

Exchange Rate Shocks and Inflation Co-movement in the Euro Area*

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This paper decomposes the time-varying effect of exogenous exchange rate shocks on euro-area countries' inflation into country-specific (*idiosyncratic*) and regionwide (*common*) components. To do so, we propose a flexible empirical framework based on dynamic factor models subject to drifting parameters and exogenous information. We show that exogenous shocks are behind an important share of nominal EUR/USD fluctuations over the recent years. Our main results indicate that headline inflation in euro-area countries has become significantly more affected by exchange rate shocks since the early 2010s. While in the case of headline inflation this increasing sensitivity is solely reliant on the *idiosyncratic* component, for energy inflation it is based on both *idiosyncratic* and *common* components. By contrast, exchange rate shocks do not seem to have a significant impact on the core component of headline inflation.

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1. Introduction

Exchange rate fluctuations over a short period of time may be due to a variety of reasons, which can be broadly grouped into three

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categories: (i) fresh developments relating to growth fundamentals of each economy, on either the demand or supply side; (ii) perceived changes in countries' respective monetary policies, since they have a bearing on the relative return of financial assets associated with each economy; and (iii) risk premium shocks not directly linked to economic or monetary fundamentals which can prompt strong and swift movements in exchange rate dynamics that are hard to identify and predict (these are usually referred to as exogenous exchange rate shocks).

From a policymaker's standpoint, assessing the effects that currency movements may have on price inflation is crucial for the design of a monetary policy framework. A clearer understanding of the transmission channels may improve not only the ability to predict the impact but also the ability to better understand the effects of central banks' actions in this context. As a result, a prolific literature has focused on analyzing the degree to which a country's import, producer, or consumer prices change in response to its exchange rate fluctuations. This is commonly known as exchange rate pass-through (hereafter, ERPT).¹ The literature on ERPT ranges from seminal theoretical studies (Dornbusch 1987; Krugman 1987; and Corsetti, Dedola, and Leduc 2008), which showed that ERPT to prices was incomplete due to imperfect competition and pricing-to-market, to cross-country empirical evidence (Campa and Goldberg 2005, 2010), which focused on slow-moving structural determinants, such as changes in the composition of imports. Recently, there have been more efforts to identify the factors behind the changes in ERPT over time from a micro data perspective on firm pricing (Gopinath, Itskhoki, and Rigobon 2010; Berger and Vavra 2013; Devereux, Tomlin, and Dong 2015; and Amiti, Itskhoki, and Konings 2016). These works highlight drivers such as the role of invoicing currency, whether the transactions take place between or within firms, the frequency and dispersion of price adjustments, and the role of competition in final product markets.

A recent line of empirical research has provided evidence that the size, the duration, and even the sign of the ERPT depend on the origin of the shocks behind exchange rate fluctuations. For

¹More specifically, it is usually defined as the percentage change in prices in response to a 1 percent change in the exchange rate.

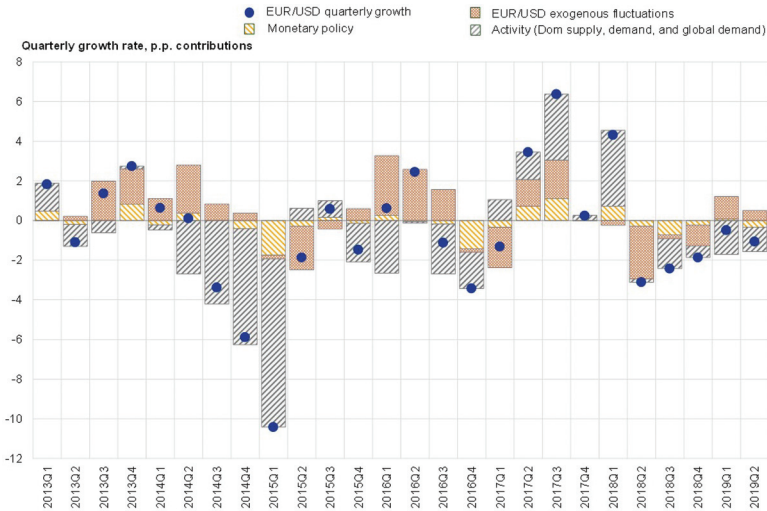
instance, Forbes, Hjortsoe, and Nenova (2015, 2018), following the work of Shambaugh (2008), estimate a structural vector autoregression (SVAR) framework for the United Kingdom as a small open economy. The authors highlight that it is essential to distinguish the driving forces behind the exchange rate fluctuations (i.e., whether they are due to domestic demand, global demand, domestic monetary policy, global supply shocks, domestic productivity, etc.) in order to explain how the ERPT has evolved. They also find that domestic monetary policy shocks are those with a relatively higher ERPT. A similar result was found for the euro area by Comunale and Kunovac (2017), using the same methodology. Their estimates point to a large but volatile ERPT to import prices and a very small ERPT to consumer inflation, lower than in previous decades.²

Theoretical models suggest a number of ways in which the exchange rate–prices nexus is shock dependent. These channels are corroborated by the related empirical literature. Yet, if the impact on prices varies in the euro area due to the changing composition of shocks driving the exchange rate movements, are they related to country-specific and/or euro-area-wide forces? The above-mentioned literature is silent on the cross-country heterogeneity inherent to a set of economies sharing their currency and monetary policy. Our proposed framework overcomes this drawback by jointly estimating the effect of euro-area (regionwide) exchange rate shocks on the inflation rates associated with the different economies (country specific).

This paper builds on the literature on shock-dependent exchange rate pass-through and elaborates further on the time variation and cross-country differences in the response of different price components to exchange rate changes in the euro area. Of all the sources of exchange rate fluctuations, this paper focuses only on exogenous exchange rate shocks (i.e., risk premium shocks not directly linked

²Using reduced-form approaches (not shock dependent), a body of empirical literature has put forward ERPT estimates for the euro area, showing evidence that the ERPT to consumer prices is about a tenth of that to import prices. Structural DSGE (dynamic stochastic general equilibrium) models, which consider the different transmission of different structural shocks, tend to deliver a higher and more gradual pass-through to consumer prices. For further details, see Ortega and Osbat (2020) and references therein such as Hahn (2003), Jašová, Moessner, and Takáts (2016), and Özyurt (2016).

Figure 1. Historical Decomposition of Nominal Exchange Rate USD/EUR



Note: Estimates based on the quarterly SVAR model of the USD/EUR exchange rate described in Section 2, where shocks are identified via sign restrictions. Estimates for 2019:Q2 are based on data available at the time of the cut-off date (September 2019). Data for U.S. and euro-area GDP in 2019:Q2 are based on flash estimates. The USD exchange rate movements refer to the quarterly rates of changes of the respective quarters. The figure depicts the average contribution of the 10,000 historical decompositions obtained from the saved iterations of the estimation algorithm.

to economic or monetary fundamentals) for at least two reasons. First, we seek to imitate insofar as possible the concept of ERPT in a shock-dependent context: we isolate the transmission to prices of “pure” exchange rate shocks from the joint reaction of prices and exchange rates to other structural shocks such as demand, supply, or monetary policy shocks. Second, we focus on exogenous exchange rate shocks for an empirical reason. As shown in our empirical results (see Figure 1), structural shocks other than exogenous exchange rate shocks account for an important share of the change in the nominal EUR/USD exchange rate—for around 65 percent since 1995—to be precise. However, exogenous exchange rate shocks have played a bigger part in unanticipated nominal exchange rate movements,

not only in recent years but also during turning-point periods.³ Our findings indicate that they are behind more than 50 percent of nominal EUR/USD exchange rate fluctuations in more than a third of the quarters of the past six years.

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

$$INF_{i,t} = \phi_i(L)INF_{i,t-1} + \beta_{i,t}\epsilon_t^{ER} + v_{i,t}, \quad (1)$$

where $INF_{i,t}$ is the inflation rate of country i at time t , the term $\phi_i(L)$ helps control for past inflation dynamics, the exchange rate shocks are measured by ϵ_t^{ER} , and $v_{i,t}$ represents an error term.⁴ Note that in Equation (1), our object of interest is the dynamics of $\beta_{i,t}$, which measures the changing sensitivity of inflation to exchange rate shocks.

Second, we decompose the sensitivity of inflation to exchange rate shocks across euro-area economies into two parts: one is exclusively related to the inflation dynamics of country i and the other is common to all euro-area countries. In other words, the latter can be interpreted as the sensitivity of country i inflation to exchange rate shocks that is formed jointly with other countries of the region. The following equation illustrates this decomposition:

$$\beta_{i,t} = IDI_{i,t} \times COM_t, \quad (2)$$

where $IDI_{i,t}$ denotes the idiosyncratic, country-specific component and COM_t denotes the common, regionwide component. The information contained in Equation (2) can be useful for policymakers to understand the extent to which movements in inflation of a given country, brought about by exchange rate shocks, can be attributed to its exclusive and intrinsic economic performance or to the overall performance of all monetary union partners.

³Turning-point periods are defined as switching states of EUR/USD valuations (i.e., transitions from appreciation to depreciation and vice versa) based on the monthly nominal EUR/USD reference exchange rate provided by the European Central Bank (ECB).

⁴The lag operator is denoted by L .

