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Exchange rate pass-through in the euro area: a counterfactual SVAR approach

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VERY PRELIMINARY — PLEASE DO NOT CITE

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Abstract

We study exchange rate pass-through (ERPT) in the euro area using a novel counterfactual Bayesian SVAR approach. By constructing scenarios in which the exchange rate channel is shut down while all other transmission channels remain operative, we isolate the causal effect of exchange rate movements on inflation, purging conventional ERPT measures of contamination from the broader inflationary impulse of the underlying shock. We obtain several novel conclusions, including the reversing of the negative pass-through for demand shocks, somewhat smaller size of ERPT estimates, and smaller ERPT heterogeneity compared to previous studies. We further show that the strikingly heterogeneous co-movements between the exchange rate and inflation documented in the existing literature are perfectly consistent with an underlying causal ERPT that is relatively homogeneous across shocks, while remaining agnostic about the true degree of heterogeneity in the causal pass-through itself. Historical decompositions reveal sizable exchange rate contributions to euro area inflation during key episodes that conventional measures would easily miss.

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1 Introduction

Exchange rate pass-through (ERPT) - the extent to which movements in the nominal exchange rate translate into changes in domestic prices - is a key parameter in international macroeconomics, with direct implications for the conduct of monetary policy, the choice of exchange rate regime, and the international transmission of shocks (Burstein and Gopinath, 2014; Goldberg and Knetter, 1997; Shambaugh, 2008).

Yet estimating ERPT has proven challenging - it is well documented that its magnitude varies over time and depends on both the prevailing state of the economy and the nature of the underlying shock.[1] The task is further complicated by the fact that the exchange rate is not an exogenous policy instrument that can be manipulated independently of the other shocks affecting the economy. Rather, it is a general equilibrium outcome, jointly determined by the same underlying shocks that simultaneously drive inflation through multiple other channels. Any observed co-movement between the exchange rate and prices, therefore, need not be a measure of pass-through: it only reflects the joint response of both variables to a common macroeconomic disturbance. In practice, a shock moves the exchange rate directly, but at the same time exerts independent pressure on prices through other channels - demand conditions, supply costs, monetary policy responses, and financial conditions - rendering these effects inherently difficult to disentangle. Isolating the component of inflation dynamics attributable specifically to the exchange rate channel, that is, the pass-through, requires separating it from the full constellation of overall price pressures generated by the same shock through all channels. This identification challenge lies at the heart of the methodological evolution of the empirical exchange rate pass-through literature, and remains, to date, largely unresolved by any existing approach. In this paper, we propose a method to separate causal ERPT from co-movement between bilateral USD/EUR exchange rate and price inflation.

Two examples illustrate the problem. Consider first a positive aggregate demand shock hitting the euro area, inflationary by definition: higher activity raises wages and prices directly. At the same time, strong domestic demand tends to appreciate the nominal exchange rate - capital is attracted by higher expected returns and the central bank may tighten monetary policy in response (Corsetti and Dedola, 2005; Corsetti et al., 2008, 2014). This appreciation is, in isolation, deflationary: it lowers import costs and reduces inflationary pressure from abroad. But the deflationary exchange rate effect and the inflationary demand effect are both generated by the same shock, operating simultaneously,

[1] A large body of evidence documents that pass-through has declined over time in both advanced and emerging economies, a trend commonly attributed to the establishment of credible low-inflation monetary policy regimes and increased competition from global supply chains (Taylor, 2000; Campa and Goldberg, 2005; Gagnon and Ihrig, 2004). ERPT is also state-dependent: its magnitude varies with the inflationary environment, the size and direction of exchange rate changes, and the position of the business cycle (Shambaugh, 2008; Forbes et al., 2018; Ha et al., 2020). Furthermore, the currency in which international trade is invoiced plays a critical role in determining the speed and extent of pass-through, with the dominance of the US dollar as an invoicing currency implying that bilateral exchange rate movements may have limited direct effects on import prices for many country pairs (Gopinath, 2015; Gopinath et al., 2010; Boz et al., 2022).

offsetting each other and often difficult to separate. Any attempt to measure pass-through by looking at what happened to prices when the exchange rate appreciated will pick up the net outcome of these two opposing forces. Importantly, in many cases the demand effect dominates, so the measured co-movement between the exchange rate and inflation is positive - the exchange rate appreciation appears to be inflationary - yielding the opposite of the true, partially stabilising role it actually played, see Forbes et al. (2015) or Zhai and Yoshida (2025) for example. A second, structurally distinct example involves a positive relative demand shock in the euro area relative to the United States - for instance, a perceived cyclical upturn in European activity while the US economy weakens. The shock appreciates the euro, which, through the conventional exchange rate channel, reduces the domestic-currency cost of imports and exerts downward pressure on euro area prices. But the same shock that appreciated the euro simultaneously weakened the US economy, prompting the Federal Reserve to ease monetary policy. The consequences of US monetary loosening, however, may not stop at the US border. Given the centrality of the dollar in global financial intermediation, Federal Reserve easing has well-documented global reach through the global financial cycle: it compresses risk premia, relaxes global credit conditions, and stimulates capital flows and asset prices worldwide (Rey, 2015; Miranda-Agrippino and Rey, 2020). As global financial conditions ease, the ECB faces an environment of recovering global demand, rising asset prices, and capital inflows that generates its own inflationary pressures - entirely unrelated to, and working in the opposite direction from, the deflationary impulse of the euro appreciation. The ECB may also respond by accommodating the global easing, further adding to domestic inflationary pressure.[2] The net outcome of these opposite forces - deflationary pressures due to euro appreciation and central bank accommodation via the financial cycle channel - is highly uncertain.[3] Indeed, Corbo and Di Casola (2022) explicitly find that the observed exchange

[2] The global financial cycle - the co-movement of global risk appetite, capital flows, and asset prices driven predominantly by US monetary policy - has been documented by Rey (2015) and Miranda-Agrippino and Rey (2020). Its relevance for ERPT arises because US monetary policy shocks have direct inflationary or deflationary effects on the euro area through capital flows and financial conditions, independently of their effect via the bilateral exchange rate. The role of the US dollar as a vehicle and invoicing currency - documented by Goldberg and Tille (2008) and Boz et al. (2022) - amplifies these spillovers by ensuring that a large share of world trade is priced in dollars, making euro area import costs particularly sensitive to dollar-denominated commodity prices and global financial conditions. The theoretical foundations for endogenous currency choice in invoicing were developed by Devereux et al. (2004) and Bacchetta and van Wincoop (2005), who showed that the currency of invoice is itself a firm-level decision, so that ERPT cannot be treated as a stable parameter independent of the monetary regime. Corsetti et al. (2022) provide causal evidence on how anticipated permanent exchange rate changes alter pricing-to-market behaviour using the Brexit referendum as a natural experiment. The general theme that multiple simultaneous transmission channels make it inherently difficult to attribute inflation movements to any single factor is emphasised by Goldberg and Tille (2009).

[3] The empirical evidence on the potency of US monetary policy spillovers through financial channels is extensive. Dedola et al. (2017) find that a surprise US monetary tightening leads to a dollar appreciation, a decline in foreign industrial production and inflation, with significant heterogeneity across countries in the response of asset prices and cross-border flows. Degasperi et al. (2021) show that financial channels dominate over demand and exchange rate channels in the global transmission of US monetary policy, and that flexible exchange rates cannot fully insulate domestic economies due to movements in risk premia. Kalemli-Özcan (2019) documents that US monetary policy generates international risk spillovers through shifts in risk premia that operate independently of, and alongside, exchange rate movements.

rate pass-through following global demand shocks is of opposite sign to what is usually expected.

The empirical literature on exchange rate pass-through (ERPT) has undergone substantial methodological evolution over the past three decades, driven by a growing recognition of the limitations inherent in earlier approaches. The earliest and most widely adopted strand of the literature relied on a single-equation framework, in which domestic inflation was regressed on lagged exchange rate changes alongside a limited set of control variables capturing foreign cost pressures and domestic demand conditions, for example Goldberg and Knetter (1997), Campa and Goldberg (2005, 2008), Choudhri and Hakura (2006), Taylor (2000), Gagnon and Ihrig (2004), Ben Cheikh and Rault (2015), and Burstein and Gopinath (2014). While tractable and straightforward to implement, single-equation specifications rest on an unrealistic assumption: that the exchange rate is fully exogenous with respect to the domestic macroeconomic environment. In reality, the nominal exchange rate is a general equilibrium outcome, jointly determined by the same forces - aggregate supply and demand conditions, monetary policy, and global financial markets - that simultaneously influence domestic inflation. Treating the exchange rate as an exogenous regressor therefore introduces simultaneity bias, rendering ERPT estimates inconsistent (Osbat and Wagner, 2006; Flaccadoro, 2024).[4]

In response to these concerns, multivariate vector autoregressive (VAR) frameworks model both the exchange rate and inflation as jointly endogenous variables. Within this literature, identification of structural shocks has most commonly been achieved through the Cholesky recursive decomposition, for example in Hahn (2003), McCarthy (2007), Ca' Zorzi et al. (2007), Hüfner and Schröder (2002), Choudhri and Hakura (2006), Ito and Sato (2008), and Kohlscheen (2010). Although the VAR approach addresses endogeneity by embedding the exchange rate within a dynamic system, the Cholesky decomposition imposes strong and often theoretically unwarranted exclusion restrictions on the contemporaneous impact matrix, and the resulting ERPT estimates are sensitive to the ordering of variables. By construction, Cholesky identification yields statistically orthogonal shocks - exchange rate shocks included - that nevertheless prove difficult to interpret in economic terms. More fundamentally, although existing Cholesky-based analyses of ERPT typically fail to report any variance or historical decomposition of exchange rate dynamics, nearly all variation in such specifications tends to be attributed to own-shocks - a highly implausible result indicating that the recursive ordering restrictions imposed by the Cholesky decomposition are too weak to isolate the true structural sources of exchange rate fluctuations.

To circumvent the limitations of Cholesky-based identification, subsequent contributions replaced recursive restrictions with restrictions more firmly grounded in economic theory, usually sign and zero restrictions. Shambaugh (2008), based on such a framework, was the first to demonstrate that the correlation between inflation and the exchange rate varies substantially across supply, demand, and monetary policy disturbances. Forbes et al. (2015, 2018) developed this idea further in highly influen-

[4] These specifications attempt to control for macroeconomic environment by using a small number of controls, but given the high number of potential omitted variables, such controls are unlikely to account for the underlying macroeconomic shocks; see Flaccadoro (2024).

tial work covering the United Kingdom and a broader cross-section of countries, finding that monetary policy shocks are associated with the highest measured pass-through, while demand shocks yield considerably lower or even negative estimates. Comunale and Kunovac (2017) confirmed this pattern for the euro area, and corroborating evidence advocating the existence of conditional pass-through has since accumulated across a wide range of country settings and methodological frameworks, including Corbo and Di Casola (2018, 2022) for Sweden and small open economies, Leiva-León et al. (2020) for disaggregated euro area price indexes, Osbat et al. (2021) for industry-level producer prices, An et al. (2021) and Zhai and Yoshida (2025) for Japan, and Ha et al. (2020) in a large cross-country panel. The emerging consensus holds that the standard unconditional estimate of ERPT - averaging over all shocks - constitutes an insufficient statistic for monetary policy purposes, which instead requires an understanding of how specific structural shocks transmit to prices through the exchange rate channel. The key empirical finding motivating this departure from Cholesky identification is that exogenous exchange rate movements - those attributable to a pure exchange rate shock - account for only a minor share of the overall variation in the nominal effective exchange rate: approximately 10% in the euro area (Comunale and Kunovac, 2017) and around 20% for the UK, Sweden and Canada (Corbo and Di Casola, 2022; Forbes et al., 2015). The bulk of exchange rate variation is thus driven by other macroeconomic shocks, implying that ERPT estimates conditioned exclusively on a pure exchange rate shock are insufficient for a comprehensive and policy-relevant assessment.

Despite this conceptual advance, the workhorse measure of ERPT employed in this structural VAR literature - the price-to-exchange-rate ratio (PERR), as labelled by Ortega and Osbat (2020) - suffers from a fundamental interpretive limitation. PERR is defined as the ratio of the cumulative impulse response of prices to the cumulative impulse response of the exchange rate following a given structural shock. As such, it measures the conditional co-movement between the exchange rate and prices, not the causal contribution of the exchange rate to the price response. Only in the special case of a pure, exogenous exchange rate shock - one that moves the exchange rate but affects prices exclusively through the exchange rate channel - does PERR recover the true ERPT. For every other economically meaningful shock, the shock simultaneously affects prices through multiple channels, both directly and through its effect on the exchange rate. PERR captures the total joint response of prices and exchange rate to the shock without isolating the portion of the price response attributable to the exchange rate channel specifically. The causal exchange rate contribution to inflation is therefore not identified by PERR in these cases, rendering it a measure of correlation rather than pass-through in the proper sense (Ortega and Osbat, 2020).

This paper addresses identification and channel confounding issues in the literature by proposing a counterfactual Bayesian VAR methodology designed to isolate the causal contribution of the exchange rate to the inflation response conditional on each structural shock. The key idea, following the counterfactual methodology of Bachmann and Sims (2012) and Wong (2015), is to construct for each shock of interest a hypothetical scenario in which the shock is prevented from affecting the exchange rate - while leaving all other channels of transmission intact - and to compare the resulting counterfactual inflation path with the benchmark impulse response. The difference between the two paths measures precisely the amplification role of the exchange rate: how much of the total inflationary or deflationary effect of each shock is attributable to the exchange rate channel, as distinct from the direct mechanisms through which the shock affects prices independently of the currency. This counterfactual design enables a clean separation between co-movement and causality, addressing directly the identification challenge set out in Section 2 and providing an economically interpretable measure of ERPT that is robust to the entanglement of the exchange rate channel with competing transmission mechanisms. To the best of our knowledge, this paper is the first to apply this counterfactual framework systematically to the estimation of ERPT across the full set of structural shocks driving the euro area economy. Our counterfactual approach removes this contamination of other mechanisms, and the result is striking: once the exchange rate channel is properly isolated, the estimated ERPT is remarkably similar across all four identified shocks. We emphasise, however, that this finding is conditional on the linear specification of the model, which is standard in the literature but constrains the model's ability to accommodate genuine state- or shock-dependent variation in pass-through. We therefore do not claim that the true causal ERPT is universally homogeneous. Rather, we claim that the dramatic cross-shock heterogeneity documented in previous studies primarily reflects differences in co-movement structure rather than differences in the exchange rate channel itself. We show that the dramatic heterogeneity in co-movement of exchange rate and inflation is perfectly consistent with the causal ERPT being relatively homogeneous, and we leave to future research the question of whether a richer nonlinear specification would reveal genuine heterogeneity in ERPT across shocks.

The remainder of the paper is organised as follows. Section 2 outlines the identification challenges in the existing literature and presents our approach to addressing them, followed by a description of the data. Section 4 presents and discusses the main results. Section 5 conducts an array of robustness checks. Section 6 concludes.

2 Methodology

We estimate a Bayesian Vector Autoregression (BVAR) and identify structural shocks through sign restrictions, following Uhlig (2005) and Canova and De Nicoló (2002). Our central methodological contribution is to measure ERPT via novel *counterfactual IRF comparisons*—a procedure that isolates the exchange-rate channel from all other transmission mechanisms operative in a given shock—alongside the conventional relative response (PERR-style) measure, enabling a rigorous assessment of the bias embedded in the previous estimates.

Consider the structural VAR:

$$A_0\, y_t = \sum_{i=1}^{p} A_i\, y_{t-i} + \epsilon_t, \tag{1}$$

with reduced form $y_t = \sum_{i=1}^{p} B_i\, y_{t-i} + u_t$, where $B_i = A_0^{-1} A_i$ and $u_t = A_0^{-1}\epsilon_t$. The system contains four variables: GDP, HICP inflation, the policy interest rate, and the nominal effective exchange rate.

We use $p = 4$ lags. The variables are in relative Eurozone-US terms. Meaning that they capture the difference in movements of the variables in Eurozone and the US. [5]

We identify four structural shocks—monetary policy, aggregate demand, aggregate supply, and sentiment—by imposing sign restrictions on impact responses, as summarised in Table 1. The identification set follows Farrant and Peersman (2006) and is broadly consistent with the approaches used in the related literature on shock-dependent exchange rate pass-through (Forbes et al., 2018; Comunale and Kunovac, 2017; Corbo and Di Casola, 2022). Bayesian inference is conducted under an independent Normal–Inverse Wishart prior for the reduced-form parameters; structural rotation matrices are drawn following Arias et al. (2018), ensuring that posterior inference properly conditions on the sign restrictions.

Table 1: Sign Restrictions on Impact

	Structural Shocks			
Variable	Monetary Policy	Demand	Supply	Sentiment
GDP	−	+	+	−
HICP	−	+	−	−
Interest Rate	+	+		−
Exchange Rate	+	+		+

Notes: Sign restrictions imposed on impact impulse responses. "+" ("−") denotes a positive (negative) restriction; blank entries are unrestricted.

