LATVIJAS BANKA
EIROSISTĒMA

ISBN 978-9934-578-39-7

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WORKING PAPER
2 / 2021

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On the Time-varying Effects of the ECB's Asset Purchases

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October 26, 2021

Abstract

This paper (re-)evaluates the effectiveness of central bank asset purchases in the euro area given their prominent role in the ECB's response to the pandemic as well as the evidence from the US suggesting diminishing returns of this policy measure over time. We analyse their macroeconomic impact in the euro area using a time-varying parameter structural vector autoregression with stochastic volatility and perform identification via sign and zero restrictions of Arias et al. (2018), their fusion with high frequency information approach akin to Jarociński and Karadi (2020) and a novel method which merges high frequency identification with narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018). We find that the potency of the ECB's asset purchases to lift inflation has indeed considerably declined over time with several factors contributing to a more muted response of prices to central bank asset purchases. Our results show that the reanchoring channel is no longer active while the counterproductive effects via the mechanism outlined in Boehl et al. (2020), which we dub the capacity utilization channel, have emerged lately and are further complemented with disinflationary effects stemming from the cost channel. Also, the effects passed through more standard transmission channels of central bank asset purchases like portfolio rebalancing and signalling, while still significant, appear to be less persistent recently. Overall, our findings point to a diminishing returns of the ECB's asset purchases to stabilize inflation and its expectations in the euro area.

Keywords: quantitative easing, central bank asset purchases, monetary policy, euro area, non-linearities

JEL Codes: C54, E50, E52, E583

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1 Introduction

Central bank asset purchases, also known as quantitative easing (QE), have become a major monetary policy tool in plethora of advanced economies to provide additional monetary policy accommodation against the backdrop of persistently low inflation and natural interest rates. Both phenomena contribute to longer and more frequent zero lower bound (ZLB) periods when standard monetary policy instruments are insufficient to bring inflation back to the target (Williams (2016), Kiley (2018)).[1] In this paper, we focus on the macroeconomic effects of the European Central Bank's (ECB) large-scale asset purchases in the euro area. The ECB first introduced the Asset Purchase Programme (APP) in 2015 to prevent the economy from entering a deflationary spiral. Net purchases under the "first round" of the APP ended in December 2018, however, they were soon resumed in an open-ended fashion in September 2019. Additionally, in March 2020 the ECB launched the Pandemic Emergency Purchase Programme (PEPP) to counter financial fragmentation risks and, ultimately, ensure price stability.

The existing empirical evidence, primarily emanating from the initial round of the APP, suggests that the ECB's asset purchases had successfully substituted the policy rate setting as it has largely been constrained by the effective lower bound. Literature suggests that the APP had significantly lowered borrowing costs for sovereigns as well as firms and households and generated favourable macroeconomic outcomes, significantly contributing to the ECB's efforts in maintaining price stability (see e.g. Rostagno et al. (2019)). However, the current literature on the ECB's asset purchases lacks evidence on their non-linear or time-varying effects despite the evidence from the US suggesting diminishing returns over time (see Borio and Zabai (2016) for discussion). This evidence from the US, coupled with the prominent role of the PEPP in the ECB's response to the pandemic (Lagarde (2020)) as well as the recent strategy review, calls for a comprehensive (re-)evaluation of the ECB's asset purchase effectiveness over time in the euro area.

Hence, we fill this gap and expand the literature on the effectiveness of ECB's asset purchases as follows: first, we analyse their macroeconomic impact over time using a time-varying parameter structural vector autoregression with stochastic volatility (TVP-SVAR-SV) and perform identification via both sign and zero restrictions of Arias et al. (2018) as well as their fusion with the high

[1] Although a growing list of literature questions the empirical relevance of the ZLB (see Altavilla et al. (2019), Debortoli et al. (2020), Zlobins (2020c)), suggesting that standard monetary policy tools are still effective beyond zero, Zlobins (2020c) also shows that their ability to lift inflation is significantly weakened, thus requiring additional unconventional tools to ensure price stability.

frequency identification (HFI) approach akin to Jarociński and Karadi (2020). The latter is a novel application of this approach in the QE literature to pin down their real effects. Second, we propose a novel approach to identify the real effects of central bank asset purchases by merging HFI with narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018) which allows us to control for the presence of multiple monetary policy shocks in policy announcements, further sharpening the identification. Finally, we provide empirical evidence on the importance of various transmission channels, including those which have received relatively little attention in the existing literature.

We find that the impact of the ECB's asset purchases on output has remained broadly stable over time, but their potency to lift inflation has considerably declined over time with several factors contributing to a more muted reaction of price pressures to central bank asset purchases. Our results suggest that the reanchoring channel (Andrade et al. (2016)) is no longer active, while the counterproductive effects via the mechanism outlined in the Boehl et al. (2020), which we dub the capacity utilization channel, have emerged lately and are further complemented with disinflationary effects stemming from the cost channel (Barth III and Ramey (2002), Christiano et al. (2005), Ravenna and Walsh (2006)). However, two major transmission channels of the ECB's asset purchases – portfolio rebalancing and signalling – have remained broadly intact. Overall, our findings point to a diminishing returns of this policy instrument to stabilize inflation and its expectations in the euro area.

The paper proceeds as follows. Section 2 reviews the relevant literature, while Section 3 describes the empirical framework, data and identification strategies used in our paper to pin down the macroeconomic effects of central bank asset purchases. Section 4 presents the results and discusses the transmission channels. Section 5 is devoted to robustness checks of our findings. Finally, Section 6 concludes.

