Exchange Rate Shocks and Inflation Comovement in the Euro Area[*]

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December 19, 2018

Abstract

In this paper, we decompose the effect of exchange rate shocks on euro area countries inflation into country-specific (*idiosyncratic*) and region-wide (*common*) components from a time-varying perspective. In doing so, we propose a flexible empirical framework that is based on factor models subject to drifting parameters and exogenous information. Contrary to what the literature established a few years ago, our results indicate that exogenous shocks to the euro/dollar exchange rate have passed to headline inflation with more intensity during recent years, in particular, for the largest economies of the region. The main source of this pattern is found to be in the country-specific component, as a result of increasing commonalities in inflation dynamics. Instead, the region-wide component has remained steady. A similar pattern holds for the energy and food, but not for the core component, of headline inflation.

Keywords: exchange rate, inflation, factor model, structural VAR model.

JEL Classification: E31, F3, F41.

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[*] The views in this paper are those of the authors and do not represent the view of the Banco de España, the European Central Bank or the Eurosystem. No part of our compensations was, is or will be directly or indirectly related to the specific views expressed in this paper. All the remaining errors are our own responsibility.

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1 Introduction

In the context of flexible exchange rate markets, such as the one of the euro and the USD, the exchange rate becomes a relative price which reacts to incoming data that generate changes in the perception of the value of real and financial assets of the corresponding economies. In particular, fluctuations exhibited by the exchange rate may be due to several reasons, which can be broadly grouped into three categories. First, new developments related to fundamentals that determine the economic growth of a country, either on the demand or supply side. Second, changes in the relative monetary policies, which determine the official interest rates affecting the relative performance of the financial assets associated to each country. Third, variations in the exchange rate explained by alternative drivers, which are not directly linked to fundamentals or monetary policy, and can cause strong and rapid movements in the exchange rate dynamics that are hard to identify and predict. These driving forces are explained by changes in the confidence or sentiment of agents, operating in the exchange market, in favor of one economy and against another, and are usually referred to as exogenous exchange rate shocks.

From a policy maker standpoint, assessing the impact that those exogenous exchange rate shocks may have on inflation is crucial for the design of monetary policy frameworks. A prolific literature has focused on analyzing the effect that exchange rate fluctuations may have on prices, starting from seminal theoretical studies, such as Krugman (1987) and Dornbusch (1987), which showed that the exchange rate pass-through to prices was incomplete due to imperfect competition and pricing-to-market, to cross-country empirical evidence, as in Campa and Goldberg (2005, 2010), focusing on slow-moving structural determinants such as changes in the composition of imports. More recently, several papers have tried to identify those factors behind the evolution of the exchange rate pass-through (ERPT) to prices over time from a micro data on firm pricing perspective. Among them it is worth mentioning seminal papers by Gopinath et al. (2010), Berger and Vavra (2013), Devereaux et al. (2015), and Amiti et al. (2016). They hihglight drivers such as the role of invoicing currency, whether the transactions take place between or within firms, the frequency and disperson of prices adjutstments and the role of competition in final products markets.

Yet, albeit there exists a general consensus that the exchange rate pass-through to prices is state dependent (i.e., the exchange rate and prices are both endogenous variables and will be jointly driven by other shocks), very few attempts to measure its changes over time have been conducted from an empirical macroeconomic modelling approach.[1] A recent line of research focusing on the different response of prices depending on the origin of the shocks behind exchange rate fluctuations is an exception. For example, Forbes et al. (2015, 2018), following the work of Shambaugh (2008), estimate a structural Vector Autoregression (SVAR) framework for the UK as a small open economy and find that inflation is more sensitive to exchange rate movements in the wake of the crisis. They highlight the fact that in order to explain changes through time, it is essential to distinguish the driving forces behind the fluctuations in the exchange rate (i.e., whether it is due to domestic demand, global demand, domestic monetary policy, global supply shocks, domestic productivity, etc.), finding that domestic monetary policy shocks are those with relatively higher price response relative to that of the exchange rate. Comunale and Kunovac (2017) apply the same methodology to the case of the euro area and its four largest members - Germany, France, Italy and Spain- and find a similar result: the sensitivity of prices to exchange rate changes is not constant over time but depends on the composition of economic shocks driving the exchange rate, with the largest pass-through stemming from relative monetary policy shocks and exogenous exchange rate shocks.

This paper builds from this literature of non constant pass-through of exchange rate changes to inflation. Starting from the identification of the shocks behind exchange rate fluctuations in the euro area in recent years, we elaborate further on the time variation and cross-country differences in the response of prices to exchange rate movements. This paper proposes a new unified multi-country framework to jointly assess both the time-variation in the sensitivity of inflation to exchange rate shocks and the decomposition of such sensitivity into country-specific and region-wide components in the euro area economies.

In particular, we first identify exogenous exchange rate shocks from a structural vector autoregression for the aggregate euro area economy. We focus in those movements that

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[1] In the empirical macroeconomic arena, the standard approach for estimating the average exchange rate pass-through was based on long-term historic relationships However, this approach clearly neglect the time-varying nature of the relationship.

are purely exchange rate movements rather than induced by changes in fundamentals, that is, exogenous exchange rate shocks typically motivated by changes in market sentiment in favor of one economy. To ensure that the extracted shocks from the VAR have the expected effect on the macroeconomy, according to theoretical models or stylized facts, we rely on shock identification based on sign restrictions as in Forbes (2015, 2018) and Comunale and Kunovak (2017). Next, we use these exchange rate shocks as exogenous information in a dynamic factor model with drifting coefficients estimated jointly on the HICP inflation of all euro area countries. This empirical framework allows us to provide accurate comparisons of the results across economies. Then, the same time-varying dynamic factor model with exogenous information is estimated for the various inflation components.

The contribution of this paper is twofold. First, we investigate potential changes over time in the effect that exogenous exchange rate shocks have on the headline inflation of euro area countries, and on its corresponding components. For ease of exposition, we can express this goal in simple terms with following equation,

$$INF_{i,t} = \phi(L)INF_{i,t-1} + \beta_{i,t}\epsilon_t^{Exo\_ER} + v_{i,t}, \tag{1}$$

where $INF_{i,t}$ is the inflation rate of country i at time t, the term $\phi(L)$ helps to control for past inflation dynamics, the exogenous exchange rate shocks are measured by $\epsilon_t^{Exo\_ER}$, and $v_{i,t}$ represents an error term. Notice that in equation (1), our object of interest is $\beta_{i,t}$, which measures the changing sensitivity of inflation to the shocks.

Second, we provide information about the underlying sources of changes in the effect on inflation of exogenous exchange rate shocks. In doing so, we decompose such an effect into two parts. The first one measures the part of the effect that is exclusively related to the inflation dynamics of country i. Instead, the second one measures the part of the effect that is common across all countries that belong to the euro area. This decomposition can be illustrated with the following equation,

$$\beta_{i,t} = IDI_{i,t} \times COM_t, \tag{2}$$

where $IDI_{i,t}$ denotes the idiosyncratic, or country-specific, component, while COM_t denotes the common, or region-wide, component.[2] The information contained in equation (2) can be useful for policy makers to understand up to which extent movements in inflation of a given country, induced by exchange rate shocks, can be attributed to its exclusive and intrinsic economic performance or to the overall performance of all the partners in the monetary union.

Overall, the paper provides a full spectrum of the effect of exogenous exchange rate shocks on inflation across (i) countries, (ii) subcomponents, and (iii) time. In particular, the main results show that the sensitivity of headline inflation to exogenous exchange rate shocks has increased since the early 2010s. That is, an unexpected appreciation of the euro versus the dollar, occurred after 2010, leads to larger declines in inflation than before that time. This increase is systemic: most euro area countries have experienced it. Moreover, when assessing the source of such increasing sensitivity, it is found that the region-wide component, which can be interpreted as the effect of exchange rate shocks to the aggregate euro area inflation, has remained relatively stable over time. Instead, the country-specific component has exhibited a substantial increase since the early 2010's. This implies that the increasing sensitivity of headline inflation to exchange rate shocks heavily relies on a sustained surge in comovement between the inflation rates of euro area countries.

When applying the proposed empirical framework to different subcomponents of headline inflation, that is, energy, food and core components, the results indicate a heterogeneous pattern. For the case of the energy component of inflation, its sensitivity to exogenous exchange rate shocks has also significantly increased in recent years. However, unlike the case of headline inflation, such increasing sensitivity relies equally on both the country-specific and region-components. For food-related inflation rates, the pattern is similar to the case of headline inflation, although with less significance. The case of core inflation is somehow different. Core inflation across countries does not seem to be meaningfully affected by exogenous exchange rate shocks. This is not due to the country-specific component, but to the region-wide component.

The structure of the paper proceeds as follows. Section 2 sets out the empirical approach. Section 3 discusses the main results. Section 4 concludes.

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[2] In a recent work, Leiva-Leon and Uzeda (2018) provide a novel empirical framework to also endogenously assess the underlying structural sources driving parameter instabilities in VAR models.

2 Empirical Framework

In this section we provide an empirical framework to investigate the effects of exchange rate shocks on euro area inflation across both the geographic dimension and time-dimension. Therefore, we are interested in a modelling approach that fulfills three main features. First, that allows to properly identify exchange rate shocks for the euro area economy as a whole, given the unified monetary system. Second, that allows us to estimate how the effect of those exchange rate shocks propagate across the different countries in the euro area. Third, that provides us information about the potential changes over time in the degree of exposure of each country to those socks.

We proceed in two steps. First, we make use of a structural VAR model to identify purely exogenous exchange rate shocks. Second, conditional on those exchange rate shocks, obtained from the first step, we investigate their time-varying effect on inflation across euro area countries.

2.1 Structural VAR Model

We employ a structural VAR (SVAR) model to investigate the exchange rate sensitivity of euro area inflation by taking into account how different theory-based shocks may impact the exchange rate and prices. In particular, we are interested in assessing the effects of five shocks to the euro area economy: domestic supply, domestic demand, global demand, relative monetary policy and exogenous exchange rate shocks. Under such a setting, a euro appreciation mainly driven by higher relative growth of the euro area demand is expected to increase inflation[3], limited by cheaper imported products. However, if the appreciation responds to a relative tightening of monetary policy in the euro area, which promotes a higher relative assets yields in euros, demand is expected to decrease along with prices in the euro area. In addition, the appreciation reduces import prices measured in euros, thus intensifying the fall in prices after the monetary restriction. Similarly, if the appreciation is due to an exogenous change, not based on fundamentals regarding real activity or monetary

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[3] Due to the higher weight of domestic against imported goods in the european economies, an increase in the demand of goods in euros would exert an upward pressure on the euro pricing. Apart from that, if the monetary authority reacts to higher inflation by rising the interest rates, the higher asset yields in euros would exert further pressures towards a euro appreciation.

policy, import prices are expected to fall and therefore, although to a lesser extent, so will consumer prices.[4]

The SVAR model is estimated using data on real GDP growth rate (GDP), HICP inflation (INF), relative shadow short-term interest rates (INT)[5], nominal bilateral euro/dollar exchange rate (FX), and the share of euro area GDP relative to that of the US (EA/US).[6] Accordingly, let the vector collecting of the variables be, $\mathbf{Y}_t = [GDP_t, INF_t, INT_t, FX_t, EA/US_t]$, then the SVAR model is given by,

$$\mathbf{Y}_t = \Phi_0 + \sum_{p=1}^{P} \Phi_p \mathbf{Y}_{t-p} + \mathbf{B}\epsilon_t, \tag{3}$$

with $\epsilon_t \sim N(0, I)$, being the structural innovations. Hence, the reduced form innovations, defined as $\mathbf{u}_t$, are related to the structural innovations through the impact multiplier matrix $\mathbf{B}$, that is, $\mathbf{u}_t = \mathbf{B}\epsilon_t$.[7]

To identify the structural shocks of interest, we rely on imposing sign restrictions in some of the entries of the impact multiplier matrix. In particular, we assume that a positive domestic supply shocks, $\epsilon_t^{Dom\_Sup}$, increases output and relative euro area activity share, while it decreases inflation, interest rate and depreciates the euro. Instead, a positive domestic demand shocks, $\epsilon_t^{Dom\_Dem}$, would increase inflation, interest rate, output and relative euro area activity. An unexpected tightening in the monetary policy stance of the euro area relative to the US, $\epsilon_t^{Mon\_Pol}$, is assumed to decrease output and inflation, while increasing the interest rate. We also assume that a positive shock in global demand, $\epsilon_t^{Glo\_Dem}$, is associated to increase in output and inflation, but to declines in relative euro

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[4] For example, in September 2017, the European Central Bank (see Coeuré, 2017) estimatons suggested that the recent appreciation against the US dollar was motivated approximately equally by three factors: (i) a higher relative demand in the euro area with respect to the US; (ii) a looser tone of the ECB's monetary policy: and (iii) an appreciation of the euro not based on fundamentals. The last two factors would imply a downward pressure on inflation, but the former mitigated it resulting in an estimated impact on inflation which was very limited.