The restrictions we impose reflect several relatively uncontroversial ideas. The relative aggregate demand shock is associated with a positive co-movement between output and prices, a tightening of the relative monetary policy stance, and an appreciation of the euro, consistent with standard open-economy New Keynesian models (Galí and Monacelli, 2005; Clarida et al., 1999). Intuitively, stronger cyclical conditions in the euro area relative to the US generate upward pressure on activity and inflation, to which the ECB responds by tightening relative to the Fed, and which attracts capital inflows into euro-denominated assets.

The relative aggregate supply shock is identified through the opposing movement of output and prices that characterizes productivity and cost-push disturbances (Blanchard and Quah, 1989; Galí, 1999), with an ambiguous effect on interest and exchange rates. The monetary policy shock is identified by assuming that a contractionary shock lowers GDP and inflation and appreciates the nominal

[5] As already noted in the introduction, potential asymmetries may arise in the transmission of monetary policy shocks depending on their origin — whether the exchange rate movement is driven by the Federal Reserve tightening or the ECB easing, for instance. Given the dollar's dominant role in global trade and finance, Fed decisions reverberate across the world economy far more forcefully than those of the ECB, and the inflationary consequences of an equivalent exchange rate movement may therefore differ depending on which central bank is the source. However, the relative specification of our model does not distinguish between these two sources of variation, and exploring this asymmetry is left for future research.

exchange rate (Forbes et al., 2018; Boeckx et al., 2014).

The sentiment shock captures movements in the bilateral exchange rate that are driven neither by the relative macroeconomic cycle nor by systematic central bank responses, but by changes in investor risk appetite, safe-asset demand, and perceptions of relative uncertainty. We identify it as a shock that appreciates the euro while simultaneously lowering euro-denominated yields as investor preferences shift, accompanied by a contraction in relative output and a decline in relative prices. This pattern is consistent with a risk-off episode that compresses US yields through flight-to-safety flows into Treasuries, a mechanism documented by Habib and Stracca (2012), Lilley et al. (2019), and Jiang et al. (2021), and which is closely related to the global financial cycle channel of Miranda-Agrippino and Rey (2020). The bilateral exchange rate is well known to be driven in substantial part by factors that cannot be attributed to cyclical or policy fundamentals, with exogenous exchange-rate shocks typically accounting for between 10 and 25 per cent of exchange rate variation (Forbes et al., 2018; Comunale and Kunovac, 2017; Corbo and Di Casola, 2022).

The conventional PERR measure computes the ratio of the impulse response of inflation to that of the exchange rate following a given shock. However, the existence of several transmission channels may introduce noise into this measure. Formally, letting $\Psi_{\pi,k,s}$ and $\Psi_{q,k,s}$ denote the impulse responses of inflation and the exchange rate to shock s at horizon k, the PERR coincides with the true causal ERPT coefficient β if and only if

$$\Psi_{\pi,k,s} = \beta \cdot \Psi_{q,k,s} \quad \forall\, k \geq 0, \tag{2}$$

that is, if inflation responds to shock j solely and proportionally through the exchange rate at every horizon. This condition holds only if the exchange rate q is the unique transmission channel from shock j to inflation π. This requirement is satisfied by construction for a pure exogenous exchange rate shock, but fails for demand, supply, or monetary policy shocks, all of which affect inflation through channels that are independent of the exchange rate.

This makes PERR a biased measure of the truly causal pass-through coefficient. In our view PERR is more suited as a measure of the co-movement between the exchange rate and inflation, which is an important object, but can not be interpreted causality. Our counterfactual approach, described next, is designed to eliminate exactly this bias and allow for a causal interpretation of ERPT in a macroeconomic setting studying various structural shocks. As previously explained, the logic is most clearly illustrated in the case of a demand shock. A demand shock is simultaneously appreciatory and inflationary, producing an effect that is not merely biased in magnitude but also incorrectly signed. When using our approach and taking the difference between the benchmark and counterfactual cases, a demand shock exerts a deflationary effect through the exchange rate channel.

2.1 Counterfactual IRFs and the Measurement of ERPT

Our primary methodological contribution is the construction of a *shock-specific counterfactual* in which the exchange rate is held fixed throughout the transmission of each structural shock, so that the difference between the baseline and counterfactual inflation response can be attributed *exclusively* to the exchange-rate channel. This approach follows the ideas of Bachmann and Sims (2012) and Wong (2015), and connects to the broader tradition of Sims and Zha (2006) and Kilian and Lewis (2011). We construct the counterfactual using two distinct approaches. The first creates a series of offsetting shocks calibrated to hold exchange rate movements at exactly zero. The second imposes zero impact and long-run restrictions to build a counterfactual model in which the response of the exchange rate to structural shocks is approximately zero by construction. We adopt the offsetting shocks approach as our benchmark, and the remainder of this section is devoted to its exposition. The zero-restriction approach is described in detail in Section 5.

Working in companion-form notation (see Appendix C for the full construction), let $\Psi_{j,k,s}$ denote the impulse response of variable j at horizon k to a one-standard-deviation structural shock s, computed from

$$\Psi_{j,k,s} = e_j \, \Lambda^k \, \zeta_s, \qquad \forall \, k \in \mathbb{N}_0, \tag{3}$$

where Λ is the companion matrix of the reduced-form VAR, e_j is the unit selector for variable j, and $\zeta_s = \tilde{A}_0^{-1} e_s'$ translates the structural shock into a reduced-form impulse. We seek a sequence of *offsetting* shocks $\{\hat{\epsilon}_k^s\}_{k=0}^{\infty}$ applied to a chosen instrument variable f such that the counterfactual exchange-rate response is identically zero at every horizon:

$$\hat{\Psi}_{c,k,s} = 0, \qquad \forall \, k \in \mathbb{N}_0, \tag{4}$$

where c indexes the exchange rate. These offsetting shocks are computed recursively (details in Appendix C), and the resulting counterfactual IRF for any variable j is:

$$\hat{\Psi}_{j,k,s} = \Psi_{j,k,s} + \sum_{n=0}^{k} e_j \, \Lambda^{k-n} \, \tilde{A}_0^{-1} \, F_f' \, \hat{\epsilon}_n^s, \qquad j = 1, \ldots, N, \tag{5}$$

where F_f is a row vector that activates the offsetting shock(s). This enables us to answer the question: What would the responses of a variable j to shock s look like if variable c had been held constant?

In our benchmark results, we assign weights w_k using the *historical decomposition* of shocks driving the constrained variable (exchange rate). This is unlike the choice of Bobeica et al. (2019), who use an *equally-weighted* combination of all shocks. Specifically, each structural shock is weighted according to its contribution to the sample variance of the exchange rate, as defined in equations 41–43. This approach ensures that shocks which historically account for a larger share of exchange rate fluctuations receive greater weight in the offsetting combination, making the composite offsetting shock more reflective of the actual drivers of exchange rate dynamics in the data. Equal weighting, by contrast, implicitly treats all structural shocks as equally plausible sources of exchange rate variation, regardless of their empirical relevance.[6] To our knowledge, this weighting scheme has not been previously employed in the counterfactual SVAR literature, and represents a natural bridge between the historical decomposition and counterfactual analysis that are typically conducted separately. As a robustness check, we verify that our main results are not sensitive to this choice by repeating the analysis under equal weights, as well as under individual shocks.

Since the model is estimated with sign restrictions, the matrix A_0 is replaced by the draw Q at each posterior iteration. Thus the entire counterfactual construction is therefore repeated for every accepted draw conditional for the drawn matrix Q, yielding a full posterior distribution over counterfactual IRFs.

Beyond the impulse-response comparison, we bring the counterfactual into the historical data to construct an alternative time series in which no structural shock was allowed to move the exchange rate. Formally, the counterfactual series for variable i is:

$$\underbrace{\tilde{y}_{i,t}}_{\text{counterfactual}} = \underbrace{y_{i,t}}_{\text{actual}} - \underbrace{\sum_{s=0}^{t-1} \sum_{j=1}^{N} \left(\Psi_{i,j,s} - \hat{\Psi}_{i,j,s} \right) u_{j,t-s}}_{\text{contribution of the muted exchange-rate channel}} , \tag{6}$$

where $u_{j,t}$ are the estimated structural shocks, $\Psi_{ij,s}$ and $\hat{\Psi}_{ij,s}$ are the actual and counterfactual IRFs from equations (3) and (5), and j indexes the four structural shocks. The difference $\tilde{y}_{i,t} - y_{i,t}$ thus measures, period by period, how much of the realised inflation path was driven by exchange-rate movements triggered by each shock—a shock-conditional, time-varying measure of pass-through that is not available from PERR.

Our counterfactual approach delivers two distinct methodological gains over standard PERR. First, the counterfactual cleanly separates the exchange-rate channel from other direct and indirect effects of each shock on inflation, eliminating the econometric biases inherent in PERR under the realistic assumption that shocks have multiple transmission channels. Second, the historical decomposition in equation (6) translates IRF-based counterfactuals into an economically interpretable narrative about specific inflationary episodes - a feature that is directly useful for policy analysis. To our knowledge, this is the first application of this methodology in the context of ERPT.

3 Data

In this chapter, we describe the data used for the empirical analysis. A summary of data sources with their identifiers is further provided in the Appendix. The data covers the period from 1999Q1 to 2025Q4 at a quarterly frequency. The GDP series are taken as gross domestic product at market prices, chain-linked volumes (2015=100), calendar and seasonally adjusted. The domestic price level is captured by the Harmonised Index of Consumer Prices (HICP) for the euro area and the Consumer Price Index (CPI) for the US, both seasonally adjusted. The import prices index is the implicit deflator for imports of goods and services, seasonally adjusted. The bilateral exchange rate is the

[6] In this context, for example supply shock would get the same weight as the sentiment shock, but as can be seen in the Figure 11, contributes very little to the actual changes of the exchange rate.

reference nominal exchange rate USD/EUR, averaged over the quarter, where an increase denotes an appreciation of the euro.

To capture the relative stance of monetary policy, we use the differential between the euro area and US 2-year sovereign bond yields, constructed as quarterly averages of daily observations. Yields at medium maturities are preferred over the short-term policy rate for two reasons.

First, in periods when the short-term policy rate has been close to or at the effective lower bound, changes in the monetary policy stance operated primarily through forward guidance and unconventional measures such as asset purchase programs, rather than through the policy rate itself. The 2-year yield embeds market expectations of the future policy path and is therefore responsive to both conventional and non-standard measures (Gürkaynak et al., 2005; Hanson and Stein, 2015; Swanson, 2021). Moreover, 2-year yields are directly observable at daily frequency and are not the output of an auxiliary estimation model, which avoids the model-dependence inherent in shadow-rate constructions (Krippner, 2020). Second, yields at medium maturities contain information that a short-term policy rate, by construction, can not reflect. In addition to expectations about the future path of the policy rate, 2-year yields also embed time-varying term and risk premia, shifts in the convenience yield on safe assets, and changes in the global demand for US dollar-denominated securities (Krishnamurthy and Vissing-Jorgensen, 2012; Du et al., 2018; Jiang et al., 2021), and are therefore more relevant for identifying the sentiment shock, which captures movements in the exchange rate driven neither by the relative macroeconomic cycle nor by systematic central bank responses, including flight-to-safety episodes.[7]

All the series, except the yields, are transformed as log first differences. Specifically, real GDP, prices, import prices, and the exchange rate enter the model in relative terms. The yields variable is the simple differential between the euro area and the US rate ($i_{EA} - i_{US}$) in percentage points.

[7] Using yields from longer-dated maturities increases the correlation between exchange rate and interest rates, as the term-premia component increases. In the SVAR algorithm, this increases the importance of monetary policy and demand shocks (as they are identified by the positively correlated movements between interest and exchange rates on impact), and decreases the importance of sentiment shocks (which are identified by the interest and exchange rates moving in the opposite direction).

4 Results

We present the results of our counterfactual approach and document the heterogeneity across different shocks. We then compare these results to conventional PERR-style measures and conduct a wide range of robustness checks to ensure that the findings are not driven by our choice of modeling assumptions or counterfactual construction.

Our SVAR model allows us to obtain an impulse response functions from four structural shocks, and to obtain the impulse response functions under the counterfactual where the exchange rate is held constant by the counteracting shocks, which negate the original shocks effect on the exchange rate.[8] Comparison of the two sets of results (benchmark and counterfactual) along several dimensions, forms the foundation of our analysis of ERPT. We report the results for two versions of the model, one for consumer price and one for import price pass-trough.

4.1 The baseline model

Before turning to the ERPT estimates themselves, we first conduct a sanity check of the model's performance by comparing the estimated impulse responses to the predictions of economic theory after a standard shocks of the one standard deviation size. Our model builds on Farrant and Peersman (2006), a specification we regard as well-established and broadly uncontroversial in the open-economy VAR literature. It should be emphasised, however, that the counterfactual approach developed in this paper is not specific to this particular model. Rather, it is a general methodology that can in principle be applied to any structural VAR framework with a suitable identification scheme. As shown in Figure 1, focusing on the blue lines representing the baseline results (ignoring the counterfactuals for the moment), the SVAR model performs well — its responses are broadly consistent with macroeconomic theory across all four shocks.

The *monetary policy shock* produces responses that are broadly consistent with the theoretical predictions of New Keynesian open-economy models. Looking at the first column in the Figure 1, GDP falls and remains persistently negative reflecting the contractionary effect of tighter monetary conditions on aggregate demand — in line with Christiano et al. (1999). HICP also declines and stabilizes at a negative level, indicating a disinflationary effect with no evidence of a price puzzle, which is a reassuring sign of correct shock identification. The interest rate rises sharply and persistently, as expected. The exchange rate appreciates on impact and then gradually reverts toward zero, which is consistent with the Dornbusch (1976) overshooting hypothesis and the UIP condition, capturing the fact that tighter monetary policy attracts capital inflows, causing an immediate appreciation that slowly unwinds. The long run effects of the monetary policy shock is not zero. However, since the cumulative IRFs from a relative (instead of a single-economy) model are presented, this is not

[8] We can construct a counterfactual also by estimating a differently specified model where by forcing zero restrictions, the exchange rate response (in the counterfactual model is kept close to zero. The details of this approach are in Appendix XX. We report the results from this exercise as a robustness check.

surprising.[9]

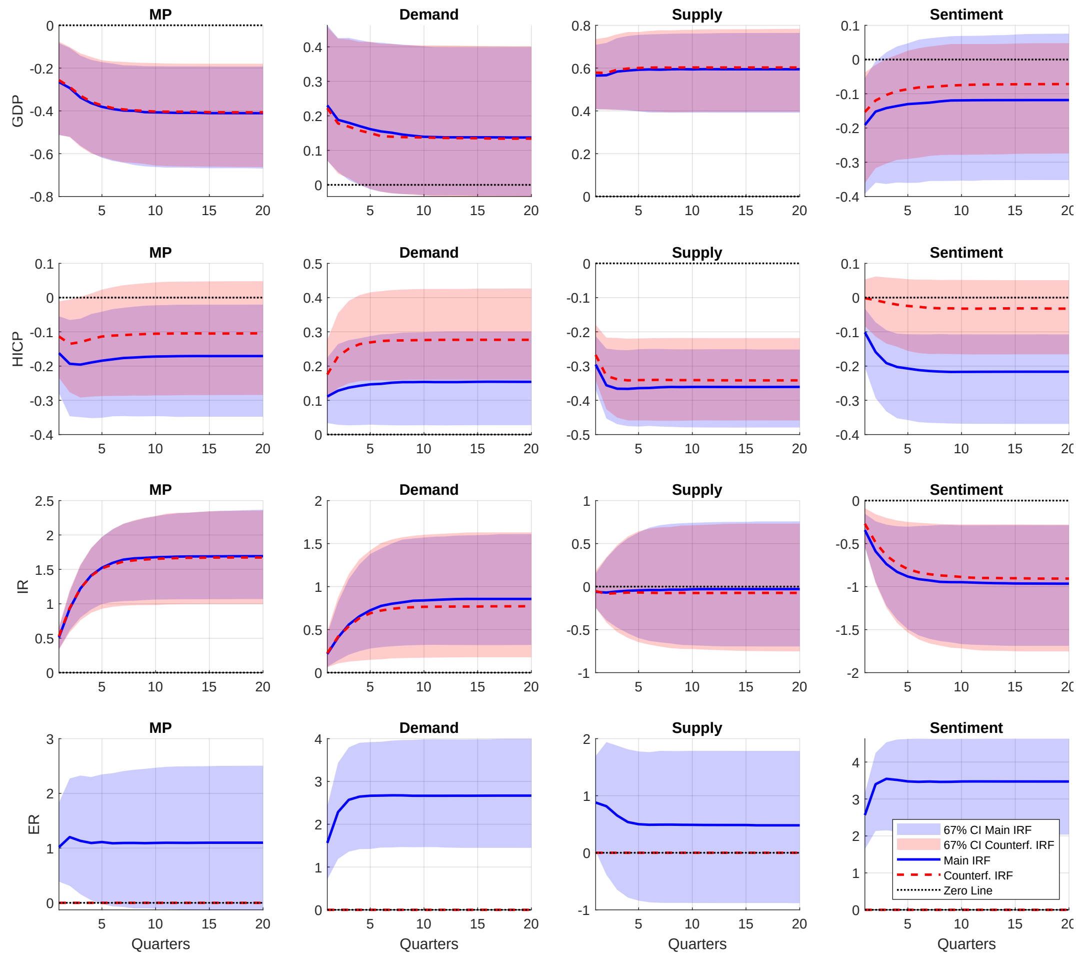
The *demand shock* responses align well with standard New-Keynesian theory. GDP rises and remains persistently positive. HICP increases gradually, confirming the inflationary nature of a positive demand shock, consistent with the aggregate demand-aggregate supply framework and the New Keynesian Phillips curve (Clarida et al., 1999). This particular response is important, as the demand shock is both inflationary and appreciates the exchange rate, and will serve well to demonstrate the usefulness of our counterfactual approach to ERPT. The interest rate rises, reflecting either an endogenous monetary policy tightening response and/or demand-driven upward pressure on rates. The exchange rate appreciates substantially and persistently, which is consistent with open-economy models where positive demand shocks attract capital inflows and strengthen the domestic currency (Galí and Monacelli, 2005).

