area VAR and 'Euro area' in the US VAR. The spreads are calculated as the interest rate in question minus the short-term interest rate, except for the Corporate bond spread which is the average spread of a BBB 7 to 10-year corporate bond over government bond of the same maturity.

NBER at 2007Q4. Then we forecast consumer prices conditionally on the actual path of the real activity variables in the Great Recession and afterwards. We plot the forecast with the 68% posterior uncertainty band, along with the actual data, in the first panel of Figure 1. The VAR is specified in terms of the level of the price index, but for the purpose of reporting we transform the levels into year-on-year growth rates. The two vertical lines mark the beginning of 2009 and the end of 2011, delimiting the period of the missing disinflation puzzle as defined e.g. in Coibion and Gorodnichenko (2015).

We can see that the VAR does not confirm the missing disinflation puzzle: based on the joint dynamics of all the variables prior to the Great Recession and the real activity in the Great Recession, the VAR predicts a disinflation that is, if anything, less deep, and not deeper than what was actually observed. The conditional forecast in the first panel stands in contrast with the predictions of reduced-form Phillips curves, which, as shown e.g. in Coibion and Gorodnichenko (2015) tend to be much lower. For example, the green line with circles, labeled 'CG Phillips curve prediction', shows the prediction of their baseline Phillips curve specification, which is indeed much lower.[1] We have tried many VAR specifications with different sets of variables and all of them conditionally predicted significantly more inflation than the above reduced-form Phillips curve. Why do VARs predict a higher inflation than reduced-form Phillips curves?

Part of the reason lies in the inertia that the VAR captures. In particular, inflation was temporarily high just before the crisis, and this raises the whole forecast path. If, instead of starting the conditional forecast at the NBER-dated peak of real activity before the recession, we start in 2008Q3, when inflation peaked, we predict even higher inflation (see panel 2). By contrast, if we start in 2007Q1, before inflation picked up, the conditional forecast of inflation is lower and comes closer to replicating the missing disinflation puzzle (see panel 3).

When instead of conditioning on real activity we condition on global variables the forecast becomes almost perfect irrespective of when we start the forecast (panels 4-6). After the first three plots one might have suspected that the conditional forecasts from this VAR are not very responsive to the conditioning assumptions, e.g. because the Bayesian prior is too restrictive and suppresses all relations between variables. However, panels 4-6 show that this is not the case.

In the next two panels we bring financial variables into the picture. The structural accounts

[1]We have replicated their Figure 1, Panel B. The only reason why the figures look differently is that the plot in their paper shows annualized quarterly inflation while the plot in this paper shows annual inflation.

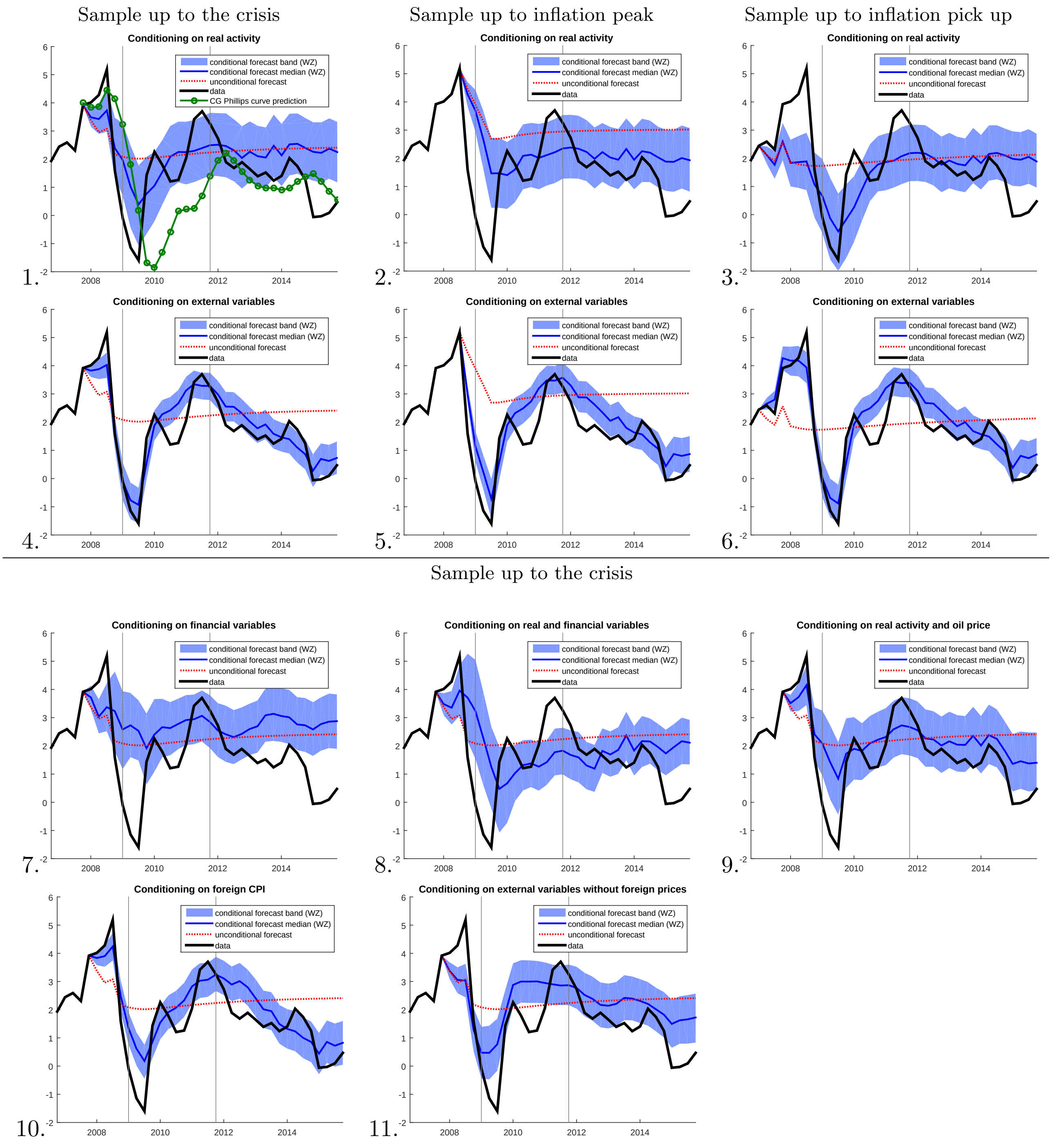


Figure 1: Conditional forecasts of US CPI (year-on-year growth)

of the Great Recession in Del Negro et al. (2015) and Christiano et al. (2015) suggest that interest rates and spreads, or their interaction with real activity, are important for inflation. However, the forecasts conditional on financial variables (panel 7) and on both real activity and financial variables (panel 8) do not match actual inflation particularly well. This does not necessarily contradict the mentioned structural accounts of the Great Recession, because the Sims and Zha prior we use might be pushing the VAR parameters away from the cross-equation restrictions of these models. But the bottom line is that our VAR does not provide a 'smoking gun' evidence in favor of the structural accounts that rely on financial frictions.

Coibion and Gorodnichenko (2015) argue, instead, that the price of oil is crucial for understanding inflation in the Great Recession, so in panel 9 we condition on real activity and the price of oil. In this case we forecast a higher inflation than when conditioning on real activity alone. This improves the match of the forecast somewhat in 2011, but worsens it in 2009, so the VAR fails to produce a 'smoking gun' evidence in favor of the role of oil prices too.

The strongest message from the VAR is on the importance of the global nature of inflation. When we condition the forecast on only one variable, the euro area consumer prices, the resulting forecast becomes almost as good as in panel 4 (see panel 10). When we condition on the global variables excluding euro area consumer prices, the fit of the forecast is good but worsens compared with panel 4 (see panel 11).

We conclude that the VAR estimated for the US up to the Great Recession does not find the missing disinflation puzzling in light of the observed real activity developments. The conditional forecasts are, however, particularly close to actual data when we condition on global variables. This confirms the global nature of inflation.

We now turn to the missing disinflation and missing inflation puzzles in the euro area. Figure 2 presents the conditional forecasts of euro area inflation generated with the euro area VAR. The first column focuses on the missing disinflation puzzle, while the second and third columns focus on the missing inflation puzzle. We start with the missing disinflation.

Panel 1 shows that there is no missing disinflation in the data according to the euro area VAR either. We estimate the VAR on the data up to the peak before the first recession, dated by the CEPR at 2008Q1 (and marked by a vertical line in the plot). We forecast inflation conditional on actual domestic real activity during the recession and afterwards. We focus first on the period up to the peak before the second recession, dated by the CEPR at 2011Q3 (and marked by the second vertical line in the plot). Based on the the sample 1990Q1-2008Q1, a researcher who learns about the extent of the first euro area recession expects inflation to fall only by about 0.5 percentage point compared with his unconditional forecast. This is much less than the 4 percentage points fall actually observed. Adding the financial variables to the conditioning set yields a lower inflation forecast after some delay (panel 4).