To jointly assess both the time variation in the sensitivity of inflation to exogenous exchange rate shocks and its decomposition into country-specific and regionwide components, we adopt a unified multi-country perspective. In particular, we first identify such exchange rate shocks using a structural VAR model for the aggregate euro-area economy. To ensure that shocks have the expected effect on the macroeconomy, according to theoretical models or stylized facts, we base our identification scheme on sign restrictions, along the lines of Shambaugh (2008), Forbes (2015, 2018), and Comunale and Kunovac (2017). Next, we use the exchange rate shocks as exogenous information in a dynamic factor model with drifting coefficients for inflation in the euro-area economies.⁵ This empirical framework allows us to make accurate comparisons of the results across the different economies. In particular, it provides a full spectrum of the effect of exogenous exchange rate shocks on inflation (i) across countries, (ii) by subcomponents, and (iii) over time.

The main results show that the sensitivity of headline inflation to exchange rate shocks has increased since the early 2010s. In other words, an unexpected appreciation of the euro versus the dollar leads to larger declines in inflation than before. Such an increase is systemic and broad based, since most euro-area countries have experienced it. When assessing the source of such recent increased sensitivity of headline inflation to exchange rate shocks, it is found that (i) the euro-area-wide component, which can be interpreted as the effect of exchange rate shocks on aggregate euro-area inflation, has remained relatively stable over time; by contrast (ii) the country-specific component has displayed a substantial increase since the early 2010s. This implies that the growing sensitivity of headline inflation to exchange rate shocks is heavily reliant on the increasing similarities between inflation rate dynamics associated with the euro-area countries.

⁵The euro-area monetary union comprises 19 EU member states: Belgium (BE), Germany (DE), Estonia (EE), Ireland (IE), Greece (GR), Spain (ES), France (FR), Italy (IT), Cyprus (CY), Latvia (LV), Lithuania (LT), Luxemburg (LU), Malta (MT), the Netherlands (NL), Austria (AT), Portugal (PT), Slovenia (SI), and Finland (FI). Results for Slovakia (SK) are not reported due to data limitations.

By subcomponents—that is, energy, food, and core prices—the results are heterogeneous. First, the sensitivity of the energy component to exogenous exchange rate shocks has also increased significantly in recent years. Contrary to the case of headline inflation, this result relies equally on the country-specific and common components. Second, food inflation estimated sensitivity is similar to that of headline inflation, albeit less statistically significant. Third, core inflation sensitivity estimates behave somewhat differently: core inflation across countries does not seem to be meaningfully affected by exogenous exchange rate shocks, along the lines of the empirical literature findings (Ortega and Osbat 2020). Therefore, our results suggest that the increase in the ERPT has been induced by an increasing headline inflation co-movement, mainly driven by its energy component.⁶

The structure of the paper is as follows: Section 2 sets out the empirical approach; Section 3 discusses the main findings, with particular focus on the assessment of inflation co-movement across countries; and Section 4 sets out the conclusions.

2. Empirical Framework

In this section, we provide an empirical framework to investigate the effects of exchange rate shocks on inflation in euro-area countries across both geographic and time dimensions. Therefore, we are interested in a modeling approach able to meet four main criteria: (i) to properly identify exchange rate shocks for the euro-area economy as a whole, given the unified monetary system; (ii) to estimate how the effect of those exchange rate shocks spreads across the different euro-area countries; (iii) to provide information on the potential changes over time in the sensitivity of each country to those shocks; and (iv) to decompose the changing sensitivity into its country-specific and regionwide components.

We proceed in two steps. First, we use a structural VAR model to identify purely exogenous exchange rate shocks. Second, according to the exogenous exchange rate shocks identified in the first step,

⁶At the same time, this component is highly influenced by shocks to global factors, such as oil prices.

we investigate their time-varying effect on inflation across euro-area countries using factor models.⁷

2.1 Structural VAR Model

We employ a structural vector autoregression model to investigate the exchange rate sensitivity of euro-area inflation, considering how different theory-based shocks may affect the exchange rate and prices. More specifically, we are interested in assessing the effects of five shocks on the euro-area economy: domestic supply, domestic demand, global demand, relative monetary policy, and exogenous exchange rate shocks. This is a similar variety of shocks as previously considered in related literature and should encompass all shocks that could be relevant drivers of exchange rate fluctuations. For instance, a sudden increase in domestic risk aversion would be captured as an exogenous exchange rate shock. To the extent that such unanticipated shocks may drive movements in the EUR/USD exchange rate, they may also determine the magnitude and duration of pass-through.

However, a major concern in this context is to link economic theory to identify the shocks of interest with appropriate restrictions on variables' impulse responses. The identification strategies historically used by the related literature in estimating ERPT—conditional on underlying shocks—have a number of limitations and are only able to identify a restricted set of shocks. More specifically, the seminal work of Shambaugh (2008) uses long-run restrictions to identify separately domestic supply, relative demand, nominal shocks, and foreign price shocks. The interpretation of the latter three types of shocks, however, is not straightforward and does not easily translate into standard macroeconomic models, and the identification strategy does not allow for disentangling shocks originating in different regions.

To address the identification challenge, we impose several short-run sign restrictions which are motivated by open-economy DSGE

⁷Similar methodological approaches have been used for exogenous changes in oil prices (Kilian 2009) or for potential output distinguishing between demand and supply shocks (Coibion, Gorodnichenko, and Ulate 2017).

models. In particular, these restrictions are consistent with the two-country New Keynesian model described in de Walque et al. (2017, 2020), the Banque Nationale de Belgique model of the euro-area economy, which entails the standard open-economy main characteristics. This DSGE model integrates two closed-economy models—for the euro area and the United States—through international trade in goods and assets, and it is rather rich in terms of features: sticky local-currency pricing, distribution sector, intermediate goods in the production function, and a demand elasticity increasing with the relative price. The shock transmission mechanisms of this standard open-economy model are described in more detail in the online appendices for this paper (available at <http://www.ijcb.org>).

Accordingly, to identify the main shocks driving the dynamics of the euro exchange rate against the U.S. dollar, we estimate an endogenous multivariate model that uses quarterly information about the euro-area real GDP growth rate (GDP), euro-area HICP inflation (INF), relative short-term interest rates (INT) between the euro area and the United States, the EUR/USD nominal exchange rate (FX), and the relative euro-area activity share with respect to the United States (EA/US). Therefore, let the vector collecting of the variables be $\mathbf{Y}_t = [GDP_t, INF_t, INT_t, FX_t, EA/US_t]$; the estimated model is a SVAR(p) model given by

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

where $\epsilon_t \sim N(0, I)$ are the structural innovations. The reduced-form innovations, defined as \mathbf{u}_t , are related to the structural innovations through the impact multiplier matrix \mathbf{B} , that is, $\mathbf{u}_t = \mathbf{B}\epsilon_t$.⁸

To identify the structural shocks of interest following the macro-economic relations explained above, we impose sign restrictions on some of the entries of the impact multiplier matrix.⁹ These sign

⁸In our empirical application, we let the number of lags of the endogenous variables be $p = 2$. Robustness tests on different lags are reported in the online appendices.

⁹A similar approach is used in Leiva-Leon (2017) for the case of Spain and Estrada et al. (2020) for emerging market economies.

restrictions have been widely used in the literature, have been shown to be consistent with theoretical models (see online appendices for further reference), and are based on four sets of assumptions.

First, we assume that a positive domestic supply shock, $\epsilon_t^{Dom_Sup}$, is associated with an increase in domestic output and the relative euro-area activity share and a decrease in inflation, interest rates, and foreign exchange rates.¹⁰ By contrast, a positive domestic demand shock, $\epsilon_t^{Dom_Dem}$, would be associated with higher output and relative euro-area activity, higher HICP inflation, higher interest rates, and euro appreciation. Second, we assume that an unexpected tightening of the monetary policy stance, $\epsilon_t^{Mon_Pol}$, that increases the short-term interest rate is associated with lower inflation, output growth, and relative share of euro-area activity with respect to the United States. Third, we impose that an unexpected euro appreciation, $\epsilon_t^{Exo_ER}$, which increases the EUR/USD exchange rate, would lead to declines in inflation and the interest rate.¹¹ Fourth, we assume that a positive global demand shock, $\epsilon_t^{Glo_Dem}$, that reduces the relative size of the euro-area economy compared with the world economy (proxied by the United States) exerts upward pressure on euro-area output and inflation, but would lead to a relatively looser monetary policy in the euro area than in the United States, where demand expansion would be larger after the positive global demand shock.¹² All these restrictions can be formalized as follows:

$$\begin{bmatrix} u_t^{GDP} \\ u_t^{INF} \\ u_t^{INT} \\ u_t^{FX} \\ u_t^{EA/US} \end{bmatrix} = \begin{bmatrix} + & + & - & * & + \\ - & + & - & - & + \\ - & + & + & - & - \\ - & + & * & + & * \\ + & + & - & * & - \end{bmatrix} \begin{bmatrix} \epsilon_t^{Dom_Sup} \\ \epsilon_t^{Dom_Dem} \\ \epsilon_t^{Mon_Pol} \\ \epsilon_t^{Exo_ER} \\ \epsilon_t^{Glo_Dem} \end{bmatrix}, \quad (4)$$

¹⁰A decrease in the FX rate is defined as a reduction in the EUR/USD exchange rate, i.e., euro depreciation.