2 Literature Review

The existing empirical literature on the ECB's asset purchases has primarily focused on the initial round of the APP, suggesting that it had favourable effects on a broad spectrum of financing conditions (see Altavilla et al. (2015), Blattner and Joyce (2016), De Santis (2016), Koijen et al. (2016), Eser et al. (2019) and Dedola et al. (2021)) and sizable macroeconomic impact (see Andrade et al. (2016),Garcia Pascual and Wieladek (2016), Hartmann and Smets (2018), Rostagno et al. (2019), Gambetti and Musso (2020) for area-wide results and Mandler and Scharnagl (2020) and Zlobins (2020a) for member-state level evidence). Similar evidence of positive macroeconomic effects of central bank asset purchases has also been found in other advanced economies, including Japan, the US and the UK (see e.g. Chung et al. (2011), Schenkelberg and Watzka (2013), Baumeister and Benati (2013), Gambacorta et al. (2014), Weale and Wieladek (2016), Haldane et al. (2016)). However, evidence from the US, which has gained considerably more experience with its QE programmes, shows that the subsequent expansions of purchases have been less effective (see Yu (2016), Borio and Zabai (2016)). These studies outline several factors contributing to diminishing returns of later rounds of purchases. First, QE1 was launched at the height of the Great Recession, with unprecedented levels of uncertainty in financial markets, substantially lowering the market segmentation and risk aversion via the portfolio rebalancing mechanism (see Vayanos and Vila (2009) for theoretical underpinnings of this mechanism). Thus, with risk levels subsiding over time, QE2 and QE3 left a markedly lower footprint on yields. Second, the initial announcement of the QE1 was more successful in pushing down the trajectory of future policy rate path since the later announcements were to some degree expected by market participants and already priced in the forward curve (see literature on the signalling channel of central bank asset purchases, e.g. Eggertsson and Woodford (2003), Bauer and Rudebusch (2014), Bhattarai et al. (2015)). Besides, Boehl et al. (2020), contrary to conventional wisdom, argue that the Federal Reserves' asset purchases have actually depressed inflation despite having positive impact on output. They show that asset purchases have predominantly boosted investment with negligible or even negative impact on household consumption, thus increasing the productive capacity of the economy and lowering price pressures.

Despite the evidence from the US and the major role of the APP and the PEPP in ECB's toolkit, the current empirical literature has devoted little attention to non-linear or time-varying effects of ECB's asset purchases. Notable exceptions are Eser et al. (2019) and Lhuissier and Nguyen (2021), providing evidence on the APP impact on the term structure and macroeconomic outcomes, respectively. Eser et al. (2019) suggests that the effects regarding the yield curve have remained persistent over time, reaching the peak in mid-2016 and remaining at a similar level since then. While Lhuissier and Nguyen (2021) shows that the subsequent recalibrations of the APP have been as successful as the original announcement in January 2015, generating similar effects over time on both output and inflation. However, both contributions derive their conclusions from constant parameter reduced-form econometric frameworks, assuming no change in agents' behaviour to succeeding central bank balance sheet expansions, making their findings vulnerable to the Lucas critique. This also runs somewhat counter to the theoretical contribution of Karadi and Nakov (2021), who argue that quantitative easing is only effective when financial intermediaries face funding constraints, implying that asset purchases are not a perfect substitute for policy rate setting when it is constrained by the ZLB. This is contrary to many previous papers evaluating the effectiveness of quantitative easing in DSGE models (Gertler and Karadi (2011), Carlstrom et al. (2017), Sims and Wu (2020)), which assume that central bank asset purchases are always effective. Thus, establishing solid and robust empirical evidence on the non-linear effects of quantitative easing is not only important for policy implications but also for academic debate.

3 Empirical framework

In this section, we describe our econometric approach to evaluate the time-varying impact of the ECB's asset purchases on the macroeconomic and financial variables. As our workhorse model, we employ a TVP-SVAR-SV along the lines of Primiceri (2005) as it allows to remain agnostic about the potential structural changes in the transmission of asset purchases, giving it a clear advantage over other non-linear vector autoregressions (VAR), e.g. Markov-switching or threshold VARs, which require to set a specific number of regimes ex ante. Also, given our focus on the euro area and taking into consideration the data sample covering the period from January 2009 to June 2020, time variation in both the parameter space and the error variance-covariance matrix is extremely useful and almost prerequisite to obtain robust evidence. During this period, the euro area experienced a change in the monetary policy regime as the ECB switched from traditional policy rate setting to an unconventional policy mix, using negative policy rates alongside asset purchases and forward guidance. Stochastic volatility is necessary as the euro area has been exposed to several large shocks – the Great Recession, sovereign debt crisis and the COVID-19 pandemic – likely rendering the residuals not identically distributed across time. It is the pandemic that has generated some extremely volatile observations, requiring additional attention to alleviate the impact of these outliers on inference; we discuss this more thoroughly later on in the section.

Regarding the identification strategies, we utilise both the sign and zero restrictions of Arias et al. (2018) as well as their fusion with high frequency information approach à la Jarociński and Karadi (2020), which is a novel application of this approach in the QE literature estimating its macroeconomic impact. While HFI has indeed been previously used in the literature to pin down the effects of the central bank asset purchases, these papers have either focused on their financial market effects (Altavilla et al. (2019) or have used a different approach to control for the information effect (Kim et al. (2020).

For $t = 1, \ldots, T$ let y_t denote a vector of endogenous variables which evolve according to:

$$y_t = C_t + A_{1,t}y_{t-1} + ... + A_{p,t}y_{t-p} + \epsilon_t \tag{1}$$

where C_t is an $n \times 1$ vector of constants, A_j ($j = 1, \ldots, p$) is an $n \times n$ array of coefficients related to the *j-th* lag and ϵ_t is an $n \times 1$ structural error vector with zero mean and diagonal time-varying variance-covariance matrix Σ_t and T is the sample size. For convenience, we stack matrices of SVAR coefficients from equation 1 into vector ${}_t = (\mathrm{C}_t{}', vec(A_{1,t})', ..., \mathrm{vec}(\mathrm{A}_{p,t})')$. The time variation of coefficients is then assumed to evolve according to a random walk process:

$$\theta_t = \theta_{t-1} + \upsilon_t \quad \upsilon_t \sim N(0, \Omega) \tag{2}$$

where υ_t is a white noise vector with covariance matrix Ω.