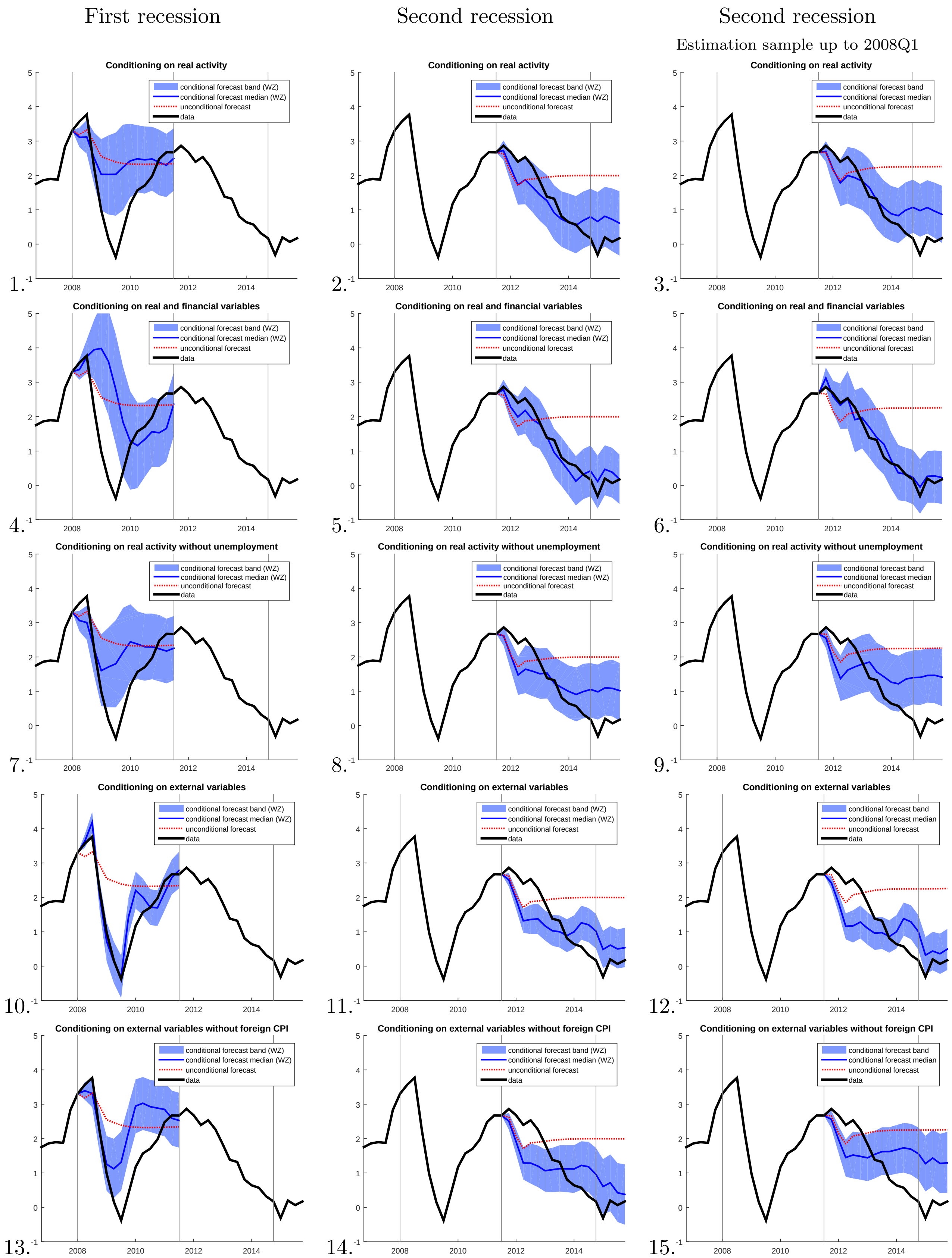


Figure 2: Conditional forecasts of euro area HICP (year-on-year growth)

Inflation again appears to be a global phenomenon: when in the same VAR we condition on the actual path of the external variables the forecast matches actual outcomes very well (panel 10). Similarly to the US case, it turns out that the inflation of another major economy (here - US) is the crucial variable among the global ones. When we exclude the US inflation from the set of the conditions, the forecast conditional on the remaining variables gets farther from actual inflation (panel 13). However, this forecast is still much better than the forecast conditional on real activity. We conclude that the VAR suggests a global nature of inflation and a rather limited role for domestic real activity in the first disinflation.

The missing inflation period is very different. We report the evidence for this in the second column in Figure 2. For the purpose of this paper we define the missing inflation period as 2011Q3-2014Q4 (the end of this period is marked with the third vertical line). When we reestimate the VAR on the data up to 2011Q3, before the start of the second recession according to CEPR, the forecast based on the actual path of real activity variables in the missing inflation period matches the outcomes very well (panel 2). The VAR predicts a steady fall in inflation, similar to what was observed, and hence implies no missing inflation puzzle in actual data. The conditional forecast improves further after incorporating financial variables in the conditioning set (panel 5). The unemployment rate, which reached record high levels in the second recession, turns out to be the single most important variable among real activity indicators. When we omit the unemployment rate, the match between the conditional forecast and inflation becomes clearly worse (panel 8).

The forecast conditional on the external variables matches the outcomes poorly (panel 11). This forecast is too low initially, but then stays above 1% at the time when actual inflation was falling gradually but steadily. When we exclude the US consumer prices from the conditioning set, the forecast becomes even poorer (panel 14).

At the end of the sample, after 2014Q4, external variables again appear to be relevant for inflation. Recall that in his period the price of oil dropped substantially and the Chinese economy slowed down. These developments can be seen in the shape of the conditional forecasts based on external variables - they turn sharply downwards.

Comparing plots 1 and 2 one might suspect that the slope of the Phillips curve changed in the Great Recession. According to this interpretation, a VAR estimated on the pre-crisis sample would imply a weak relation between real activity and inflation, i.e. a flat Phillips curve. Then, after incorporating the data from the first recession, when inflation fell sharply, the VAR parameters would change to imply a steeper Phillips curve. However, the plots in the third column suggest that this is not the case, and there is no evidence of a change in the slope of the Phillips curve implied by the VAR. In the third column we conditionally forecast inflation starting in 2011Q1, but using the posterior of the VAR parameters based on the data up to 2008Q1.[2] Comparing panel 3 with panel 2 we see that the disinflation conditional on the second recession is roughly the same in the VAR estimated up to 2008Q1 and in the VAR estimated up to 2011Q3, suggesting that the relation between real activity and inflation remained roughly constant across the two VARs. The similarity of panels 5 and 6 suggests that the relation between real and financial variables, and inflation, also remained roughly constant.

What might have changed somewhat, although the evidence is weak, is the link between euro area inflation and global variables other than US inflation. If we focus on how much the conditional forecast deviates from the unconditional forecast (plotted as the dotted line), we can see that this deviation is somewhat smaller in the VAR estimated up to 2008Q1 (panel 15), and somewhat larger in the VAR estimated up to 2011Q3 (panel 14), which might suggest that the link between inflation and global variables has become stronger. Such finding is to be expected if the data for 2008-2011 contain a disinflation driven more than usually by global variables.

Figure 3 presents the conditional forecasts based on the VAR estimated up to 2008Q1 and extended to the end of 2015. This figure is a concise illustration of the point that the first disinflation appears to be driven more by global variables (the two bottom plots fit the first disinflation better) and the second more by domestic variables (the two top plots fit the second disinflation better).

To summarize, in light of VAR conditional forecasts, the missing disinflation and missing inflation episodes are very different from each other, but none of them appears to be puzzling. The first disinflation was not small, but rather large judging by the previous experience, but it can be explained by the dynamics of the global variables. The second disinflation was broadly in line with the past experience, and it can be explained by the weak domestic real activity. Adding the data on the Great Recession to the pre-crisis sample does not lead to a reassessment of the relation between real activity and inflation. If anything, it leads to a somewhat stronger estimated relation between global variables and inflation.

The above discussion of the nature of the inflation fluctuations since the Great Recession,

[2]To keep the experiment clean, this time we sample directly from this posterior, without using the Gibbs sampler of Waggoner and Zha (1999) that would update it with the information contained in the assumed scenario.

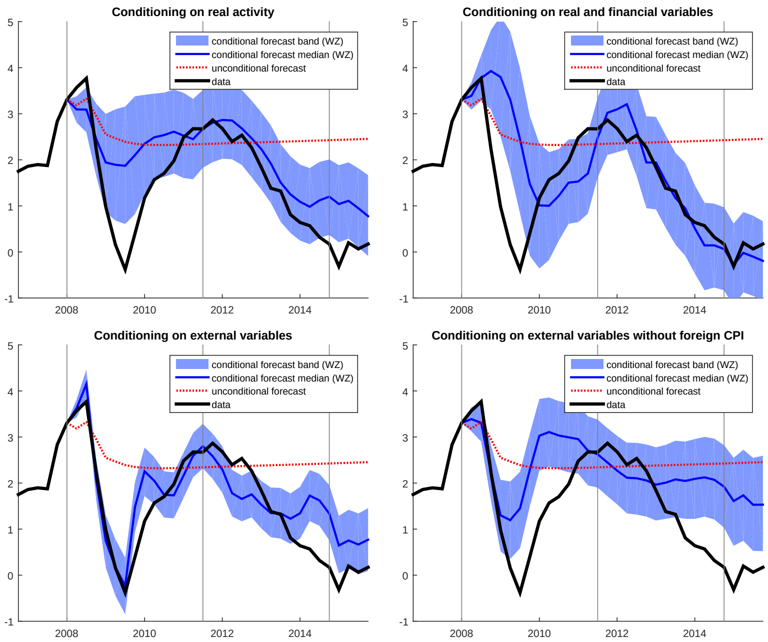


Figure 3: Conditional forecast of euro area HICP (year-on-year growth) extended to the end of 2015, VAR estimated on the sample up to 2008Q1.

while suggestive, is reduced form and does not warrant conclusions on the types of shocks driving inflation in the two episodes. To identify the shocks we move on to structural VARs.