The *supply shock* generates responses that closely match classical supply-side theory. GDP increases strongly and persistently, while HICP falls sharply and stabilizes at a negative level — the classic combination of higher output and lower prices associated with a positive technology or productivity shock (Blanchard and Quah, 1989; Galí, 1999). This negative co-movement between output and prices is the key identifying feature distinguishing supply from demand shocks. The interest rate response is modest and ambiguous, which is theoretically plausible given the competing forces at play. The exchange rate shows a brief positive spike on impact that quickly dissipates (and is later mostly not statistically distinguishable from 0), suggesting a transitory appreciation that fades as the shock propagates through the economy.

For the purposes of our study, *sentiment shock* is perhaps the most theoretically interesting. Both GDP and HICP decline, suggesting this shock captures a negative shift in confidence or expectations. The interest rate responds negatively and substantially, consistent with an accommodative monetary policy reaction to deteriorating economic conditions. The exchange rate, however, shows a large and highly persistent appreciation — the strongest and most prolonged exchange rate response across all four shocks. This combination of falling output and a strongly appreciating exchange rate is envisaged to capture a safe-haven (particularly relevant for the recent episodes of exchange rate changes in 2025) and/or risk-off effect, where negative sentiment triggers capital flows into euro-denominated assets despite weakening fundamentals. Alternatively, given that the model is estimated on relative EUR–US data, this pattern may partly reflect diverging expectations between the two economies embedded in the shock structure.

[9] In an single-economy SVAR, with non-cumulative IRFs this might be a cause for concern, as the usual interpretation is that it's a purely nominal shock and it should not influence the real variables such as GDP in the long-run. In a relative EUR-US model the shock need not be purely nominal, as it can reflect a permanent difference in the stance of the monetary authorities. Furthermore, a contractionary shock leaves lasting effects on productive capacity, so that even a disturbance originating in monetary conditions need not be neutral in the long run (Cerra et al., 2023; Blanchard and Summers, 1986).

Figure 1: Cumulative Impulse response functions to a one st. dev. shock, equally-weighted offsetting shock



Note: Figure depicts cumulative impulse response functions to a one standard deviation shocks, when the equally-weighted offsetting shocks used (benchmark case). Shaded are the confidence intervals. The columns depict shocks and rows different variables in the model.

4.2 Counter-factuals

Here, we report the outcomes of our benchmark counterfactual scenario in relation to the baseline results. The counterfactual scenario is constructed to mute the exchange rate channel by introducing offsetting shocks. Since we are working with a structural model, we need to decide how to construct them, and there are several intuitive choices available. For the benchmark results, we assign weights to the offsetting shocks based on the historical variance decomposition of the exchange rate, as described in Section 2. This ensures that shocks which have historically been the primary drivers of exchange rate fluctuations receive greater weight in the offsetting combination, making the composite offsetting shock more grounded in the empirical dynamics of our sample.The importance of this weighting becomes clear when considering shocks with asymmetric effects on the exchange rate and inflation. Supply shocks, for instance, exert only a modest influence on the exchange rate but have a large and direct impact on inflation. Assigning equal weight to supply shocks in the counterfactual construction (alongside shocks that have historically accounted for the bulk of exchange rate variation) would introduce disproportionately large movements in inflation that are unrelated to the exchange rate channel, thereby contaminating the pass-through measure. By weighting shocks according to their historical contribution to exchange rate fluctuations, we avoid this distortion and ensure that the counterfactual isolates the exchange rate channel as cleanly as possible.

Since the choice of offsetting shocks is inevitably subject to some degree of arbitrariness, we verify the robustness of our findings under alternative weighting schemes in Section 5. These alternatives include: an equal-weight combination of all four shocks, following Bobeica et al. (2019); the individual sentiment shock, which is the most natural single-shock alternative given that it has the largest impact on the exchange rate relative to other variables in our framework[10], and a individual monetary policy shock that has a somewhat intuitive interpretation.[11] In addition, we also report the results where counterfactuals are obtained using an entirely different approach, inspired by Bachmann and Sims (2012), in which the exchange rate channel is muted by imposing zero restrictions directly on the exchange rate. The main conclusions of the paper are robust to alternative counterfactual modeling choices. Our benchmark choice of the offsetting shock combinations produce somewhat conservative estimates of the pass-trough compared to the alternative ones.

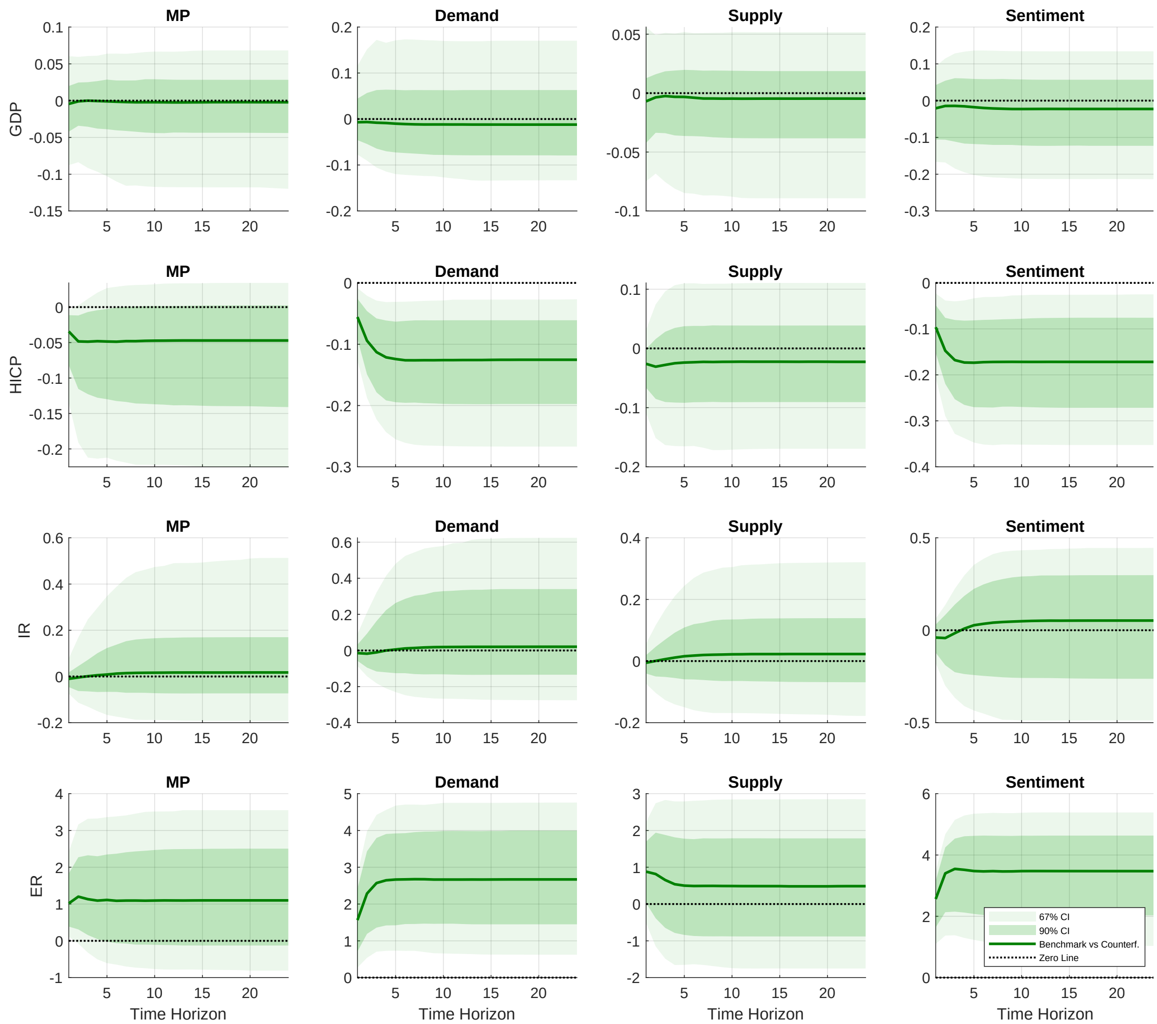
Focusing on the benchmark counterfactual results, i.e. red lines in the Figure 1 we can see that muting the exchange rate channel can cause the other IRFs to be very different from the baseline results. The movements in other variables is sometimes dampened, sometimes amplified, and sometimes even changes the direction, such as the sentiment shocks impact on inflation. As explained earlier, our preferred measure of ERPT comes from comparing the difference in effects in the baseline and the counterfactual scenario. We can see that the red lines are usually above the blue ones for the HICP variable, indicating that the appretiation is deflationary. This includes the case with demand shock, where the baseline inflation is positive, but in the case where the exchange rate doesn't move, it would be even more inflationary! When thinking about the exact distributions, sizes and statistical difference, Figure 1 is not sufficient, as it communicates the median distributions and it's confidence intervals, while missing the correlation between the IRFs across the Bayesian draws. The outcomes are, unsurprisingly, correlated between the draws, meaning that for a particular matrix Q drawn, a high baseline inflation also entails a high appreciation in baseline and a high inflation in the counterfactual scenario. This is why one needs to consider the joint distribution of the difference of the two (and if normalized by the movement in the exchange rate; three) IRFs. This is shown in the Figure 2. When we normalize the response by the current period cumulative IRF in exchange rate (like in the case of the PERR measure), we can more directly compare the results to the usual PERR measure, shock-

[10]Therefore, the sentiment shock is the object in our framework that is most similar to the hypothetical "pure" exogenous exchange rate shock.

[11]Acknowledging the Lucas critique, it is a counterfactual where the monetary authority exactly offsets the exchange rate changes, but the agents in the economy are constantly surprised by the actions of the monetary authority, since their believes do not incorporate this as a goal when forming their expectations.

by-shock. The results are presented in Figure 5, where the ERPT measures are computed within each draw of the rotation matrix Q, thereby preserving the joint distribution of all impulse responses.[12]

Figure 2: Difference between a baseline and counterfactual IRFs



Note: Figure depicts difference in a baseline and a counterfactual cumulative impulse response functions to a one standard deviation shocks, when the equally-weighted offsetting shocks used (benchmark case). Shaded are the confidence intervals. The columns depict shocks and rows different variables in the model.

As we can see on the Figure 2, our preferred measure of the ERPT after a shock is negative and statistically different from zero on impact for all shocks (!) and remains significantly different from zero for demand and sentiment shocks. If one wants to standardize the shocks by a movement in the exchange rate, the joint distribution of the two variables (HICP and exchange rate) across the two scenarios (baseline and counterfactual) can be seen in Table 2, right and Figure 5.

[12] The joint distributions of the following variables are used: baseline and counterfactual distributions for inflation IRF and a baseline distribution for the exchange rate IRF. The counterfactual distribution for exchange rate is degenerate, as it is by construction always equal to 0.

4.3 ERPT on consumer prices

Here we present our estimates of ERPT after various macroeconomic shocks. Our preferred measure is the cumulative difference in the IRFs after a one standard deviation of each shock. These are reported in the Table 2.

Table 2: ERPT on HICP, *p.p.* difference

Cumulative quarters	1 st. dev. shock				10% exchange rate depreciation after 1 year			
	MP	Demand	Supply	Sentiment	MP	Demand	Supply	Sentiment
1	0.03	0.02	0.05	0.03	0.31	0.21	0.48	0.27
4	0.05	0.12	0.03	0.07	0.44	0.46	0.47	0.49
8	0.05	0.13	0.02	0.17	0.44	0.48	0.43	0.49
20	0.05	0.13	0.02	0.17	0.43	0.47	0.42	0.49

Note: Table reports the cumulative exchange rate pass-through (ERPT) to HICP inflation in percentage point differences, conditional on each structural shock. Left panel reports responses to a one standard deviation shock; right panel normalizes to a 10% *exchange rate depreciation after one year.*

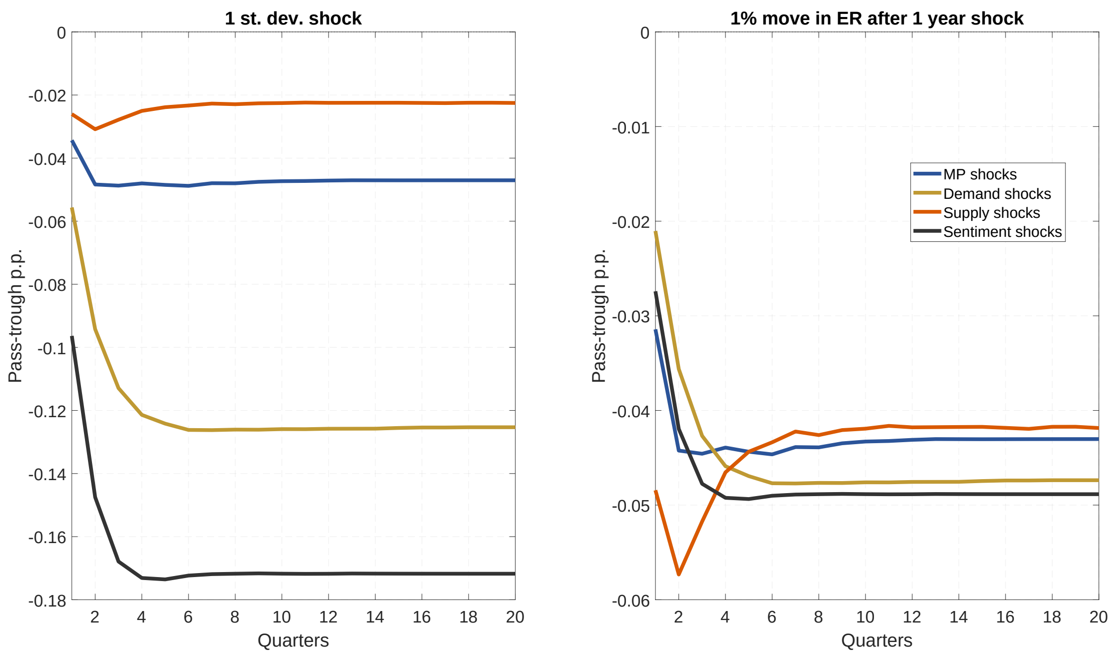
The dynamics of exchange rate pass-through differ substantially depending on the nature of the underlying structural shock. Monetary policy, and especially the supply shocks, tend to generate a rather transitory exchange rate movement : following a contractionary monetary policy shock, the exchange rate appreciates on impact, with the maximum effect occurring within one to two quarters before gradually depreciating back to baseline (Bjørnland, 2009; Gründler et al., 2023; Rüth, 2020). The associated pass-through to prices is therefore front-loaded and, despite the small size, low on impact, and dissipates quickly as the exchange rate movement reverses. This is in line with the pattern obtained by Forbes et al. (2018).[13] In contrast, sentiment and demand shocks generate a more muted initial exchange rate response that builds up slowly over time and is highly persistent, with the peak effect occurring several quarters after the shock.[14]. Similarly, demand shocks tend to produce a gradual and persistent exchange rate appreciation, resulting in a more drawn-out pass-through (Clarida and Galí, 1994; Forbes et al., 2018). This heterogeneity in exchange rate dynamics across shocks implies that the timing and persistence of the exchange rate movement, rather than its magnitude alone, is a key determinant of the degree of pass-through to consumer prices.