¹¹For the sake of robustness, an alternative identification scheme concerning an unexpected appreciation of the nominal euro exchange rate (exogenous exchange rate shock or risk premium shock) is further developed in the online appendices. It provides broadly similar results.

¹²An important related aspect is the link between oil prices and exchange rate developments. In the online appendices, we further discuss this issue and provide model-based evidence of little impact on the key results by means of an SVAR-X approach.

where the “*” in the impact multiplier matrix indicates that the entries have been left unrestricted. This combination of sign restrictions is the minimum number of theory-based economically sensible restrictions that allows us to identify the shocks of interest and at the same time to ensure their orthogonality.¹³

We estimate the SVAR model, described in Equations (3)–(4), using quarterly data for the euro area and the United States for the period from 1995:Q1 to 2019:Q2 on the following six variables: (i) the euro-area real gross domestic product (GDP) growth rate from the European Commission (Eurostat); (ii) inflation based on the Harmonised Index of Consumer Prices (HICP) for the euro area from the European Commission (Eurostat); (iii) relative short-term interest rates between the euro area and the United States, and for the zero lower bound period, shadow rates based on quarterly averages of monthly estimates from Krippner (2013);¹⁴ (iv) quarterly average of the monthly nominal EUR/USD reference exchange rate provided by the European Central Bank (ECB);¹⁵ and (v) relative euro-area activity calculated as the ratio of euro-area to U.S. GDP, based on GDP data provided by the European Commission (Eurostat) and the U.S. Bureau of Economic Analysis (BEA). All variables except the relative interest rate are transformed into quarterly log differences.

Finally, the SVAR model is estimated using Bayesian methods. In particular, an independent normal-inverse-Wishart prior is assumed to simulate the posterior distribution of the parameters. Structural shocks are identified by following Arias, Rubio-Ramirez, and Waggoner (2018), where sign restrictions are imposed on impulse

¹³A wide range of estimation methodology robustness checks is discussed in the online appendices. The estimates obtained are qualitatively similar to those obtained with our benchmark specification in Equations (3)–(4).

¹⁴Model results are, in any case, robust to different monetary policy measures, such as relative official interest rates in the euro area and the United States and shadow interest rates. Shadow rates are constructed using multifactor shadow rate term structure models by Wu and Xia (2016).

¹⁵Our SVAR model results are robust to an alternative estimation using the nominal effective exchange rate of the euro against its main 38 trade partners—NEER-38 countries—although some caveats arise, as the variables proxying global demand and relative monetary policy are measured only in relation to the United States, not to the full set of 38 countries used in the NEER definition.

response functions. Further details of the estimation procedure are provided in the online appendices.

2.2 Factor Model with Exogenous Information

Dynamic factor models have been widely used to characterize the degree of co-movement in the dynamics of prices from different levels of disaggregation. Two examples are Del Negro and Otrok (2007), who focus on house prices at the state level for the U.S. economy, and Cicarelli and Mojon (2010), who present a global perspective of synchronized inflation dynamics across industrialized countries. Here, we use this tool to provide a comprehensive assessment of exchange rate effects on inflation in the euro-area countries from a unified perspective.

We use the exogenous exchange rate shocks extracted from the structural VAR model described above to assess their effect on inflation in the n euro-area countries. As suggested by Mumtaz and Sunder-Plassmann (2013), the effects associated with exchange rate fluctuations in advanced economies are subject to substantial changes over time. Hence, as we are primarily interested in assessing changes in the exchange rate sensitivity of inflation over time, we rely on a multivariate framework subject to time-varying coefficients.¹⁶

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

$$\pi_{i,t} = \gamma_{i,t}f_t + u_{i,t}, \quad (5)$$

$$f_t = \phi_t f_{t-1} + \lambda_t \epsilon_t^{Exo-ER} + \omega_t, \quad (6)$$

for $i = 1, 2, \dots, n$, and where $u_{i,t} \sim N(0, \sigma_i^2)$ and $\omega_t \sim N(0, 1)$. Note that Equation (5) decomposes country-specific inflation, $\pi_{i,t}$, into a common component, f_t , and an idiosyncratic component,

¹⁶A similar factor model with time-varying coefficients is also used in Ductor and Leiva-Leon (2016) to unveil an increasing synchronization in global real activity.

$u_{i,t}$, whereas Equation (6) assumes that the common factor follows autoregressive dynamics and that it is also influenced by exogenous information—in particular, by the exogenous exchange rate shocks ϵ_t^{Exo-ER} .

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

$$\gamma_{i,t} = \gamma_{i,t-1} + \vartheta_{i,t} \quad (7)$$

$$\phi_t = \phi_{t-1} + \vartheta_{\phi,t} \quad (8)$$

$$\lambda_t = \lambda_{t-1} + \vartheta_{\lambda,t}, \quad (9)$$

where $\vartheta_{i,t} \sim N(0, \nu_i^2)$, $\vartheta_{\lambda,t} \sim N(0, \nu_{\lambda}^2)$, and $\vartheta_{\phi,t} \sim N(0, \nu_{\phi}^2)$. Most importantly, the time-varying degree of inflation co-movement across countries is captured by $\gamma_{i,t}$, while changes in the persistence of the latent factor are collected in ϕ_t , and the dynamic sensitivity of the inflation factor is measured by λ_t .

Plugging Equation (6) into Equation (5) gives us the following expression for country i inflation dynamics:

$$INF_{i,t} = \tilde{\beta}_{i,0} + \tilde{\beta}_{i,1,t}f_{t-1} + \tilde{\beta}_{i,2,t}\epsilon_t^{Exo-ER} + \tilde{v}_{i,t}, \quad (10)$$

where $\tilde{\beta}_{i,0} = \mu_{i,inf}^i$, $\tilde{\beta}_{i,1,t} = \sigma_{i,inf}\gamma_{i,t}\phi_t$, $\tilde{\beta}_{i,2,t} = \sigma_{i,inf}\gamma_{i,t}\lambda_t$, and $\tilde{v}_{i,t} = \sigma_{i,inf}(\gamma_{i,t}\omega_t + u_{i,t})$. Note that there is a direct correspondence between Equation (10) and Equation (1)—in particular, between the coefficients measuring the sensitivity of inflation to exchange rate shocks in both equations, i.e., $\tilde{\beta}_{2,i,t}$ and $\beta_{i,t}$, respectively.

The main advantage of the proposed TVP-DFX model is that it allows the effect of exchange rate shocks on inflation, $\tilde{\beta}_{2,t}^i$, to be decomposed into two components: the country-specific component, $\gamma_{i,t}$, and the euro-area-wide component, λ_t , which would correspond to the terms $IDI_{i,t}$ and COM_t , respectively, in Equation (2). The term λ_t provides information about the changing effect that exchange rate shocks have on euro-area inflation dynamics, proxied by the factor f_t . By contrast, the term $\gamma_{i,t}$ provides information on the changing propagation of those shocks across the different countries of the euro area. Equation (10) is first estimated on headline HICP inflation across the euro-area economies. Section 3.2 discusses the findings, as well as the estimation of Equation (10) on the three

components of HICP inflation (food, energy, and the core component, i.e., total HICP excluding food and energy prices). Note that an additional advantage of the proposed framework is that it can be used to incorporate structural shocks obtained from any other kind of model for validation purposes, i.e., semi-structural or DSGE models. However, in the current application we only focus on the shocks from the structural VAR model described in Section 2.1.

3. Sensitivity of Prices to Exchange Rate Shocks

3.1 *An Aggregate Assessment*

This section aims to help understand the link between movements in the EUR/USD and euro-area consumer prices. We analyze what types of shocks have driven the euro exchange rate fluctuations over the period 1995:Q1–2019:Q2 by examining historical shock decompositions from the SVAR detailed in Section 2.¹⁷ To begin with, Figure 1 presents the historical decomposition of shocks behind the evolution of quarter-on-quarter EUR/USD exchange rate. It permits a better understanding of the relative weight of different shocks and its variation over time. An increase (reduction) is defined as an increase (reduction) in the EUR/USD in exchange rate, i.e., euro appreciation (depreciation) against the USD. Focusing on the most recent period, the contributions of the potential driving factors identified in the SVAR are the following: (i) innovations to real activity (either from domestic demand and supply or from the rest-of-the-world demand); (ii) relative monetary policy shocks; and (iii) exogenous exchange rate shocks not directly linked to fundamentals or monetary policy. As discussed earlier, exogenous factors may proxy risk premium shocks, which most notably reflect changes in the confidence, sentiment, or perception (optimism or pessimism) among traders operating on foreign exchange markets. They are usually sudden, strong, and difficult to predict.

A quick glance at Figure 1 suggests that structural shocks other than exogenous exchange rate shocks account for a large share of the EUR/USD fluctuations—for around 65 percent over the sample

¹⁷Estimates for 2019:Q2 are based on data available at the time of the cut-off date (September 2019).

period, to be precise. Therefore, treating all exchange rate changes as exogenous shocks is unlikely to adequately capture the underlying dynamics—in particular, if the mix of shocks driving the exchange rate varies over time, as discussed in Section 1. However, exogenous exchange rate shocks have played a bigger part in unanticipated nominal exchange rate movements, not only in recent years but also in turning-point periods, that is, transitions either from appreciation to depreciation or from depreciation to appreciation. Our findings indicate that they are behind more than 50 percent of the exchange rate fluctuations in more than a third of the quarters of the past six years, as shown in Figure 1.