3 Structural approach: shock identification and historical decompositions

In this section we identify structural shocks and ask what their relative contributions are to the dynamics of prices since the start of the Great Recession. Since identifying shocks becomes more complex as the number of variables increases, in this section we limit the number of variables to ensure the tractability of the structural model. The variables we include are the price of oil, rest-of-the-world real GDP (or the share of domestic real GDP in the world real GDP), real GDP, consumer prices, short-term interest rate, 10-year bond spread, and the nominal effective exchange rate. In the priors we use the same hyperparameter values as Sims and Zha (1998). To study the robustness of the results we use three alternative identification schemes. Table 2 summarizes the identifying restrictions, which are all on the contemporaneous impulse responses.

I. Choleski identification

We start with the Choleski identification scheme. We order the variables so that the two

Table 2: Sign and zero restrictions used to identify shocks in the VAR

Variable \ shock	Global	Global	Domestic	Domestic	Monetary policy	Spread	Exchange rate
I. Choleski							
Price of oil	+	0	0	0	0	0	0
Rest-of-the-world real GDP	•	+	0	0	0	0	0
Real GDP	•	•	+	0	0	0	0
Consumer prices	•	•	•	+	0	0	0
Short-term interest rate	•	•	•	•	+	0	0
Spread	•	•	•	•	•	+	0
Exchange rate	•	•	•	•	•	•	+

	Oil supply	Global demand	Domestic demand	Domestic supply	Monetary policy	Spread	Exchange rate
II. Corsetti et al. (2014) (CDL)							
Price of oil	+	+	•	• (≈0)	0	0	0
Share of world real GDP	•	−	+	+	0	0	0
Real GDP	−	+	+	+	0	0	0
Consumer prices	+	+	+	−	0	0	0
Short-term interest rate	0	•	•	•	+	0	0
Spread	•	•	•	•	•	+	0
Exchange rate	+ (•)	•	•	+	•	•	+
III. Corsetti et al. (2014) and Baumeister and Benati (2013) (CDL+BB)							
Price of oil	+	+	•	• (≈0)	•	•	0
Share of world real GDP	•	−	+	+	−	•	0
Real GDP	−	+	+	+	−	−	0
Consumer prices	+	+	+	−	−	−	0
Short-term interest rate	0	•	+	•	+	0	0
Spread	•	•	•	•	−	+	0
Exchange rate	+ (•)	•	•	+	+	+	+

Notes: • = unconstrained, + = positive sign, − = negative sign, 0 = zero restriction, ≈0 = magnitude restriction that centers the error band of the responses at zero. All restrictions are imposed on impact. The exchange rate is defined so that a + means an appreciation. In parentheses we show the restrictions used for the US VAR whenever they differ from the euro area VAR.

global variables, the price of oil and the rest-of-the-world GDP, are first. We label the first two shocks as global, and the subsequent ones as domestic. This identification relies on a timing restriction: global shocks affect all variables immediately, while domestic shocks affect global variables only with a delay. Studies of the global nature of inflation, such as Ciccarelli and Mojon (2010), use a similar logic.

There is one more shock that we can label in this approach with some confidence: the *monetary policy shock*. We place the short-term interest rate after real GDP and prices, but before the spread and the exchange rate, and then the shock to the short-term interest rate is a standard recursively identified monetary policy shock (see Christiano et al., 1999 on the recursive identification of monetary policy shocks).

The last shock, labeled as the *exchange rate shock* is common to all three identification schemes in this paper. It is a residual shock that accounts for the fluctuations of the exchange rate not explained by the previous shocks, and has no contemporaneous effect on all the other variables. The shock plays very little role in the dynamics of all the variables other than the exchange rate. We also single out the Choleski shock to the spread in order to contrast it with a more interpretable spread shock that we identify later. This shock also matters very little for inflation.

II. Corsetti et al. (2014) / Conti et al. (2015) identification

The second strategy relies on sign and zero restrictions that distinguish global shocks from domestic ones, and supply shocks from demand shocks. The key step is to distinguish domestic demand shocks from global demand shocks, and to achieve this end we follow Corsetti et al. (2014) (CDL). Note that when using this identification we include in the VAR the share of the domestic real GDP in the world real GDP, instead of just the level of the rest-of-the-world real GDP. The identification focuses on the comovement of this share with the domestic real GDP. Consider a shock that increases real GDP. If the economy's share in world GDP also increases, this means that the shock had more effect on the domestic economy then on the rest of the world and we label the shock as domestic. By contrast, if the economy's share in world GDP falls, the shock had more effect on the rest of the world and we label the shock as global. CDL use the same logic to identify productivity and global demand shocks affecting US manufacturing. A caveat is that one can imagine a shock that is global in nature but increases the demand for domestic products more than the demand for rest-of-the-world products. Such a shock would generate a positive comovement between domestic GDP and its world share. Hence, we would label this shock as domestic. This means that this identification might capture some foreign shocks, but we can reasonably hope that most of the shocks that we label as domestic are indeed domestic.

Following this logic, we assume that a positive *global demand shock* increases the price of oil, consumer prices and real GDP, but reduces the domestic GDP share in the world. A positive *domestic demand shock* increases both real GDP and its world share, and consumer prices.

Next, we identify an *oil supply shock*. We assume that a contractionary oil supply shock leading to an increase in the price of oil has a negative impact on real activity and a positive one on inflation. This restriction flows from the lessons of the literature that identifies various types of oil related shocks by modelling the global crude oil market and then investigates the impact of these shocks on the key macroeconomic variables (see for example Kilian, 2009 and Baumeister and Peersman, 2013 for the case of the US). We impose a zero restriction on the immediate reaction of the short-term interest rate, because the short-term interest rate is largely controlled by the central bank and central banks try, at least initially, no to react to oil supply shocks. Finally, it turns out that in the euro area (unlike in the US) the exchange rate appreciates after a contractionary oil supply shock identified with the above restrictions. We conjecture that this is because the euro area monetary policy tends to be tighter than the US monetary policy in the wake of oil price increases. We add the positive reaction of the exchange rate as an additional restriction for the euro area, even though this restriction is basically never binding (it holds even if we do not impose it), in order to highlight that the oil supply shock is well distinguished from the domestic supply shock discussed next.

We assume that a positive *domestic supply shock* increases domestic output as well as its world share (following the CDL logic) and, in contrast to the demand shock, it reduces domestic prices. With only the above restrictions, oil supply shocks and domestic supply shocks are still not distinguished, as can be seen from their similar impulse responses. To disentangle them, we require that the exchange rate appreciates after a positive domestic supply shock. In the euro area this restriction suffices to distinguish the two shocks, and the two sets of impulse responses now become distinct. In the US this restriction does not suffice, so in the US we also impose a magnitude restriction that the response of the price of oil to a domestic supply shock is 'small' (defined here as less than 5% in absolute value). With this set of restrictions, both the euro area and the US impulse responses are all distinct. (See Figures B.1 and B.3 in the Appendix.)

III. Adding monetary policy identification of Baumeister and Benati (2013)

In the third identification scheme we keep the sign restrictions from the previous scheme and add further restrictions that identify monetary policy shocks in a different way. It turns out that this modification affects the relative importance of domestic and global shocks.

Following Baumeister and Benati (2013) (BB) we assume that a contractionary *monetary policy shock* is an increase of the short term interest rate that has an immediate negative effect on output and prices, a negative effect on the bond spread and a positive effect on the exchange rate. Since bond yields do not respond one-to-one to the short rate, the spread shrinks after a short-term rate increase. Following the CDL logic, since the monetary policy shock is a special case of a domestic demand shock, domestic output and its world share move in the same direction, i.e. the share falls.

The reason we adopt the BB identification is that we think of it as representing an opposite extreme to the recursive identification. The recursive identification implies that monetary policy shocks have no contemporaneous effect on prices or output. It is well known that with this assumption researchers tend to find that monetary policy shocks contribute very little to economic fluctuations. By contrast, the BB monetary policy shocks have their peak effect on prices and output immediately, and contribute importantly to economic fluctuations. So the recursive and the BB identification represent respectively the lower and the upper bound for the strength of the impact of monetary policy (at least within this class of identification schemes).

Following BB we also identify a *spread shock* that moves the spread, while leaving the short term interest rate unchanged. A contractionary spread shock increases the spread, appreciates the exchange rate, and reduces output and prices. This is useful to reflect nonstandard monetary policies when the short term interest rates are at their effective lower bound. This shock can, however, capture also some non-policy factors affecting the term-structure, such as the euro area sovereign debt crisis.