Besides the heterogeneity in dynamics, it is worthy to note again that the ERPT of the demand shock now behaves relatively similar to the pass-trough in the other shocks, and does not have a

[13]One can also normalize the shocks in a manner of Forbes et al. (2018), so that we compare shocks that cause a 1% movement in the exchange rate after 4 quarters. Then the supply and monetary policy shocks have relatively high movement of exchange rate, and therefore pass-trough, as can be seen in the Figure 3 right

[14]This is broadly consistent with the propagation of informational shocks in Gründler et al. (2023), who use high-frequency data on central bank announcements to distinguish pure policy and informational shocks

Figure 3: HICP ERPT



Note: Formula used: $Both_h^j = \sum_{s=0}^{h}(\Psi_{\pi,j,s} - \hat{\Psi}_{\pi,j,s})$*,* π *denoting inflation and* q *denoting exchange rate. Left, one standard deviation shocks are used, and right shocks are normalized to cause 1 % appreciation after 4 quarters. Normalization used: Left: 1st.dev. of each shock. Right: shocks cause appreciation of* 1% *after 4 quarters, historical decomposition based offsetting shocks used*

"wrong" sign, as was the case is some previous studies that use PERR-style measure. We also calculate the PERR measure using our model and contrast it to the analog from our approach, using a similar formula, where we use the difference in the inflation IRFs instead of the simple cumulative IRF of the inflation. The comparison is presented in the Figure 4. Using this measure, our estimates for the euro area ERPT are somewhat higher than 5%, which makes them in line with those obtained by Comunale and Kunovac (2017) and Ortega and Osbat (2020).[15]

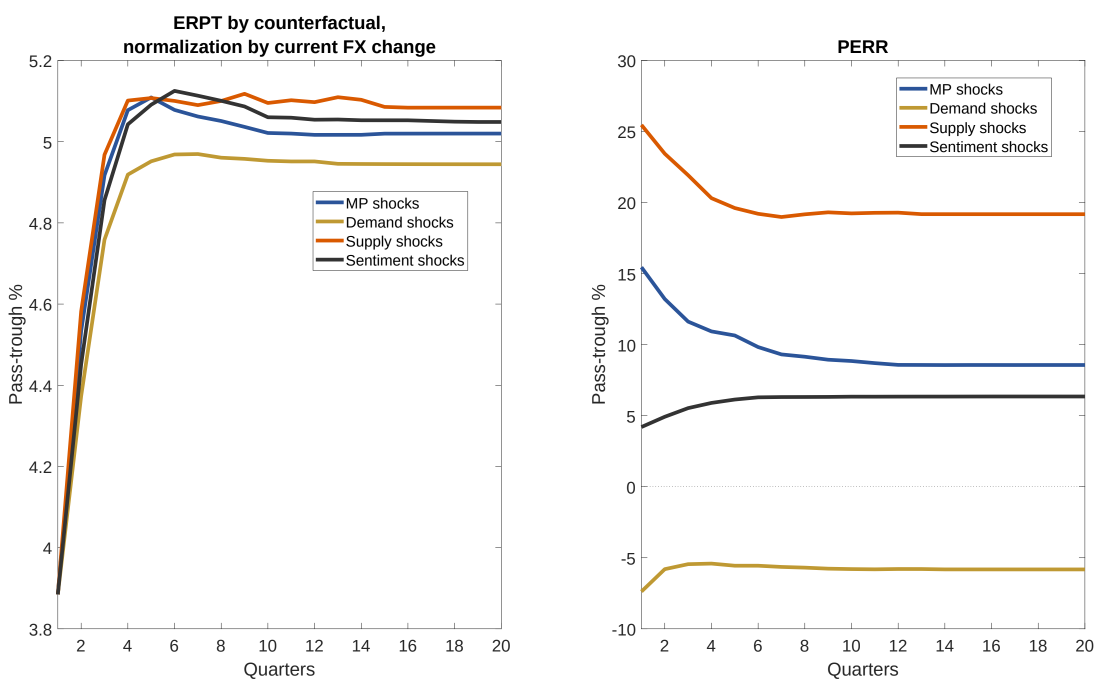
When we compare our results to the usual PERR measure, the counterfactual ERPT and PERR measures are the closes for the case of sentiment shocks, as can be seen in the Figure 5. We find this intuitive and reassuring, as the sentiment shock is the conceptually the most similar to the theoretical exogenous pure exchange rate shock. Because of that, the sentiment shock has the least confounders and additional channels trough which it affects inflation. Therefore, one would a priori expect that it is precisely sentiment shock that would have the most similar estimates of PERR and counterfactual ERPT.

Figure 5 nicely illustrates several important features of our results relative to the conventional PERR measure. First, the counterfactual ERPT estimates are markedly more homogeneous across shock types, a finding that is perhaps unsurprising given that the two measures capture related but

[15]Using alternative combinations of the offsetting shocks, the estimates are somewhat lower, but still plausibly close to the cited studies.

conceptually distinct objects. This result demonstrates that the dramatically heterogeneous heterogeneity across shocks present in the existing literature reflects heterogeneity of co-movements between the exchange rate and inflation, and is entirely consistent with an underlying causal ERPT that is relatively homogeneous. We remain agnostic, however, on whether this homogeneity reflects a genuine feature of the data or an artefact of the standard linear specification of models that mechanically constrains the degree to which pass-through can vary across shocks.[16] Second, and more substantively, the demand shock ERPT now carries the theoretically correct positive sign, resolving the puzzling negative estimates that arise under the PERR approach. Third, the posterior credible bands around our counterfactual estimates are dramatically tighter than those of the PERR, reflecting the precision gains from isolating a single well-defined transmission channel. Finally, the PERR and counterfactual estimates are most closely aligned for the sentiment shock. We argue that this is not coincidental; the sentiment shock, by its nature, operates primarily through the exchange rate channel with relatively few confounding direct effects on inflation through other mechanisms. Among the four shocks in our framework, it is therefore the closest analogue to a truly exogenous exchange rate shock, and it is precisely in this case that the conventional and causal measures are expected to converge.

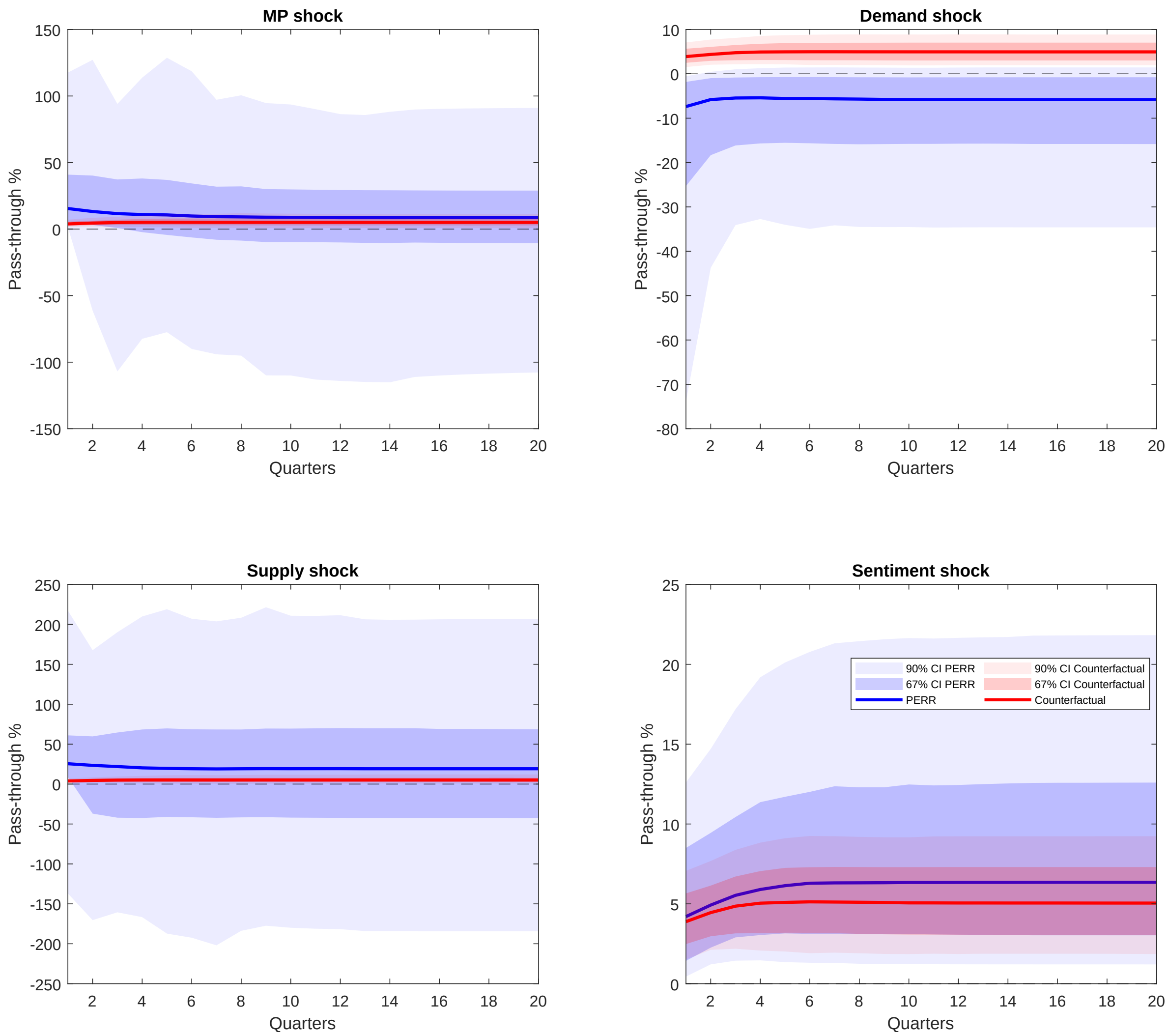
Figure 4: HICP ERPT, normalizing by the current cumulative response of the exchange rate



Note: Plotted is the ERPT when the same normalization as in PERR, for the sake for direct comparison. Left subplot formula: $Left_h^j = \frac{\sum_{s=0}^{h}(\Psi_{\pi,j,s} - \hat{\Psi}_{\pi,j,s})}{\sum_{s=0}^{h}\Psi_{q,j,s}}$. *Right subplot formula:* $PERR_h^j = \frac{\sum_{s=0}^{h}\Psi_{\pi,j,s}}{\sum_{s=0}^{h}\Psi_{q,j,s}}$, π denoting inflation and q denoting exchange rate

[16]Richer specifications incorporating state, size, or sign dependence may have the potential to uncover more subtle forms of heterogeneity in causal ERPT, and represent a natural avenue for future research.

Figure 5: Comparison of benchmark ERPT to PERR, normalization by the current cumulative exchange rate IRF, HICP



Note: Plotted is the ERPT when the same normalization as in PERR, for the sake for direct comparison. ERPT by counterfactual formula: $Left_h^j = \frac{\sum_{s=0}^{h}(\Psi_{\pi,j,s} - \hat{\Psi}_{\pi,j,s})}{\sum_{s=0}^{h}\Psi_{q,j,s}}$*. Price-to-exchange-rate-ratio formula:* $PERR_h^j = \frac{\sum_{s=0}^{h}\Psi_{\pi,j,s}}{\sum_{s=0}^{h}\Psi_{q,j,s}}$ *,* π *denoting inflation and* q *denoting exchange rate*

4.4 Historical decomposition of ERPT

Our framework yields several complementary insights into the role of exchange rate movements in driving inflation over the estimation sample. First, the historical decomposition allows us to quantify the overall contribution of exchange rate fluctuations to observed inflation dynamics, providing a direct measure of the importance of the exchange rate channel over time. Second, by constructing a counterfactual scenario in which structural shocks are prevented from moving the exchange rate, we can assess what the path of inflation would have been in the absence of any exchange rate transmission, thus isolating the exchange rate channel from the direct effects of the underlying shocks on prices. Third, and most importantly, our approach allows us to decompose the exchange rate contribution to inflation by the source of the underlying shock. This enables us to ask a more precise question: how much did exchange rate pass-through contribute to inflation in response to demand, monetary policy, supply, and sentiment shocks, respectively? By comparing these shock-specific contributions, we can assess whether the exchange rate channel amplified or dampened inflationary pressures differently depending on the nature of the shocks driving the exchange rate movement. We achieve this by using the equation 6. The results can be seen in the Figure 6. They show how much has each of the four identified shock contributed to the HICP *trough* the exchange rate channel.[17] Consequently, one can for example see that the monetary policy contributions are very modest. This is not implying that the monetary policy was are ineffective in fighting inflation, but instead that the monetary policy was contributing to (dis)inflation mainly directly and trough other channels. The effect trough the exchange rate changes was secondary. The Figure 7 puts these channel contributions into a context of the overall (not just the exchange rate-caused) inflation differential and exchange rate changes.

An interesting feature to notice is that the connection between inflation and exchange rate movements, previously obscured, emerges far more clearly once exchange rate pass-through is measured through the counterfactual approach. As shown in Figure 11, headline inflation — the dotted line — exhibits little correlation with exchange rate movements, meaning that episodes of sharp currency fluctuations do not systematically coincide with periods of heightened or subdued inflation. However, once we turn to the counterfactual-based measure of pass-through — the blue line — the two series move much more closely together. Indeed, the correlation coefficient jumps from -0.23 to -0.98 when exchange rate co-movement is measured against the counterfactual pass-through rather than headline inflation, underscoring the extent to which direct pass-through is masked by the simultaneous influence of other shocks on inflation.

Several interesting episodes are particularly interesting to analyze in the context of ERPT. The first is the record deflationaty estimated effect on the relative consumer prices of -0.83 p.p. in the Q2 of 2003. The main driver of the USD depreciation was the US current account deficit, which had ballooned to around 5% of GDP. One one the compounding factors for these movements was funding of

[17] This is not to be confused with a more standard decompositions reported in SVAR studies, which show how much did each shock contribute to the movement of a variable (inflation), including *all* channels. This is show in the Figure 10.

the Iraq war. Our model records this as a mainly US demand shock, coupled with a smaller sentiment shock, which is in line with the USD acting as a safe-haven currency at the time. An interesting feature of the episode can be spotted in the Figure 7; it has a record estimated effect of ERPT, and at the same time, the differences in the inflation between the two economies was basically 0! This highlights the importance of the counterfactual approach. The reason for the seemingly unintuitive result is the fact that the dominant shock in the episode was the demand shock (in the US). The demand shock is inflationary[18], but at the same time it's appreciatory effect if disinflationary. Coupled with the sentiment shocks at the time, the overall effects on inflation approximately canceled each other out, despite the exchange rate movements being strongly disinflationary for euro zone.

Preceding the 2008 crisis demand shocks in the Eurozone were much smaller than in the US, driving the US inflation to be almost 1 p.p. smaller. However, with the outbreak of the crisis, the sentiment shocks again caused the euro to depreciate, turning the inflation differential in Eurozone from negative to a positive almost 1 p.p. in Q3 2009. The ERPT continued to be volatile, during and in the aftermath the European sovereign debt crisis, which was governed by the demand and sentiment shocks, being partially offset by the monetary policy in 2011 and early 2012.

European positive demand shocks can also explain the curious episodes where the USD/EUR exchange rate and the inflation differential moved in the same, rather than in the usual, opposite direction. Moreover, the periods with present strong demand shocks are usually accompanied with the periods with negative or zero correlation between the exchange rate movements and inflation. Some of the periods that stand out are 1999-2001, 2007, when the depreciation of the euro was accompanied with the negative inflation differential, 2015 when the euro depreciated more than 20%, while the US economy grew, contrasting the Europe's struggle with the crisis in Greece and ECBs announcement of its quantitative easing program.

The Covid-19 episode is marked by the negative demand shocks and easing of the monetary policy counteracting each other and the estimated negative ERPT peaking in Q2 in 2021, with slightly less then a half of a percentage point. Another important event soon followed with the Russian invasion of Ukraine, when the sentiment shocks, monetary policy and even supply shocks contributed to the ERPT summing up to 0.61 p.p. in Q3 of 2022.

A striking recent episode of dramatic exchange rate movements is the sharp depreciation of the US dollar in 2025, which unfolded against a backdrop of extraordinary policy uncertainty surrounding US tariff introduction (and announcements) and the prospect of retaliatory measures from major trading partners. The uncertainty itself — rather than any concrete shift in trade flows — appears to have been the dominant force driving the exchange rate, as markets repriced risk and safe-haven flows shifted in ways that diverged sharply from historical patterns. Based on our estimates, euro area inflation was 0.3 p.p. lower (as opposed to the 1.8 p.p. lower import prices) as a result of the EUR/USD exchange rate changes over this period, a disinflationary effect transmitted primarily through sentiment shocks.

[18]This can also be seen in the Figure 10 in Appendix E for this particular episode, the demand shock overall contributed in 0.52 p.p. to inflation. Supply shocks were also modestly inflationary, while sentiment shock was overall disinflationary.

The demand shock was secondary and was somewhat important in Q4.

Finally, to assess the overall importance of the exchange rate channel in driving inflation dynamics over the sample period, we compute a summary measure of the exchange rate channel's contribution to the variation in inflation. Basically, we are analyzing the relationship of the full and dotted blue lines in Figure 7. Specifically, we define the exchange rate share as the ratio of the sum of squared exchange rate contributions to the sum of squared total inflation outcomes:

$$\text{ER Share} = \frac{\sum_t \left(\hat{\pi}_t^{ER}\right)^2}{\sum_t \pi_t^2} \times 100 \tag{7}$$

where $\hat{\pi}_t^{ER}$ denotes the counterfactually identified contribution of the exchange rate channel to inflation at time t, and π_t denotes total inflation. This measure captures the share of the overall variation in inflation, as measured by the sum of squared deviations, that is attributable purely to exchange rate movements operating through the exchange rate channel, as isolated by our counterfactual approach. It is important to note that this is not a variance decomposition in the structural shock sense,- it does not decompose inflation variance across the four identified shocks, but rather quantifies the fraction of total inflation variation that would have been eliminated had the exchange rate channel been entirely absent throughout the sample.