Additionally, in order to allow the error covariance matrix to be period-specific, we introduce stochastic volatility in the model as follows:

$$\Sigma_t = F\Lambda_t F' \tag{3}$$

where F is a lower triangular matrix with a unit diagonal and Λ_t is a diagonal matrix with elements denoted by $\exp(\lambda_{i,t})$ and the log-volatilities $\lambda_{i,t}$ following the AR(1) process:

$$\lambda_{i,t} = \gamma\lambda_{i,t-1} + \nu_{i,t} \quad \nu_{i,t} \sim N(0, \phi_i\ ) \tag{4}$$

where γ is a persistence parameter set to 0.8 for all volatilities and $\nu_{i,t}$ is a white noise error with variance ϕ_i. Contrary to adopting the random walk assumption of Cogley and Sargent (2005) and setting $\gamma = 1$, we choose a slightly lower value for γ, since the random walk assumption implies that shifts in volatility become permanent and it does not revert to its long-run value. Key macroeconomic variables like the real GDP and inflation will typically have higher volatility during recessions but will return to their long-run values once the economic turbulence calms down. However, Primiceri (2005) demonstrates that the choice of γ has a negligible impact on the results and we also corroborate this finding by performing robustness checks with $\gamma = 1$ in section 5.

We make the following assumptions about the prior distribution in our TVP-SVAR-SV:

$$\pi(\theta|\Omega) \sim N(0, \Omega_0) \tag{5}$$

$$\pi(f_i^{-1}) \sim N(f_{i0}^{-1}, \Upsilon_{i0}) \tag{6}$$

$$\pi(\lambda_i|\phi_i\ ) \sim N(0, \phi_0) \tag{7}$$

$$\pi(\omega_i) \sim IG(\frac{\chi_0}{2}, \frac{\psi_0}{2}) \tag{8}$$

$$\pi(\phi_i) \sim IG(\frac{\alpha_0}{2}, \frac{\delta_0}{2}) \tag{9}$$

where f_i^{-1} denotes the vector in the F^{-1} matrix containing the non-zero and non-one elements with mean f_{i0}^{-1} and covariance Υ_{i0} for i = 2, ..., n and j = 1, ..., i-1, ω_i are diagonal entries in the Ω matrix with the χ_0 and ψ_0 denoting the hyperparameters governing the shape and scale of variance. In order to make the prior non-informative, we set χ_0=ψ_0=0.001. Similarly, α_0 and δ_0 are hyperparameters related to the variance of volatility which are set to α_0=δ_0=0.001. Parameters Ω_0, f_{i0}^{-1}, Υ_{i0} and ϕ_0 are set equal to their OLS estimates from a time-invariant SVAR.

3.1 Data and identification via sign restrictions

The model includes five monthly variables – output, inflation, the short-term interest rate, the exchange rate and securities held by the Eurosystem scaled by 2015 nominal GDP – and is estimated using the data sample covering the period from January 2009 to June 2020 and the variables expressed as percentage rates enter the model in the form of levels, while other variables - as first differences of their log-levels (as in Primiceri (2005), Paul (2020)). The lag order is set to 1 due to highly computationally intensive process of estimating the TVP-SVAR-SV model.[2]

Lenza and Primiceri (2020) show that the extreme volatility in the data from March until June 2020 has a considerable impact on the parameter estimates and shock volatilities, thus implying serious consequences for identification in the VAR models. To overcome the issue, they propose a computationally efficient algorithm which allows for heteroscedasticity in residuals of months affected by the pandemic, effectively "switching on" stochastic volatility for these periods and

[2] Appendix A4 shows that the results remain robust also when using two lags.

assuming constant variance for the rest of the time. However, we abstain from their solution due to the presence of several large shocks in the past, likely making the errors non-normally distributed across time, instead we opt for the full stochastic volatility algorithm. Yet, as evidenced by the results in Appendix A3, the standard stochastic volatility approach is incapable to deal with the COVID-19 shock since it is informed by past data with substantially lower volatility (see Appendix A6). Thus, we follow Carriero et al. (2021), who, inter alia, suggest to introduce dummies in the months affected by the pandemic, which effectively soak up the excess volatility observed in this period, alleviating the impact of outliers on inference in VARs. Specifically, we include two COVID-19 related dummies as exogenous variables with the first dummy taking the value of 1 in March and April 2020, while the second one – in May and June 2020.

As our first identification approach, we use the sign and zero restrictions of Arias et al. (2018) to isolate the structural asset purchase disturbance from the central bank balance sheet variable, similarly to Garcia Pascual and Wieladek (2016), Gambetti and Musso (2020) and Zlobins (2020a) among others. A summary of our identifying restrictions is provided in Table 1. In particular, we assume that the expansion of central bank balance sheet causes the euro to depreciate against the US dollar, given that the existing evidence emphasizes the importance of the exchange rate channel in the transmission of asset purchases in the euro area (Dedola et al. (2021)). We also impose a zero restriction on the EONIA spot rate to ensure that the asset purchase shock is orthogonal to a conventional monetary policy shock. Similarly, we impose a zero restriction on both output and inflation to ensure that real variables do not instantly react to asset purchases.

Table 1: **Identification via sign and zero restrictions**

Shock	Real GDP	HICP inflation	EONIA	EUR/USD	Securities held by the Eurosystem/GDP
Monetary policy	+	+	-	-	0
Asset purchase	0	0	0	-	+

These restrictions also help to control for business cycle disturbances as aggregate demand and supply shocks are not explicitly identified due to a highly computationally intensive process of estimating the TVP-SVAR-SV model.[3] All restrictions are imposed to hold on impact, i.e. for one month only.

[3] Appendix A5 contains an additional robustness check, assuming that the standard monetary policy cannot contemporaneously impact output and inflation either. The results remain broadly in line with the baseline results.