[5] Shadow short rates are based on estimates from Krippner (2013) for the euro area and the US. Model results are robust to different monetary policy measures such as: (i) relative official interest rates in the EA and the US; and (ii) shadow interest rates from Wu and Xia (2016).

[6] SVAR model results are robust to an alternative estimation for the nominal effective exchange rate (NEER - 38 countries). Some caveats arise, though. Those variables proxying global demand and relative monetary policy are measured only in relation with the US, not the enterily set of 38 countries used in the NEER definition.

[7] In the empirical application, we use a number of lags equal to $P = 2$.

area activity. Finally, we assume that an unexpected exogenous appreciation of the euro, $\epsilon_t^{Exo\_ER}$, would lead to declines in inflation and interest rate but a rise in output. We interpret this non-fundamental appreciation of the euro against the USD as one due to a change in market sentiment in favor of the euro economy. Hence, it has a positive impact on GDP, which will put upward pressure on prices. However, the direct effect of the appreciation, i.e. cheaper imports, drives the decline in euro area consumer prices. The euro appreciation also has a downward impact on the relative interest rates of the euro area as it drives its inflation downwards while bringing US inflation upwards[8]. All these restrictions can be formalized as follows,

$$\begin{bmatrix} u_t^{GDP} \\ u_t^{INF} \\ u_t^{INT} \\ u_t^{FX} \\ u_t^{EA/US} \end{bmatrix} = \begin{bmatrix} + & + & - & + & + \\ - & + & - & - & + \\ - & + & + & - & * \\ - & * & * & + & * \\ + & + & - & * & - \end{bmatrix} \begin{bmatrix} \epsilon_t^{Dom\_Sup} \\ \epsilon_t^{Dom\_Dem} \\ \epsilon_t^{Mon\_Pol} \\ \epsilon_t^{Exo\_ER} \\ \epsilon_t^{Glo\_Dem} \end{bmatrix},$$

where the entries with an "$*$" in the impact multiplier matrix indicates that such a relation is left unrestricted. The model is estimated using Bayesian methods to deal with the dimensionality problem. In particular, the independent Normal Inverse-Wishart prior is assumed to simulate the posterior distribution of the reduced-form parameters. Structural shocks are identified by following Arias et al. (2014), where sign restrictions are imposed on impulse response functions at impact.

2.2 Factor Model with Exogenous Information

We use the exogenous exchange rate shocks estimated in the structural VAR model to assess their effect on inflation across euro area countries and across time. To that end, we rely on a multivariate framework subject to time-varying coefficients, following the line of Ductor and Leiva-Leon (2016), that allows to address the this issue from a unified perspective.

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[8] For robustness sake, an alternative identification strategy concerning an unexpected appreciation of the euro (exogenous structural exchange rate shock) is developed in the Appendix A.2. It provides broadly similar results.

Consider the standardized inflation rate of country i defined as, $\pi_{i,t} = (INF_{i,t} - \mu_{i,inf})/\sigma_{i,inf}$, where $\mu_{i,inf} = mean(INF_{i,t})$ and $\sigma_{i,inf} = std(INF_{i,t})$. We propose the following time-varying parameter factor model with exogenous information, which is referred to as TVP-DFX,

$$\pi_{i,t} = \gamma_{i,t} f_t + u_{i,t}, \tag{4}$$

$$f_t = \phi_t f_{t-1} + \lambda_t \epsilon_t^{Exo\_ER} + \omega_t, \tag{5}$$

where $u_{i,t} \sim N(0, \sigma_i^2)$ and $\omega_t \sim N(0, 1)$. Notice that equation (4) decomposes the country-specific inflation, $\pi_{i,t}$, into a common component, f_t, and an idiosyncratic component, $u_{i,t}$. Instead, equation (5) assumes that the common factor follows autoregressive dynamics, and that it can be influenced by exogenous information, in particular, by the exogenous exchange rate shocks, $\epsilon_t^{Exo\_ER}$.

The parameters of the model are assumed to evolve according to random walks to account for potential instabilities over time,

$$\gamma_{i,t} = \gamma_{i,t-1} + \vartheta_{i,t} \tag{6}$$

$$\phi_t = \phi_{t-1} + \vartheta_{\phi,t} \tag{7}$$

$$\lambda_t = \lambda_{t-1} + \vartheta_{\lambda,t} \tag{8}$$

where $\vartheta_{i,t} \sim N(0, \nu_i^2)$, $\vartheta_{\lambda,t} \sim N(0, \nu_\lambda^2)$, and $\vartheta_{\phi,t} \sim N(0, \nu_\phi^2)$

$\gamma_{i,t}$ and λ_t will be crucial parameters in the analysis conducted in this paper. The time-varying degree of inflation comovement across countries is captured by $\gamma_{i,t}$, which measures the propagation of movements in the common factor to individual countries inflation. Instead, λ_t measures the dynamic sensitivity of the common inflation factor to changes in the exogenous variable, in our case to exogenous exchange rate shocks. Finally, ϕ_t measures changes in the persistence of the common inflation factor.

When plugging equation (4) into equation (5) we remain with the following equation,

$$INF_{i,t} = \tilde{\beta}_{i,0} + \tilde{\beta}_{i,1,t} f_{t-1} + \tilde{\beta}_{i,2,t} \epsilon_t^{Exo\_ER} + \tilde{v}_{i,t} \tag{9}$$

where $\tilde{\beta}_{i,0} = \mu^i_{i,inf}$, $\tilde{\beta}_{i,1,t} = \sigma_{i,inf}\gamma_{i,t}\phi_t$, $\tilde{\beta}_{i,2,t} = \sigma_{i,inf}\gamma_{i,t}\lambda_t$, and $\tilde{v}_{i,t} = \sigma_{i,inf}(\gamma_{i,t}\omega_t + u_{i,t})$. Notice that there is a direct correspondence between equation (9) and equation (1), in particular, between the coefficients measuring the sensitivity of inflation to exchange rate shocks in both equations, that is, $\tilde{\beta}_{2,i,t}$ and $\beta_{i,t}$, respectively.

The main advantage of the proposed TVP-DFX model is that it allows us to decompose the effect of exchange rate shocks on inflation, $\tilde{\beta}^i_{2,t}$, into two components. The country-specific, $\gamma_{i,t}$, and region-wide, λ_t, components, which would correspond to the terms $IDI_{i,t}$ and COM_t, respectively, from equation (2). The term λ_t provides information about the changing effect that exchange rate shocks have on the euro area inflation dynamics, proxied by the factor f_t. Instead, the term $\gamma_{i,t}$ provides information about the changing propagation of those shocks throughout the different countries of the euro area.

3 Sensitivity of Prices to Exchange Rate Shocks

3.1 An Aggregate Assessment

After estimating the SVAR model with data from 1995Q1 to 2018Q4, we obtain the historical shock decomposition of the exchange rate dynamics. Figure 1 shows the average growth rate in each quarter during the last five years of the bilateral nominal exchange rate of the euro against the US dollar along with the contributions of the driving factors identified in the structural VAR: innovations to real activity (from domestic demand and supply, or from the rest of the world), relative monetary policy, and exogenous factors not linked to fundamentals. These exogenous factors reflect changes in market sentiments among agents who operate in foreign exchange markets in favor of one economy against the other and they seem to have played a substantial role over the sample period.

According to this analysis, the appreciation of the euro against the USD between 2017Q2 and 2018Q1 could have been mainly driven by higher relative growth in the euro area. However, exogenous factors are also found relevant, possibly indicating a relative higher confidence in the euro over the second half of 2017. Finally, the perception that the ECB's monetary policy was somewhat less loose at the end of 2017, in relative terms, than in previous quarters (in 2016Q4-2017Q1 it was the other way round) also contributed to that period of appreciation. The shocks that led to greater GDP growth in the euro area would have exerted an inflationary pressure. However, this positive effect on inflation would have been largely offset by the deflationary effect of the change in the perceived tone of monetary policy and of the exogenous factors of appreciation (through a reduction in import prices), in line with the results suggested by Coeuré (2017), with data up to 2017Q2. Instead, the recent depreciation of the euro against the USD since February 2018 seems to have been initially motivated mainly by exogenous factors, while the lower relative growth rate of activity in the euro area would also have played a relevant role in the depreciation, especially in 2018Q3.

A number of variants of our model have also been estimated to test whether the main results on the historical decomposition of shocks were sensitive to: alternative identification strategies, different lag orders and different sign restriction periods. The robustness results summarized in Appendix A.2 show no remarkable differences.

3.2 The Role of Inflation Commonalities

We then estimate time-varying panel of equation (9) on the HICP inflation rates of all euro area countries for the period 1995Q1-2018Q4 [9] and the exogenous exchange rate shock series from the SVAR. The common factor extracted from the headline inflations across individual countries is plotted in Figure 2. It shows a strikingly similar pattern to the actual headline inflation for the euro area aggregate. Therefore, the estimated factor can be interpreted as a proxy for the euro area headline inflation dynamics. Figure 3 plots the estimated time-varying sensitivity of countries headline inflation to exchange rate shocks, that is, $\tilde{\beta}_{i,2,t}$. The estimates indicate a persistent increase in the effect of shocks on inflation occurred around 2010. This is a general pattern for most of the countries, but it is accentuated for the largest ones. This is the case of France, Germany and Italy, who exhibited a sensitivity of around 0.1, before 2010, but since then it kept increasing, until reaching a value of 0.2. For the case of Spain, the increase is even larger, going from 0.2, before 2010, to 0.4 after that time. Some smaller economies, such as, Portugal, Finland or Malta, have also experience an increasing sensitivity, but with a smaller persistence.

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[9] except Slovakia, for data availability reasons.

Since the estimated common factor is a good proxy for the euro area headline inflation, the time-varying parameter λ_t can be interpreted as the changing effect of exogenous exchange rate shocks to aggregate euro area inflation rate. Chart (a) of Figure 4 plots the dynamics of λ_t, showing that, in general, it has remained steady with the only exception of the Great Recession period, when exchange rate shocks did not seem to have a significant effect on the euro area headline inflation. Instead, Chart (b) of Figure 4 shows the time-varying persistence of the inflation factor, showing a slightly declining pattern since 2008. This implies that inflation has potentially become more difficult to predict, at least with autoregressive models, since the Great Recession.

Having increasing sensitivity across countries along with a relatively stable sensitivity for the aggregate euro area, can be rationalized through an increasing degree of commonality in headline inflation across countries in the area. That is, the propagation of a similar change in the common component of inflation gets more intense after the crisis and delivers larger impacts on the individual inflation rates of the countries. Figure 5 shows the estimated time-varying loadings, which measure the changing contemporaneous relationship between country-specific inflation measures and their common factor. As expected, the figure reports sustained increases over time in the synchronization of headline inflation dynamics for most of the countries.

The TVP-DFX framework is also applied to model the subcomponents of headline inflation across euro area countries, that is, core, food and energy components. We start analyzing the case of the core component of headline inflation. Figure 6 plots the common factor on core inflation, showing that, although the factor and the euro area core inflation follow a similar pattern, their similarity is not as marked as in the case of headline inflation. This points to a potentially lower degree of comovement in the core component of inflation. Moreover, Figure 7 shows that the effect of exchange rate shocks on core inflation across countries is both negligible and very uncertain. This is also the case when assessing the effect of the shocks on the aggregate Euro Area core inflation, see Chart (a) of Figure 8. Also, Chart (b) of Figure 8 shows that the persistence of the core inflation has remained steady. As expected, Figure 9 shows that the pattern of core inflation comovement across countries is more heterogenous than for the case of headline inflation. Although some countries have exhibited increasing degree of comovement, such as Italy or France, most countries have shown a relatively stable, or even decreasing pattern, such as the case of Latvia. That is, there is a less clear pattern of significant and increasing propagation of movements in the common component to individual countries as was the case with headline inflation.

Next, we apply the same framework to the food and energy subcomponents of inflation. Figures 10 and 14 show the estimated factor, respectively, along with the corresponding euro area aggregate inflation, showing also a strikingly similar pattern, as in the case of headline inflation. While the increase in the effect of exchange rate shocks on inflation, occurred since 2010, has been significant the case of energy, it has been rather weak and more uncertain for the case of food, see figures 11 and 15. Since the degree and evolution of comovement experience by inflation rates associated to the two categories has bee relatively similar, as shown in figures 13 and 17, the difference between the sensitivity of food and energy inflation relies on the impact that exchange rate shocks have on the corresponding euro area aggregates. That is, the effect of shock on euro area food inflation has not changed substantially over time, but the sensitivity of aggregate energy inflation to unexpected exchange rate movements substantially increased since 2009, as show in Charts (a) of figures 12 a 16, respectively.