When implementing the above restrictions we randomly search for orthogonal matrices that rotate the Choleski factor of the residual variance matrix and reproduce our sign restrictions while preserving the zero restrictions. Technical details on imposing sign and zero restrictions can be found in Arias et al. (2014). It takes only a few minutes to generate 1000 draws from the posterior of the structural VAR in the CDL identification, but this time extends to several hours for the CDL+BB identification.

In a closely related recent paper Conti et al. (2015) also study structural shocks behind the 2012 disinflation in the euro area using similar sign restrictions. There are two main differences between our paper and theirs. First, our goal is to partition the total variability of inflation into the contributions of different shocks. By contrast, they are interested in the effects of a subset of shocks, and they control for a number of variables treated as exogenous. Second, we differ in other details of the implementation, e.g. they impose sign restrictions on the response of world output and not on the euro area share in world output, and they do not impose any zero restrictions, while we found the zero restrictions to be helpful.

We report the impulse responses to all the shocks in the Appendix. In the rest of this section we focus on the historical decompositions in the Great Recession and around it.

Figure 4 reports historical decompositions of inflation (year-on-year change in consumer prices). We start the decomposition in 2006Q4. The black line is the difference between the median unconditional forecast generated by our VAR and the actual series. Our VAR represents this difference as the effect of the shocks that we identified and bars show the contribution of each shock. For greater readability, we aggregate the contributions of the two global shocks (dark blue bars), the contributions of the domestic supply and demand shocks (light blue bars), and the contributions of monetary policy and spread shocks (yellow). The contributions of the exchange rate shock are very small and barely visible (dark red). The vertical lines represent the same dates as before: in the euro area the dates are 2008Q1 (the peak before the first CEPR recession), 2011Q3 (the peak before the second CEPR recession) and 2014Q4, and in the US the dates are 2009Q1 and 2011Q4 (the notional beginning and the end of the missing disinflation).

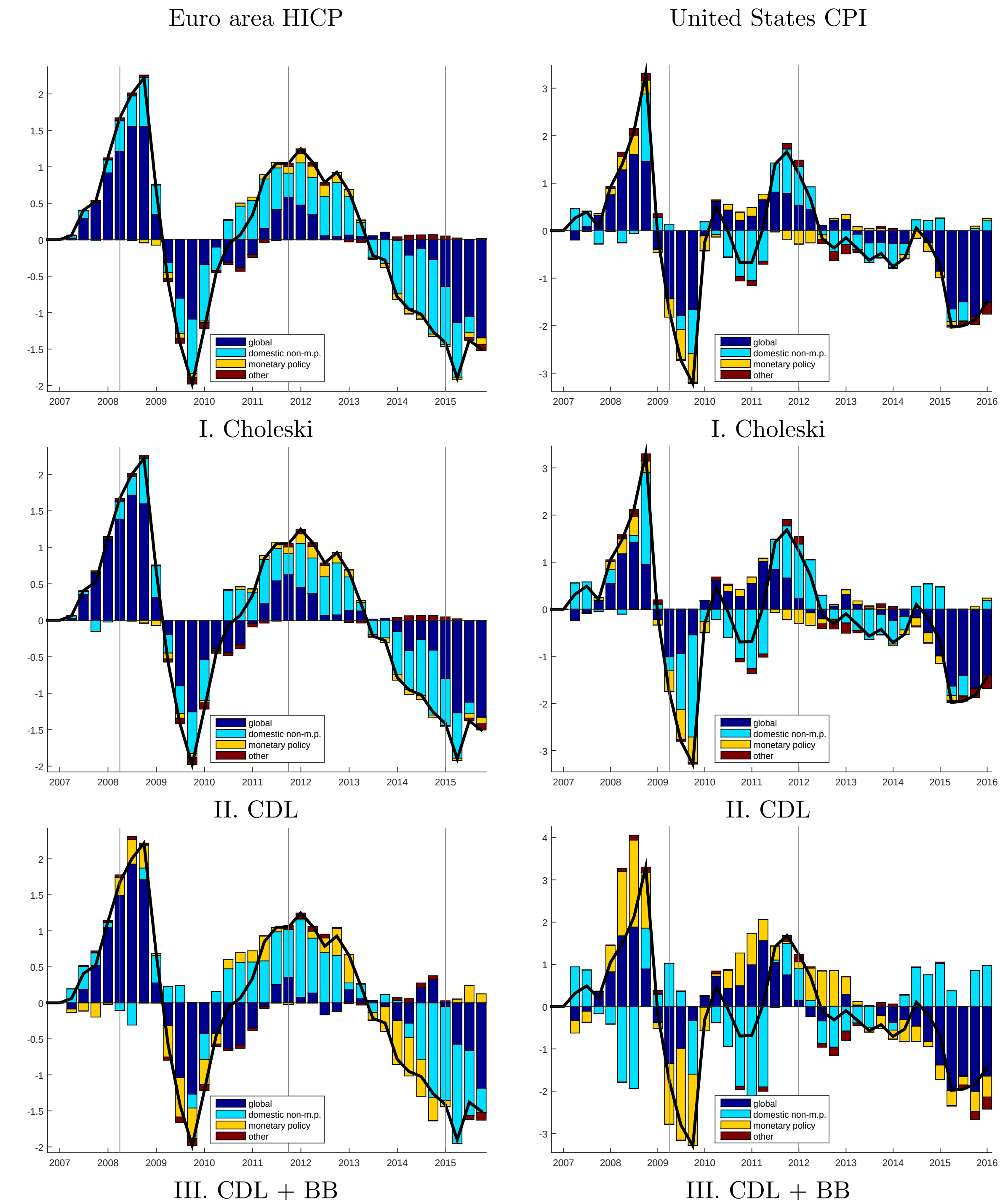
Let us focus first on the euro area missing disinflation period. The dark blue bars in Figure 4 representing global shocks account for most of the disinflation in each of the three identification schemes.

In the missing inflation period the picture is different. We see that the dominant factor behind the disinflation is the switch of the contribution of domestic shocks from positive to negative. Global shocks play some role too, but their contributions are small.

Finally, the picture changes again around the end of 2014: once more, the negative contributions of global shocks become important.

Figure 4 outlines also a range for the possible contributions of monetary policy (including spread) shocks. Recursively identified monetary policy shocks contribute very little to inflation dynamics. By contrast, the monetary policy shocks identified as in Baumeister and Benati (2013) imply that an excessively tight monetary policy contributed to both disinflations. The contribution of monetary policy becomes positive again at the end of the sample and the detailed results (reported in Appendix C) show that this is due to the spread shock, likely reflecting the quantitative easing that the ECB implemented in 2015.

To sum up, according to these results, both global and domestic shocks have driven euro area inflation in the crisis. In the missing disinflation period global shocks have played a larger role, while in the missing inflation period domestic shocks were relatively more important. These re-



Note: The black line is the deviation of year-on-year inflation from the unconditional forecast as of 2006Q4, the bars show the contributions of different types of shocks to this deviation.

Figure 4: Historical decompositions of inflation in the euro area and in the US

sults put some perspective on the literature arguing in favour of inflation in advanced countries being largely a global phenomenon. Ciccarelli and Mojon (2010), using data up to the international financial crisis, find that global inflation explains more than two thirds of the variance of national inflation rates and that it also acts as an attractor for national inflation. Ferroni and Mojon (2015) revisit the relevance of global factors in the aftermath of the crisis and find that they still explain a dominant part of national inflation, albeit to a diminished extent. We confirm that global factors account for much of inflation dynamics, but we find that the missing inflation episode in the euro area is mainly driven by domestic shocks.

Contribution of global shocks

SPF forecast error (1-year ahead)

Contribution of domestic shocks

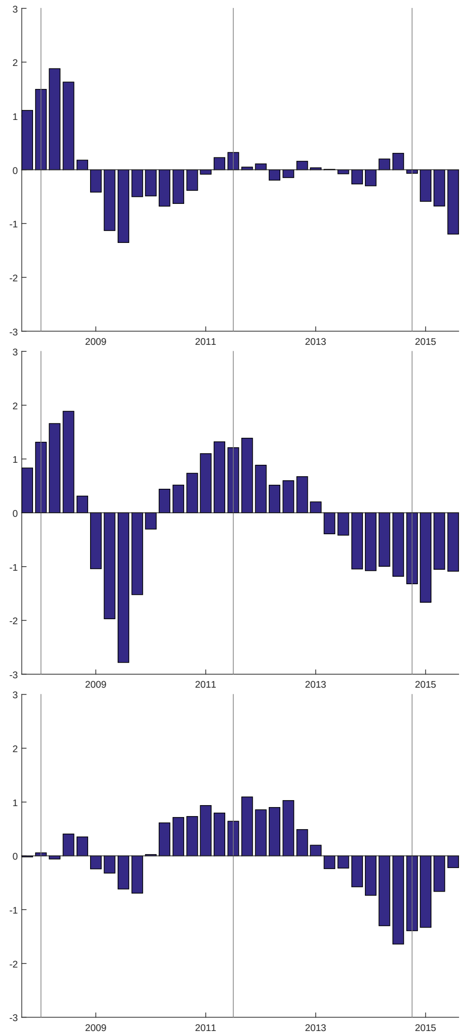


Figure 5: Errors of the SPF forecasts and the contributions of shocks

Figure 5 compares the errors made by professional forecasters and contributions of selected types of shocks. The middle panel shows the errors of 1-year ahead inflation forecasts reported in the Survey of Professional Forecasters (SPF), defined as the outcome minus the forecast. Forecasts tend to be clustered around similar values, and the errors of the official ECB forecasts, Eurozone Barometer and Consensus Economics are very similar. In the top and bottom panels we plot the contributions of, respectively, global and domestic shocks (including monetary policy), from the CDL+BB identification.