For example, according to our structural analysis, the euro's marked appreciation between 2017:Q2 and 2018:Q1 could have been driven by at least three forces. Ranked in order of importance, they are as follows: First, its appreciation may have been due to a higher relative growth of the euro area, which would have exerted an inflationary pressure. Second, it may have been due to exogenous factors exerting a deflationary effect (through a reduction in import prices). Third, it may have been because of the perception that the ECB's monetary policy was somewhat less relaxed at the end of 2017, relative to the Federal Reserve's, the latter also exerting a deflationary effect due to the relative monetary policy stance. These arguments are consistent with existing previous literature such as Cœuré (2017), which is an example of how shock-dependent estimates of the exchange rate–prices nexus are affecting the monetary policy debate. However, it has to be considered that these estimates may be very sensitive to the particular model specification (sample period, identification scheme, choice and measurement of variables), as argued in Ortega and Osbat (2020).¹⁸

¹⁸ A full set of different model variants have also been estimated to test whether our findings are sensitive to alternative identification strategies, different lag orders and sign restriction periods, third-currency effects beyond the EUR/USD bilateral relationship (i.e., considering the nominal effective exchange rate of the euro), a version of our SVAR subject to time-varying parameters (TVP-SVAR), and the role of oil prices through the lenses of a SVAR-X model. The robustness results are summarized in the online appendices and show no remarkable differences neither in the historical decomposition of exchange rate shocks nor in specific, extracted shocks.

Figure 2. Euro-Area Headline Inflation Factor (f_t)

Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area headline quarterly inflation expressed in percentage points. (For figures in color, see the online version of the paper at <http://www.ijcb.org>.)

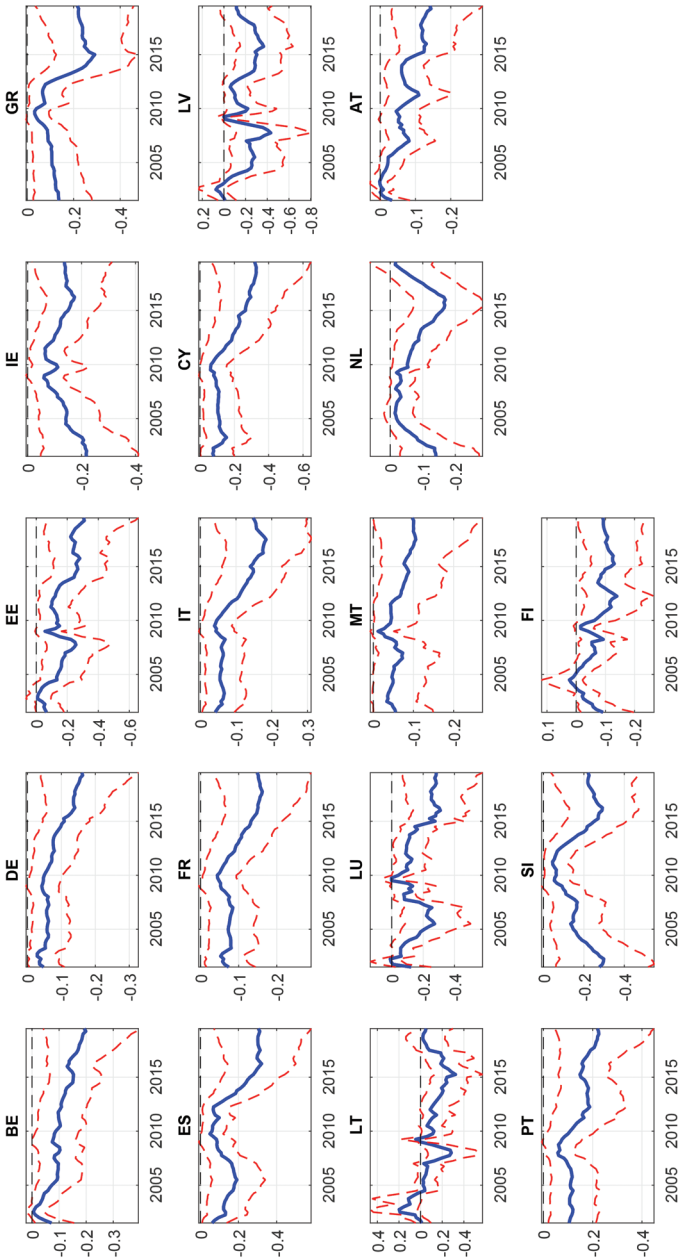
3.2 The Role of Inflation Co-movement

After estimating the proposed dynamic factor model with drifting coefficients and exogenous information, described in Equations (5)–(9), we proceed to assess the effect of exchange rate shocks on inflation (i) over time, (ii) across countries, and (iii) by price component.

We begin by focusing on the case of headline inflation. The common factor extracted from headline inflation across the euro-area countries is plotted in Figure 2. This is f_t in Equation (5), estimated using total HICP data for the euro-area countries. It shows a strikingly similar pattern to actual headline inflation for the euro area. Therefore, the estimated common factor f_t can be interpreted as a proxy for euro-area headline inflation dynamics.

Figure 3 plots the *total* estimated time-varying sensitivity of the euro-area countries' headline inflation to exchange rate shocks, that is, $\tilde{\beta}_{i,2,t}$ in Equation (10). The estimates suggest that a persistent increase in the effect of shocks on inflation occurred around 2010. This is a general pattern for most countries, but it is especially acute

Figure 3. Sensitivity of Country-Specific Headline Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\beta_{i,2,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the multivariate model.

for the largest economies. In particular, France, Germany, and Italy exhibited a sensitivity of around 0.1 before 2010, but which has since continued to increase, up to 0.2. For Spain the increase is even larger, up from 0.2 before 2010 to around 0.4 subsequently. Some smaller economies, such as Portugal, Finland, or Malta, have also experienced increasing sensitivity, but less persistently.¹⁹ These results show traces that at the zero lower bound, and under credible forward guidance of the interest rates, the pass-through of the exchange rate changes to prices is larger.²⁰

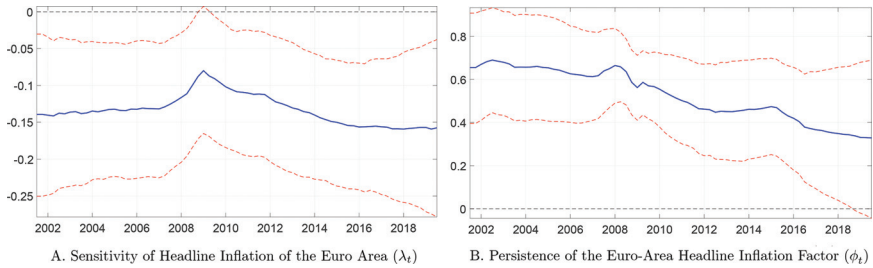
As the estimated common factor is a good proxy for euro-area headline inflation, the time-varying parameter λ_t in Equation (6) can be interpreted as the changing effect of exchange rate shocks on the aggregate euro-area inflation rate. Figure 4A plots the dynamics of the *regionwide* component of the *total* sensitivity, λ_t , showing that, in general, it has remained steady, the only exception being the Great Recession period when exogenous exchange rate shocks did not seem to have a significant effect on euro-area headline inflation. In particular, a 1 percent exogenous appreciation of the euro would be associated with a decline in euro-area HICP inflation of around 0.15 percent on impact.²¹ By contrast, Figure 4B plots the

¹⁹To assess the importance of relying on the shocks rather than simply on the movements of exchange rate, we reestimate the proposed factor model, but replacing the exogenous exchange rate shocks, in Equation (6), with a simpler measure which consists on the quarterly change of the level of the exchange rate. The results indicate that when conditioning on the movements of the exchange rate, and not on its unexpected component, its time-varying pass-through to headline inflation across countries (i) is very small in magnitude, (ii) is estimated with large uncertainty, (iii) occasionally exhibits counterintuitive signs, and (iv) does not increase or decrease over time, but instead shows only temporary changes. These results are not shown for the sake of space, but they are available upon request.

²⁰This result is consistent with the theoretical literature on the secular stagnation hypothesis and the idea that international trade relations become more conflictual at the zero lower bound (ZLB)—in particular, in those economies where a persistently low or negative natural rate of interest has led to a chronically binding ZLB and the central bank no longer dampens the effects of this kind of shocks. See Eggertsson, Mehrotra, and Summers (2016) and Eggertsson, Mehrotra, and Robbins (2019).

²¹The impact of monetary policy shocks on HICP inflation and its components has also been analyzed under the same empirical strategy, although it is beyond the scope of this paper. Empirical findings point to a decreasing path of sensitivity of inflation to these shocks.