3.2 Identification via high frequency information

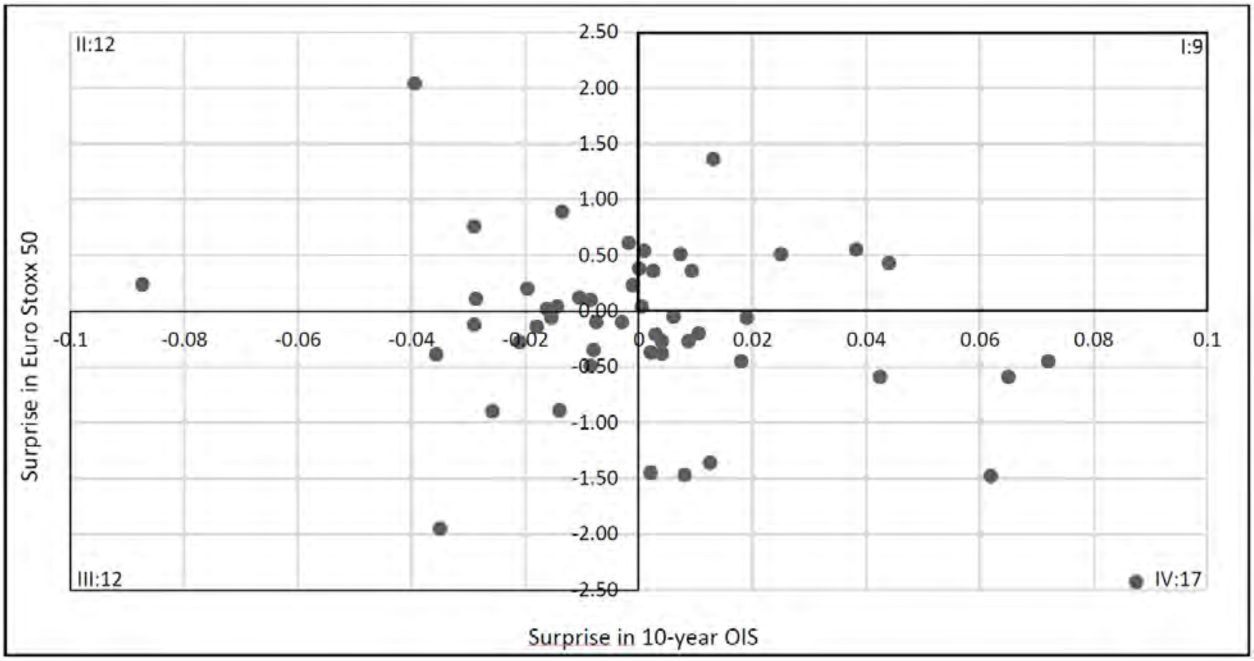
As our second identification approach, we obtain the exogenous asset purchase shock via the HFI procedure, using the high frequency co-movement of interest rates and stock prices around the ECB policy announcements. This approach has been widely used for the analysis of monetary policy effects in the US (see e.g. Kuttner (2001), Piazzesi (2002), Gürkaynak et al. (2005), Gertler and Karadi (2015) and Nakamura and Steinsson (2018)) and more recently has also been applied for the euro area monetary policy analysis (see e.g. Altavilla et al. (2019), Jarociński and Karadi (2020), Andrade and Ferroni (2021)). The application of this identification strategy has been made considerably more accessible by the release of the Euro Area Monetary Policy Event-Study Database (EA-MPD) - a high quality database created and made publicly available by Altavilla et al. (2019) and containing the responses of a broad set of financial variables to the ECB policy announcements.

In this paper, we also make use of the EA-MPD and gather high frequency surprises from the Press Conference Window where the surprises are measured as a change in the median quote from the window 14:15-14:25 before the press conference to the median quote in the window 15:40-15:50 after it. Our choice to use this particular window is motivated by the evidence from the Altavilla et al. (2019), demonstrating that the QE factor is particularly active in this window. The advantage of HFI, i.e. that the effects of monetary policy are measured during a short period of time around policy announcements, ensures that the identified asset purchase shock series is orthogonal to other non-monetary shocks hitting the economy. However, Kerssenfischer (2019), Jarociński and Karadi (2020) and Andrade and Ferroni (2021) have empirically showed that high frequency surprises around policy announcements are contaminated with the central bank information shocks because central banks provide news not only about monetary policy but also about the state of the economy during announcements. In addition, Figure 1 shows that in roughly half of the ECB policy announcements from June 2014 to June 2020 (our data sample from which we pin down high frequency reactions to the asset purchase shock; we elaborate on this in the next paragraph) the information shock dominates over the pure monetary policy shock as equity prices react opposite to what is expected from the economic theory (quadrants I and III).[4]

To control for the information effect, we follow the approach of Jarociński and Karadi (2020) and isolate it from a pure monetary policy shock via sign restrictions. In the first step, we include

[4]Excluding one observation which includes 0.

Figure 1: **Presence of information shock in the ECB policy announcements**



Note: Figure shows high frequency reaction of the 10-year OIS rate and Euro Stoxx 50 equity prices to the ECB policy announcements from June 2014 to June 2020. The highlighted quadrants I and III show that in a substantial number of cases both variables react to monetary policy innovation with the same sign, opposite to what is expected from the economic theory (see Jarociński and Karadi (2020) for discussion) due to the presence of information shocks.

high frequency surprises into the VAR and ensure that they do not depend on their own lags:

$$m_t = a_0 + \sum_{j=1}^{p} 0 \; m_{t-j} + \epsilon_t \tag{10}$$

where m_t are the high frequency reactions of the 10-year OIS rate and Eurostoxx 50 to ECB policy announcements. Our choice of the 10-year OIS rate as an instrument for asset purchases is motivated by evidence from Altavilla et al. (2019) demonstrating that the QE factor displays maximum loading on yields with 10-year maturity. This allows us to distinguish the impact of asset purchases from other ECB monetary policy measures used alongside asset purchases, like forward guidance and negative interest rates, which primarily target short- and medium-term maturities. The VAR is estimated on a monthly basis from June 2014 to June 2020 with standard Bayesian techniques by specifying an independent Normal-Wishart prior.[5] Our choice of the particular data sample is justified by the logic put forth in Altavilla et al. (2019) and Hauzenberger et al. (2020) as they both restrict the QE factor to be present post-2014 in order to obtain a shock series consistent

[5]We set the AR coefficient of the prior to 0, overall tightness λ_1=0.1, cross-variable weighting $\lambda_2 = 0.5$, lag decay $\lambda_3 = 1$ and block exogeneity shrinkage λ_5=0.001.

with the historical narrative when the ECB actually started to use asset purchases as an outright policy tool. In the second step, we apply the sign restrictions algorithm of Arias et al. (2018) and use the identifying restrictions laid out in Table 2.