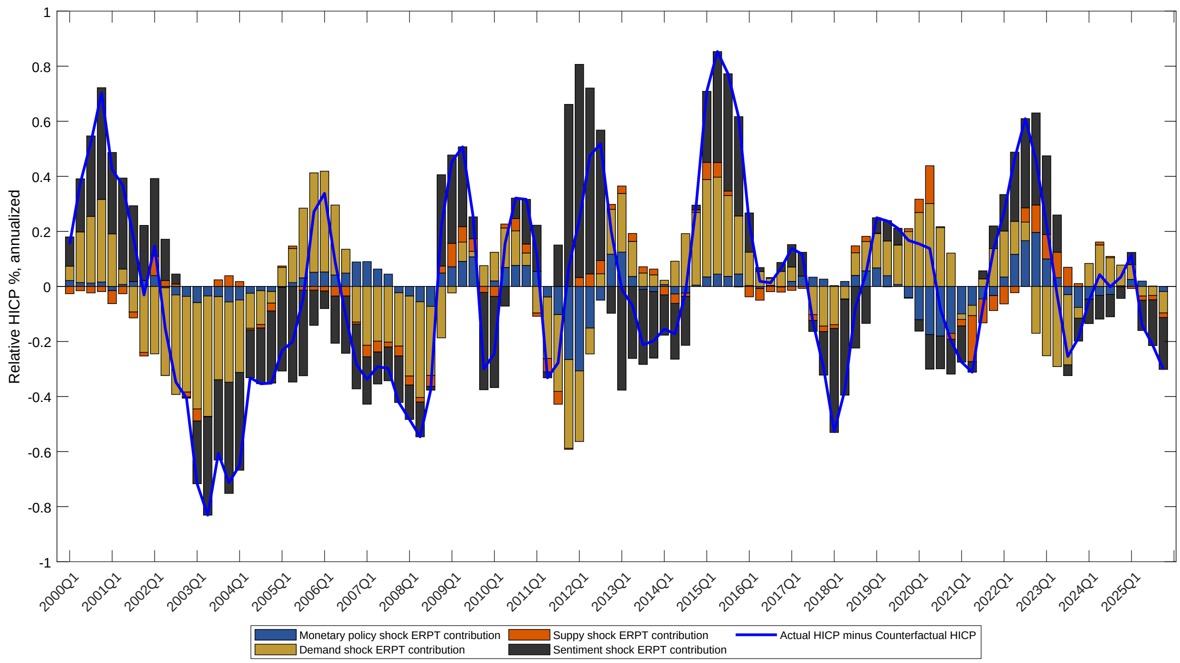
Our estimates suggest that the exchange rate channel accounts for approximately 12 percent of the total variation in euro area inflation relative to the United States over the sample period. This indicates that while the exchange rate channel is a non-trivial driver of relative inflation dynamics, the large majority of inflation variation is driven by other channels; domestic demand conditions, supply-side factors, and monetary policy operating through interest rate and other directly. In the first half of the sample (before 2013), the exchange rate was accounting for 19 percent, while in the second half of the sample (since 2013) it accounted for only 7 percent of the overall inflation differential. This is not surprising, since the shocks like Covid-19 pandemic and the Ukraine war drove the inflation differential apart in a more direct way, not necessarily trough the exchange rate channel.

4.5 ERPT on import prices

Besides the ERPT on consumer prices, which is our main object of interest, we also study the effects that the exchange rate movements have on the import prices. The figures 16, 8 and 9 present the results for the import prices. Not surprisingly ERPT is much higher compared to the HICP, while still being far from complete. This is expected because of the falling pass-trough along the price chain already discussed in the introduction. ERPT on import prices after about 10 quarters hovers around 40% of the change in the contemporary change in the exchange rate. These are the magnitudes somewhat smaller than one obtained by Comunale and Kunovac (2017), but still comparable to those obtained by Ortega and Osbat (2020).

The ERPT on import prices increases in the first several quarters, and peaks in the quarter 3 or 4 after the impact. From that point it somewhat tapers off and remains stable, as the movements in

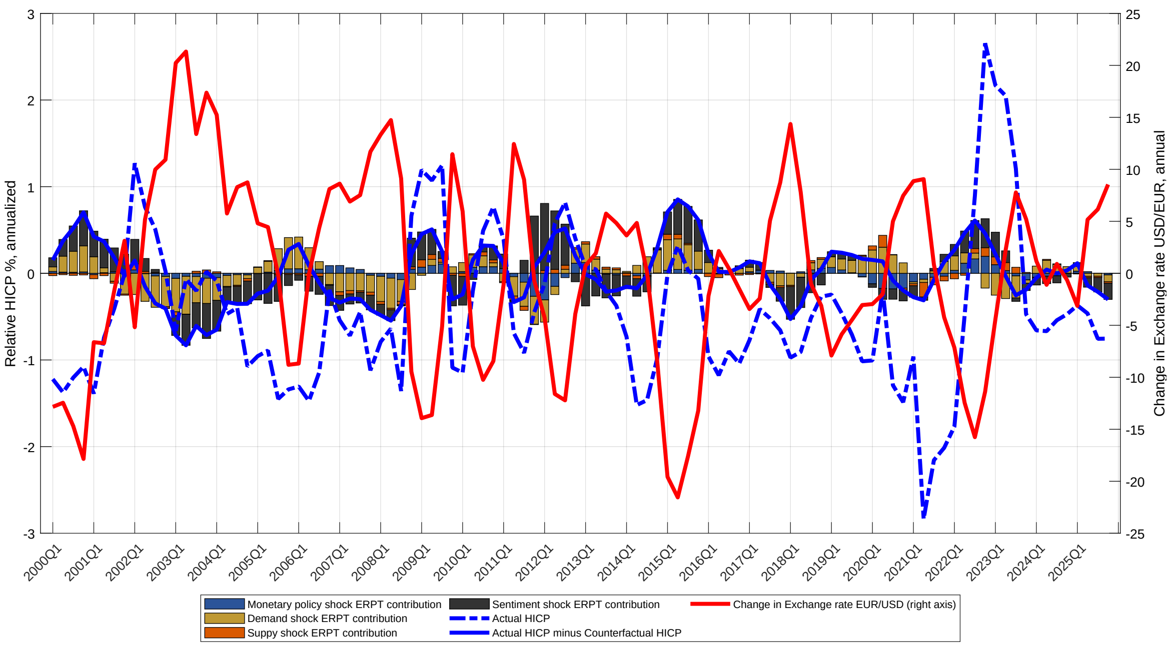
Figure 6: Historical decomposition of the relative inflation



Note: Decomposition is done for the benchmark case using the equation 6.

the exchange rate stabilize as well. Regarding the developments in 2025, our model estimates that the Eurozone import prices were 1.81$p.p.$ lower because of the ERPT.

Figure 7: Contribution of the ERPT in the relative inflation



Note: Decomposition is done for the benchmark case using the equation 6. In addition to the decomposition, raw data on overall inflation and exchange rate movements are plotted.

5 Robustness check

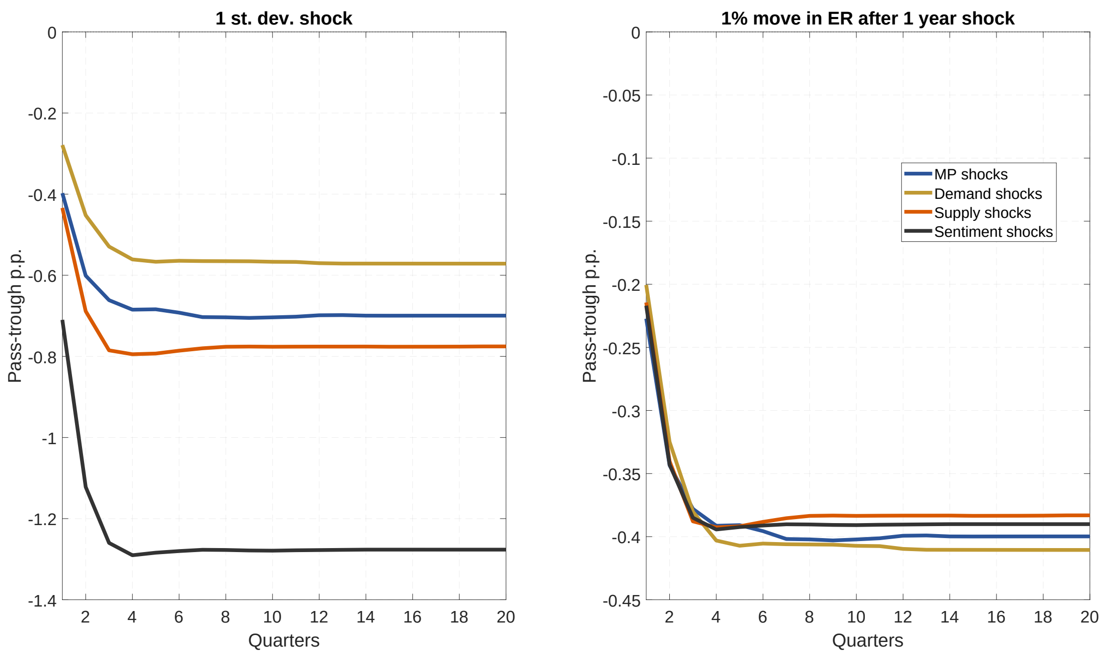
To check the results' robustness, in this section we first report the results obtained by various choices of the offsetting shocks, and second; we simulate the counterfactual in an alternative manner. The main messages of our paper remain robust to the various specifications and models.

5.1 Alternative counterfactual shock weights

The choice of offsetting shocks that are used to keep the exchange rate unchanged is not unique. Therefore, one must take a stance on what offsetting shocks to use. These can be any of the four identified shocks, or a combination of them. As a benchmark, we choose an equally-weighted combination of the 4 shocks. As we want to show that our results are not primarily driven by the arbitrary choice of offsetting shocks, here we report an array of different sets of results.

The first alternative set of results is simply choosing the sentiment shock as an offsetting shock (i.e. the weights for all other shocks are 0). This choice is made as a sentiment shock is the closest thing we have to a pure exogenous exchange rate shock. The second is choosing the weights according to the historical decomposition of shocks, and giving more weight to shocks that contributed more to the variance in our sample. The weights obtained by this method are $0.14, 0.26, 0.11, 0.50$ respectively. Lastly, we also use a monetary policy shock as an offsetting shock, as it provides a clean interpretation of the results obtained in that case. This gives us a counterfactual that says how would have the

Figure 8: ERPT on import prices;



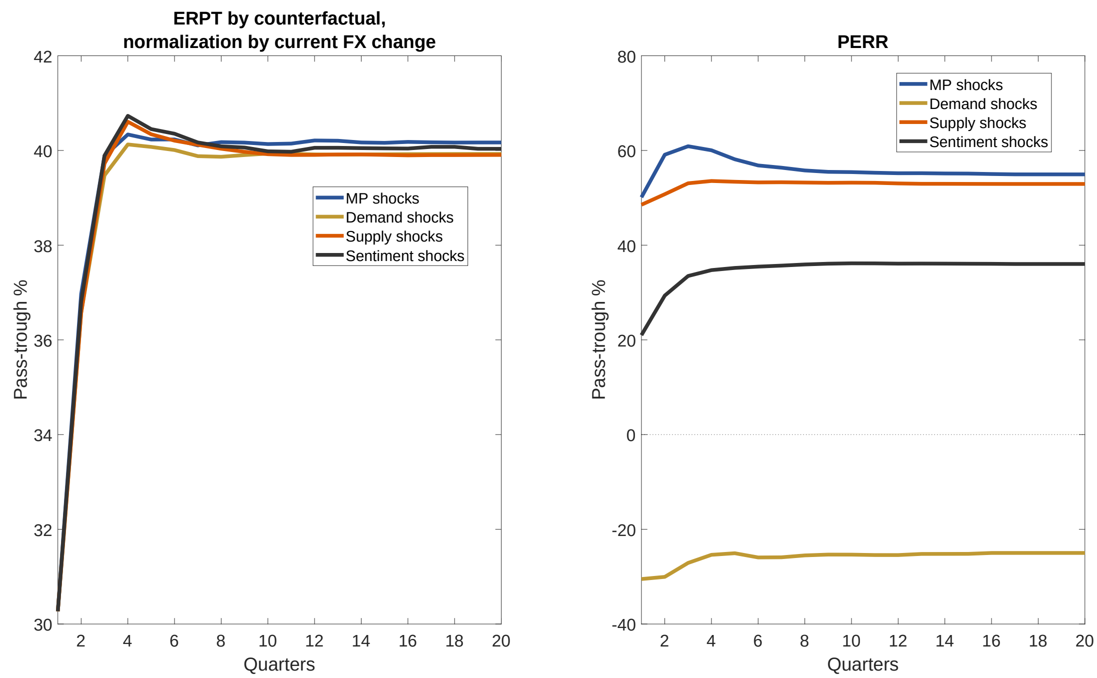
Note: Formula used: $Both_h^j = \sum_{s=0}^{h}(\Psi_{\pi,j,s} - \hat{\Psi}_{\pi,j,s})$ π *denoting imports inflation and* q *denoting exchange rate. Left, one standard deviation shocks are used, and right shocks are normalized to cause 1 % appreciation after 4 quarters. Normalization: Left: 1 st. dev shocks. Right: shocks more exchange rate* 1% *after 4 quarters, HD-weighted offsetting shocks*

inflation (and other variables) behaved, have the monetary policy kept the exchange rate the same. Here we fully acknowledge the Lucas (1976) critique, and should be careful not to interpret the results in the way that such policy is the long-term goal of the monetary authority, as the economic actors could change their behavior in accordance to that.

5.2 Models with alternative zero restrictions

In this counterfactual analysis exercise, we follow the idea outlined in Bachmann and Sims (2012) and compare two versions of the same model subject to different identification zero/sign restriction sets. The first, benchmark version model is the same as our benchmark case before. The second one is the counterfactual version model, in which we shut down the shocks effect on the exchange rate. This is achieved by doing two changes in the restriction matrix. First, we change the restriction of each shock to exchange rate to 0 on impact, and second we add an additional restriction that the long run effect of the shock in question on exchange rate is 0 as well. This leaves a possibility that the effect of the shock on the exchange rate in the counterfactual scenario is not exactly equal to 0 in every period. However, the deviations from zero are usually quite small, and we can control for these deviations when computing the ERPT using this methodology. Then the ERPT is defined as the difference between the effect that a shock has on inflation in the benchmark model, minus the effect that a shock has on

Figure 9: ERPT on import prices, normalizing by the current cumulative response of the exchange rate



Note: Plotted is the ERPT when the same normalization as in PERR, for the sake for direct comparison. Left subplot formula: $Left_h^j = \frac{\sum_{s=0}^{h}(\Psi_{\pi,j,s} - \hat{\Psi}_{\pi,j,s})}{\sum_{s=0}^{h}\Psi_{q,j,s}}$. *Right subplot formula:* $PERR_h^j = \frac{\sum_{s=0}^{h}\Psi_{\pi,j,s}}{\sum_{s=0}^{h}\Psi_{q,j,s}}$ π denoting imports inflation and q denoting exchange rate

inflation in the constructed counterfactual, controlled by the difference in the exchange rate in the two scenarios. [19]

The advantage of constructing the counterfactual in this way is it's conceptual simplicity. There is no need of additional computations and formulas in order to offset structural shocks. The main drawback is that we are essentially comparing results from two, strictly speaking, different models, which can potentially lead to inconsistencies. Furthermore, the effect on the exchange rate is not exactly 0 in every period, as already mentioned. Lastly, the new set of identifying sign restrictions has to be made, and model newly estimated, for each structural shock we want to analyze. This significantly increases the runtime needed to compute the results. Since in our model we have four structural shock, we need to estimate the model 5 times with 5 different sets of sign restrictions; one for the benchmark case and 4 for each structural shocks (shown in Table 3). A further methodological consideration concerns the computation of the pass-through measures themselves. In a Bayesian VAR identified via sign restrictions, each draw of the rotation matrix Q generates a joint set of impulse responses across all variables. Ideally, the ratio of the inflation response (the difference between baseline and counterfactual scenario) and the exchange rate response should be computed within each draw, preserving the joint distribution implied by the model, and only then summarized across draws.

[19] For example, if we divide by the difference in exchange rate, the formula adjusts the results for the deviations of IRF on exchange rate from zero in the counterfactual scenario.

Table 3: Sign Restrictions in the restriction based models counterfactual, when constructing a counterfactual of *that* shock

	Structural Shocks			
Variables	Monetary Policy	Demand	Supply	Sentiment
On impact:				
GDP	−	+	+	−
HICP	−	+	−	−
Interest Rate	+	+		−
Exchange Rate	0	0	0	0
Long-run:				
Exchange Rate	0	0	0	0

Notes: The table reports sign restrictions imposed on the impact responses of the variables to each structural shock. A "+" ("−") indicates a positive (negative) response. No restriction is imposed when the entry is blank.

When computing the differences and ratios using the approach involving different models this is not possible (as opposed to the case with the offsetting shocks), and one is instead forced to compare the median impulse responses of inflation and the exchange rate (from the two models) separately. This introduces a well-known non-linearity problem: the median of a ratio is not in general equal to the ratio of the medians. As a result, pass-through measures constructed from median impulse responses may differ - potentially non-trivially - from those that would be obtained by computing the ratio draw-by-draw and taking the median of the resulting distribution. We acknowledge this as a limitation of this robustness approach exercise.

The IRFs from this alternatively constructed counterfactuals are shown in the Appendix E.