**Figure 4. Time-Varying Coefficients of
Model for Headline Inflation**



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

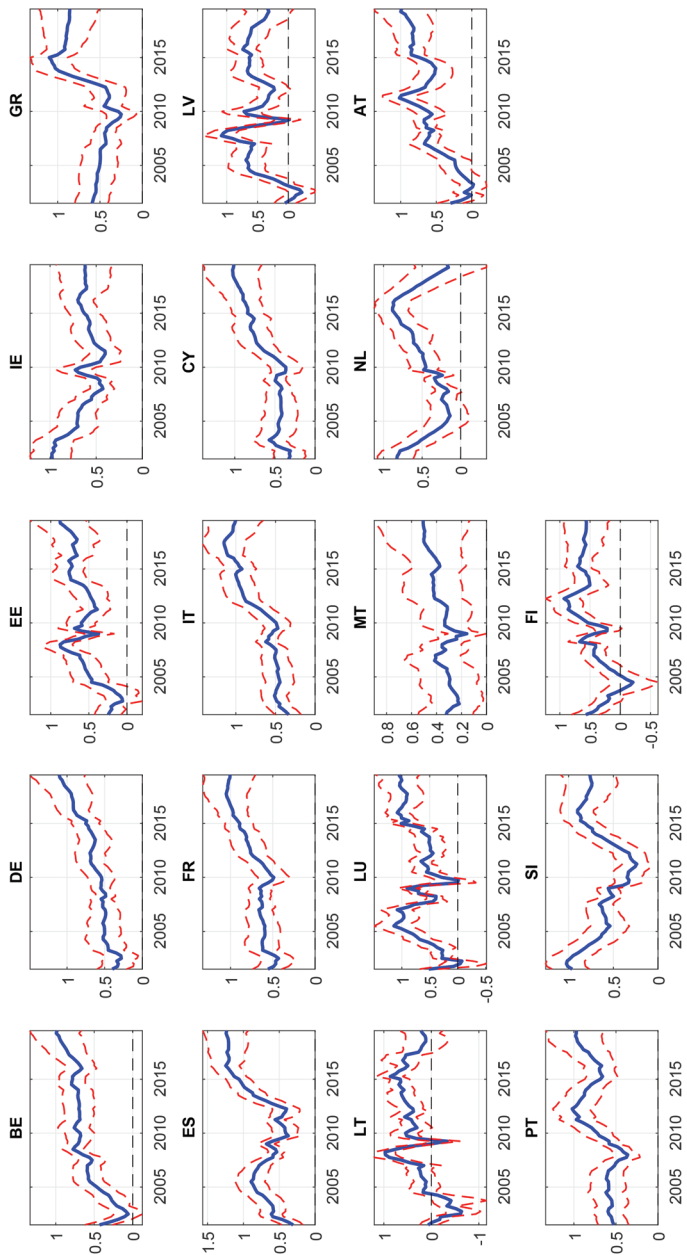
time-varying persistence of the common inflation factor, showing a slightly declining pattern since 2008.

Increasing sensitivity across countries, along with relatively stable sensitivity for the aggregate euro area, can be explained by an increasing degree of co-movement in headline inflation across euro-area countries. Figure 5 shows the estimated time-varying loadings of the common component into each country's inflation of Equation (5), that is, the *country-specific* component of the *total* sensitivity. Accordingly, the dynamics of $\gamma_{i,t}$ measure the changing contemporaneous relationship between country-specific inflation measures and their common factor. As expected, the figure reflects sustained increases over time in the synchronization of headline inflation dynamics for most countries.

In other words, the fact that inflation rates across euro-area countries have exhibited an increasing degree of co-movement over time implies that such countries are reacting in a more similar way to shocks hitting the euro area as a whole. Notice that the effect of exchange rate shocks on the common factor (which proxies the euro-area headline inflation) has just slightly increased since the Great Recession; see Figure 4A. However, this small increasing effect is amplified for the countries due to the fact that now they are more sensitive to these common shocks than in the past, as shown in the factor loadings dynamics reported in Figure 5.²²

²²The reasoning for these results relies on the evolving heterogeneity across inflation rates of euro-area countries. In particular, total inflation in some

Figure 5. Time-Varying Co-movement of Euro-Area Countries' Headline Inflation ($\gamma_{i,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

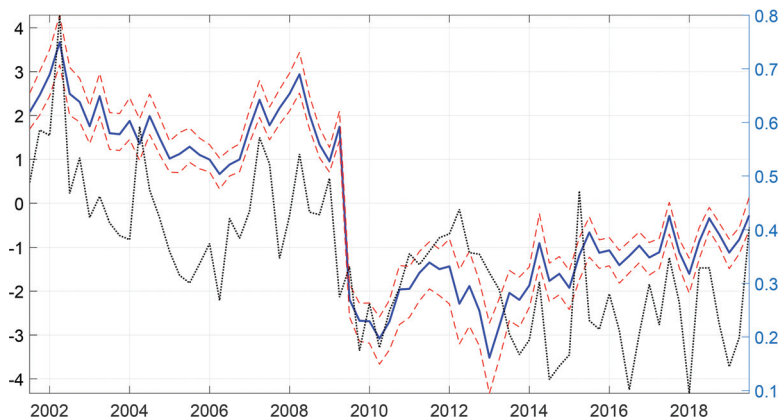
Note that if country-specific forces start to strongly move in the same direction, eventually those forces would lose their idiosyncrasy and become a euro-area-wide force. However, the distinction between those two forces is not always straightforward to define in our context and, consequently, to measure. Our framework provides an attempt to perform this measurement from a reduced-form, and unified, perspective. Undoubtedly, a wide range of structural aspects come into play in explaining these differences; however, the analysis of these aspects goes beyond the scope of this paper. An illustrative example is the case of the Baltic economies (Estonia, Latvia, and Lithuania) during 2007 and 2010, when their inflation rates exhibited a temporary, but substantial, disengagement from the inflation rates of their union partners. This illustrates that while there were euro-area forces acting like an “attractor,” there were also strong country-specific forces induced by multiple structural changes, associated with high levels of trade openness and liberal economic policies taking place around that time (see Benkovskis et al. 2009).

3.3 Breakdown by Inflation Subcomponents

In order to provide a comprehensive assessment of the exchange rate pass-through to inflation, it is also crucial to understand the impact that exchange rate shocks may have on the subcomponents of headline inflation. Therefore, the TVP-DFX framework is also used to independently model the subcomponents of headline inflation—core, food, and energy components—across euro-area countries.

We start by analyzing the core component. Figure 6 plots the common core inflation factor. Although the factor and 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 co-movement 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

individual countries can become more sensitive to exchange rate shocks. However, that total inflation can be decomposed into two parts, a common and an idiosyncratic one, which are independent. Therefore, the common part of the inflation rate of those countries (which is based on all, and not only on some, countries) does not necessarily have to also become more sensitive to exchange rate shocks.

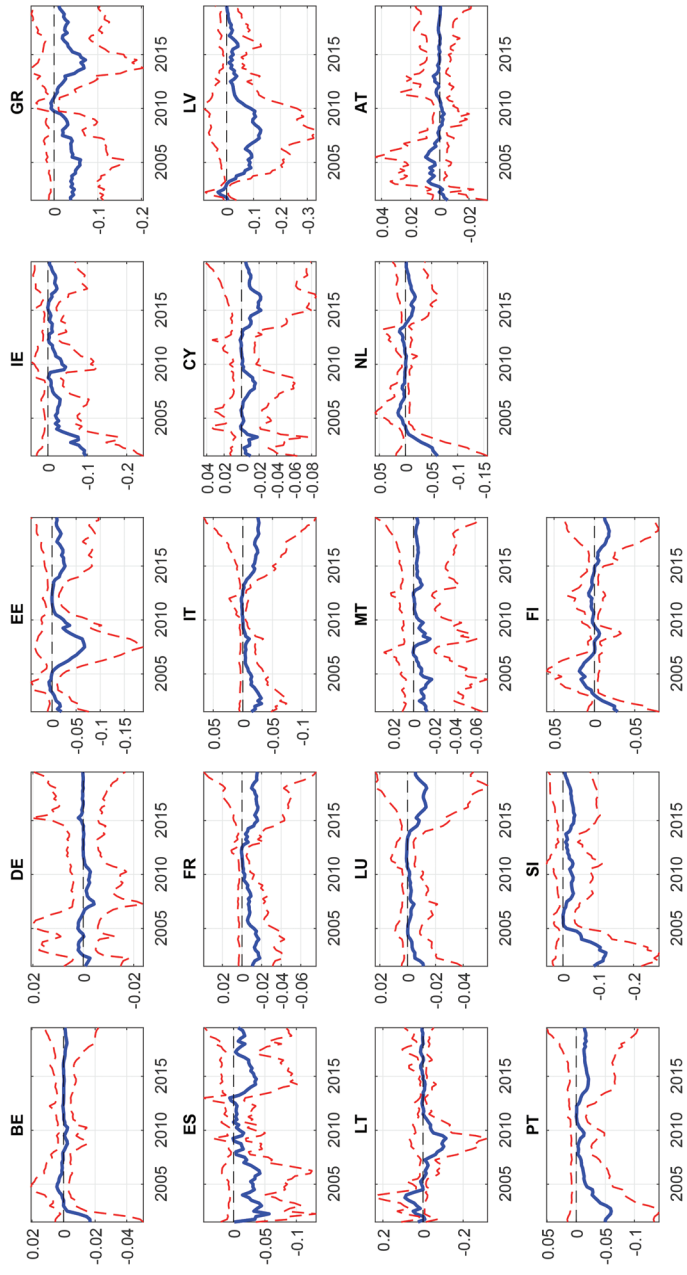
Figure 6. Euro-Area Core Inflation Factor (f_t)

Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area core quarterly inflation expressed in percentage points.

also the case when assessing the effect of the shocks on aggregate euro-area core inflation, proxied by the extracted common factor (see Figure 8A). Also, Figure 8B shows that the persistence of core inflation has remained steady. As expected, the pattern of core inflation co-movement across countries is more heterogeneous than in the case of headline inflation, which is inferred from the estimated time-varying factor loadings shown in Figure 9. Although some countries, such as Italy or France, have displayed increasing degree of co-movement, most countries have shown a relatively stable or even decreasing pattern, as in the case of Latvia.