Table 2: **Identification restrictions used in the high frequency information approach**

Shock	10-year OIS	Euro Stoxx 50
Asset purchase	-	+
Central bank information	-	-

Central bank asset purchases are assumed to boost equity prices as they inflate the expected value of future dividends, while a negative information shock triggers a fall in equity prices because announcements regarding the launch or recalibration of asset purchases signal that economic conditions are weaker than previously forecasted, depressing dividend expectations. Thus, those two shocks embedded in central bank announcements are distinguished via opposite sign restrictions on the Euro Stoxx 50.

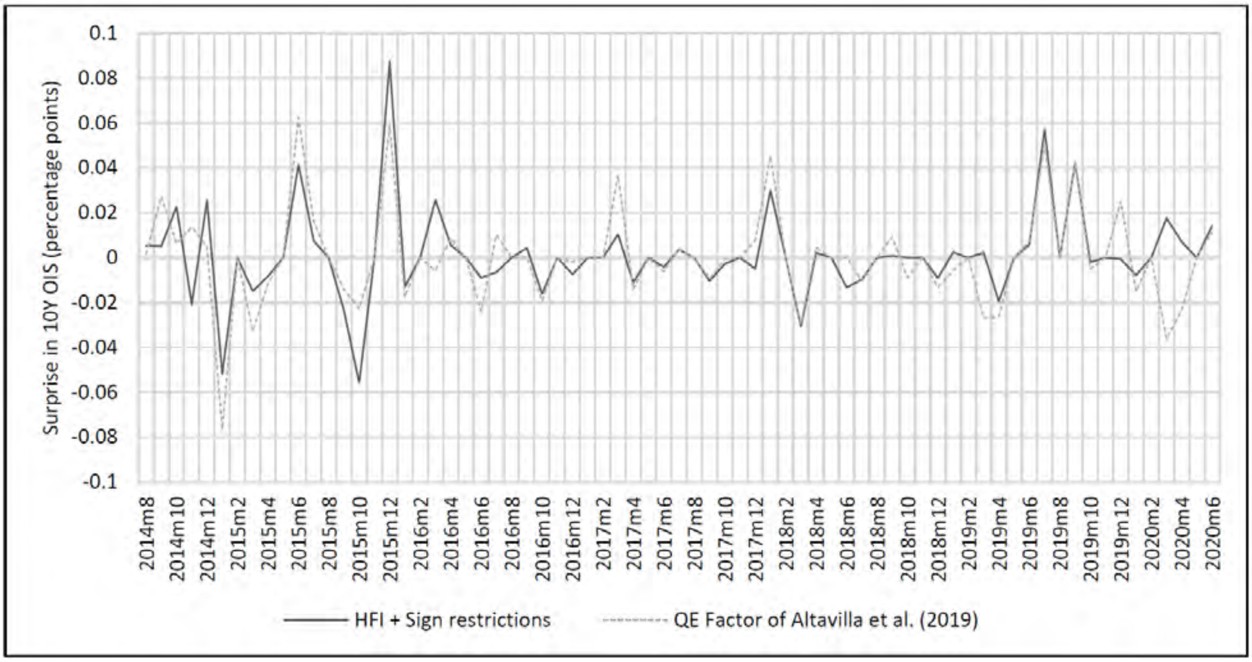
Figure 2 below shows the obtained shock series using our approach which augments HFI with sign restrictions and compares it against the updated QE factor of Altavilla et al. (2019)[6]. Despite using different methodology to extract the exogenous asset purchase shock in the euro area, as Altavilla et al. (2019) employ the factor rotation approach of Swanson (2021), both shock series are broadly similar to each other, with correlation coefficient equal to $\rho = 0.76$.

We then plug the obtained shock series directly into the TVP-SVAR-SV, following the "internal instrument" VAR literature (Romer and Romer (2004), Ramey (2011), Barakchian and Crowe (2013), Plagborg-Møller and Wolf (2021)) and perform the Cholesky decomposition. Plagborg-Møller and Wolf (2021) highlight that the "internal instrument" approach produces valid impulse responses even if the instrument is contaminated with measurement errors from other structural shocks, unrelated to the shock of interest. This gives it a clear advantage over the "external instrument" or the proxy SVAR approach of Stock and Watson (2012) and Mertens and Ravn (2013) which requires invertibility to hold.

With HFI setup, we use a slightly modified version of the TVP-SVAR-SV. First, the item "Securities held by the Eurosystem" is replaced with a 10-year government bond yield as the relevant policy indicator and the variables are ordered as follows: Real GDP, HICP inflation, QE shock series, 10-year bond yield, the EONIA and EUR/USD exchange rate. We order the identified shock

[6] We use codes from the website of Refet Gürkaynak: http://refet.bilkent.edu.tr/research.html