One-year ahead forecast errors and shock contributions are, of course, different objects, but they do have some similarities. The contributions contain the effects of new shocks, that by definition could not have been anticipated a year earlier, and the propagation of all the past shocks. Forecast errors contain the effect of the same new shocks and the part of the propagation of all the past shocks that is misspecified in the forecaster's model.

With this interpretation in mind, the comparison of the middle and the bottom panel is striking: in the missing inflation period the forecast errors are very similar to the contributions of domestic shocks. This suggests a particular interpretation of the missing inflation episode, namely that economists, attuned the global nature of inflation (which was indeed crucial in the preceding period), missed the effect of domestic shocks during this episode.

Turning now to the US historical decompositions reported in the right part of Figure 4, the key lesson is that much of the missing disinflation is explained by the positive contributions of global shocks in 2010-2011. However, in the short but deep disinflation in 2009 the alternative identification schemes produce a striking disagreement: the Choleski identification attributes the disinflation to global shocks (recall that the conditional forecasts of section 2 attributed it to global variables), while the CDL and CDL+BB identifications assign a larger role for domestic shocks. These results suggest that in 2009 the US shocks strongly and quickly spilled over to global variables. Regarding other periods, the US results confirm the role of global shocks in the post-2014 disinflation, similarly as in the euro area. Finally, monetary policy shocks identified recursively (Choleski and CDL identifications) explain a small fraction of the variance of inflation, while monetary policy shocks identified with the BB identification explain, perhaps surprisingly, a large part of its variance.

4 Conclusions

In a medium size VAR, conditional forecasts of inflation in and after the Great Recession match actual realizations very well. In light of this VAR, inflation appears to be puzzling neither during the missing disinflation in the US and the euro area, nor during the euro area missing inflation episode.

Given that the VAR can account for inflation during the 'puzzling' episodes, we use it to shed light on their nature. We find that the two disinflation episodes in the euro area are very different. Global variables, and global structural shocks that we identify in a smaller VAR, are key to understanding the first euro area disinflation. Weak domestic real activity and deflationary domestic shocks are key to understanding the second disinflation. This implies that economists and models that excessively focused on the global nature of inflation were liable to overpredict it during the missing inflation episode. Future research will clarify whether the large role that domestic factors played in this episode simply reflected the regional nature of the euro area sovereign debt crisis, or was a harbinger of the new normal resulting from the slowdown or even reversal of globalization trends.

Our results have two practical implications for economic modelling. First, an empirically successful model of inflation needs to account well for both global factors and domestic real activity. Second, the link between inflation and real activity has been relevant and remained unchanged during the studied period, which alleviates concerns about the time variation in the slope of the Phillips curve in the aftermath of the Great Recession.

Appendix A Data and sources

Table A.1: Euro area data sources and definitions

Variable	Source	Definition
	Price index	
HICP	Eurostat, ECB	Harmonized index of consumer prices, seasonally adjusted
	Domestic real activity variables	
Real GDP	Eurostat	chain linked volume, calendar and seasonally adjusted
Real Consumption	Eurostat	chain linked volume, calendar and seasonally adjusted
Real Investment	Eurostat	chain linked volume, calendar and seasonally adjusted
Total employment	Eurostat	persons, calendar and seasonally adjusted data
Unemployment rate	Eurostat	standardised unemployment rate, seasonally adjusted
Capacity utilization	BIS	sector covered: manufacturing
Consumer confidence	European Commission	survey indicator, seasonally adjusted, balance of responses
Purchasing Managers' Index (PMI)	Markit	survey indicator, seasonally adjusted
	Global variables	
GDP of the rest of the world	national sources, IMF, OECD, authors' calculations	euro area real GDP index was extracted from the world GDP index using the euro area share in world GDP (expressed in PPP)
Price of oil in USD	Bloomberg	Brent crude oil price in US dollars
Price of non-energy commodities	OECD	prices of raw materials, Index Total excluding energy (US dollars)
Nominal effective exchange rate	ECB	nominal effective exchange rate vis-a-vis 19 trading partners
USD/EUR exchange rate	ECB	exchange rate against euro, spot (mid)
US real GDP	BIS	chain linked volume, calendar and seasonally adjusted
US consumer prices	BIS	consumer price index, seasonally adjusted
Federal funds rate	BIS	daily and monthly average
	Financial variables	
EONIA	ECB, AWM	historical close, average of observations through period. Available since 1999, back-linked using data from the Area Wide Model (AWM) database
2-year government bond spread	ECB	2-year government benchmark bond yield minus EONIA
10-year government bond spread	ECB	10-year government benchmark bond yield minus EONIA
Mortgage bank lending spread	national sources, Eurostat, ECB	loans to households for house purchase, weighted average of the rates for the EA big 5 (weights based on nominal GDP) minus EONIA
Non-financial corporations bank lending spread	ECB	bank interest rates for loans to corporations (other than revolving loans and overdrafts) minus EONIA
Corporate bond spread	ECB	difference between 7 to 10-year corporate bond yield and 7 to 10-year government bond yield

Notes: The world GDP index was constructed as follows. Starting 1995, quarterly national accounts data from individual national sources were used for countries covering around 93 per cent of world GDP. For the remaining countries the annual data provided by the World Economic Outlook database (WEO) was interpolated. The interpolation does not affect the aggregate world GDP, as the share of these countries is relatively small. The aggregation of individual data has been done using the annual PPP weights of each country provided by IMF WEO and a fixed base index was constructed (2005=100). Before 1995, a large set of individual country data is either not available or not reliable. In order to back-link the world GDP index for the pre-95 period, the annual world output data provided by WEO was interpolated using the quarterly data for real output of OECD countries. This ensures that the annual growth rate of world GDP is in line with the IMF estimate and the infra-annual dynamics is given by developments in countries covering a large share of world GDP.

Table A.2: US data sources and definitions

Variable	Source	Definition
	Price index	
CPI	BIS	Consumer price index, seasonally adjusted
	Real activity variables	
Real GDP	BIS	chain linked volume, calendar and seasonally adjusted
Real Consumption	BIS	chain linked volume, calendar and seasonally adjusted
Real Investment	BIS	chain linked volume, calendar and seasonally adjusted
Total employment	BIS	thousands of persons, seasonally adjusted
Unemployment rate	BIS	seasonally adjusted
Capacity utilization	BIS	sector covered: manufacturing.
Consumer confidence	Bloomberg	conference Board Consumer Confidence, seasonally adjusted
Purchasing Managers' Index (PMI)	Bloomberg	US Chicago Purchasing Managers Index, seasonally adjusted
	Global variables	
GDP of the rest of the world	national sources, IMF, OECD, authors' calculations	US GDP index was extracted from the world GDP index using the US share in world GDP (expressed in PPP)
Price of oil in USD	Bloomberg	Brent crude oil price in US dollars
Price of non-energy commodities	OECD	prices of raw materials, Index Total excluding energy (US dollars)
Nominal effective exchange rate	BIS	nominal effective exchange rate vis-a-vis 26 trading partners
USD/EUR exchange rate	ECB	exchange rate against euro, spot (mid)
Euro area real GDP	Eurostat	chain linked volume, calendar and seasonally adjusted
HICP	Eurostat, ECB	Harmonized index of consumer prices, seasonally adjusted
Federal funds rate	BIS	daily and monthly average
EONIA	ECB, AWM	historical close, average of observations through period. Available since 1999, back-linked using data from the Area Wide Model (AWM) database
	Financial variables	
Federal funds rate	BIS	dayly and monthly average
2-year government bond spread	BIS	US Treasury 2-year bond yield minus Fed funds rate
10-year government bond spread	BIS	US Treasury 10-year bond yield minus Fed funds rate
Mortgage bank lending spread	BIS	mortgage rate (30 years maturity) minus Fed funds rate
Non-financial corporations bank lending spread	BIS	bank prime lending rate to NFCs minus Fed funds rate
Corporate bond spread	ECB	difference between 7 to 10-year corporate bond yield and 7 to 10-year government bond yield