Notice that the exogenous exchange rate shocks, extracted from the structural VAR model in Section 2.1, represent a key piece of information in our analysis. Therefore, for robustness purposes, we repeat all the estimations about the time-varying effect of exchange rate shocks on inflation and its underlying source but using different measure of exogenous shocks. These alternative measures of shocks are based on Comunale and Kunovac (2017) and Forbes et al. (2018). The first approach identifies six economic shocks: euro area aggregate supply shock, euro area aggregate demand shock, global supply shock, global demand shock and finally, an exogenous exchange rate shock. Block exogeneity is needed in contrast to Forbes et al. (2018), whose model is based on a small open economy and applied to the UK. In the latter, persistent against transitory global demand shocks are also taken into consideration.

The effect of the alternative exchange rate shocks on the different measures of euro area inflation are plotted in Figures 19 and 20, showing estimates that are consistent with the ones obtained with the shocks based on the VAR proposed in this paper, providing additional support for our results.[10]

4 Conclusions

In this paper, we decompose the time-varying effect that exogenous unexpected movements in the euro/dollar exchange rate have on different measures of inflation of the euro area countries into a country-specific and region-wide component. In doing so, we propose an econometric framework that relies on a dynamic factor model subject to drifting coefficients and exogenous information. The main results indicate that headline inflation, and in particular its energy-related component, has become significantly more affected by exchange rate shocks since the early 2010s. While such increasing sensitivity relies solely on a sustained surge in the degree of comovement for headline inflation stemming from an intensified propagation of changes to the euro area-wide component of inflation, it is also based on a higher sensitivity of the region-wide inflation to the shocks for the case of energy-related inflation. For the case of food-related inflation, the effect of exogenous exchange rate shocks is similar to that of headline inflation, but to a much lower extent. Instead, exogenous shocks do not seem to have a significant effect on the core component of headline inflation.

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[10] For the sake of space we only report the effect of the alternative shocks on the aggregate measures of inflation. However, we have computed the effect on the corresponding country-specific inflation. These results are available upon request.

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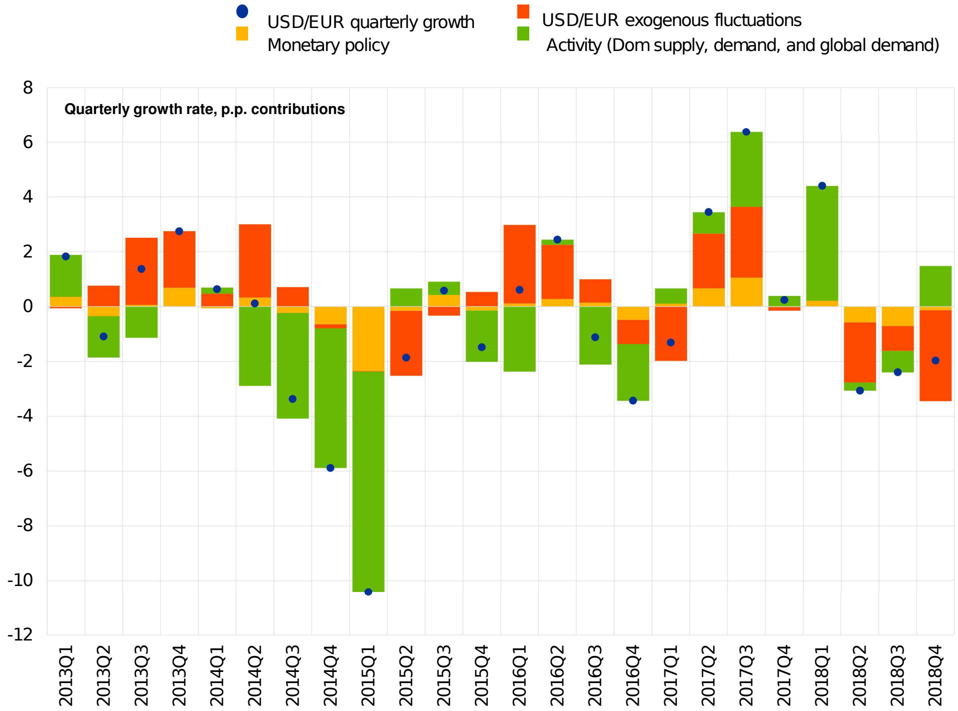
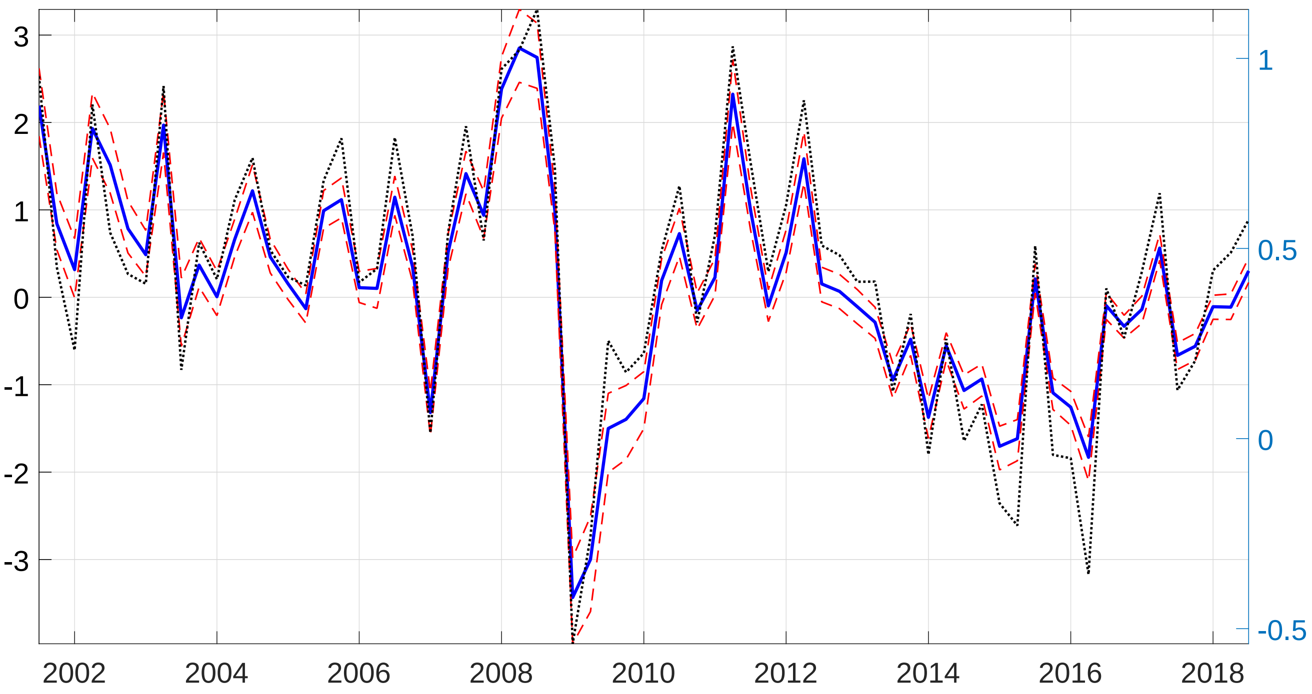
Figure 1: Historical decomposition of nominal exchange rate USD/EUR



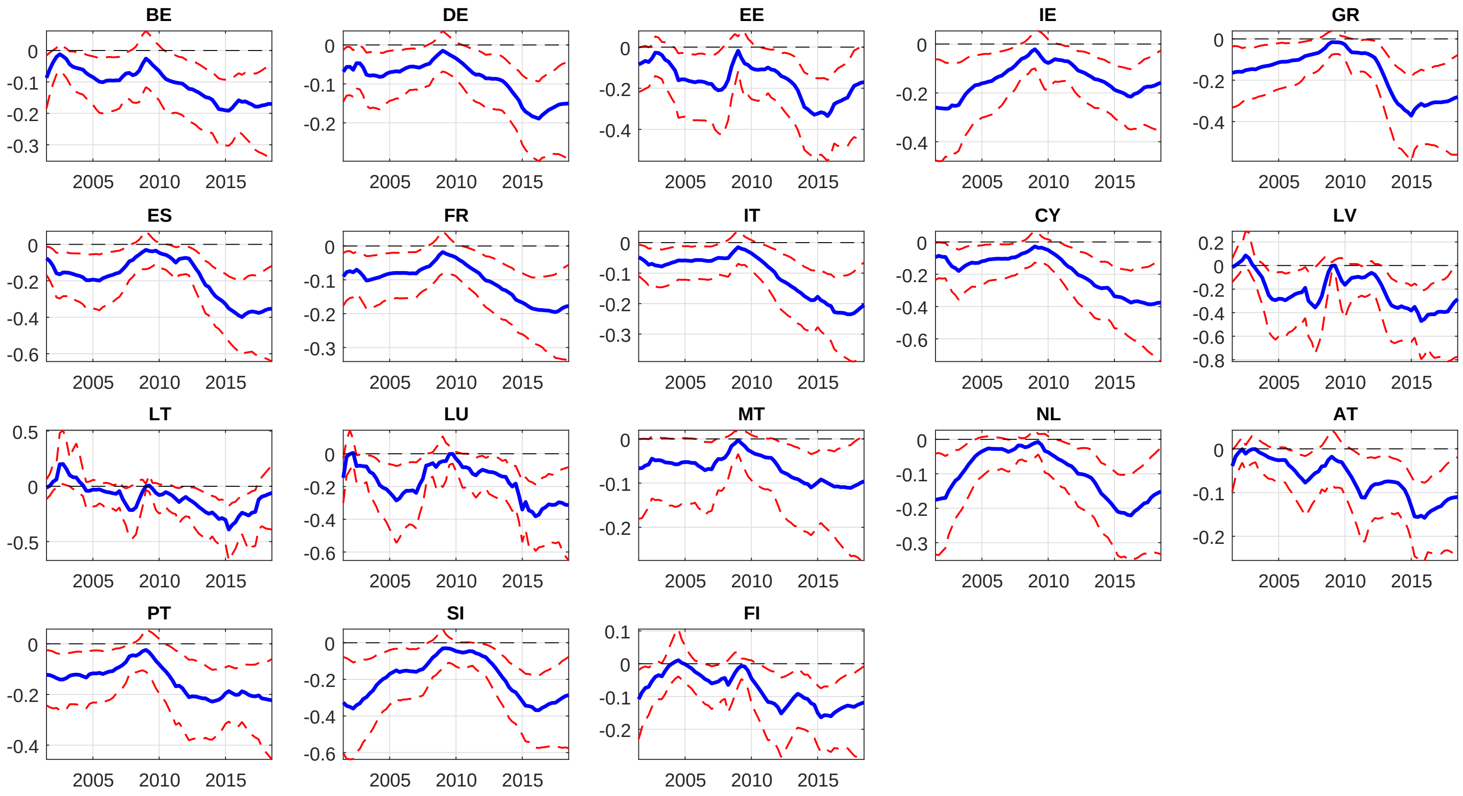
Note: Estimates based on a quarterly SVAR model of the USD/EUR exchange rate where shocks are identified via sign and zero restrictions. Estimates for 2018Q4 are based on data available at the time of the cut-off date (Dec 11, 2018). Data for US and euro area GDP in 2018Q4 are based on nowcasted values, while inflation and monetary policy are approximated based on the respective averages of Oct and Nov 2018. The USD exchange rate movements refer to the quarterly rates of changes of the respective quarters.

Figure 2: Euro area headline inflation factor (f_t)



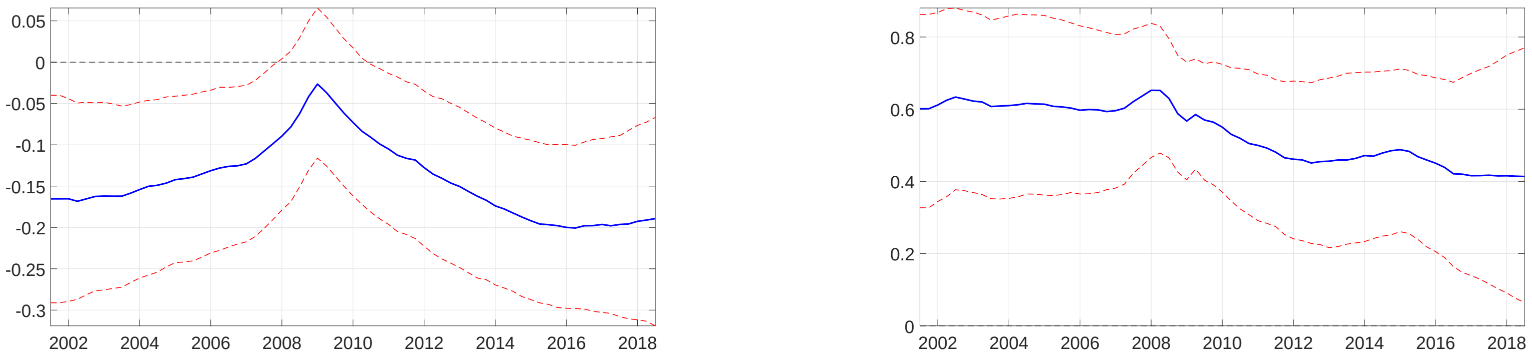
Note: Red dashed lines, aligned with left axis, make reference to the 16th and 84th percentile of the corresponding posterior distribution. Black dotted line, aligned with right axis, make reference to the euro area headline inflation.