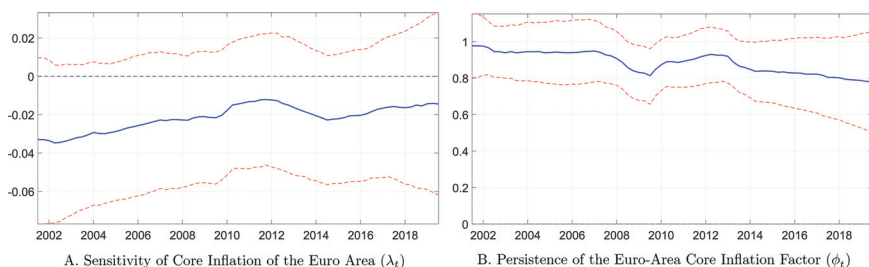
Next, with regard to food and energy subcomponents of inflation, Figures 10 and 11 show their estimated inflation factors, along with the corresponding euro-area aggregate inflation. Similar to the case of headline inflation, the path is one of striking accord. The increase in the effect of exchange rate shocks on inflation, occurred since 2010, has been significant for food prices (see Figure 12). However, it has been rather weak and more uncertain for energy inflation (see Figure 13). The degree and development of co-movement experienced by food and energy inflation rates have been relatively similar, as shown

Figure 7. Sensitivity of Country-Specific Core Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 8. Time-Varying Coefficients of Model for Core Inflation



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

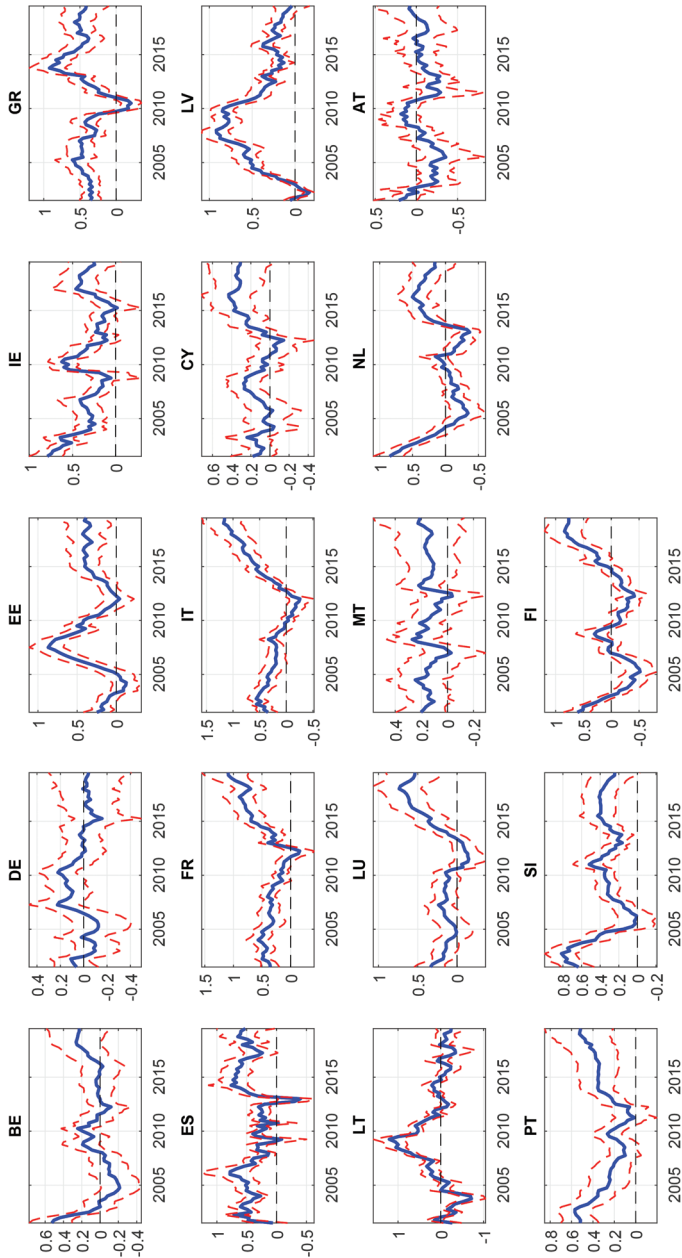
in Figures 14 and 15. Therefore, the difference between the sensitivity of food and energy inflation relies on the impact that exchange rate shocks have on the corresponding euro-area aggregates, that is, the *regionwide* component.²³

Based on the findings obtained with the multivariate framework in Equations (5)–(9), it is important to emphasize that both *country-specific* and *regionwide* channels of the ERPT are relevant, and their relative importance largely depends on the type of price component. Also note that an important feature of the proposed multivariate framework is that it is able to both estimate and decompose the sensitivity of inflation to exchange rate shocks. Such a decomposition could be extremely useful for policymakers. It provides a timely assessment of movements in inflation in a given country—brought about by exchange rate shocks—disentangling whether they are mainly driven by the country’s exclusive and intrinsic economic performance, by the overall performance of all monetary union partners, or by a combination of both.²⁴

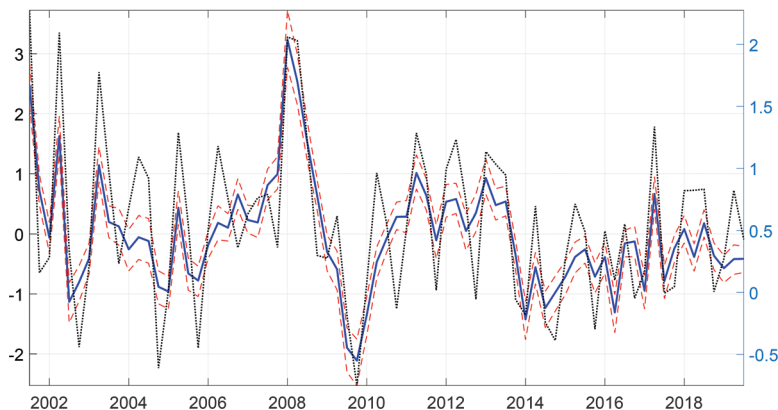
²³Thus, the effect of exogenous exchange rate shocks on euro-area food inflation has not changed substantially over time, but the sensitivity of aggregate energy inflation to unexpected exchange rate movements has increased considerably since 2009, as shown in Figures 16A and 17A, respectively.

²⁴This type of decomposition is in line with that proposed by Ozdagli and Weber (2017) based on spatial autoregressions. In particular, the authors focus on decomposing the total effect of monetary policy shocks on a given asset price

Figure 9. Time-Varying Co-movement of Euro-Area Countries' Core Inflation ($\gamma_{i,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 10. Euro-Area Food-Related Inflation Factor (f_t)

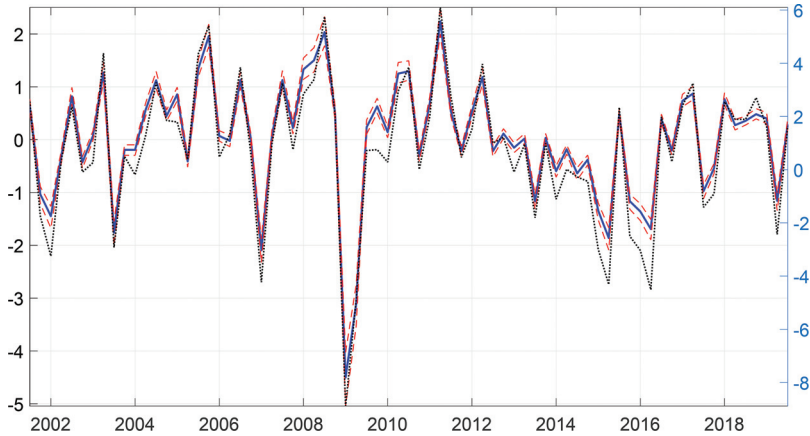
Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area food-related quarterly inflation expressed in percentage points.

The entire set of empirical results are summarized in Table 1. They suggest that the gradual increase of the EPRT to headline inflation over time can be mainly attributed to its energy component. Across euro-area countries, the energy component is highly influenced by global factors such as oil and other commodity prices. Hence, the increasing influence of global factors in recent years could explain the increasing interlinkages between the energy inflation across euro-area economies, yielding a higher sensitivity of headline inflation to exogenous exchange rate shocks.

3.4 Robustness

In order to verify that the ERPT dynamics across countries estimated using the proposed multivariate framework do not represent an artifact solely driven by the degree of co-movement, measured by the time-varying factor loadings, we perform a robustness exercise

into (i) a *direct effect*, which would be the equivalent of our *country-specific* component; and (ii) an *indirect effect*, which takes into account the joint interaction of that given asset with the other assets in the economy, i.e., the network effect, which could be interpreted as our *regionwide* component.