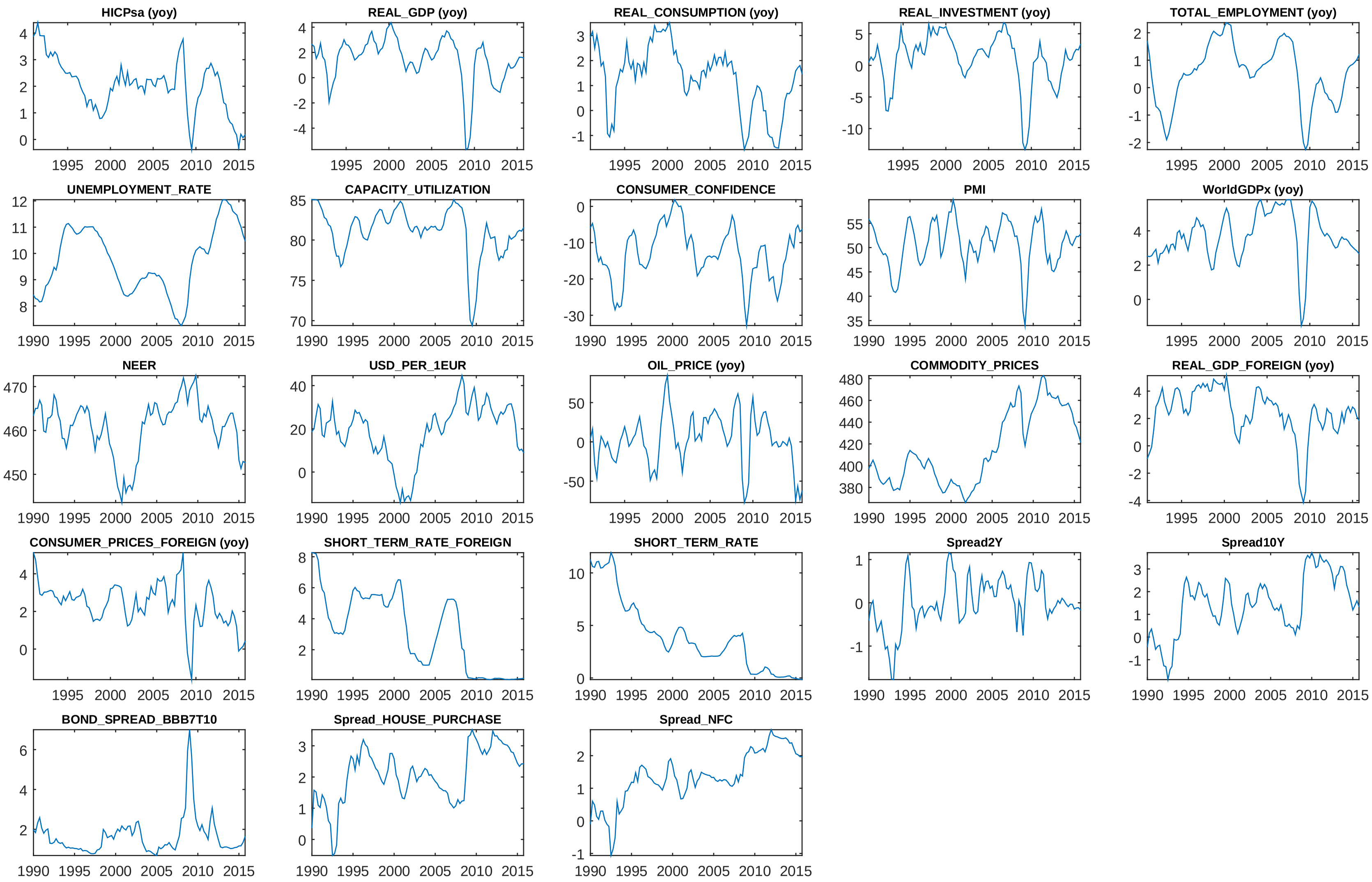


Figure A.1: Euro area data. The series marked (yoy) have been transformed to year-on-year changes for this plot, but we used levels for the estimation.

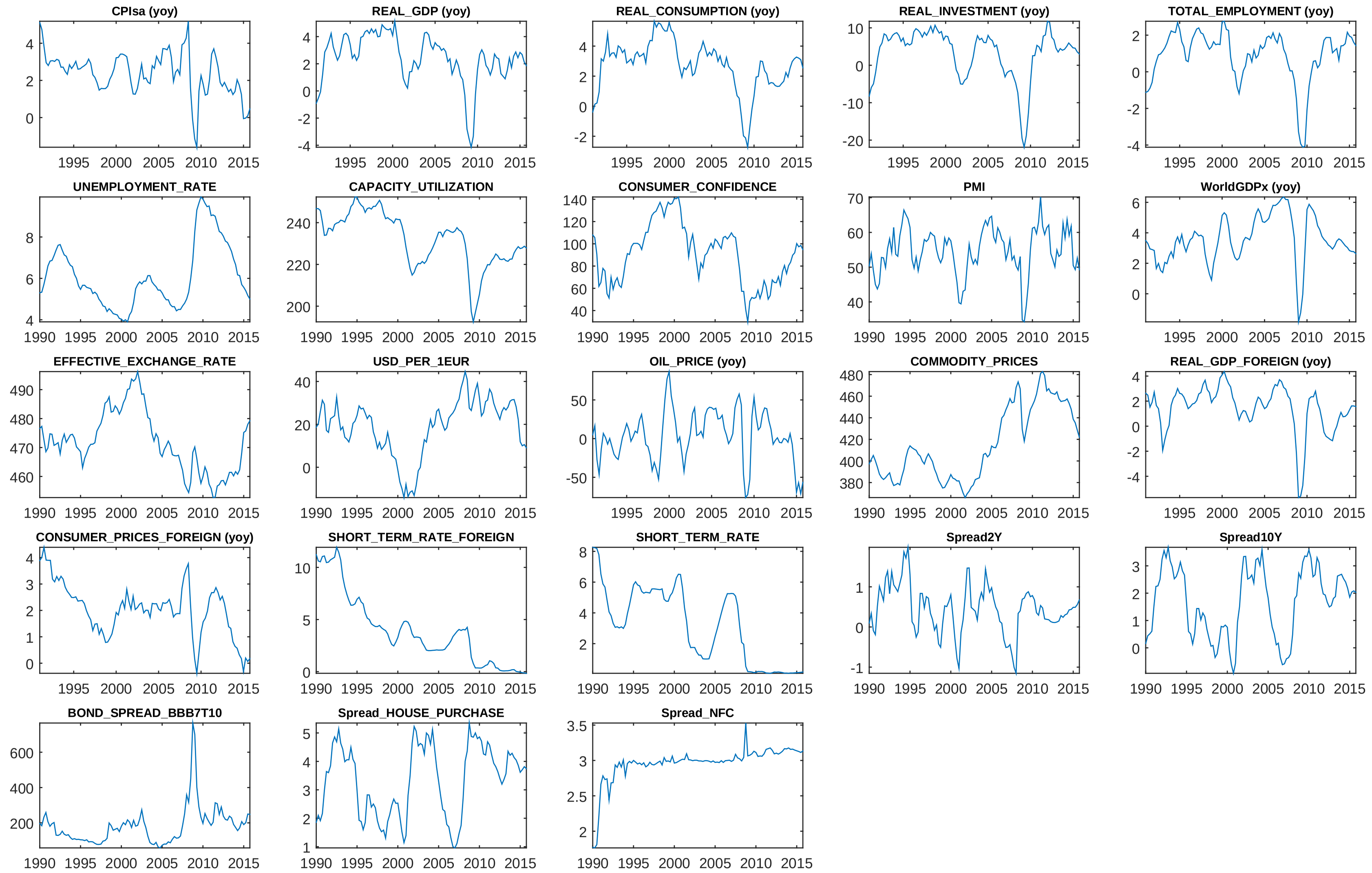


Figure A.2: US data. The series marked (yoy) have been transformed to year-on-year changes for this plot, but we used levels for the estimation.