5.3 Comparison

Tables 4 and 5 confirm that the main patterns in the results are preserved across alternative counterfactual constructions, even as the precise magnitudes vary. When monetary policy shocks are used to construct the counterfactual, the estimated ERPT is somewhat higher. This is expected, as monetary policy shocks transmit to inflation more directly and more powerfully than the other structural shocks in the model. Namely, the interest rate channel operates on prices through multiple reinforcing mechanisms simultaneously. Nevertheless, the estimates remain in a similar range, and neither the dynamics nor the relative importance of the individual shocks are materially affected by this choice of counterfactual construction.

Demand and supply shocks are less well-suited for this purpose for distinct reasons. Demand shocks are simultaneously inflationary and appreciatory, meaning that offsetting the exchange rate movement also partially offsets the inflationary impulse itself, conflating the two channels and complicating the interpretation of the resulting ERPT measure. Supply shocks, on the other hand, generate only a very small exchange rate response, leaving little variation to exploit in the counterfactual construction and producing estimates that are close to zero and statistically uninformative.

When zero-restriction models are used to construct the counterfactual, the heterogeneity in ERPT estimates across shocks is more pronounced. A likely explanation lies in the treatment of the posterior distribution. Unlike the baseline approach, this specification does not compute the ERPT ratio within each draw of the rotation matrix and then aggregate across draws. Instead, it compares median impulse responses directly. Since the correlation between the inflation and exchange rate impulse responses varies across draws, as is to be expected, failing to condition on the same draw can amplify apparent heterogeneity across shocks. The median of the ratio and the ratio of the medians need not coincide, and this discrepancy is likely larger in cases where the joint distribution of the impulse responses is more dispersed, as may be the case for certain shock types. Nonetheless, we argue that this approach remains valuable as a robustness check, as it demonstrates that our benchmark results are not an artifact of the particular choice of counteracting shock used in the counterfactual construction.

Table 4: Comparison of the different counterfactual construction methods: HICP

		1 st. dev. shock								Shocks normalized to 1% depreciation after 1 year							
		MP		Demand		Supply		Sentiment		MP		Demand		Supply		Sentiment	
	Method	1	20	1	20	1	20	1	20	1	20	1	20	1	20	1	20
Offsetting Shocks	Benchmark (HD)	0.03	0.05	0.06	0.13	0.03	0.02	0.10	0.17	0.31	0.43	0.21	0.47	0.48	0.42	0.27	0.49
	Equally-weighted	0.07	0.08	0.12	0.21	0.05	0.03	0.18	0.25	0.62	0.69	0.44	0.80	1.00	0.53	0.51	0.72
	Sentiment	0.03	0.06	0.05	0.16	0.23	0.31	1.01	2.16	0.31	0.58	0.20	0.61	0.43	0.58	0.29	0.62
	MP	0.16	0.17	0.21	0.37	0.10	0.03	0.37	0.44	1.48	1.56	0.79	1.41	1.87	0.54	1.06	1.25
0 restr.	Model comparison	0.08	0.10	0.01	0.08	0.09	0.09	0.08	0.10	0.08	0.94	0.09	0.31	1.05	1.89	0.31	0.30

Note: Columns labeled 1 and 20 denote the horizon in quarters. Reported values are cumulative differences in HICP (in percentage points) following a depreciationary shock. The left panel reports responses to a one standard deviation shock; the right panel normalizes shocks to a 1% exchange rate depreciation after one year.

Table 5: Comparison of the different counterfactual construction methods: import prices

		1 st. dev. shock								Shocks normalized to 10% depreciation after 1 year							
		MP		Demand		Supply		Sentiment		MP		Demand		Supply		Sentiment	
	Method	1	20	1	20	1	20	1	20	1	20	1	20	1	20	1	20
Offsetting Shocks	Benchmark (HD)	0.40	0.70	0.28	0.57	0.43	0.78	0.71	1.28	2.27	4.00	2.00	4.11	2.14	3.83	2.17	3.90
	Equally-weighted	0.37	0.62	0.26	0.50	0.41	0.68	0.66	1.08	2.13	3.53	1.86	3.61	2.03	3.36	2.01	3.29
	Sentiment	0.22	0.58	0.16	0.46	0.25	0.65	0.48	1.08	1.27	3.32	1.11	3.28	1.23	3.19	1.46	3.30
	MP	0.73	1.12	0.46	0.83	0.72	1.09	1.13	1.70	4.17	6.43	3.37	5.95	3.53	5.38	3.44	5.21
0 restr.	Model comparison	0.44	0.72	0.30	0.57	0.33	0.65	0.43	0.70	3.25	3.98	3.18	3.95	2.11	3.20	1.78	2.17

Note: Columns labeled 1 and 20 denote the horizon in quarters. Reported values are cumulative differences in import prices (in percentage points) following a depreciationary shock. The left panel reports responses to a one standard deviation shock; the right panel normalizes shocks to a 10% exchange rate depreciation after one year.

6 Conclusion

We revisit the well-studied question of exchange rate pass-through in the euro area, but through the lens of counterfactual VAR analysis. To the best of our knowledge, we are the first to apply this methodology to the study of ERPT, and obtain important additional insights. By constructing counterfactual scenarios in which the exchange rate channel is shut down while all other transmission channels remain operative, we are able to isolate the pure causal effect of exchange rate movements on inflation, therefore purging the measure of contamination from other structural channels that co-move with the exchange rate but are orthogonal to pass-through itself.

We show that employing the novel methodology is far from just a technical curiosity. Focusing on causality rather than correlation leads to conclusions that differ from the existing literature in several important respects. First, the estimated pass-through to euro area inflation is on the lower side of the previously reported results, suggesting that conventional measures partly capture inflationary dynamics that are driven by the same underlying shocks as the exchange rate, rather than by the exchange rate itself. Second, we resolve the puzzling negative sign of pass-through estimated for demand shocks in the existing literature, recovering the theoretically consistent positive ERPT once the demand channel is properly isolated from the exchange rate channel. Third, once we control for the size of the exchange rate movement, heterogeneity in pass-through across shock types is markedly reduced. This suggests that part of the heterogeneity documented in previous studies reflects differences in the co-movement structure of shocks rather than genuine differences in transmission. What appears as stark heterogeneity under existing methodologies can in fact be relatively homogeneous; uncovering more substantive heterogeneity would require a genuinely non-linear specification.

Finally, our historical decomposition reveals that the contribution of the exchange rate channel to inflation was substantial during several key episodes. These effects would remain obscured under conventional pass-through measures that do not distinguish the exchange rate channel from the broader inflationary impulse of the underlying shock.

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A (Micro)economic origin of the incomplete pass-trough

Before turning to the empirical framework, we briefly ground our analysis in a micro-founded pricing equation that clarifies what pass-through measures on an microeconomic level.

Consider a foreign exporter supplying a differentiated variety to the home market. We define the exchange rate E as units of foreign currency per unit of home currency, so that an increase in E represents a *domestic appreciation*. The exporter sets a home-currency price $P = \mu(X)\, MC^*/E$, where MC^* denotes marginal cost in foreign currency and $\mu(X)$ is the markup, which depends on the relative price $X \equiv P/P^{\text{comp}}$ against competitors.

In logs, this pricing equation is:

$$p = \tilde{\mu} + mc^* - e, \tag{8}$$

where $p \equiv \ln P$, $mc^* \equiv \ln MC^*$, $\tilde{\mu} \equiv \ln \mu(X)$ and $e \equiv \ln E$.

On a microeconomic level, ERPT, defined as $-\frac{\partial p}{\partial e}$ will be complete ($= 1$), if the demand for the good is governed by the constant elasticity of substitution utility function. However, if the elasticity of substitution in not constant, the markup $\tilde{\mu}$ will depend on the exchange rate e and ERPT will be typically smaller than 1. This is the case for example with the Kimball (1995) demand aggregator, as shown in the Appendix B. Furthermore, a recent microeconomic study by Sangani (2026), while not studying exchange rate directly, shows that if the underlying demand function imply absolute desired markups (dollar/euros...) rather than relative ones (share of costs), the markup is nearly complete in levels, while still being incomplete in percentages. This puts a new light on using purely 8 and interpreting ERPT as a share of the percentage change of the exchange rate. Their results would imply that having the equation 8 in levels rather than logs would more accurately capture the pass-trough dynamics.

Apart from such microeconomic mechanisms, there are also macroeconomic phenomena that drive ERPT on a macroeconomic level and contribute to its incompleteness. Such phenomena include substitution effects between foreign and domestic goods, aggregation and presence of local non-traded components and distribution margins in consumer pricing (Burstein and Gopinath, 2014), dominant-currency pricing and invoicing practices and pricing-to-market. An important take-away is that macroeconomic ERPT cannot be recovered from a single pricing equation, however carefully specified. A clean identification strategy is needed that strips pass-through estimates of confounding aggregate dynamics. The next section describes our empirical approach, which is designed precisely to address this challenge.

B Derivation of the Micro-Founded ERPT Equation

We define the exchange rate as the amount of foreign currency per home currency. With this convention, an increase in E corresponds to a domestic currency appreciation.

The foreign exporter sets the home-currency price:

$$P = \mu(x)\,\frac{MC^*}{E}, \tag{9}$$

where MC^* is marginal cost in foreign currency and

$$x \equiv \frac{P}{P^{\text{comp}}} \tag{10}$$

is the price relative to competition. $\mu(x)$ is an important object which denotes markup that the firm charges to its consumers. If the demand is assumed to take the shape of a constant elasticity of substitution, the model does not generate the empirically observed features like pricing to market. Thus, we assume a also standard Kimball demand aggregator, where the elasticity of the demand, and consequently desired markup, depends on the relative prices of the products.

Therefore, the consumption is defined implicitly by a Kimball (1995) aggregator:

$$\int_0^1 G\left(\frac{C_i}{C}\right) di = 1, \tag{11}$$

where $G(\cdot)$ is increasing and strictly convex, C_i is consumption of variety i, and C is aggregate consumption.

Cost minimization implies demand of the form

$$\frac{C_i}{C} = D\left(\frac{P_i}{P^{\text{comp}}}\right), \tag{12}$$

with relative price $X \equiv P_i/P^{\text{comp}}$ and elasticity

$$\varepsilon(X) = -\frac{D'(X)X}{D(X)}, \tag{13}$$

which varies with X. The optimal markup is therefore

$$\mu(X) = \frac{\varepsilon(X)}{\varepsilon(X) - 1}. \tag{14}$$

Taking logs:

$$\ln P = \ln \mu(X) + \ln MC^* - \ln E \tag{15}$$

and defining $\ln P = p$, $\ln E = e$, $\ln MC^* = mc^*$ and $\ln \mu(X) = \tilde{\mu}$, we can write

$$p = \tilde{\mu} + mc^* - e \tag{16}$$

Differentiate with respect to $\ln E$ (holding MC^* and P^{comp} fixed):

$$\frac{\partial \ln P}{\partial \ln E} = -1 + \frac{\partial \ln \mu}{\partial \ln E}. \tag{17}$$

Therefore we can write:

$$\underbrace{-\frac{\partial \ln P}{\partial \ln E}}_{ERPT} = 1 - \underbrace{\frac{\partial \ln \mu}{\partial \ln E}}_{>0} \tag{18}$$

If we would use the CES aggregator, we would always have ERPT=1, since there would not be a price-to-market (second) term.

Since the markup depends on the relative price X,

$$\frac{\partial \ln \mu}{\partial \ln E} = \frac{\partial \ln \mu}{\partial \ln E} \cdot \frac{\partial \ln X}{\partial \ln E}. \tag{19}$$

Because $X = P/P^{\text{comp}}$ and P^{comp} is fixed,

$$\frac{\partial \ln X}{\partial \ln E} = \frac{\partial \ln P}{\partial \ln E}. \tag{20}$$

Define

$$s \equiv \frac{\partial \ln \mu}{\partial \ln X}. \tag{21}$$

Substituting gives

$$\frac{\partial \ln P}{\partial \ln E} = -1 + s\,\frac{\partial \ln P}{\partial \ln E}. \tag{22}$$

Rearranging,

$$(1-s)\frac{\partial \ln P}{\partial \ln E} = -1. \tag{23}$$

Therefore, exchange-rate pass-through is

$$\boxed{-\frac{\partial \ln P}{\partial \ln E} = \frac{1}{1-s}}. \tag{24}$$

Because elasticity varies with the relative price, we define the *super-elasticity* (curvature of demand) as the elasticity of $\varepsilon(X)$ with respect to X:

$$\eta \equiv \frac{\partial \ln \varepsilon(X)}{\partial \ln X} = \frac{X}{\varepsilon(X)}\frac{\partial \varepsilon(X)}{\partial X}. \tag{25}$$

Thus, η measures how quickly the price elasticity of demand changes when a firm changes its relative price.

Under the Kimball demand structure,

$$s = -\frac{\eta}{\varepsilon - 1}, \tag{26}$$

where η is the super-elasticity of demand. Hence,

$$\boxed{ERPT = -\frac{\partial p}{\partial e} = \frac{1}{1 + \frac{\eta}{\varepsilon - 1}}}. \tag{27}$$

C Counterfactual IRF Construction

The aim of this paper is to offset the effect of each structural shocks on the exchange rate (this is the variable that we want to keep constant), which is done by calculating the combination of innovations to exactly counteract the examined structural shock. The methodology used to construct such a counterfactual is following the ideas from Wong (2015), Sims and Zha (2006), Kilian and Lewis (2011) andBachmann and Sims (2012), and refined by Bobeica et al. (2019) for the case of structural shocks with sign restrictions.

The companion form representation is:

$$X_t = \Lambda X_{t-1} + v_t \tag{28}$$

where:

$$X_t = \begin{pmatrix} y_t \\ y_{t-1} \\ \vdots \\ y_{t-p+1} \end{pmatrix}, \quad \Lambda = \begin{pmatrix} A_0^{-1}A_1 & \cdots & \cdots & A_0^{-1}A_p \\ I & 0 & \ddots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \cdots & \cdots & I & 0 \end{pmatrix}, \quad v_t = \begin{pmatrix} A_0^{-1}\epsilon_t \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{29}$$

Since in this paper we are using sign restriction identification, the matrix A_0 is given by the current draw of the matrix Q. Therefore, the procedure described below is repeated for each drawn Q that satisfies the sign restrictions.

For a one-standard-deviation shock to the structural shock s, define:

$$\zeta_s = \tilde{A}_0^{-1} e_s' \tag{30}$$

A_0^{-1} is a normalized version of $\tilde{A}_0^{-1}$ with ones on the diagonal. Once we have drawn a Q matrix, we obtain the matrix by:

$$\tilde{A}_0 = Q' \,/\, \mathrm{chol}(\Sigma) \tag{31}$$

e_s is a indicator row vector with 0s everywhere except on the element s.

The impulse response function of variable j at horizon k to the shock s can be computed as:

$$\Psi_j^k = e_j \Lambda^k \zeta_s \tag{32}$$

The goal is to construct a sequence of shocks $\{\hat{\epsilon}_k^s\}_{k=0}^{\infty}$ to all variables in the system, such that the counterfactual IRF of the exchange rate is zero at all horizons:

$$\hat{\Psi}_c^k = 0, \quad \forall k \in \mathbb{N}_0 \tag{33}$$

This answers the question: What would the responses of other variables look like if variable c had been held fixed by having it's innovations exactly offsetting all the other effects? We denote by s a particular shock at a time horizon k and its affect on a variable j. We want to keep the variable c constant (in our case the exchange rate).

At the initial shock ($k = 0$), we require:

$$e_c \zeta_s + e_c \tilde{A}_0^{-1} e_f' \hat{\epsilon}_0^{\pi^e} = 0 \tag{34}$$

Solving for $\hat{\epsilon}_0^s$:

$$\hat{\epsilon}_0^s = -\frac{e_c \zeta_s}{e_c \tilde{A}_0^{-1} e_f'} \tag{35}$$

For $k \geq 1$, the counterfactual shock is computed recursively:

$$\hat{\epsilon}_k^s = -\frac{\Psi_c^k + \sum_{n=0}^{k-1} e_c \Lambda^{k-n} \tilde{A}_0^{-1} e_f' \hat{\epsilon}_n^s}{e_c \tilde{A}_0^{-1} e_f'} \tag{36}$$

Interpretation of terms:

Ψ_c^k is the original IRF of variable c at horizon k (what we want to offset).

Furthermore, $\sum_{n=0}^{k-1} e_c \Lambda^{k-n} \tilde{A}_0^{-1} e_f' \hat{\epsilon}_n^s$ is the cumulative effect of past counterfactual shocks on variable c at horizon k.