Figure 11. Euro-Area Energy-Related Inflation Factor (f_t)

Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area energy-related quarterly inflation expressed in percentage points.

that omits any information on inflation co-movement in the euro area. In particular, we estimate the effect of exchange rate shocks on inflation for each country, independently, based on the following univariate regression model subject to parameter time variation:

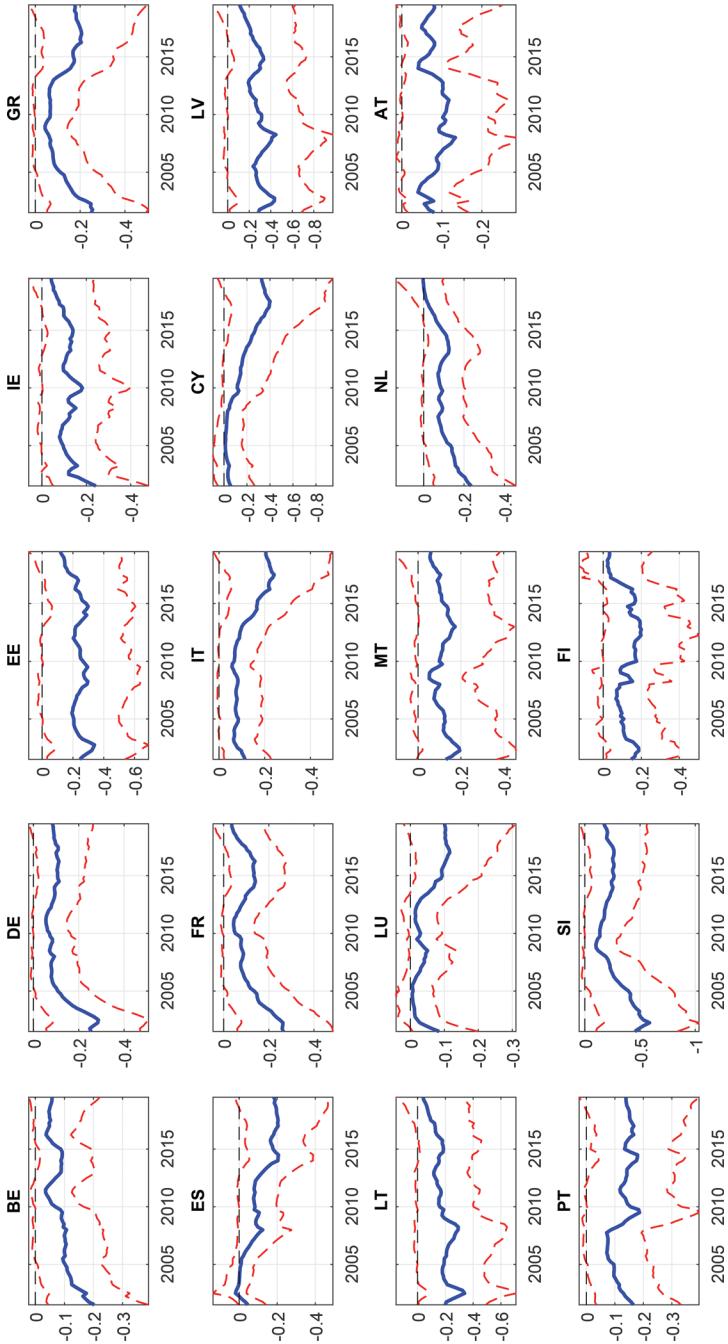
$$\pi_{i,t} = \hat{\phi}_{i,t}(L)\pi_{i,t-1} + \hat{\beta}_{i,t}\epsilon_t^{ER} + \hat{v}_{i,t}, \quad (11)$$

for $i = 1, 2, \dots, n$, and where the element of interest is given by the dynamics of the ERPT coefficient $\hat{\beta}_{i,t}$.²⁵

The estimated time-varying ERPT across countries associated with headline inflation is plotted in Figure B.4 of Online Appendix B to save space. The findings indicate that the ERPT obtained from the univariate models closely tracks the dynamics of the ERPT

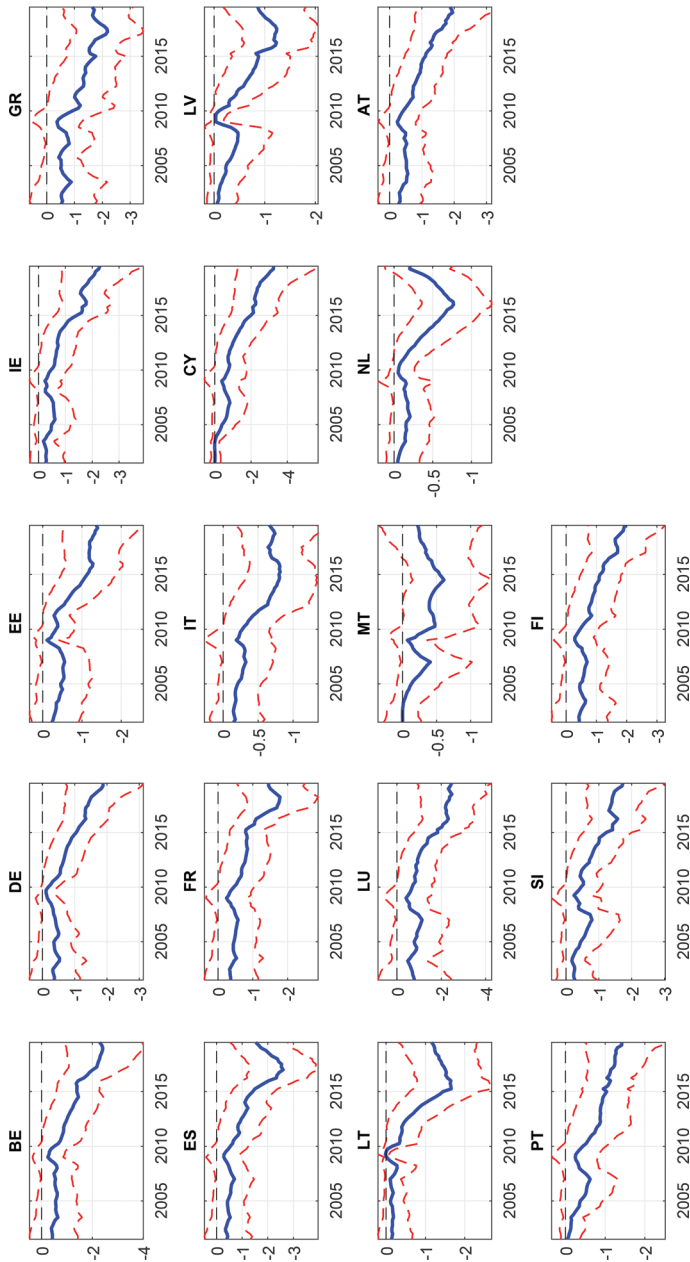
²⁵Each univariate time-varying parameter regression is estimated independently with Bayesian methods, assuming $L = 1$ for consistency with the multivariate approach. The estimation algorithm follows the corresponding simplified version of the one described in Section A.1 of the online appendices, and follows the same number of Gibbs sampling iterations and corresponding priors.

Figure 12. Sensitivity of Country-Specific Food-Related Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



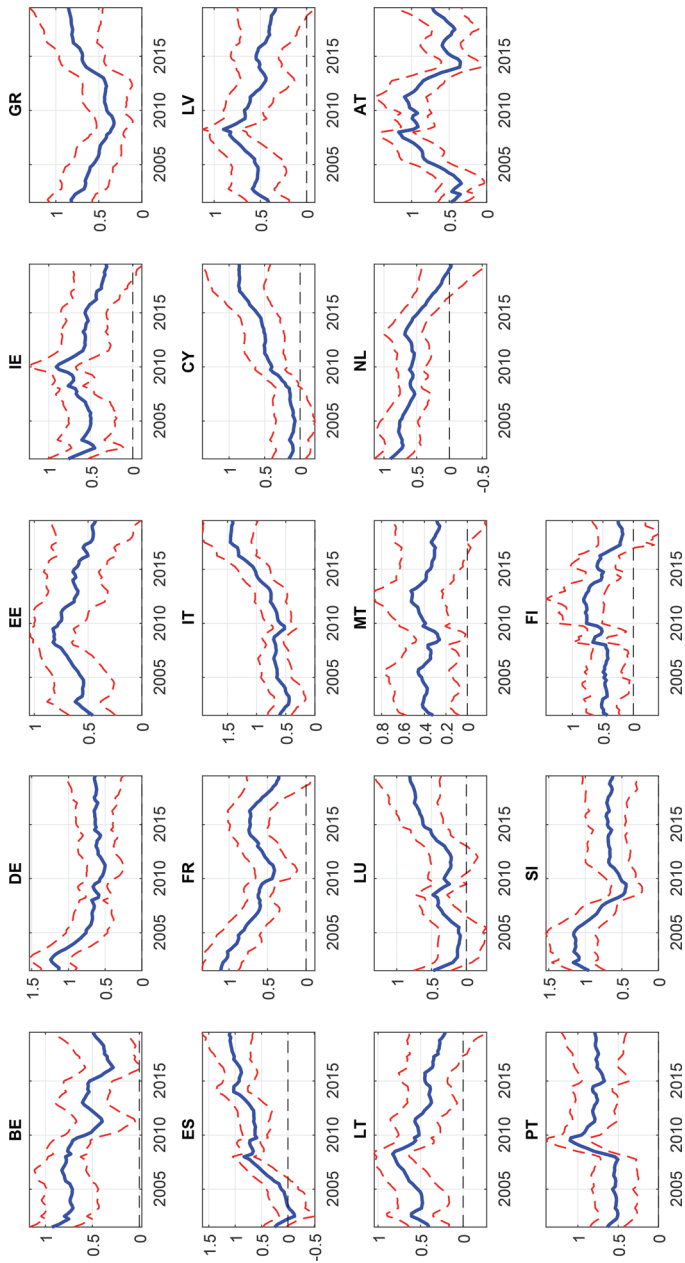
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 13. Sensitivity of Country-Specific Energy-Related Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