Appendix B Impulse responses to all shocks

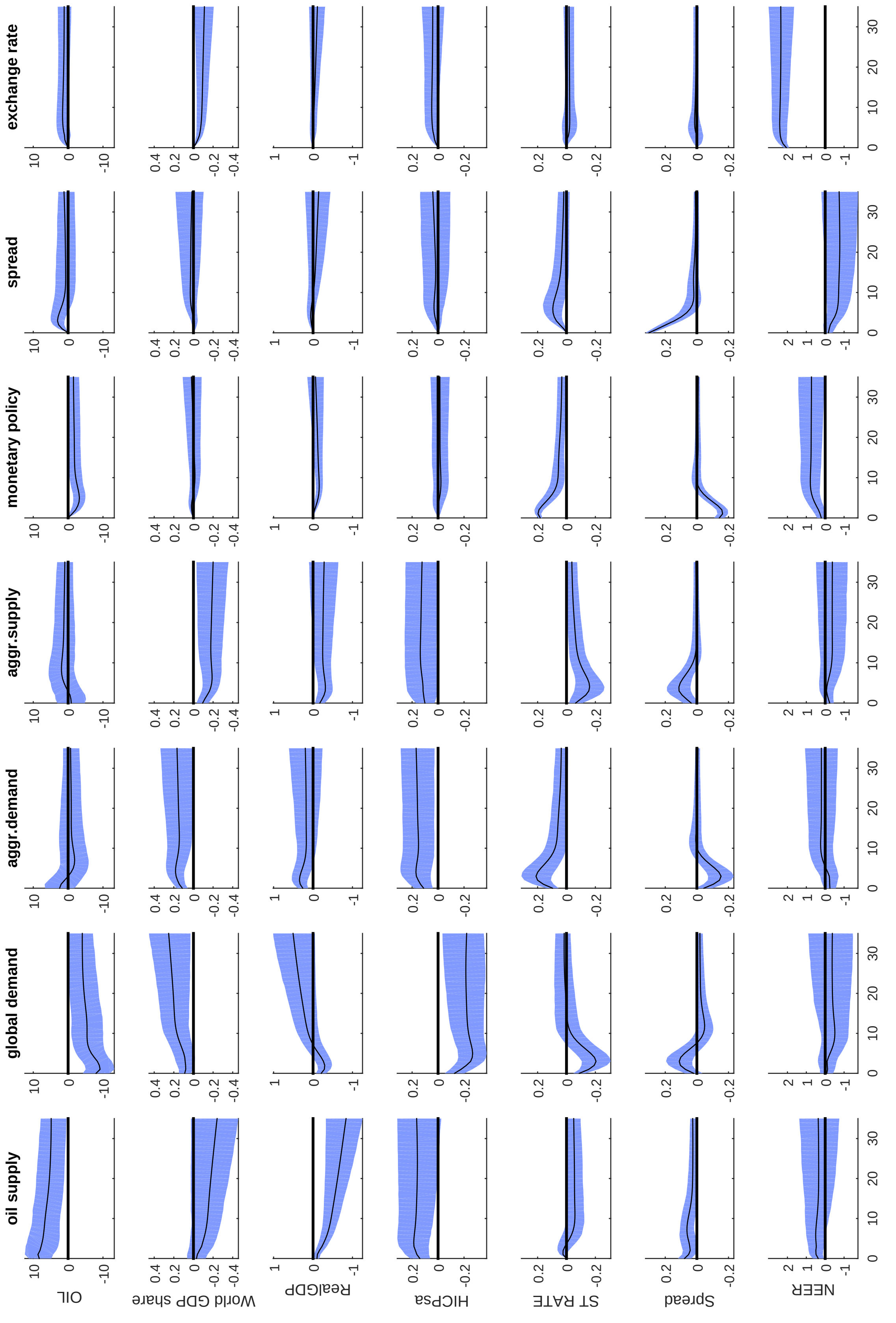


Figure B.1: Euro area impulse responses, identification II (CDL)

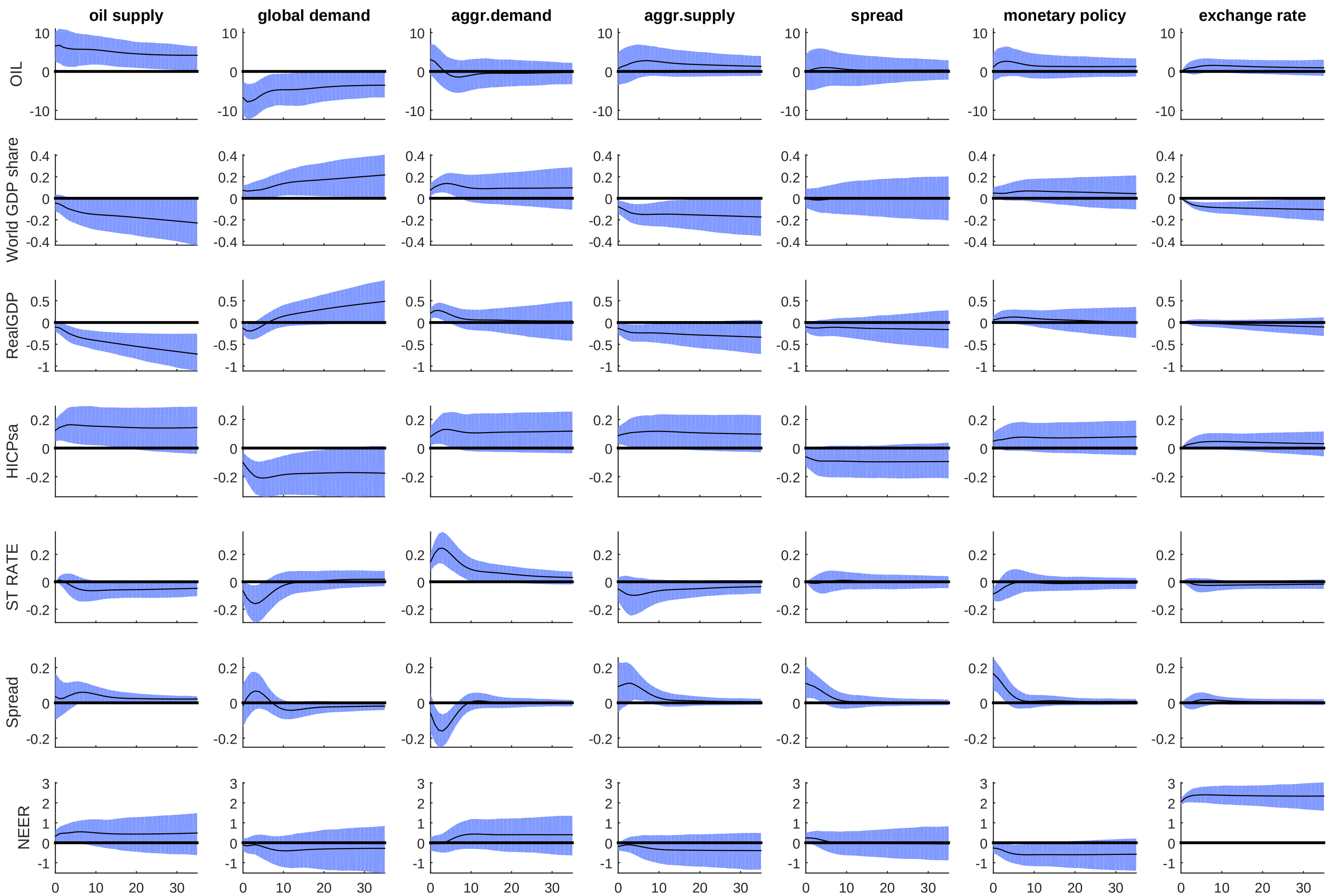


Figure B.2: Euro area impulse responses, identification III (CDL+BB)

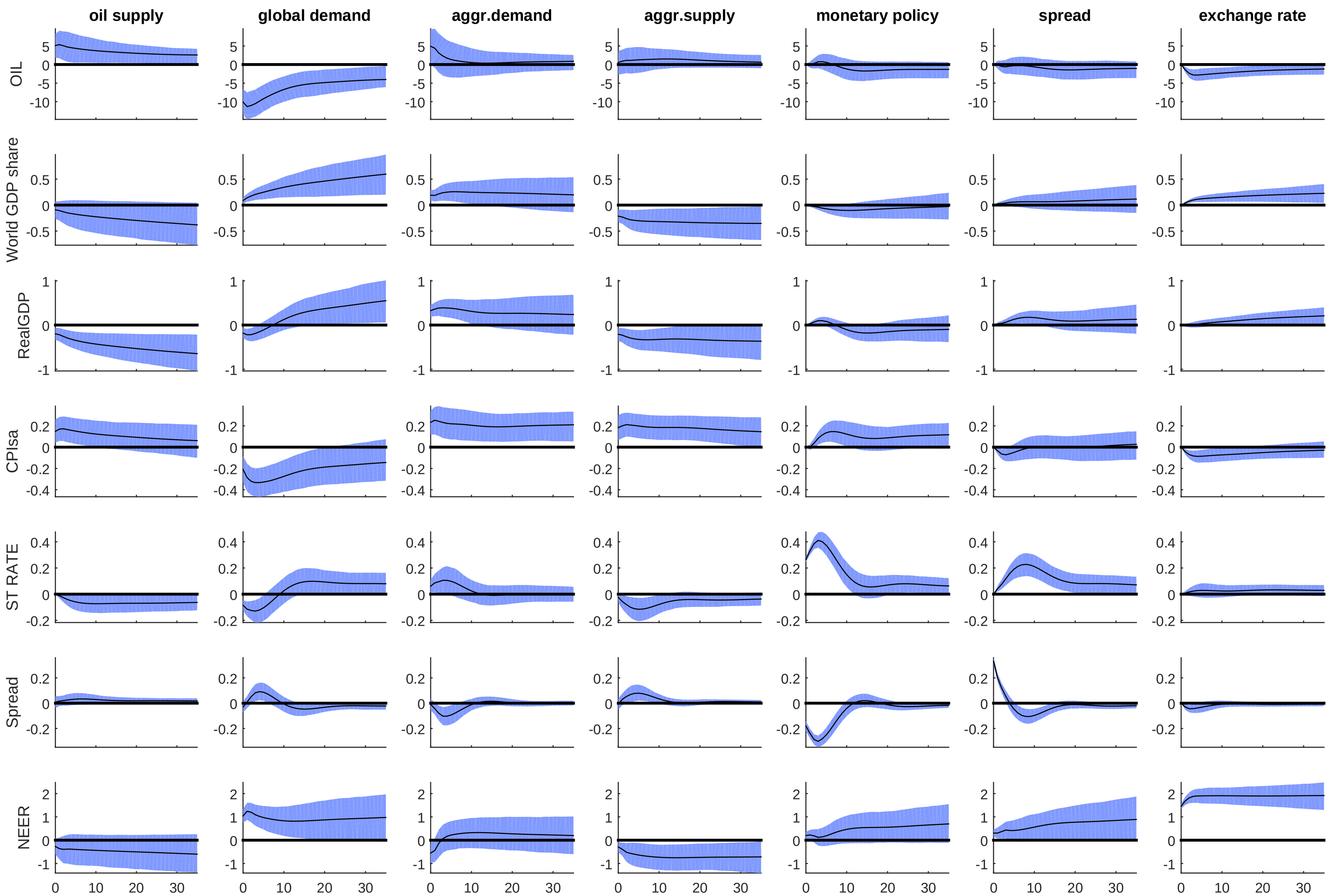


Figure B.3: US impulse responses, identification II (CDL)