The counterfactual IRF for variable j at horizon k is:

$$\hat{\Psi}_j^k = \Psi_j^k + \sum_{n=0}^{k} e_j \Lambda^{k-n} \tilde{A}_0^{-1} e_f' \hat{\epsilon}_n^s, \quad j = \{1, 2, \ldots, N\} \tag{37}$$

Finally, we can offset the effect of the shock s on the variable c in multiple ways, and e_f is the indicator vector indicating which shock we are using to offset the initial shock. We can use each of the existing 4 shocks to offset the studied shock (if we use the same shock to offset the studied shock, the IRFs of all the variables are consequently 0). If we use a particular shock for offsetting effects, e_f is a equal to 0 everywhere except for the shock f. If we use a combination of all shocks for the purpose of offsetting, then we replace e_f with a sum of all indicator variables: $F_f = \sum_{l=1}^{N} e_l$ (all the elements are equal to 1), with the equations from above changing to:

The counterfactual IRF for variable j at horizon k, offset by a combination of all shocks:

$$\hat{\Psi}_j^k = \Psi_j^k + \sum_{n=0}^{k} e_j \Lambda^{k-n} \tilde{A}_0^{-1} F_f' \hat{\epsilon}_n^s, \quad j = \{1, 2, \ldots, N\} \tag{38}$$

$$\hat{\epsilon}_0^s = -\frac{e_c \zeta_s}{e_c \tilde{A}_0^{-1} F_f'} \tag{39}$$

For $k \geq 1$, the counterfactual shock is computed recursively:

$$\hat{\epsilon}_k^s = -\frac{\Psi_c^k + \sum_{n=0}^{k-1} e_c \Lambda^{k-n} \tilde{A}_0^{-1} F_f' \hat{\epsilon}_n^s}{e_c \tilde{A}_0^{-1} F_f'} \tag{40}$$

In our benchmark scenario, we use a historical decomposition of exchange rate, to assign weights of the offsetting shocks. The shocks that impacted the exchange rate more intensively are given a higher share in the overall weights. The details are described below.

Let $hd_{t,k}$ denote the historical contribution of structural shock k to variable C at time t, obtained from the historical decomposition of the estimated SVAR:

$$hd_{t,k} = \sum_{\tau=1}^{t} \Psi_{C,k}(\tau - s) \cdot \varepsilon_{\tau,k} \tag{41}$$

where $\theta_{C,k}(h)$ denotes the impulse response function of variable C to structural shock k at horizon h, and $\varepsilon_{s,k}$ is the realised structural shock k at time s. The weight assigned to shock k as an offsetting shock is proportional to its contribution to the sample variance of variable C:

$$v_k = \frac{1}{T-1} \sum_{t=1}^{T} \left(hd_{t,k} - \bar{hd}_k \right)^2, \tag{42}$$

where $\bar{hd}_k = \frac{1}{T} \sum_{t=1}^{T} hd_{t,k}$ is the sample mean of the contribution series. The weights are then normalised to sum to unity:

$$w_k = \frac{v_k}{\sum_{j=1}^{N} v_j}, \qquad \sum_{k=1}^{N} w_k = 1. \tag{43}$$

To construct a counterfactual in our benchmark scenario, we use historical decomposition of shocks driving the exchange rate to assign weights offseting the shocks.

D Data sources

Table 6: Data sources and description

Variable	**Description**	**Source**
Real GDP (EA)	Gross domestic product at market prices, chain-linked volumes, seasonally adjusted (2015=100)	Eurostat
Real GDP (US)	Gross Domestic Product: Chain-type Price Index, seasonally adjusted (2017=100)	FRED
HICP (EA)	Harmonised Index of Consumer Prices, seasonally adjusted	ECB SDW
CPI (US)	Consumer Price Index for All Urban Consumers, seasonally adjusted	FRED
Import Deflator (EA)	Implicit deflator for imports of goods and services	Eurostat
Import Deflator (US)	Implicit price deflator for imports of goods and services, seasonally adjusted	FRED
USD/EUR	Reference nominal exchange rate USD/EUR	ECB SDW
2-Year Yield (EA)	Euro area 2-year government benchmark bond yield	ECB SDW
2-Year Yield (US)	Market Yield on U.S. Treasury Securities at 2-Year Constant Maturity	FRED

E Additional tables and figures

Figure 10: Historical decomposition: HICP

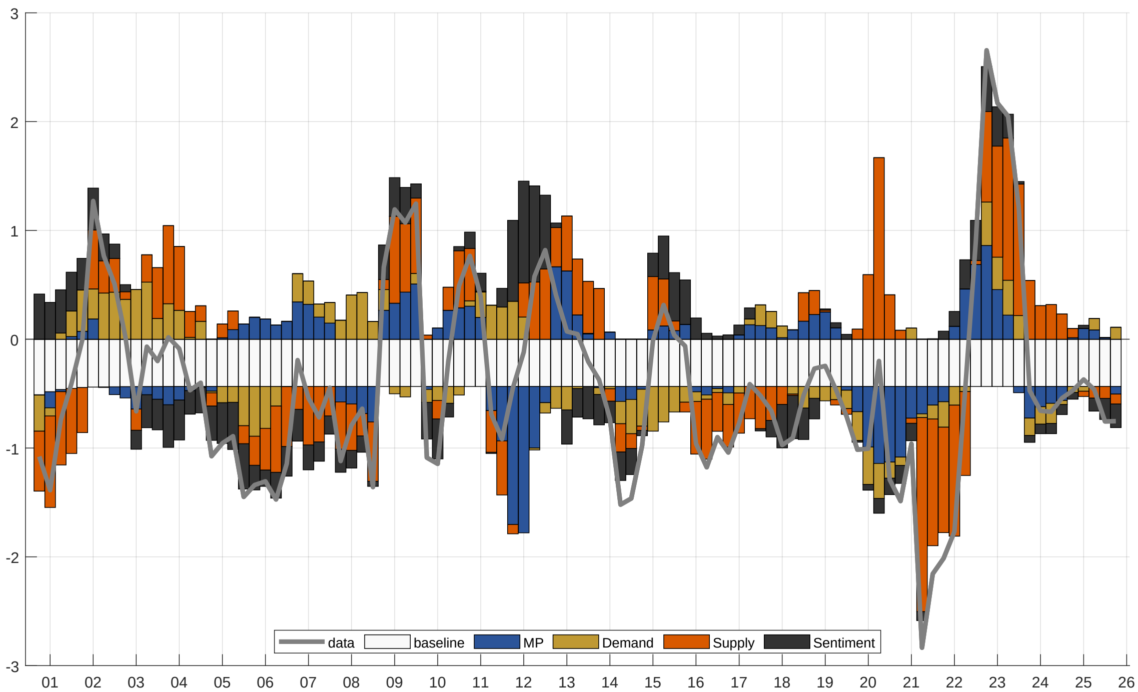

Table 7: Cumulative difference in the p.p. HICP after a depreciationary shock: Lag and prior robustness check

		1 st. dev. shock								Shocks normalized to 1% depreciation after 10 year							
		MP		Demand		Supply		Sentiment		MP		Demand		Supply		Sentiment	
	Method	1	20	1	20	1	20	1	20	1	20	1	20	1	20	1	20
Benchmark offsetting	Benchmark (HD)	0.03	0.05	0.06	0.13	0.03	0.02	0.10	0.17	0.31	0.43	0.21	0.47	0.48	0.42	0.27	0.49
	2 lags	0.04	0.05	0.06	0.12	0.03	0.02	0.1	0.17	0.32	0.44	0.21	0.46	0.5	0.43	0.28	0.47
	6 lags	0.04	0.05	0.06	0.13	0.03	0.03	0.1	0.19	0.36	0.48	0.25	0.53	0.52	0.51	0.3	0.56
	Loose prior $\lambda_1 = 0.5$	0.03	0.03	0.06	0.16	0.03	0.02	0.1	0.16	0.73	0.67	0.18	0.54	2.58	1.64	0.32	0.54
	Tight prior $\lambda_1 = 0.1$	0.04	0.07	0.06	0.12	0.03	0.04	0.11	0.19	0.25	0.42	0.24	0.47	0.28	0.38	0.27	0.48

Note: 1 and 20 columns denote the horizon in quarters.

Figure 11: Historical decomposition: Exchange rate

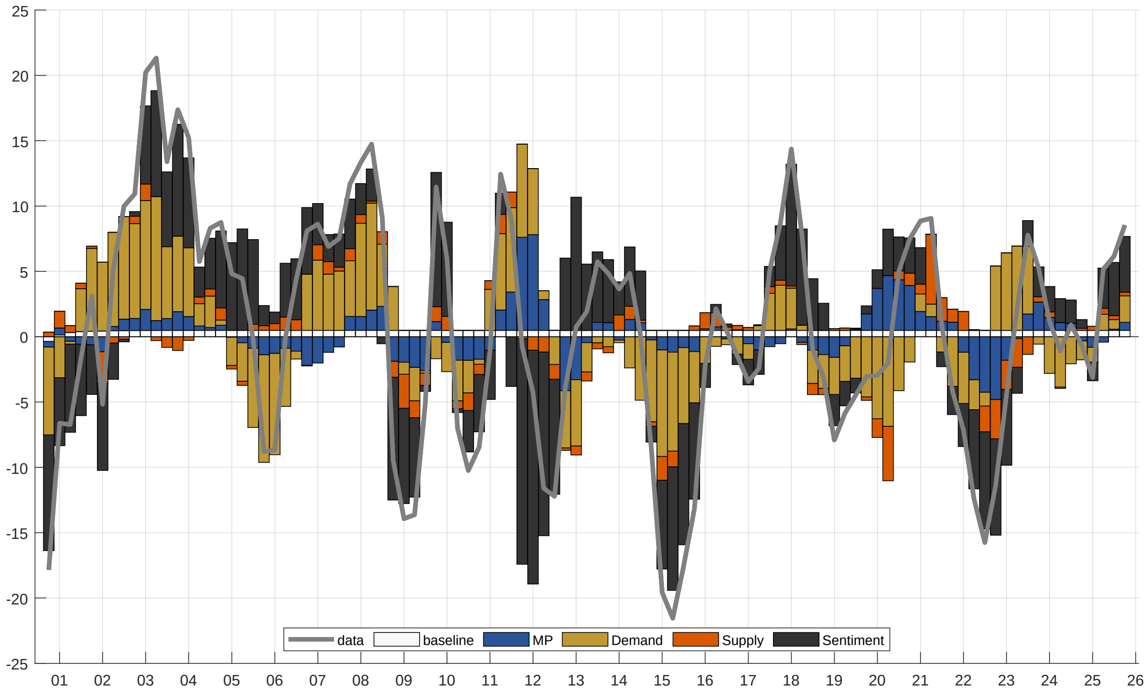

Table 8: PERR based on Cholesky identification

Cumulative quarters	Import Prices	HICP
8	-0.370	-0.058
12	-0.371	-0.058
4	-0.365	-0.056
1	-0.290	-0.051

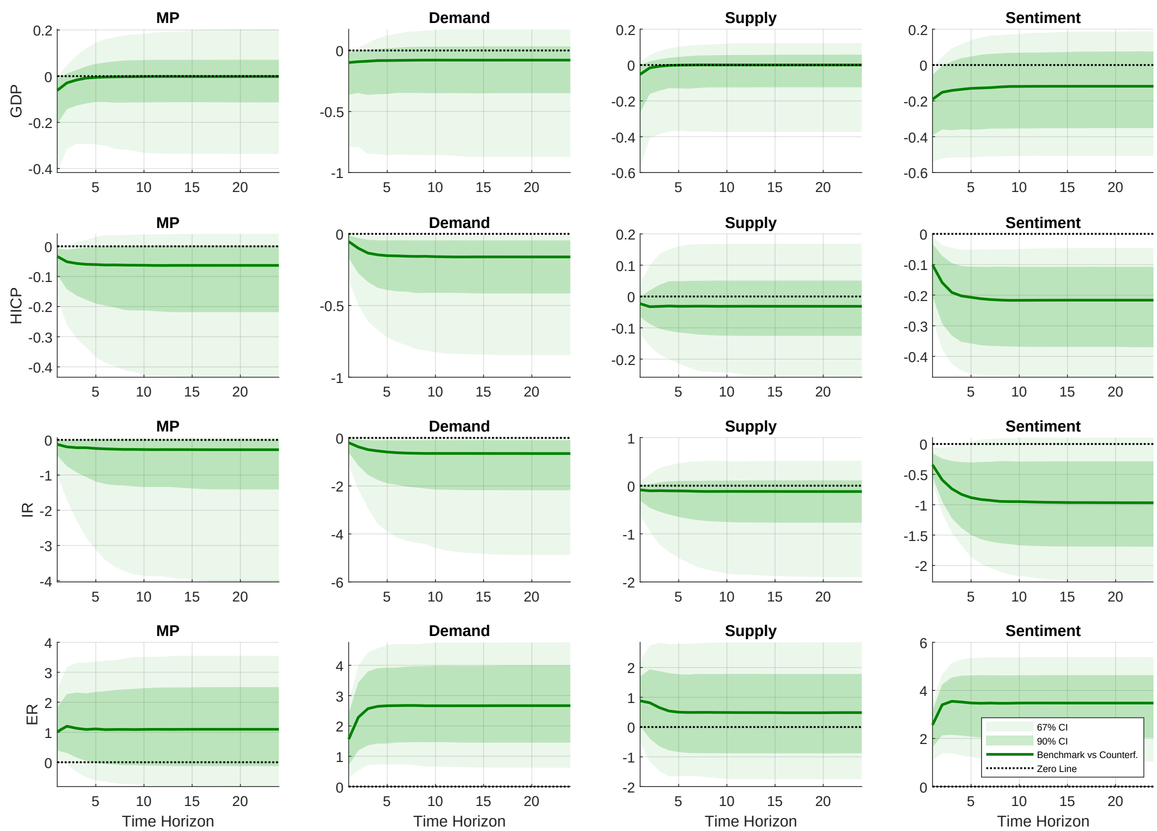

Figure 12: Difference between a baseline and counterfactual cumulative IRFs: HICP (one st. dev. shock, **sentiment** offsetting shocks used)

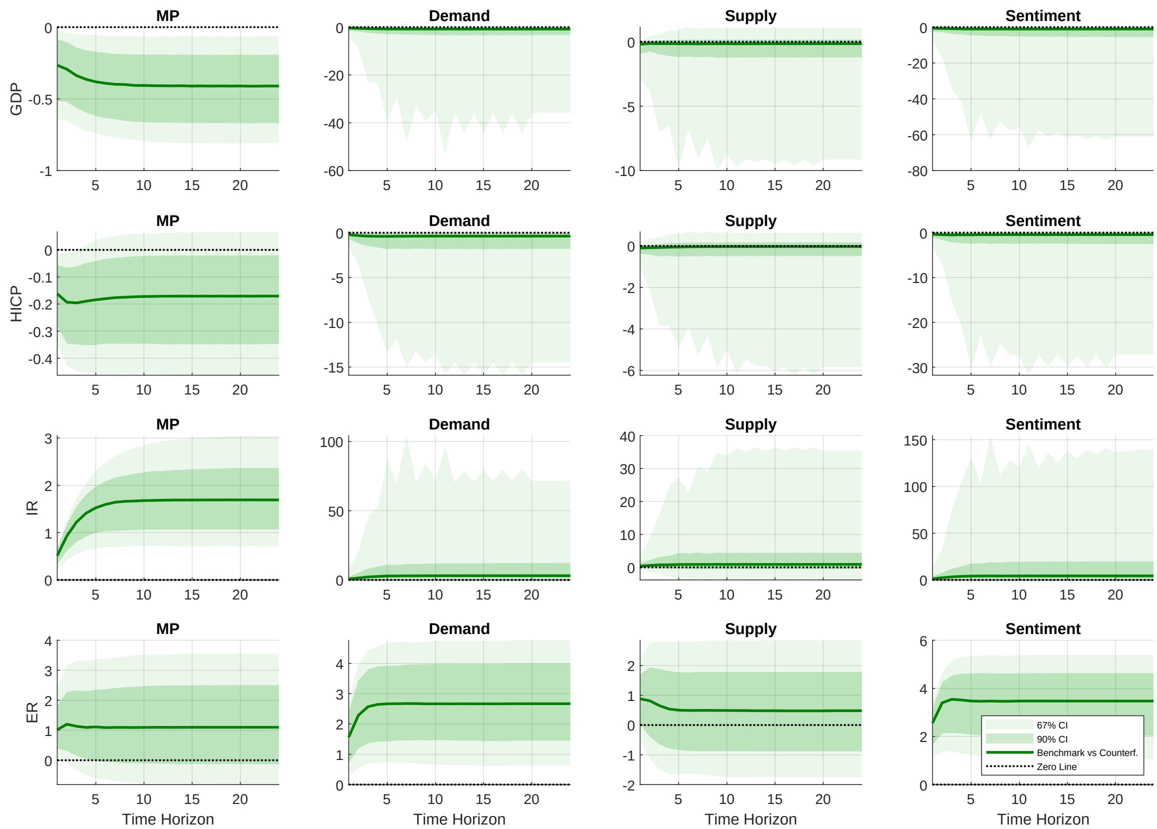

Figure 13: Difference between a baseline and counterfactual cumulative IRFs: HICP (one st. dev. shock, **monetary policy** offsetting shocks used)