Figure 2: **Asset purchase shock time series**

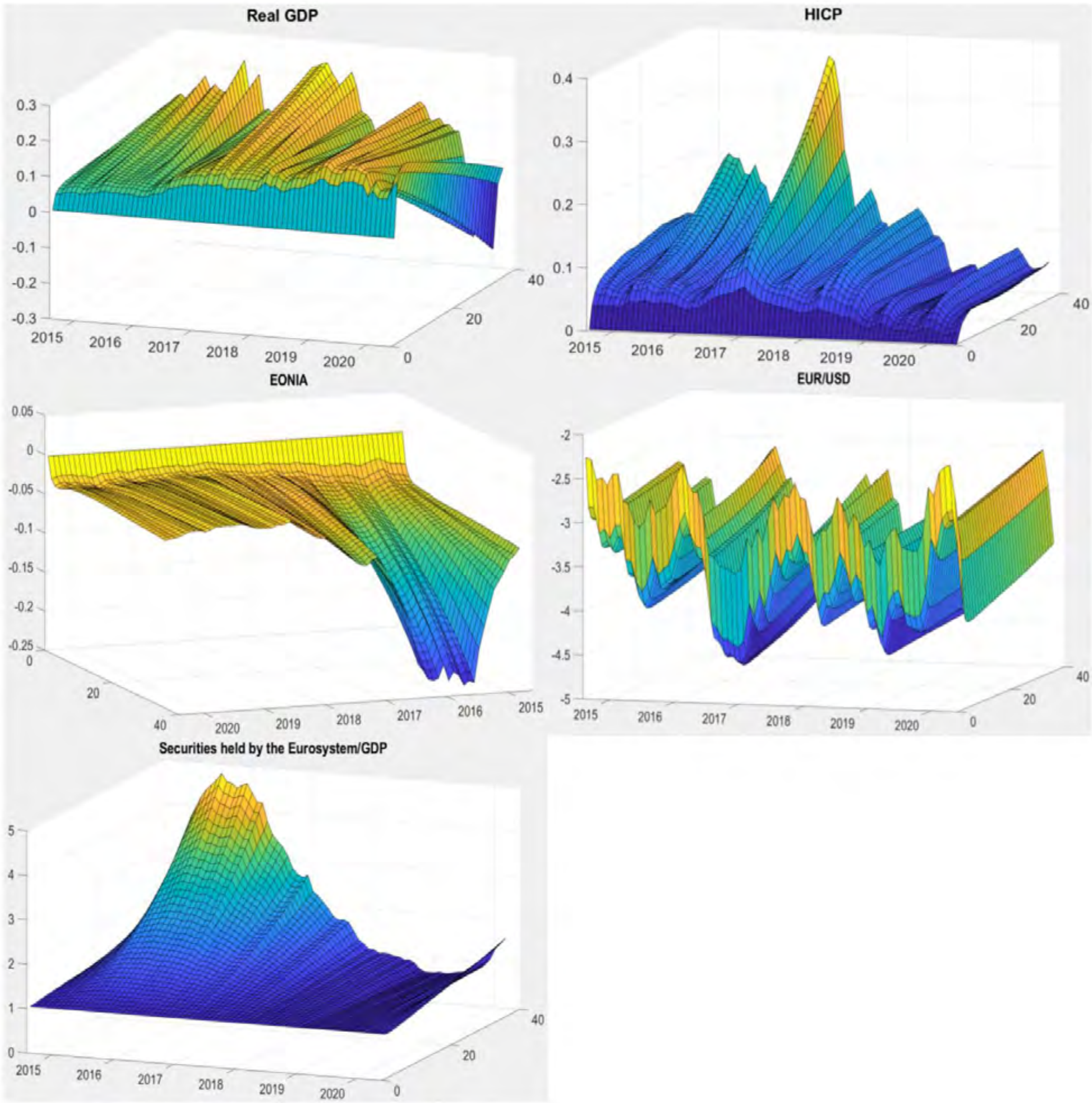


series after output and inflation as in Romer and Romer (2004) and Barakchian and Crowe (2013), assuming that asset purchases cannot contemporaneously affect the slow-moving real variables, but can still shift the fast-moving financial variables on impact. Second, all variables, including those expressed as percentage rates, enter the model as differences, contrary to the case when we use the sign restrictions approach for identification, since the shock series is I(0) by construction.

4 Results

Figure 3 shows the results from the TVP-SVAR-SV model and the case when the identification is performed via a mixture of sign and zero restrictions. The results are represented as impulse response functions (cumulative for real GDP and EUR/USD exchange rate to back out the impact on their level as they are included in the model as first differences). The asset purchase shock in this case has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP or roughly 100 billion EUR in each period, allowing the estimated elasticities to be comparable over time. The y axis shows the year of the impulse response function, the z axis shows the impact on the macroeconomic indicators and is expressed in percent, while the x axis shows the number of months since the shock. Impulse response functions are generated from 15 000 Gibbs sampler iterations with the first 10 000 discarded as burn-in.

Figure 3: **Baseline results from the TVP-SVAR-SV and identification via sign restrictions**



Note: Figure shows impulse response functions (cumulative for real GDP and EUR/USD) to the asset purchase shock, identified via a mixture of sign and zero restrictions, which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP.