Figure 3: Time-varying sensitivity of headline inflation of the euro area countries based on a multivariate model ($(\tilde{\beta}^i_{2,t})$)



Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 4: Time-varying coefficients of model for headline inflation

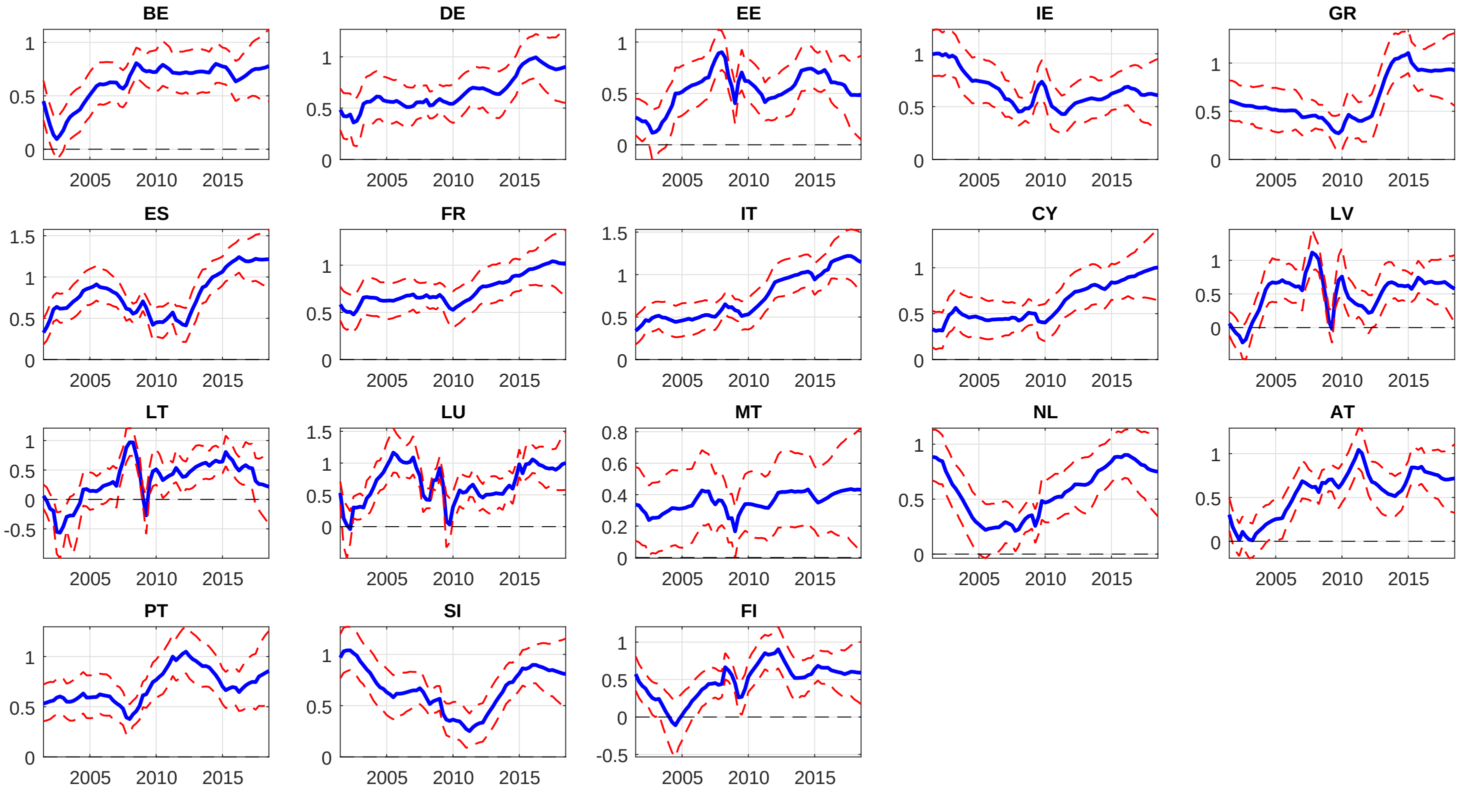


(a) Sensitivity of headline inflation of the euro area (λ_t)

(b) Persistence of the euro area headline inflation factor (ϕ_t)

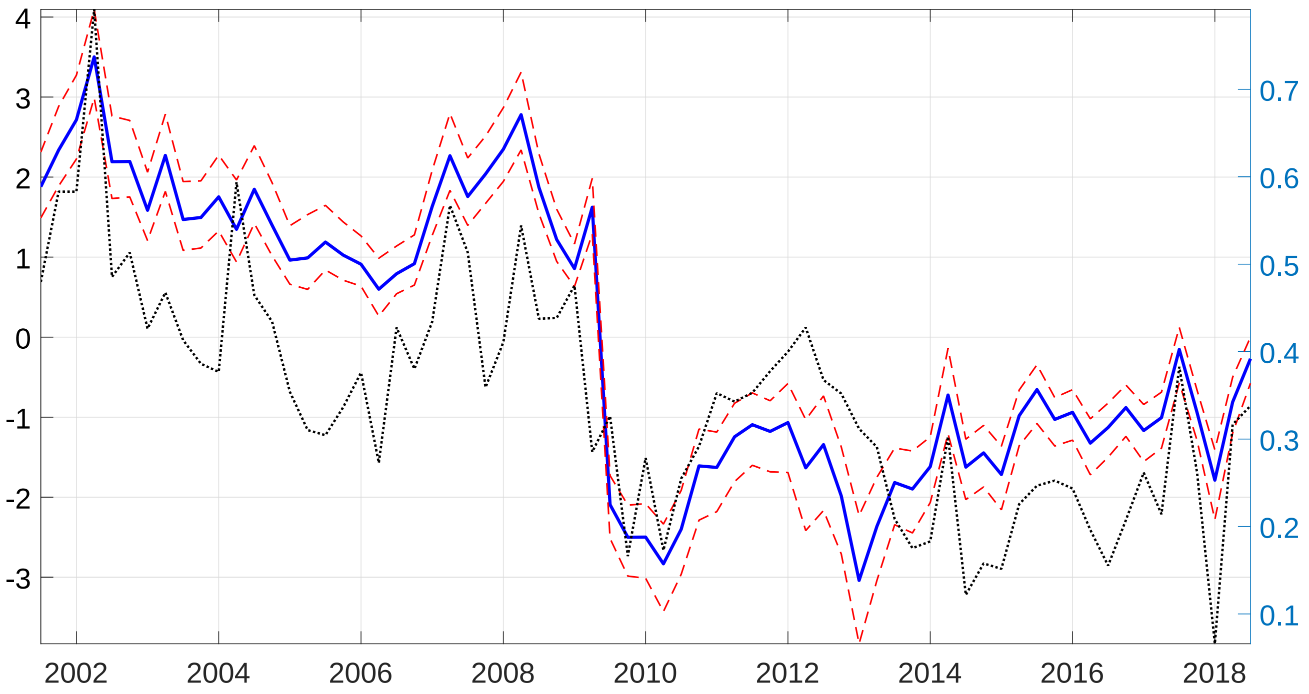
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 5: Time-varying comovement of euro area countries headline inflation ($\gamma_{i,t}$)



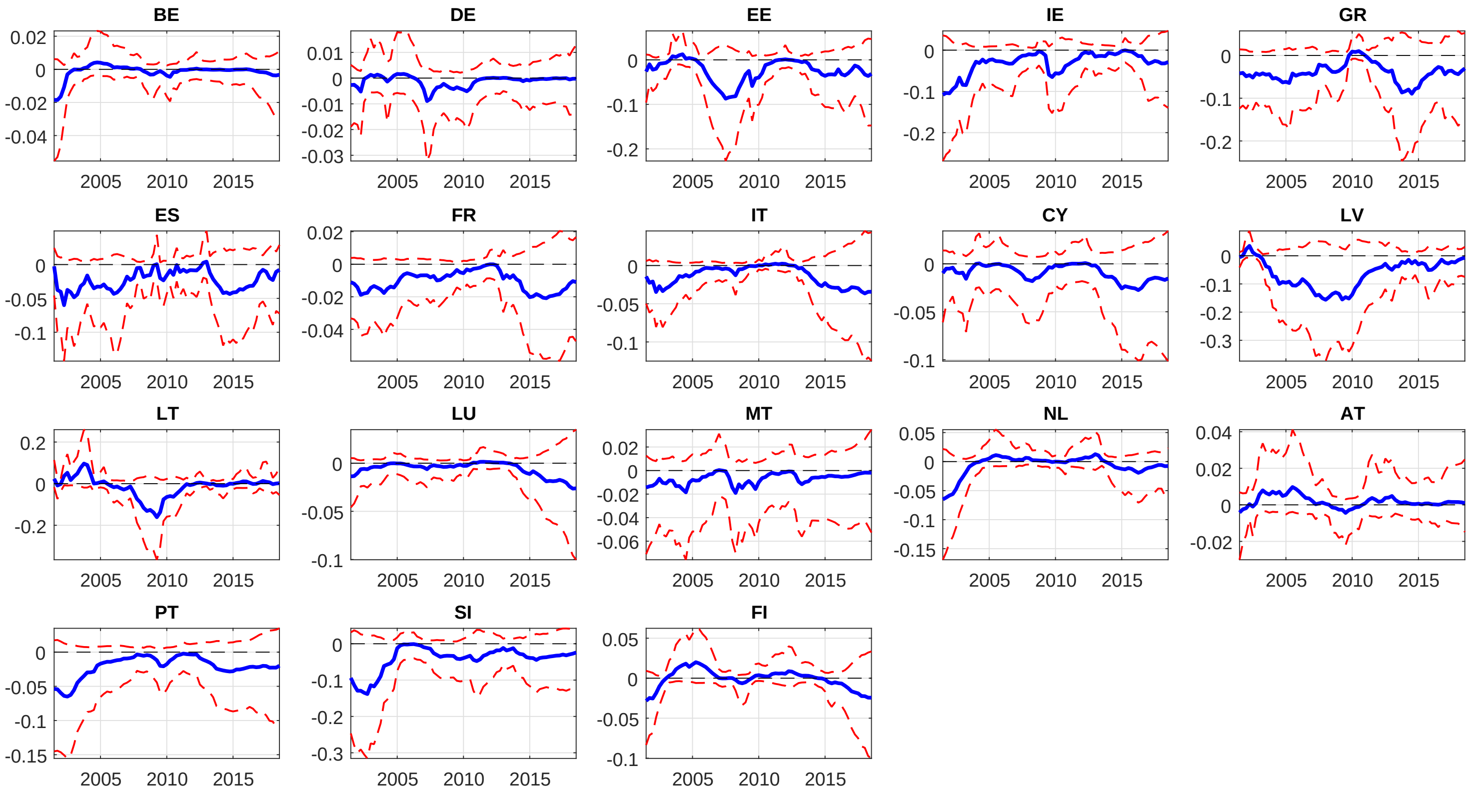
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 6: Euro area core inflation factor (f_t)



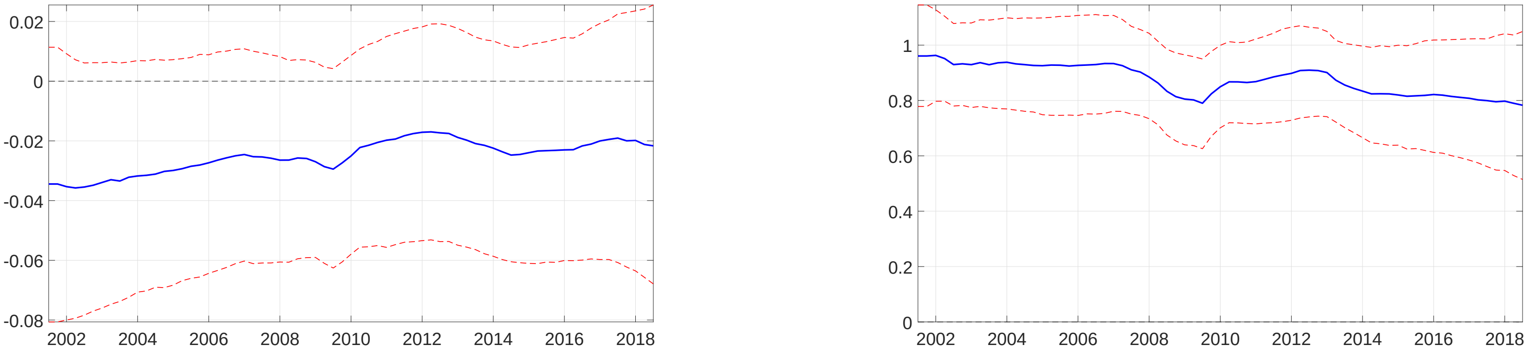
Note: Red dashed lines, aligned with left axis, make reference to the 16th and 84th percentile of the corresponding posterior distribution. Black dotted line, aligned with right axis, make reference to the euro area core inflation.