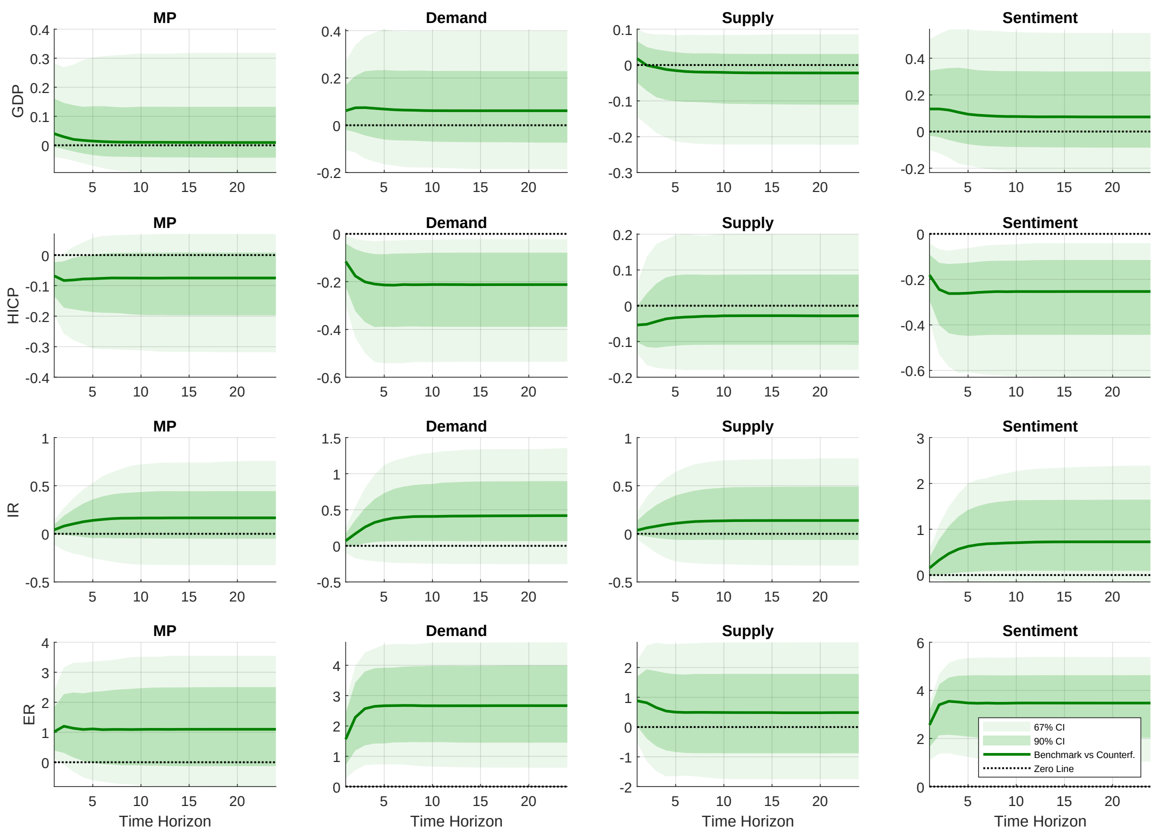

Figure 14: Difference between a baseline and counterfactual cumulative IRFs: HICP (one st. dev. shock, **equally-weighted** offsetting shock)

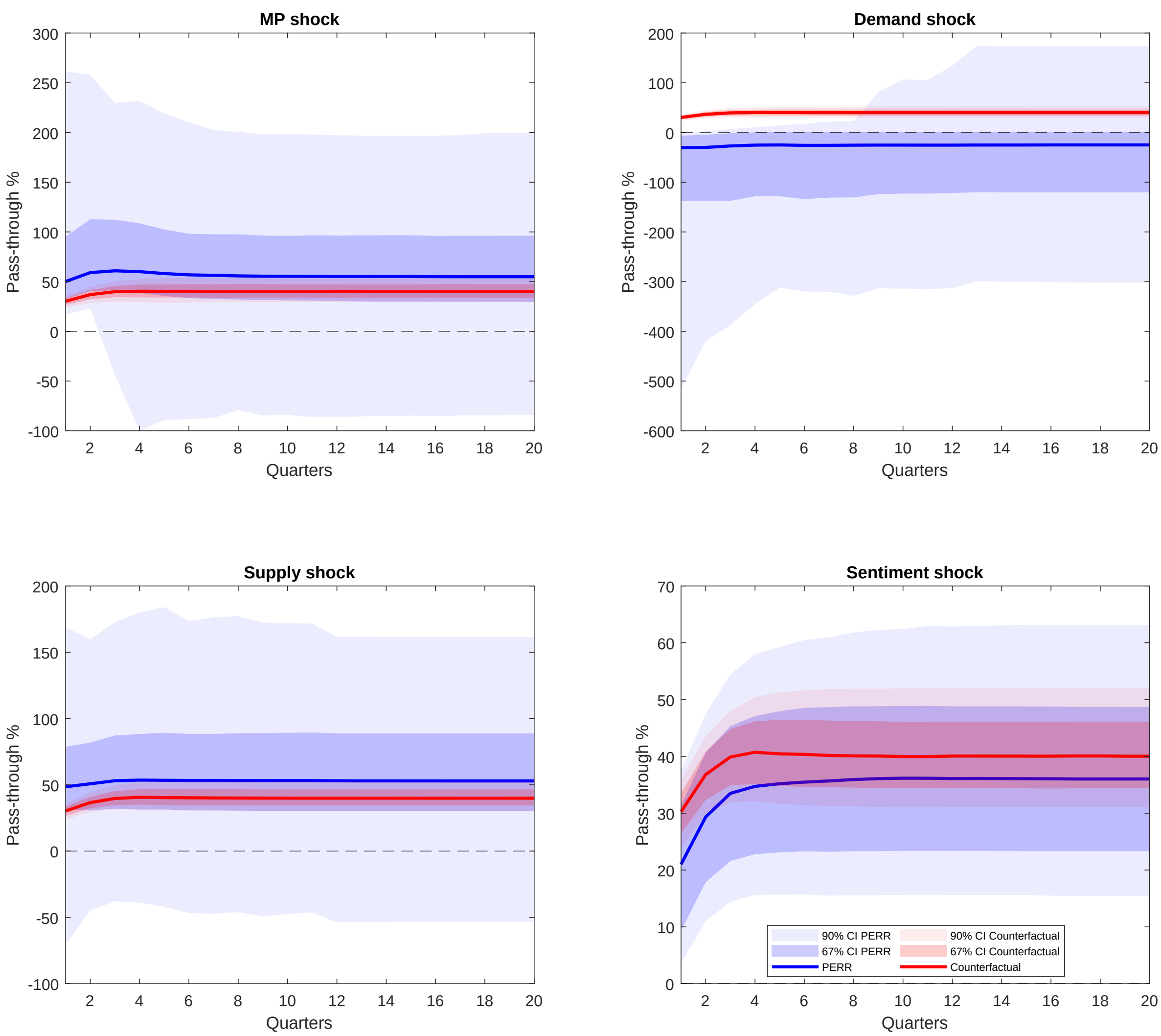

Figure 15: Comparison of benchmark ERPT to PERR, normalization by the current cumulative exchange rate IRF, Import prices

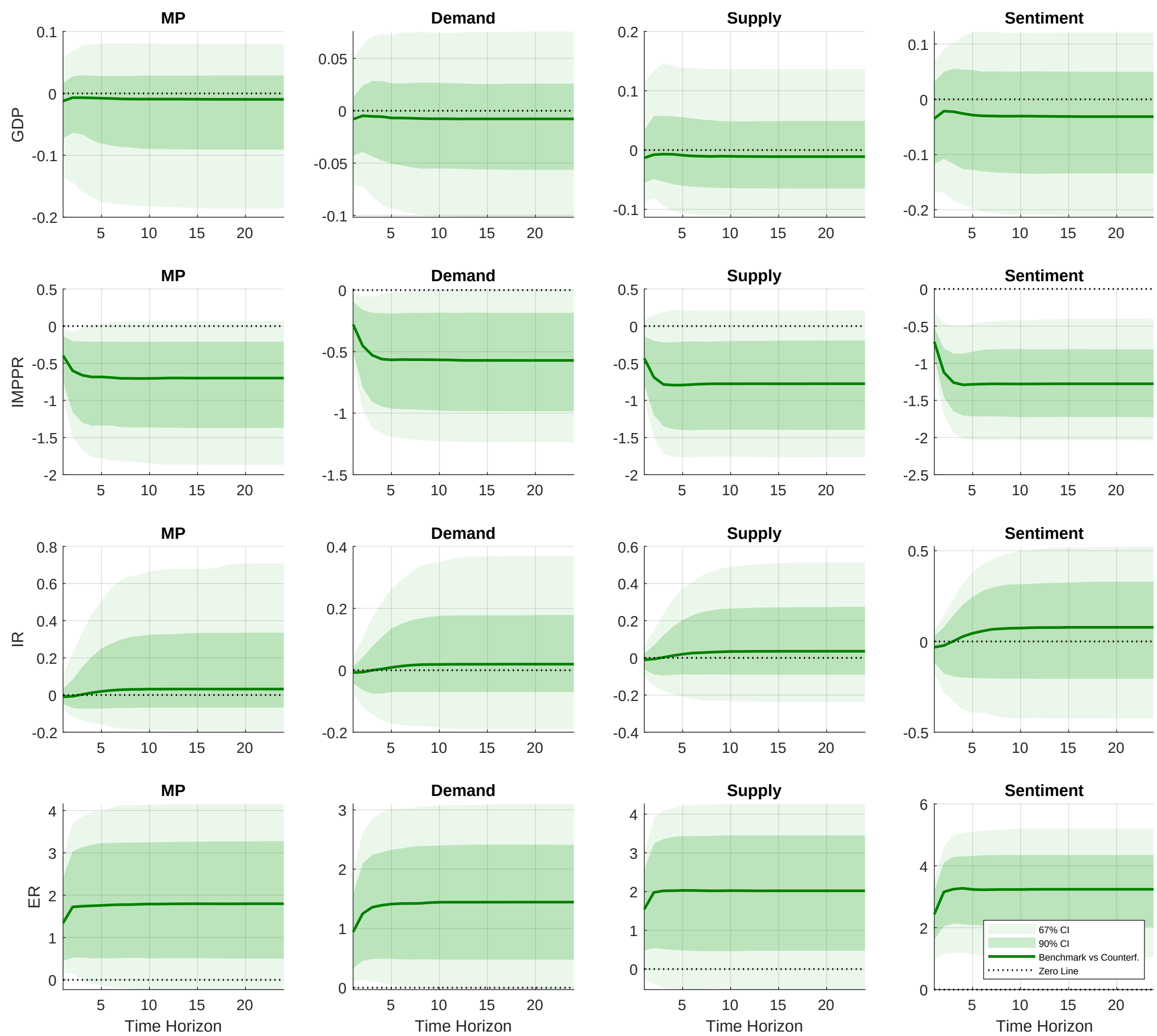

Figure 16: Difference between a baseline and counterfactual cumulative IRFs: Import prices (one st. dev. shock, HD-weighted offsetting shocks offsetting shocks used)

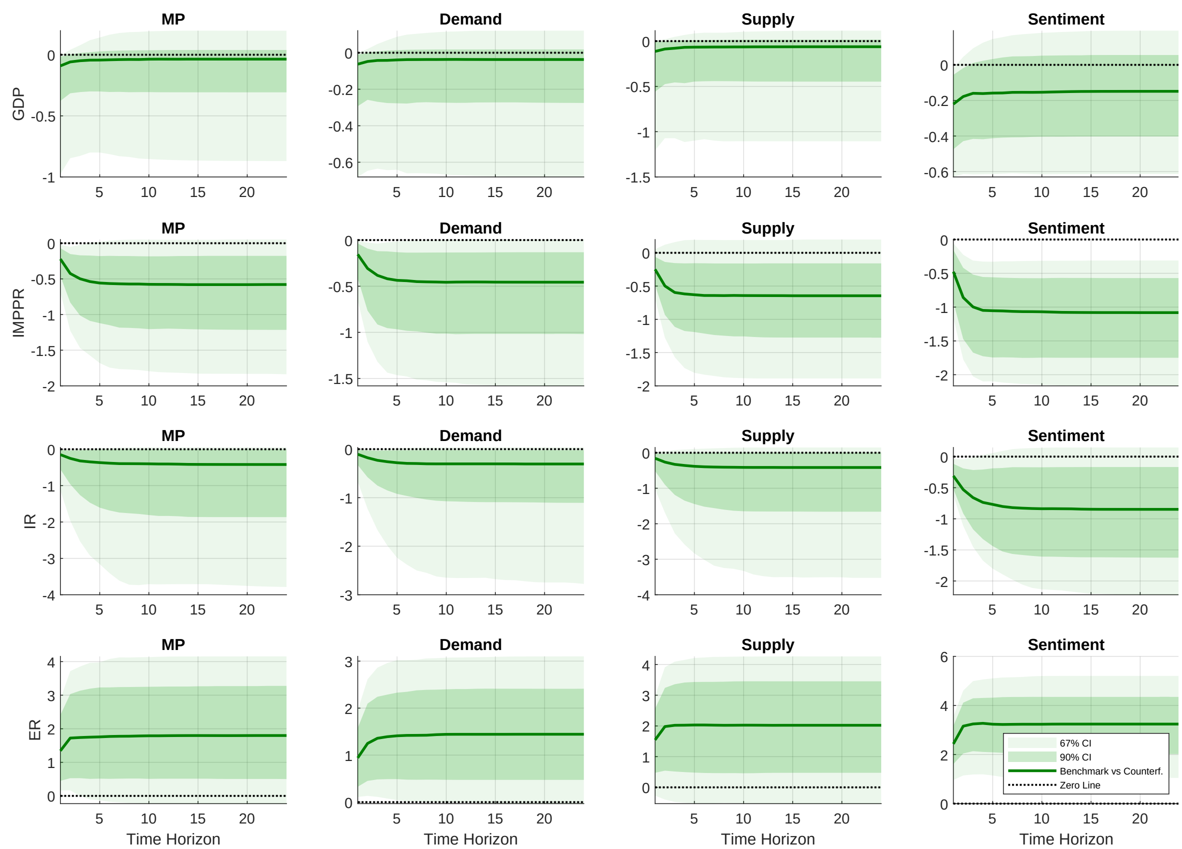

Figure 17: Difference between a baseline and counterfactual cumulative IRFs: Import prices (one st. dev. shock, **sentiment** offsetting shocks used)

Figure 18: Difference between a baseline and counterfactual cumulative IRFs: Import prices (one st. dev. shock, **monetary policy** offsetting shocks used)

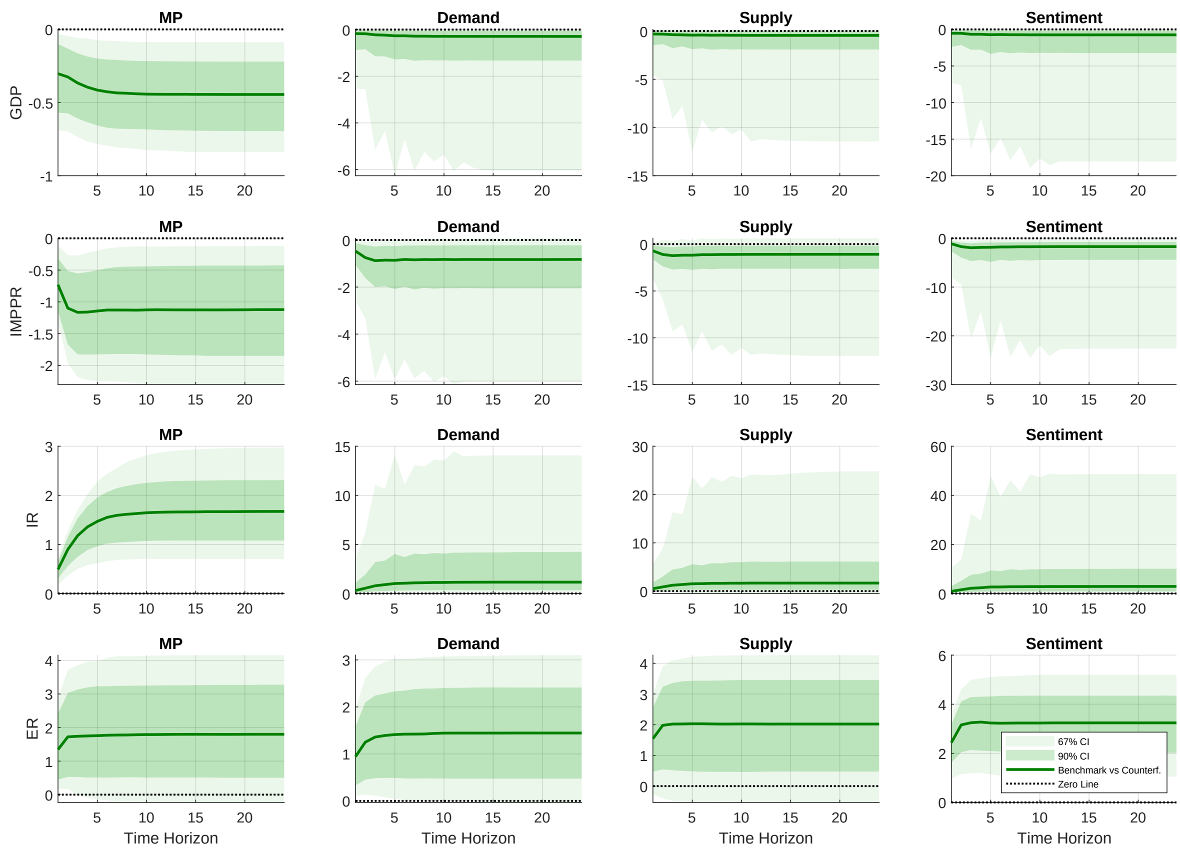

Figure 19: Difference between a baseline and counterfactual cumulative IRFs: Import prices (one st. dev. shock, **equally-weighted** offsetting shocks used)