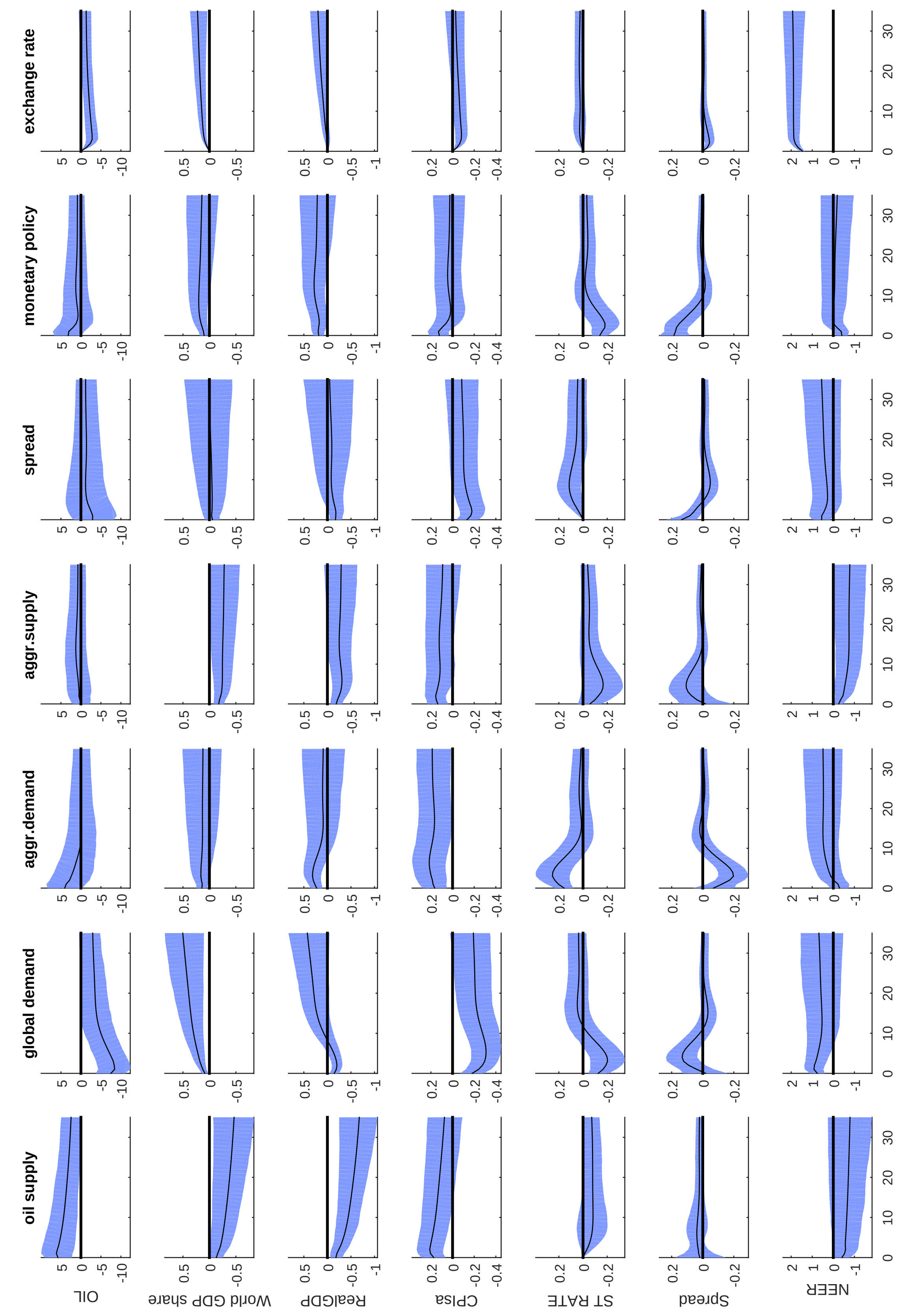


Figure B.4: US impulse responses, identification III (CDL+BB)

Appendix C Detailed historical decompositions

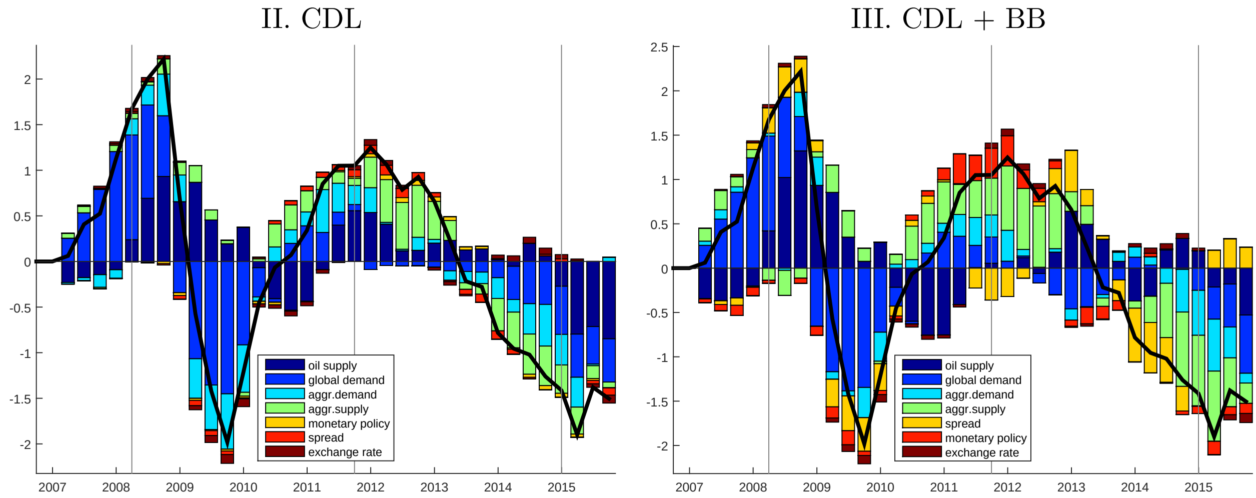


Figure C.1: Historical decompositions of euro area HICP: disaggregated effects of all the shocks

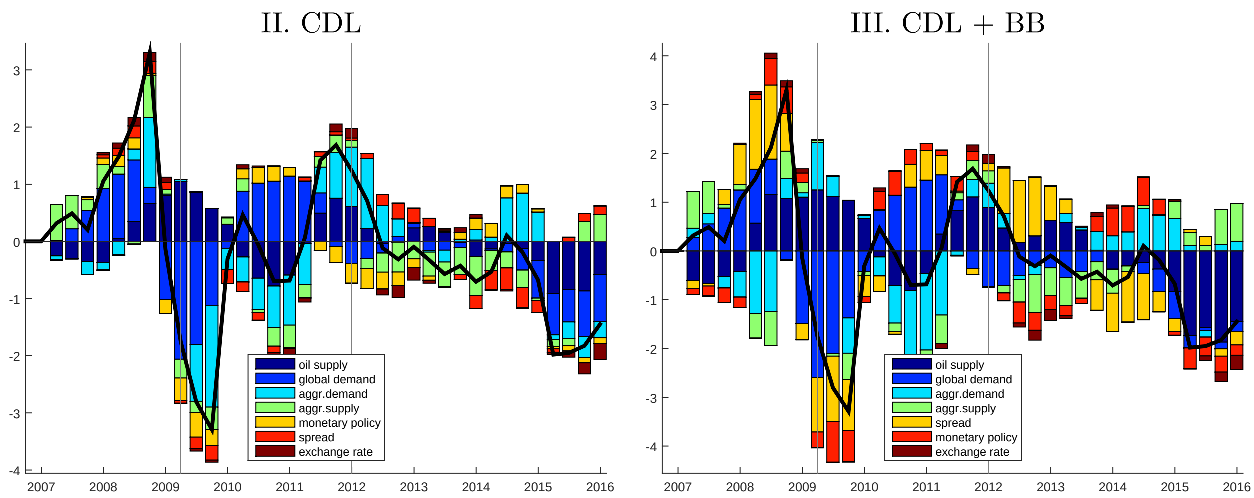


Figure C.2: Historical decompositions of US CPI: disaggregated effects of all the shocks

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