Figure 7: Time-varying sensitivity of core inflation of euro area countries based on a multivariate model ($\tilde{\beta}^{i}_{2,t}$)



Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 8: Time-varying coefficients of model for core inflation

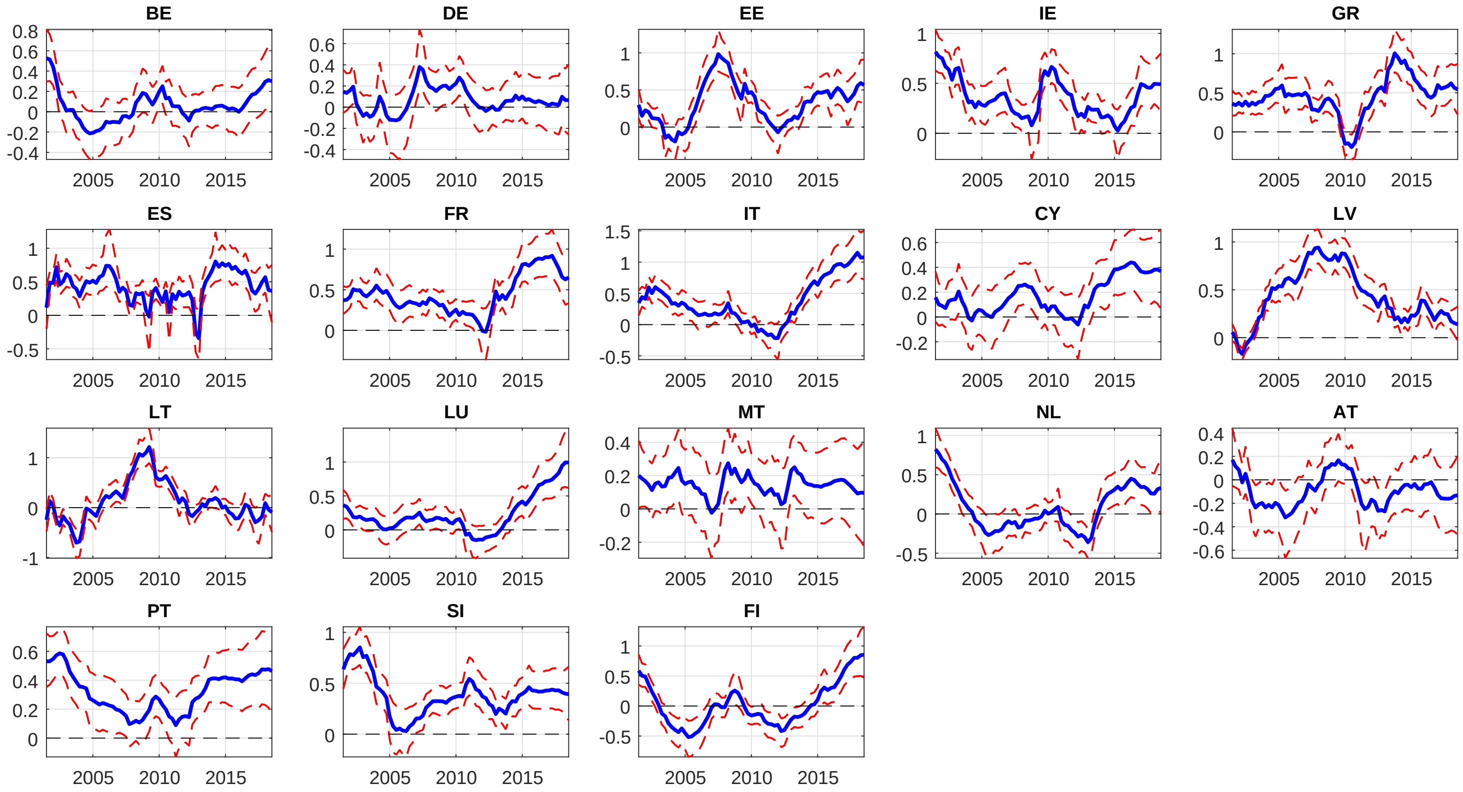


(a) Sensitivity of core inflation of the euro area (λ_t)

(b) Persistence of the euro area core inflation factor (ϕ_t)

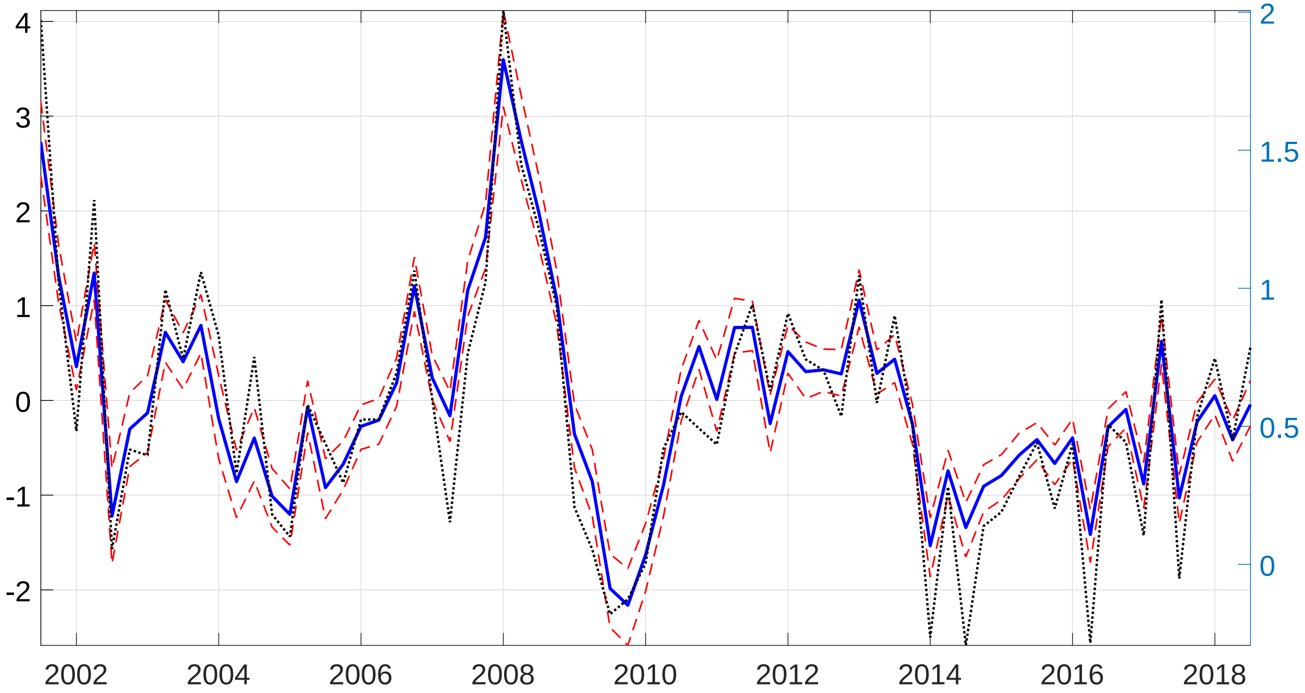
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 9: Time-varying comovement of euro area countries core inflation ($\gamma_{i,t}$)



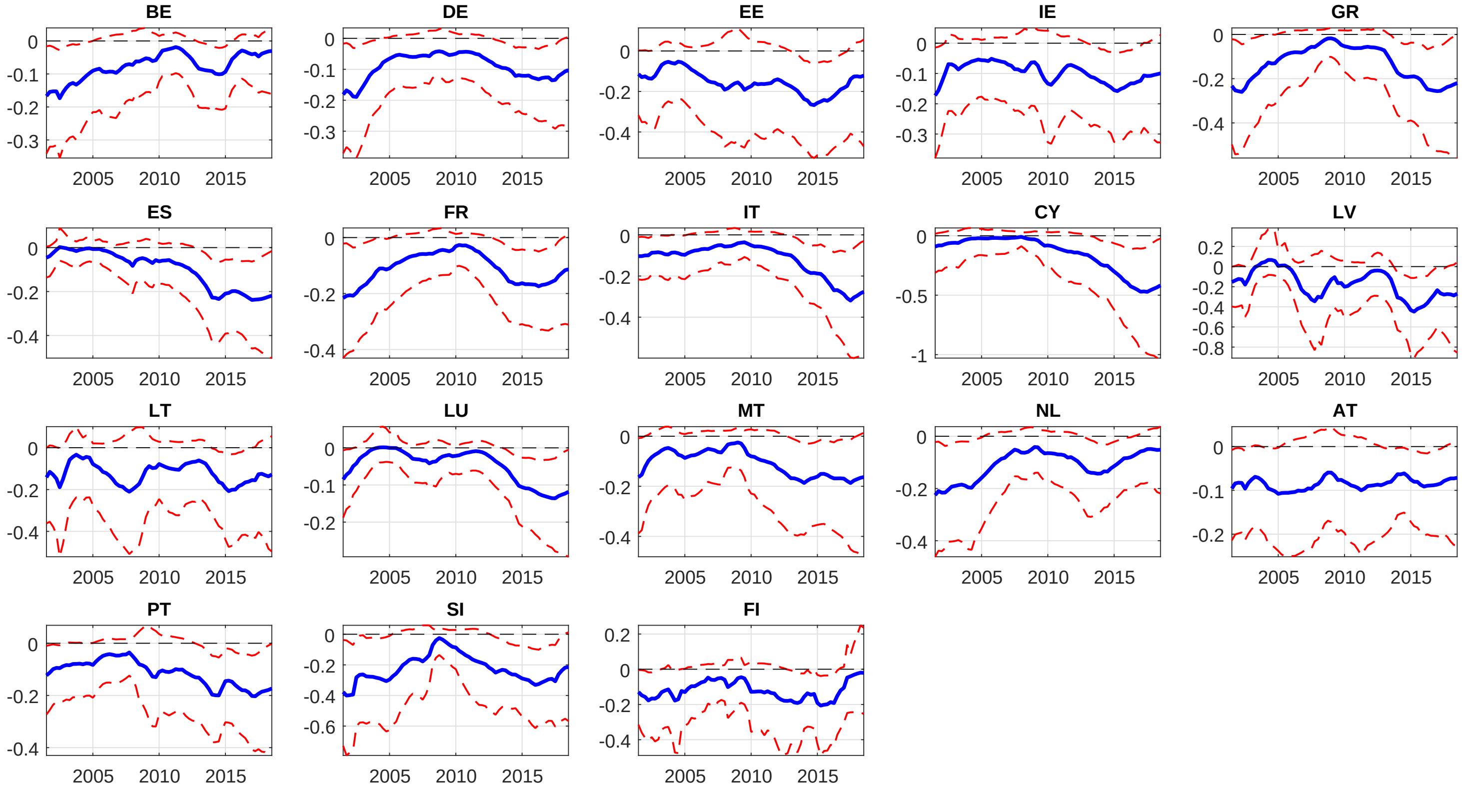
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 10: Euro area food-related inflation factor (f_t)



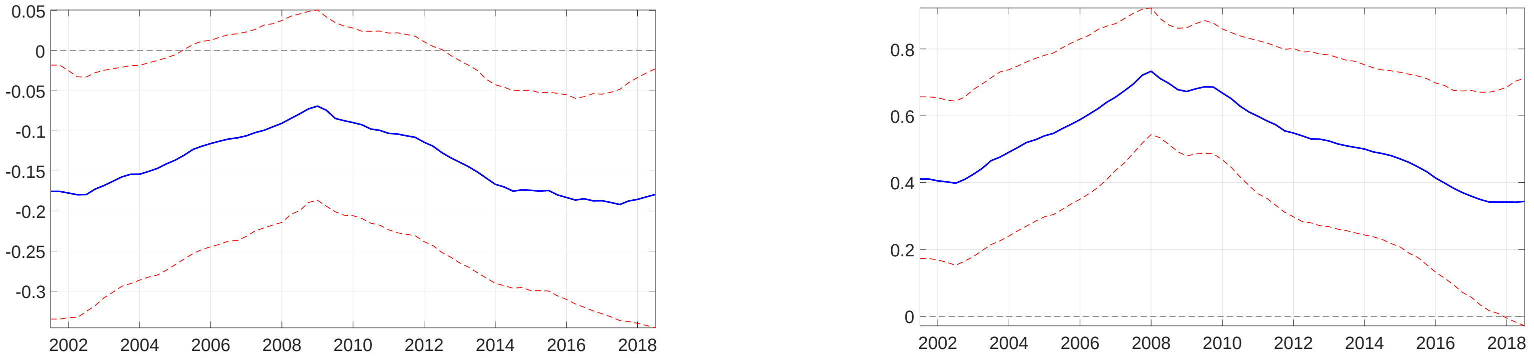
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 11: Time-varying sensitivity of food-related inflation of euro area countries based on a multivariate model ($\tilde{\beta}^{i}_{2,t}$)



Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 12: Time-varying coefficients of model for food-related inflation

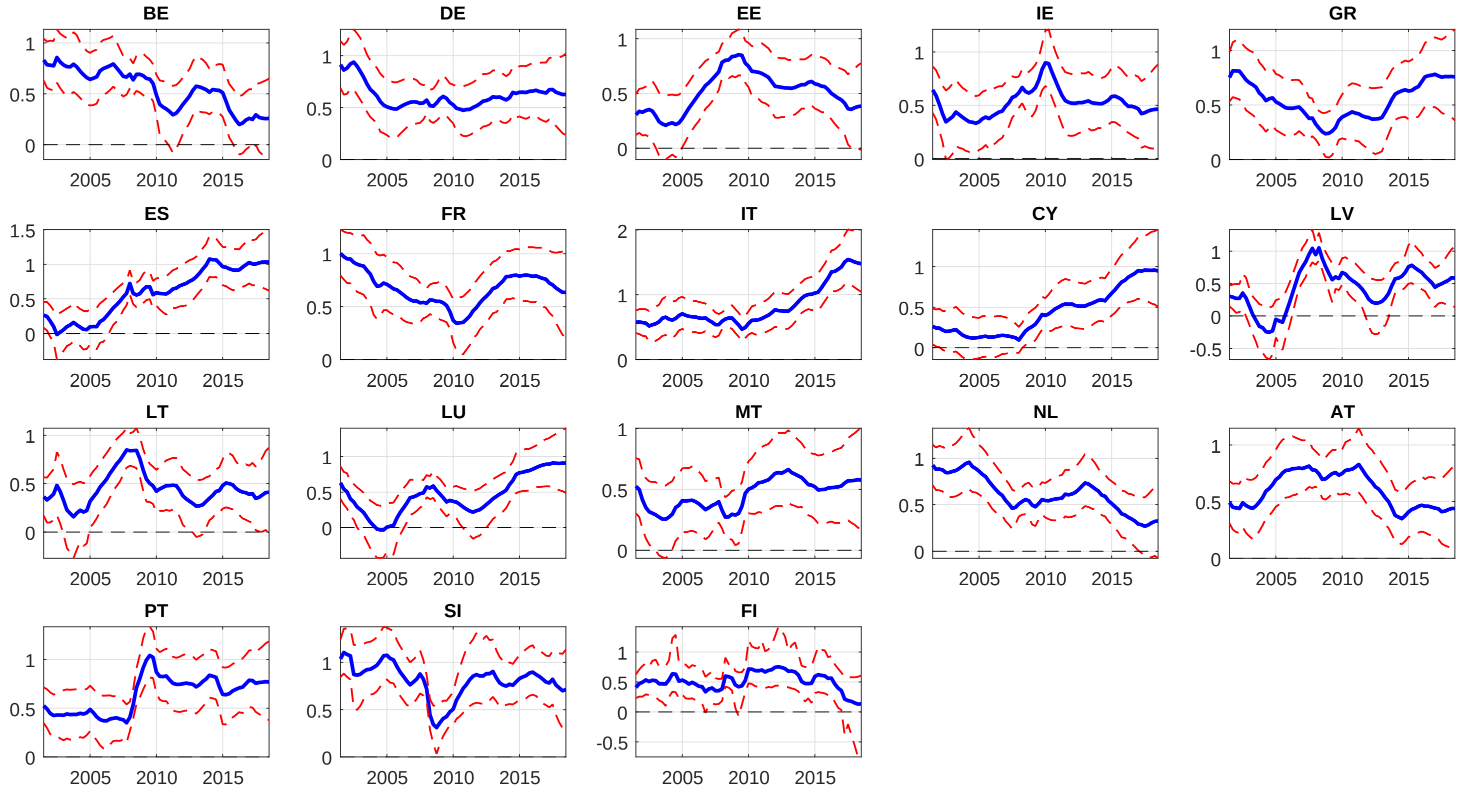


(a) Sensitivity of food-related inflation of the euro area (λ_t)

(b) Persistence of the euro area food-related inflation factor (ϕ_t)

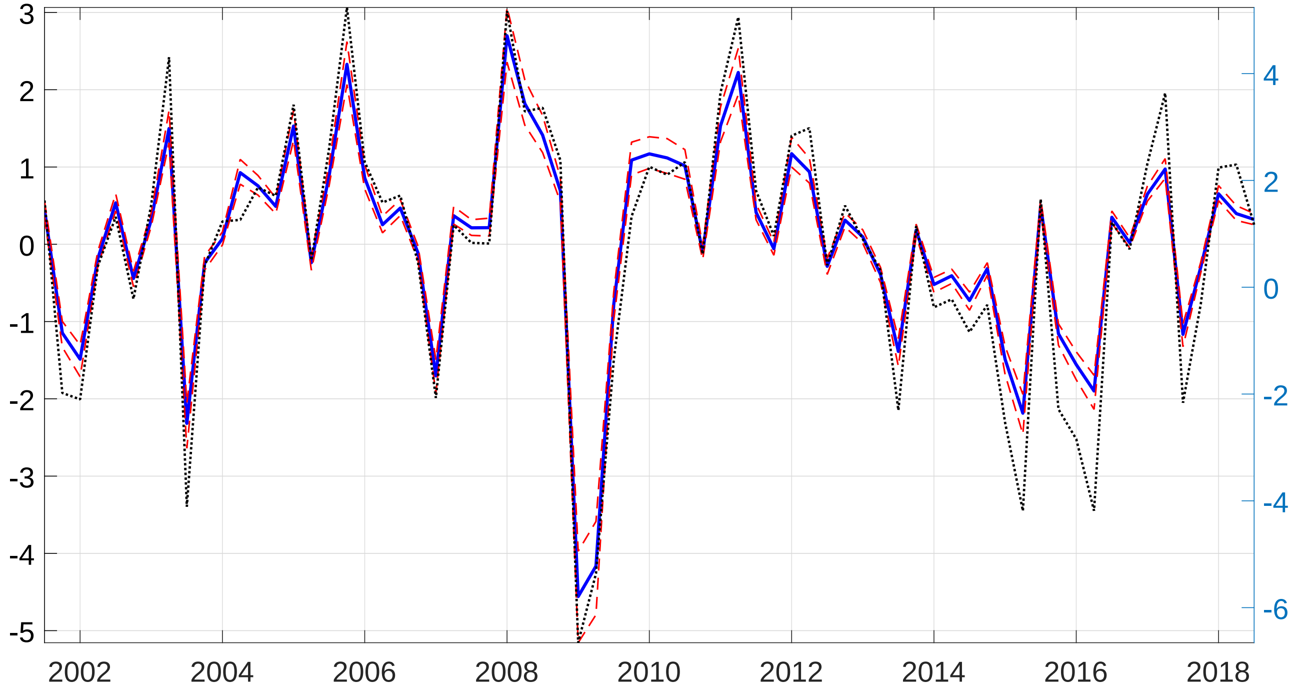
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 13: Time-varying comovement of euro area countries food-related inflation ($\gamma_{i,t}$)



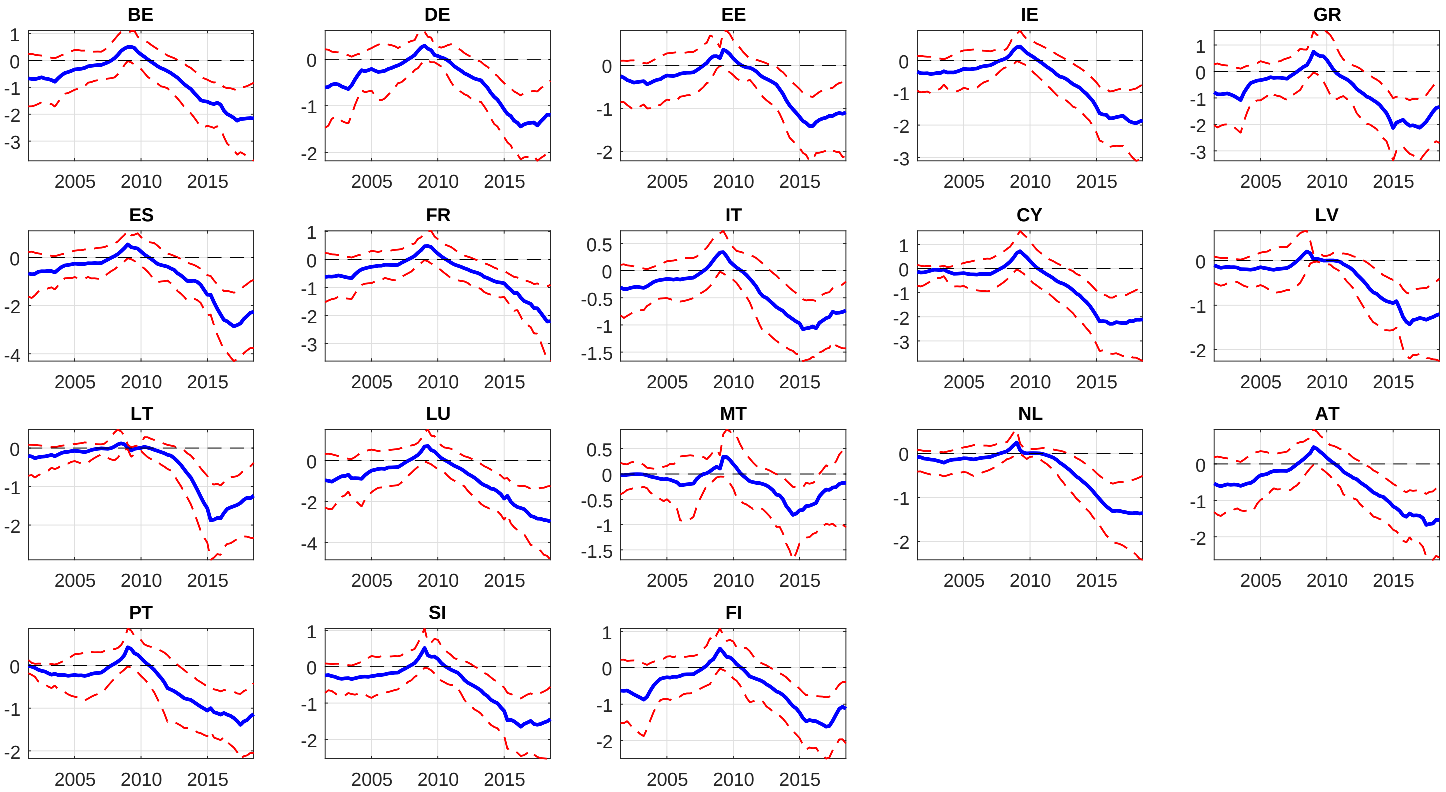
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 14: Euro area energy-related inflation factor (f_t)



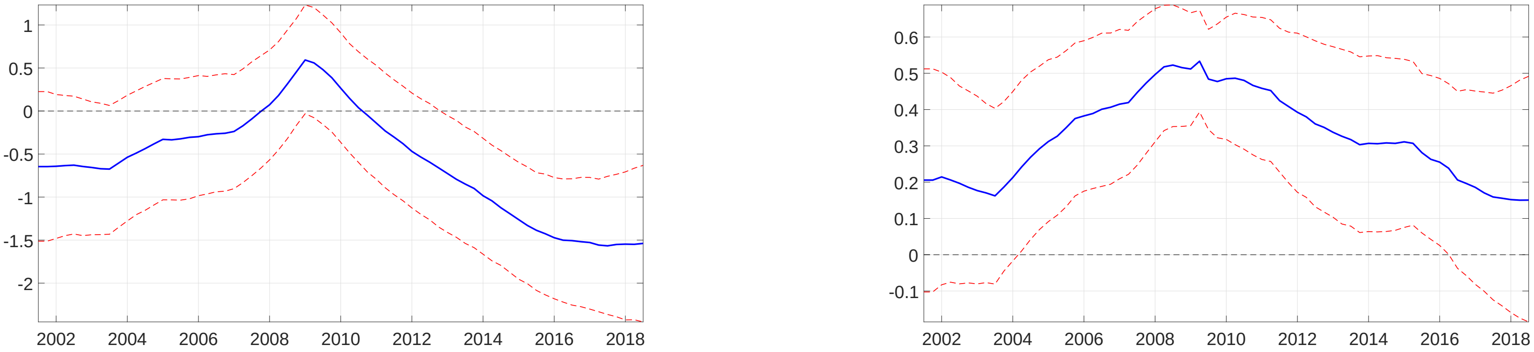
Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 15: Time-varying sensitivity of energy-related inflation of euro area countries based on a multivariate model ($\tilde{\beta}^{i}_{2,t}$)



Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 16: Time-varying coefficients of model for energy-related inflation

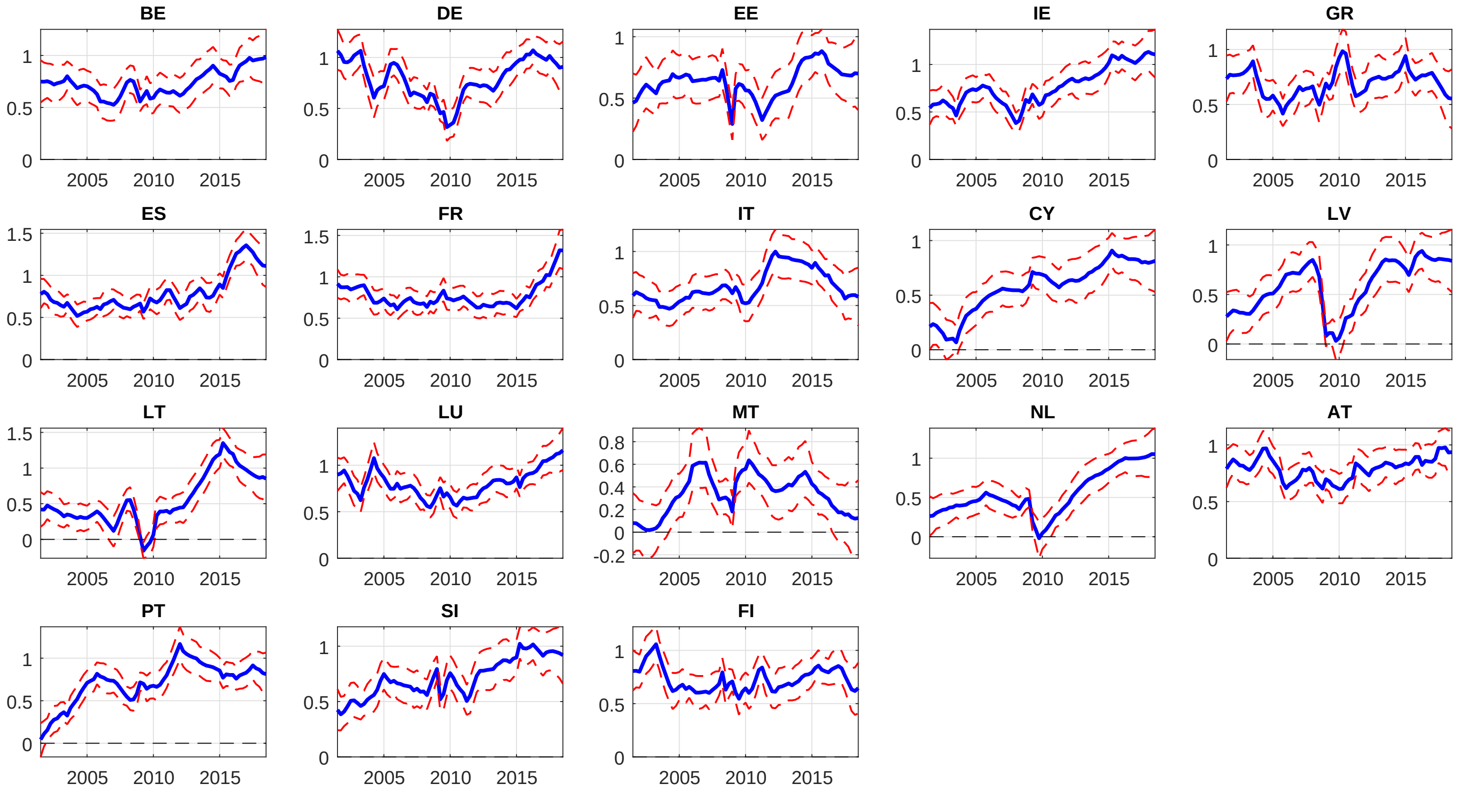


(a) Sensitivity of energy-related inflation of the euro area (λ_t)

(b) Persistence of the euro area energy-related inflation factor (ϕ_t)

Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 17: Time-varying comovement of euro area countries energy-related inflation ($\gamma_{i,t}$)



Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

A Online Appendix

A.1 Estimation of TVP factor model with exogenous information

The proposed estimation algorithm relies on Bayesian methods, in particular, we use the Gibss sampler to approximate the posterior distribution of parameters and latent variables involved in the time-varying parameter factor model with exogenous information (TVP-DFX). Let the vectors of observed variables defined as $\widetilde{\pi}_T = \{\pi_{1,t}, ..., \pi_{n,t}\}_{t=1}^{T}$, $\widetilde{x}_T = \{\epsilon_t^{Exo\_ER}\}_{t=1}^{T}$, and the vectors of latent variables as, $\widetilde{f}_T = \{f_t\}_{t=1}^{T}$, $\widetilde{\lambda}_T = \{\lambda_t\}_{t=1}^{T}$, $\widetilde{\phi}_T = \{\phi_t\}_{t=1}^{T}$, and $\widetilde{\gamma}_T = \{\widetilde{\gamma}_{1,T}, ..., \widetilde{\gamma}_{i,T}, ..., \widetilde{\gamma}_{n,T}\}$, where $\widetilde{\gamma}_{i,T} = \{\gamma_{i,t}\}_{t=1}^{T}$, for $i = 1, ..., n$. The parameters of the model, which consists of the variances associated to the different innovation processes, are given by $\Sigma = diag(\sigma_1^2, ..., \sigma_n^2)$, $\Omega = \{\nu_1^2, ..., \nu_n^2\}$, $\Pi = diag(\nu_\lambda^2, \nu_\phi^2)$, and can be collected in $\Theta = \{\Sigma, \Omega, \Pi\}$ to simplify notation. The algorithm consists of the following steps:

- ***Step 1***: Sample $\widetilde{f}_T$ from $P(\widetilde{f}_T|\widetilde{\pi}_T, \widetilde{x}_T, \widetilde{\lambda}_T, \widetilde{\phi}_T, \widetilde{\gamma}_T, \Theta)$

We cast the proposed factor model a in state space representation, with measurement equation given by,

$$\begin{bmatrix} \pi_{1,t} \\ \vdots \\ \pi_{n,t} \end{bmatrix} = \begin{bmatrix} \gamma_{1,t} \\ \vdots \\ \gamma_{n,t} \end{bmatrix} f_t + \begin{bmatrix} u_{1,t} \\ \vdots \\ u_{n,t} \end{bmatrix}, \tag{10}$$

and transition equation defined as,

$$f_t = \mu_t + \phi_t f_{t-1} + \omega_t , \tag{11}$$

where $\mu_t = \lambda_t \epsilon_t^{Exo\_ER}$, and similarly to other parameters of the state space model, are observed in this step of the algorithm. The innovations are assumed to be Gaussian, $(u_{1,t}, ..., u_{n,t})' \sim N(0, \Sigma)$, and $\omega_t \sim N(0, 1)$. Notice that the variance ω_t is set to one, this restriction is assumed for identification of the factor model. Conditional on the time-varying parameters being observed, the Carter and Kohn (1994) simulation smoother is applied to generate inferences of the latent factor, f_t.

- ***Step 2***: Sample $\widetilde{\gamma}_T$ from $P(\widetilde{\gamma}_T|\widetilde{\pi}_T, \widetilde{f}_T, \Omega, \Sigma)$

Given that Σ is a diagonal matrix, we sample the time-varying factor loadings associated to each observable independently from each other by employing the following state space representation

$$\begin{aligned}\pi_{i,t} &= \gamma_{i,t}\ f_t\ + u_{i,t}, \\ \gamma_{i,t} &= \gamma_{i,t-1} + \vartheta_{i,t},\end{aligned}$$

where $u_{i,t} \sim N(0, [\Sigma_{ii}])$ and $\vartheta_{i,t} \sim N(0, \nu_i^2)$, for $i = 1, ..., n$. Conditional on the factor, f_t , being observed, the Carter and Kohn (1994) simulation smoother is applied to generate inferences of the factor loadings, $\gamma_{i,t}$.

- ***Step 3***: Sample Ω from $P(\Omega|\widetilde{\gamma}_T)$

We sample the elements of $\Omega = \{\nu_1^2, ..., \nu_n^2\}$ conditional on the dynamics of the time-varying factor loadings by relying on a prior inverse Gamma distribution, $IG(\underline{\eta}, \underline{v})$, with $\underline{\eta} = \kappa \times T$, and $\underline{v} = 0.01 \times (\underline{\eta} - 1)$. The coefficient κ measures the degree of uncertainty about the prior belief of the innovations variance of the factor loadings. The larger (smaller) the κ the smaller (larger) the uncertainty about the prior belief. If there is a relatively high (low) degree of underlying comovement, a factor model would be more (less) suitable for the data, and the uncertainty about the dynamics of the factor loadings would be smaller (larger). Therefore, we set $\kappa = 0.1 \times std^{-1}$, where std measures the median, cross-sectional and over time, of the squared differences of inflation between two countries, which provides a simple measures of overall comovement in the data. Accordingly, draws are sampled from independent posterior distributions

$$\nu_i^2 \sim IG(\bar{\eta}, \bar{v}),$$

with $\bar{\eta} = \underline{\eta} + T$, and $\bar{v} = \underline{v} + (\gamma_{i,t} - \gamma_{i,t-1})'(\gamma_{i,t} - \gamma_{i,t-1})$, for $i = 1, ..., n$.

- ***Step 4***: Sample Σ from $P(\Sigma|\widetilde{\pi}_T, \widetilde{f}_T, \widetilde{\gamma}_T)$

We sample the elements of $\Sigma = diag(\sigma_1^2, ..., \sigma_n^2)$ conditional on the observed data, factor and time-varying factor loadings by relying on a prior inverse Gamma distribution, $IG(\underline{\eta}, \underline{v})$. Hence, draws are sampled from independent posterior distributions

$$\sigma_i^2 \sim IG(\bar{\eta}, \bar{v}),$$

with $\bar{\eta} = \underline{\eta} + T$, and $\bar{v} = \underline{v} + (\pi_{i,t} - \gamma_{i,t} f_t)'(\pi_{i,t} - \gamma_{i,t} f_t)$, for $i = 1, ..., n$.

- ***Step 5***: Sample $\widetilde{\lambda}_T, \widetilde{\phi}_T$ from $P(\widetilde{\lambda}_T, \widetilde{\phi}_T | \widetilde{f}_T, \widetilde{x}_T, \Pi)$

We sample jointly the time-varying coefficients, $\widetilde{\lambda}_T, \widetilde{\phi}_T$, by using the following state space representation

$$\begin{aligned} f_t &= \begin{bmatrix} f_{t-1} & \epsilon_t^{Exo\_ER} \end{bmatrix} \begin{bmatrix} \phi_t \\ \lambda_t \end{bmatrix} + \omega_t, \\ \begin{bmatrix} \phi_t \\ \lambda_t \end{bmatrix} &= \begin{bmatrix} \phi_{t-1} \\ \lambda_{t-1} \end{bmatrix} + \begin{bmatrix} \vartheta_{\phi,t} \\ \vartheta_{\lambda,t} \end{bmatrix}, \end{aligned}$$

where $\omega_t \sim N(0,1)$ and $(\vartheta_{\phi,t}, \vartheta_{\lambda,t})' \sim N(0, \Pi)$. Conditional on the dynamics of the factor and the exogenous variable being observed, the Carter and Kohn (1994) simulation smoother is applied to generate inferences of the time-varying coefficients.

- ***Step 6***: Sample Π from $P(\Pi | \widetilde{\lambda}_T, \widetilde{\phi}_T)$

We sample the elements of $\Pi = diag(\nu_\lambda^2, \nu_\phi^2)$ conditional on the dynamics of the corresponding time-varying coefficients by relying on a prior inverse Wishart distribution, $IW(\underline{\eta}, \underline{V})$, with $\underline{V} = I_2 \times \underline{v}$. Hence, draws are sampled from the posterior distribution

$$\Pi \sim IW(\bar{\eta}, \bar{V}),$$

with $\bar{\eta} = \underline{\eta} + T$, and $\bar{V} = \underline{V} + (\xi_t - \xi_{t-1})'(\xi_t - \xi_{t-1})$, where $\xi_t = (\phi_t, \lambda_t)'$.