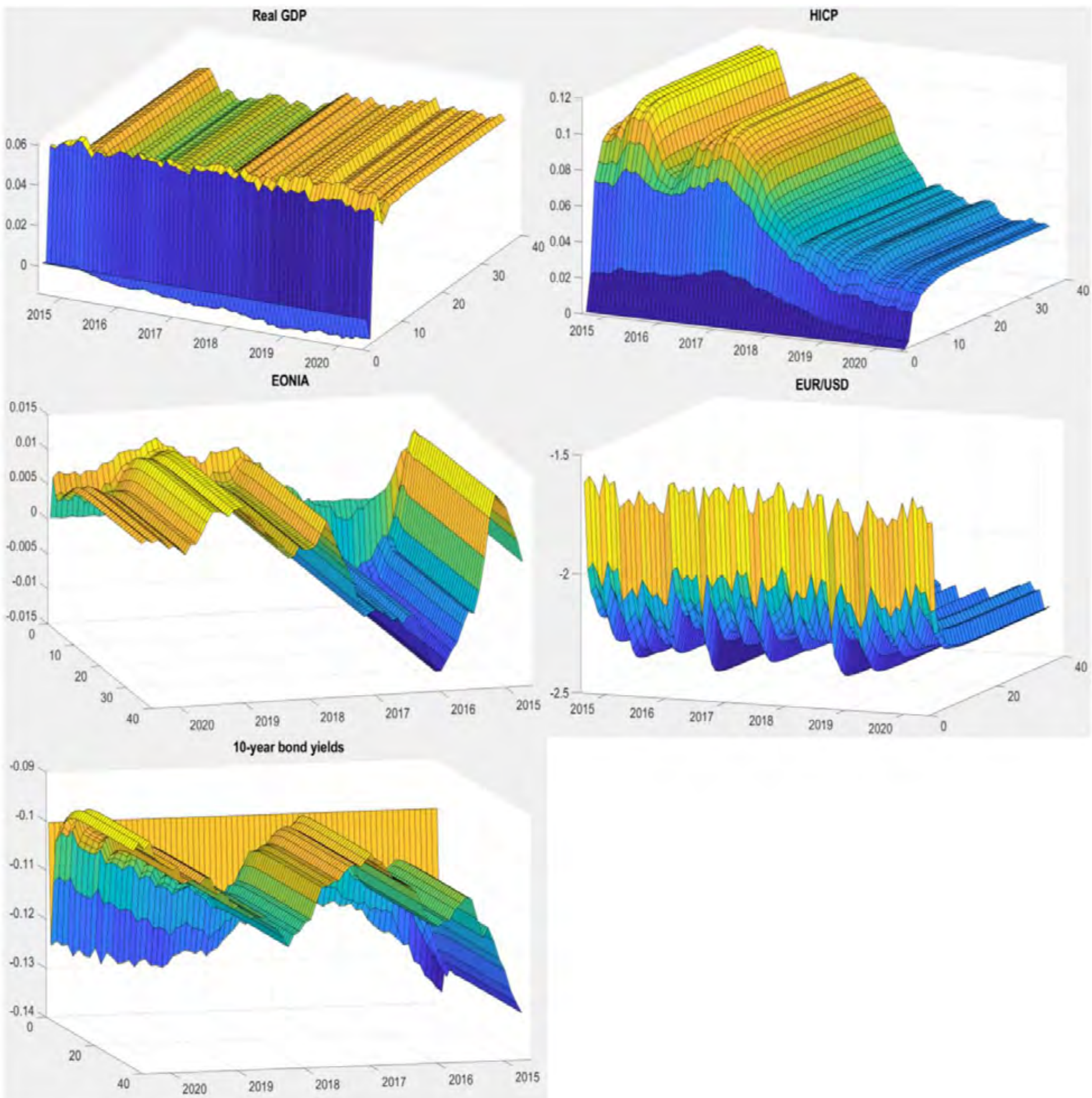
The results in Figure 3 suggest that the reaction of output has remained quite stable over the period from August 2014 to June 2020, with median peak impact in this sample reaching 0.16% in response to a 1 pp increase in the Eurosystem asset holdings. Similarly, the median peak impact on inflation over the same time has reached 0.11 pp. The estimated median effects on both the output and inflation are broadly similar to the previous literature on the macroeconomic effects of the ECB's asset purchases (see e.g. Zlobins (2020a), Lhuissier and Nguyen (2021) and references therein), indicating that the sign restrictions approach captures the exogenous asset purchase shock quite well despite the limited set of restrictions used for identification. Also, the responses of financial variables – EUR/USD and the EONIA – have remained broadly stable over the sample with the latter displaying more pronounced reaction around 2016, likely reflecting the ECB's decision to accompany the recalibration of the APP with a policy rate cut deeper into negative territory. However, one striking result emerges – the response of inflation has considerably declined since 2018 onwards. This result justifies the use of non-linear econometric framework for estimating the macroeconomic effects of the ECB's asset purchases and has important policy implications given the prominent role of the PEPP in ECB's policy package to revive inflationary pressures in the euro area during the COVID-19 pandemic.[7] Thus, this finding cautions against overreliance on this instrument to stabilize inflation and, ultimately, ensure price stability.

Furthermore, impulse responses obtained via alternative – HFI – approach, shown in Figure 4, tell a similar story of asset purchase effectiveness in the euro area. This identification strategy also suggests that the potency of asset purchases to lift inflation has gradually declined since circa 2018, confirming the robustness of this finding. Note, though, that in this case the relevant policy indicator is the 10-year government bond yield, instead of the Eurosystem asset holdings, and the shock is scaled to a 10 bps drop in long-term interest rates, making the obtained impact on macroeconomic variables not directly comparable between both identification approaches. However, Andrade et al. (2016) compile the evidence from a range of event studies, reporting that the inaugural announcement of the APP in January 2015 worth 10% of GDP lowered the 10-year bond yields by 27-64 bps with a median estimate of 43 bps, roughly implying the elasticity of 4.3 bps per 100 billion EUR of purchases. However, model-based estimates in Rostagno et al. (2019), using the term-structure model of Eser et al. (2019), suggest slightly higher effects on the yield curve, reaching a peak of around 100 bps in 2016. Considering the original announcement worth 1140 billion EUR and subsequent extensions in December 2015 and March 2016, equal to 360 and 240 billion EUR, respectively, this implies the elasticity of 5.7 bps per 100 billion EUR. All in all, an asset purchase shock generating a 10 bps drop in 10-year sovereign bond yields is approximately equal to purchases of 200 billion EUR or 2% of nominal GDP. Thus, the estimated macroeconomic impact is markedly lower when the shock is identified via the HFI approach, with median peak impact over the sample

[7]Since our data sample ends in June 2020, we cannot fully estimate the macroeconomic effects of the PEPP, thus our results should be interpreted with caution about the PEPP effectiveness in the future.

reaching 0.025% and 0.04% for output and inflation, respectively, in response to a 5 bps drop in 10-year government bond yields. More conservative effects obtained using the HFI strategy can likely be explained by the idea of Wright (2019) that the OIS curve (from which we purge high frequency reactions to policy announcements) cannot fully capture the impact of central bank asset purchases since they primarily work by compressing the term premia of sovereign spreads. Still, and more