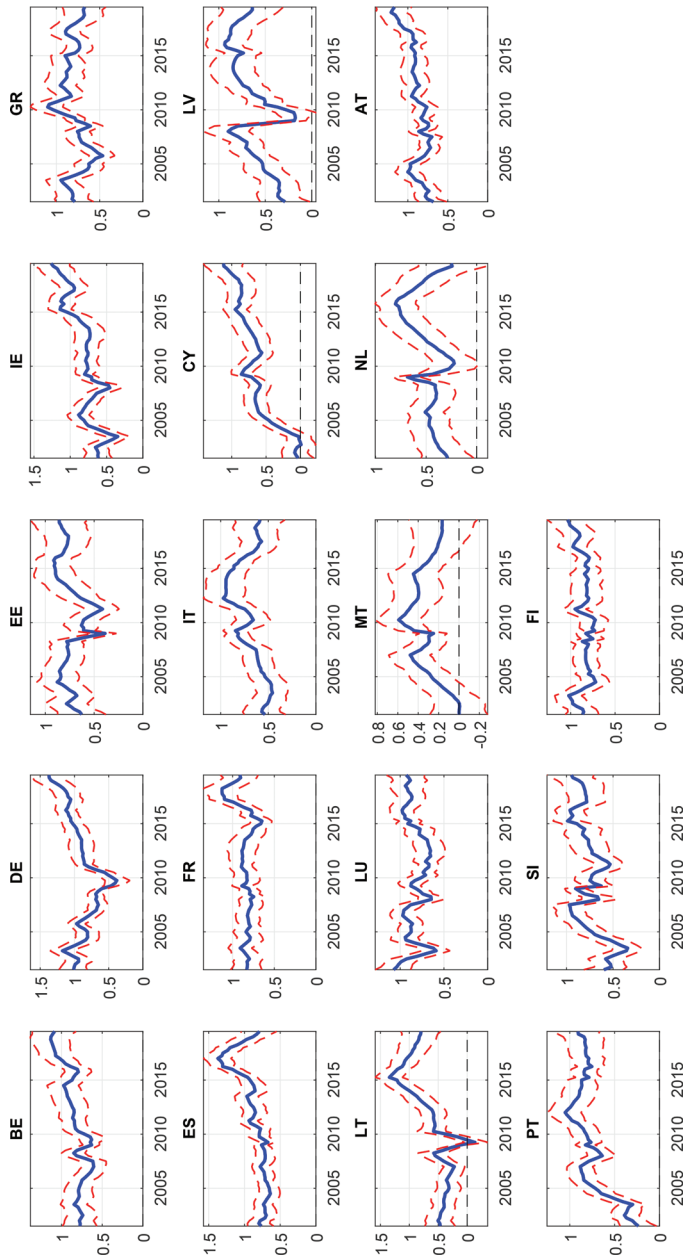
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 14. Time-Varying Co-movement of Euro-Area Countries' Food-Related Inflation ($\gamma_{i,t}$)



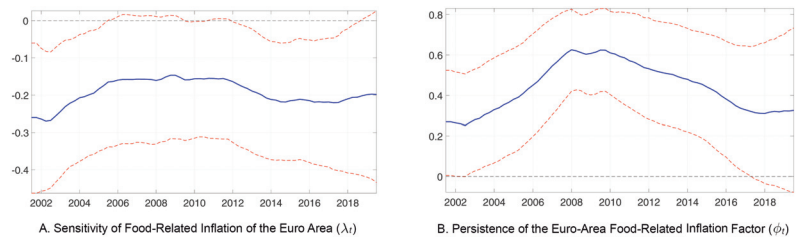
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 15. Time-Varying Co-movement of Euro-Area Countries' Energy-Related Inflation ($\gamma_{i,t}$)



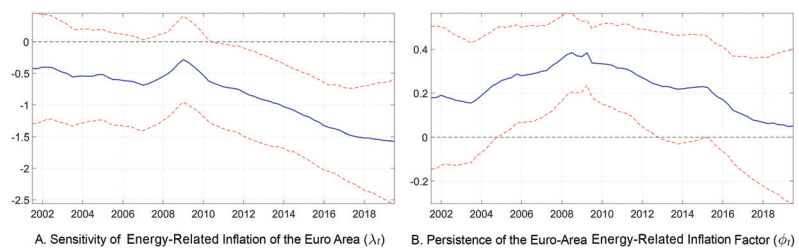
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 16. Time-Varying Coefficients of Model for Food-Related Inflation



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 17. Time-Varying Coefficients of Model for Energy-Related Inflation



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Table 1. Summary of Exchange Rate Pass-Through to Inflation

	Headline	Core	Food	Energy
Total Pass-Through	✓	—	—	✓
Country-Specific Component	✓	—	—	✓
Regionwide Component	—	—	—	✓

Note: The table summarizes the main results from the empirical analysis. An entry with “✓” indicates that there has been a significant increase in the total exchange rate pass-through, or its components, to the corresponding type of inflation. An entry with “—” indicates that there has not been a significant increase in the total exchange rate pass-through, or its components, to the corresponding type of inflation.

obtained from the proposed multivariate approach. This is the case for almost all the euro-area countries, with the only exceptions being Malta and Finland. In the case of core inflation, although the estimates obtained from the two approaches do not always look similar, the ERPT estimates from the univariate models point to the same message as that provided by the multivariate model, which is that the sensitivity of core inflation to exchange rate shocks tends to be of a smaller magnitude and, more importantly, the estimates tend to be more uncertain (Figure B.5).²⁶ Lastly, regarding the food and energy subcomponents of headline inflation, the estimates from univariate models also follow a similar path to the estimates from the multivariate model, as shown in Figures B.6 and B.7, respectively. These findings evidence that while independent univariate regressions can only measure the degree of sensitivity of euro-area countries' inflation to exogenous exchange rate shocks, the proposed factor model is able to perform the same task, while also providing a decomposition of such sensitivity into *country-specific* and *regionwide* effects.

4. Concluding Remarks

This paper proposes an innovative approach that should improve our ability to assess the effect of exchange rate fluctuations on prices across countries—especially from a time-varying and cross-country unified perspective—and by taking into account the source of exchange rate changes.

To this end, we decompose into a country-specific and regionwide component the time-varying effect that unexpected movements in the EUR/USD nominal exchange rate have on different measures of inflation in the euro-area countries. Of all the sources of exchange rate fluctuations, this paper focuses only on exogenous exchange rate shocks. This is partly because we seek to imitate insofar as possible the concept of exchange rate pass-through in a shock-dependent context: we isolate the transmission to prices of “pure” exchange

²⁶When adding information on lagged shocks as additional explanatory variables in Equation (11), we find that the associated time-varying coefficients are not statistically significant. This is the case for both headline and core inflation rates. These results are not shown for the sake of space, but are available upon request.

rate shocks from the joint reaction of prices and exchange rates to other structural shocks such as demand, supply, or monetary policy shocks.

We propose an econometric framework that relies (i) on an SVAR model to identify purely exogenous exchange rate shocks; and (ii) on a dynamic factor model subject to drifting coefficients and exogenous information to identify the pass-through to inflation of such exogenous exchange rate shocks. The estimates suggest that exogenous shocks to the EUR/USD are paramount. They are behind more than 50 percent of the nominal EUR/USD exchange rate fluctuations in more than a third of the quarters of the past six years, especially in turning-point periods.

Our main findings indicate that headline inflation, and in particular its energy component, has become significantly more affected by these exogenous exchange rate shocks since the early 2010s, especially in the largest economies of the region. While in the case of headline inflation this increasing sensitivity is solely reliant on a sustained surge in the degree of co-movement, in the case of energy inflation it is also based on a higher regionwide effect of the shocks. The effect of exogenous exchange rate shocks in food inflation is similar to, but much lower than, the impact on headline inflation. By contrast, purely exogenous shocks do not seem to have a significant effect on the core component of headline inflation, which also displays a lower degree of co-movement across euro-area countries.

The information obtained with this type of decomposition can be useful for policymakers to understand the extent to which movements in inflation of a given country, brought about by exchange rate shocks, can be attributed to its exclusive and intrinsic economic performance or to the overall performance of all monetary union partners. In particular, the documented sustained surge in the degree of inflation co-movement would represent a favorable feature for the conduct of monetary policy.

The framework described here is not intended or able to capture structural differences across countries that are key to explaining different impacts of exchange rate movements, such as the role of invoicing currency, whether the transactions take place between or within firms, the frequency and dispersion of price adjustments, integration in global value chains, or the role of competition in final product markets, but it still adds an important new dimension

to the standard approach for analyzing ERPT. Decomposing the effect of pure exogenous exchange rate shocks on euro-area countries' inflation into country-specific (*idiosyncratic*) and regionwide (*common*) components from a time-varying perspective should improve our understanding, to allow us to better assess the impact of currency movements and, as a result, help central banks set appropriate monetary policy.

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