To approximate the posterior distribution of both the parameters and latent variables involved in the model, each step of the algorithm is recursively repeated $M = 20,000$ times, discarding the first $m = 10,000$ iterations.

A.2 Alternative SVAR specifications

In order to test if those results reported in previous sections are robust to different specifications, we summarize a series of extensions and sensitiviy tests. First, to alternatively identify the structural shocks with regard to the unexpected appreciation of the euro, we rely on imposing a different set of sign restrictions in some of the entries of the impact multiplier matrix. We now assume that an unexpected appreciation of the euro, $\epsilon_t^{Exo\_ER}$, would lead to declines in inflation, along with further appreciation of the euro and a rise in output (through confidence channels) and in the global demand. All these restrictions can be formalized as follows,

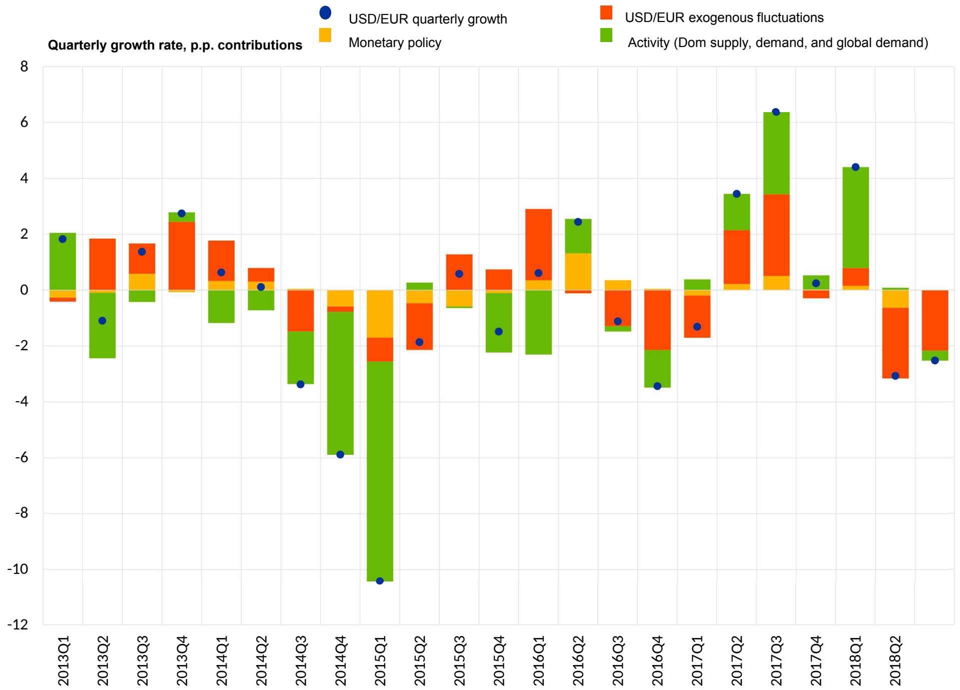
$$\begin{bmatrix} u_t^{GDP} \\ u_t^{INF} \\ u_t^{INT} \\ u_t^{FX} \\ u_t^{EA/US} \end{bmatrix} = \begin{bmatrix} + & + & - & + & + \\ - & + & - & - & + \\ - & + & + & * & * \\ - & * & * & + & * \\ + & + & - & + & - \end{bmatrix} \begin{bmatrix} \epsilon_t^{Dom\_Sup} \\ \epsilon_t^{Dom\_Dem} \\ \epsilon_t^{Mon\_Pol} \\ \epsilon_t^{Exo\_ER} \\ \epsilon_t^{Glo\_Dem} \end{bmatrix},$$

where the entries with an "$*$" in the impact multiplier matrix indicates that such a relation is left unrestricted.

The historical decomposition of shocks reported in Figure 1S are little changed from the baseline analysis (Figure 1).

As an additional set of robustness tests, we analyse any effect of changes in the SVAR specification, in terms of lag orders and timing of sign restrictions in the vein of Forbes et al. (2018). The results in Table 2S (columns 2-4) show no remarkable differences by changing the lag structure compared to our baseline results (lag of order 2). In addition, our results do not seem to be sensitive to imposing longer sign restrictions of 2 or 4 quarters (columns 5 and 6)

Figure 18: Historical decomposition of nominal exchange rate USD/EUR



Note: Estimates based on a quarterly SVAR model of the USD/EUR exchange rate where shocks are identified via sign and zero restrictions. Values for 2018Q3 are based on data available at the time of the cut-off date (Sep 1, 2018). Data for US and euro area GDP in 2018Q3 are based on nowcasted values, while inflation and monetary policy are approximated based on the respective averages of Jul and Aug 2018. The USD exchange rate movements refer to the quarterly rates of changes of the respective quarters.

Table 1: Forecast error variance decomposition of the nominal exchange rate of the euro against the USD for different lag orders and sign restriction periods

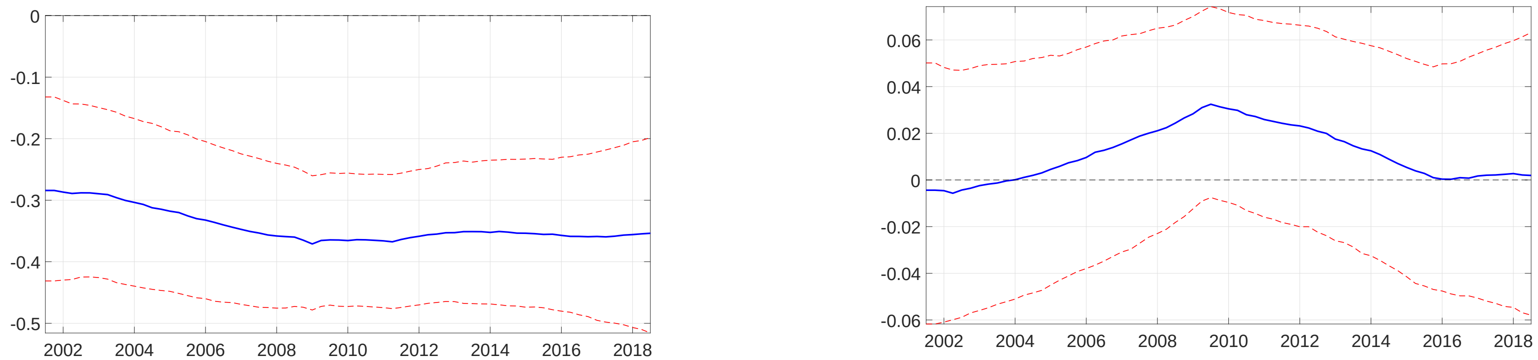
	SVAR estimated with:					
	Baseline	1 lag	3 lags	4 lags	2-per	4-per
	[1]	[2]	[3]	[4]	[5]	[6]
Domestic demand	14%	17%	15%	17%	23%	24%
Domestic supply	31%	29%	32%	31%	27%	30%
Rel monetary policy	16%	15%	13%	13%	11%	14%
Exchange rate	25%	24%	25%	23%	27%	21%
Global demand	15%	15%	15%	16%	12%	11%

Notes: Estimated using SVAR model described in Section 2.1. N-per refers to sign restrictions of N periods

Figure 19: Time-varying sensitivity of inflation of the euro area (λ_t) - CK

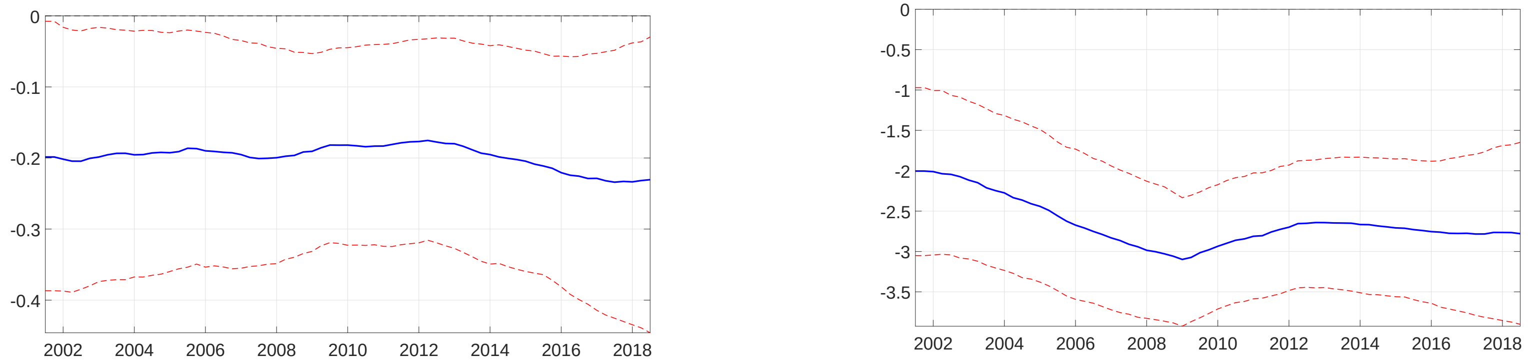
(a) Headline

(b) Core



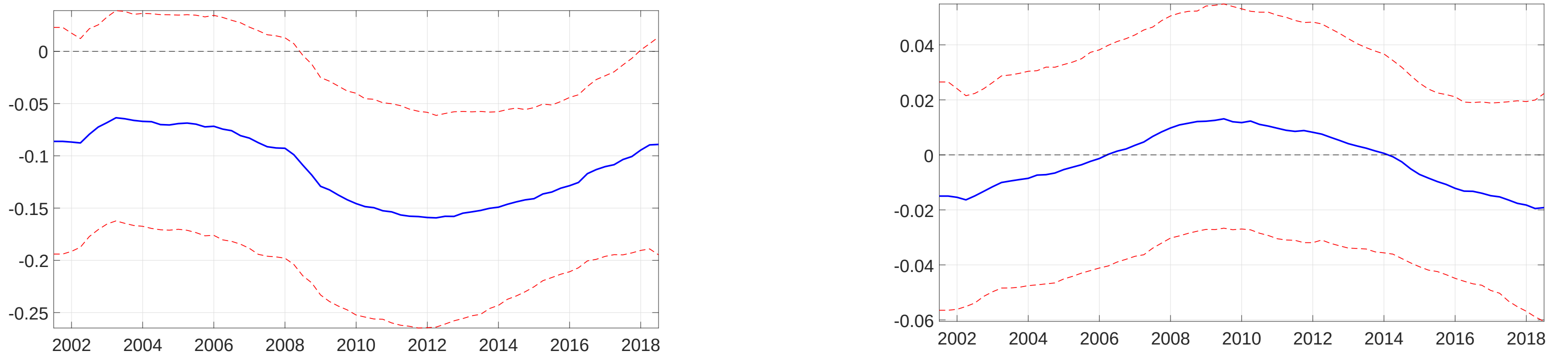
(c) Food

(d) Energy

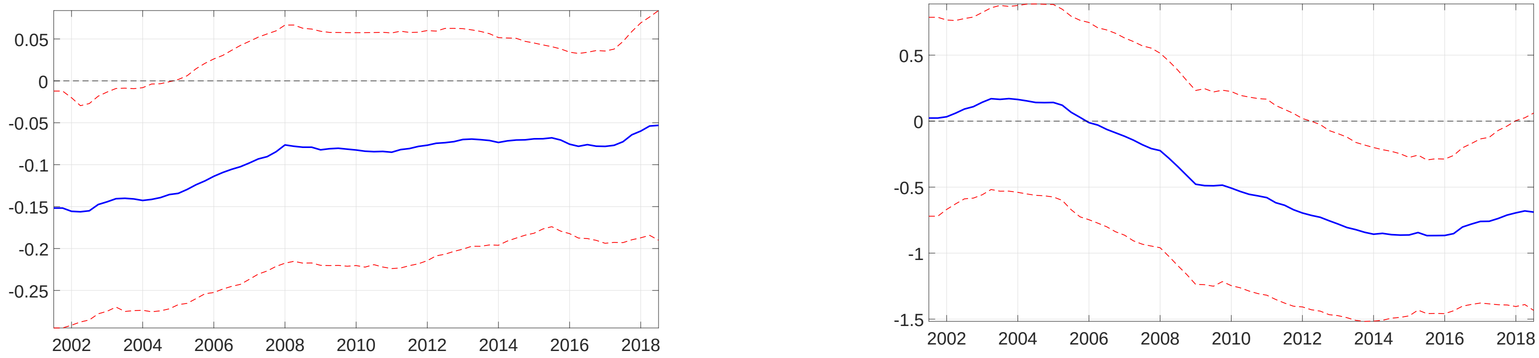


Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.

Figure 20: Time-varying sensitivity of inflation of the euro area (λ_t) - Forbes


(a) Headline

(b) Core


(c) Food

(d) Energy

Note: Red dashed lines make reference to the 16th and 84th percentile of the corresponding posterior distribution.