Figure 4: **Baseline results from the TVP-SVAR-SV and identification via the HFI approach**



Note: Figure shows cumulative impulse response functions to the asset purchase shock, identified via the fusion of HFI and sign restrictions approaches, which has been normalized to a 10 bps drop in the 10-year government bond yield.

importantly for ECB policymakers, both identification strategies indicate that reaction of inflation has considerably declined over time, contrary to the existing evidence in the literature. This could be a by-product of the Phillips curve flattening in the euro area, which is well documented in the literature (see e.g. Bobeica and Sokol (2019) and Eser et al. (2020)). Both papers argue that the disconnect between slack reduction and inflationary pressures became particularly apparent from late 2017 onwards, which coincides with our results. Thus, our findings could imply that the effectiveness of asset purchases to lift inflation has not decreased over time, especially since their ability to reduce slack has remained intact, but they simply reflect an economic environment with a weak pass-through of costs to prices, which in turn is driven by factors outside the control of the central bank. Therefore, in the next subsection we investigate the effects of asset purchases passed through different transmission channels over time to determine whether the effectiveness of quantitative easing has indeed diminished over time or the results simply reflect the recent Phillips curve flattening.

4.1 Transmission mechanism of asset purchases

In order to analyse the potential changes in the transmission mechanism of asset purchases in the euro area over time, we expand the baseline specification, consisting of five variables[8], with additional variables one by one.

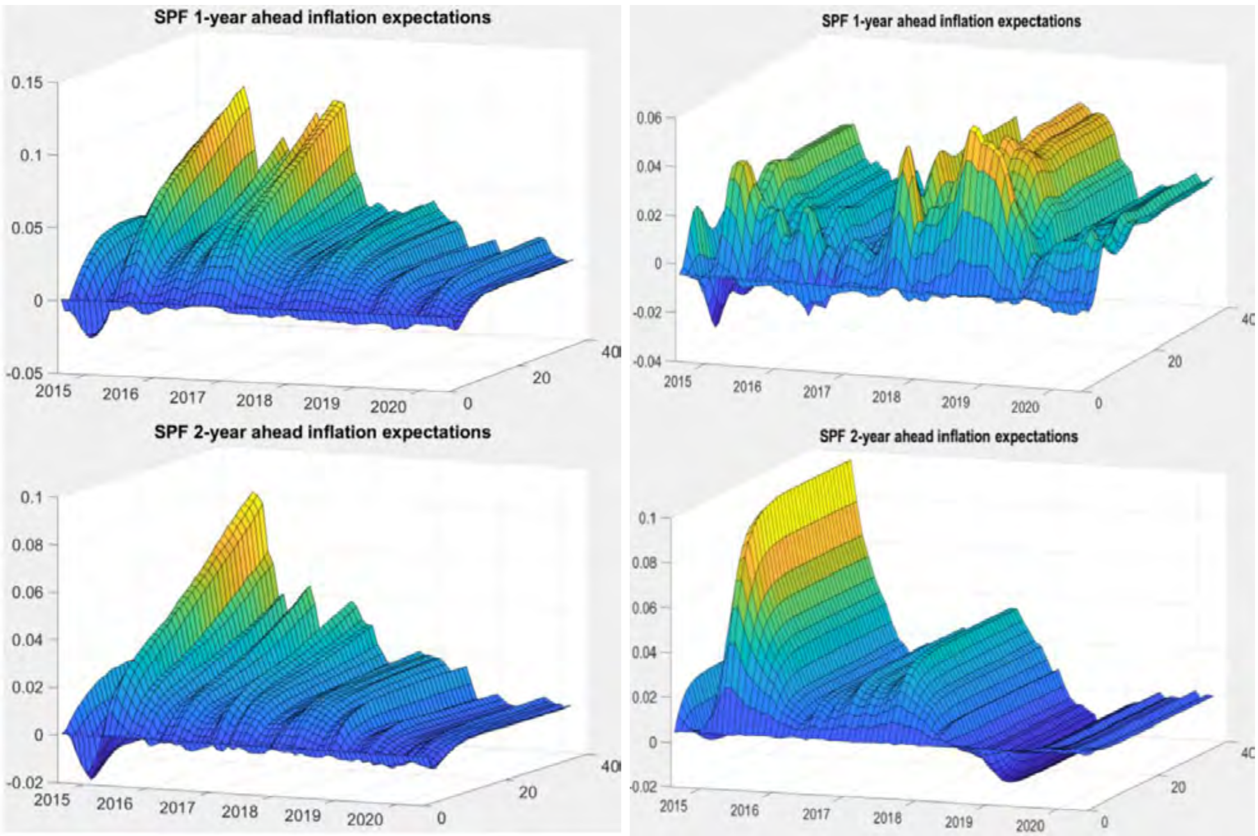
We start with the analysis of reanchoring channel, initially proposed by Andrade et al. (2016), suggesting that central bank asset purchases lift the perceived long-term inflation target since the agents observe the central bank policy action, which, by embarking on large-scale asset purchases, demonstrates that it is not content with low inflation. Consequently, asset purchases help to anchor inflation expectations, also raising the actual inflation towards the target. Simulations of Andrade et al. (2016) suggest that this channel has been particularly relevant in the propagation of the initial round of purchases under the APP to inflation, accounting for around one third of the overall impact. Our results in Figure 5 broadly confirm their findings, showing that purchases under the APP until 2017 were indeed successful at reanchoring the inflation expectations, but this effect has largely dissipated from 2019 onwards. With the reanchoring channel being no longer active, evidence points that the efficacy of asset purchases as a monetary policy instrument has indeed diminished recently as agents are no longer readjusting their inflation expectations in response to

[8] When using the HFI approach, we also include the shock series in the model, increasing the total variable count to six.

central bank policy actions, resulting in a weakened ability to ensure price stability.

Figure 5: **Reanchoring channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions



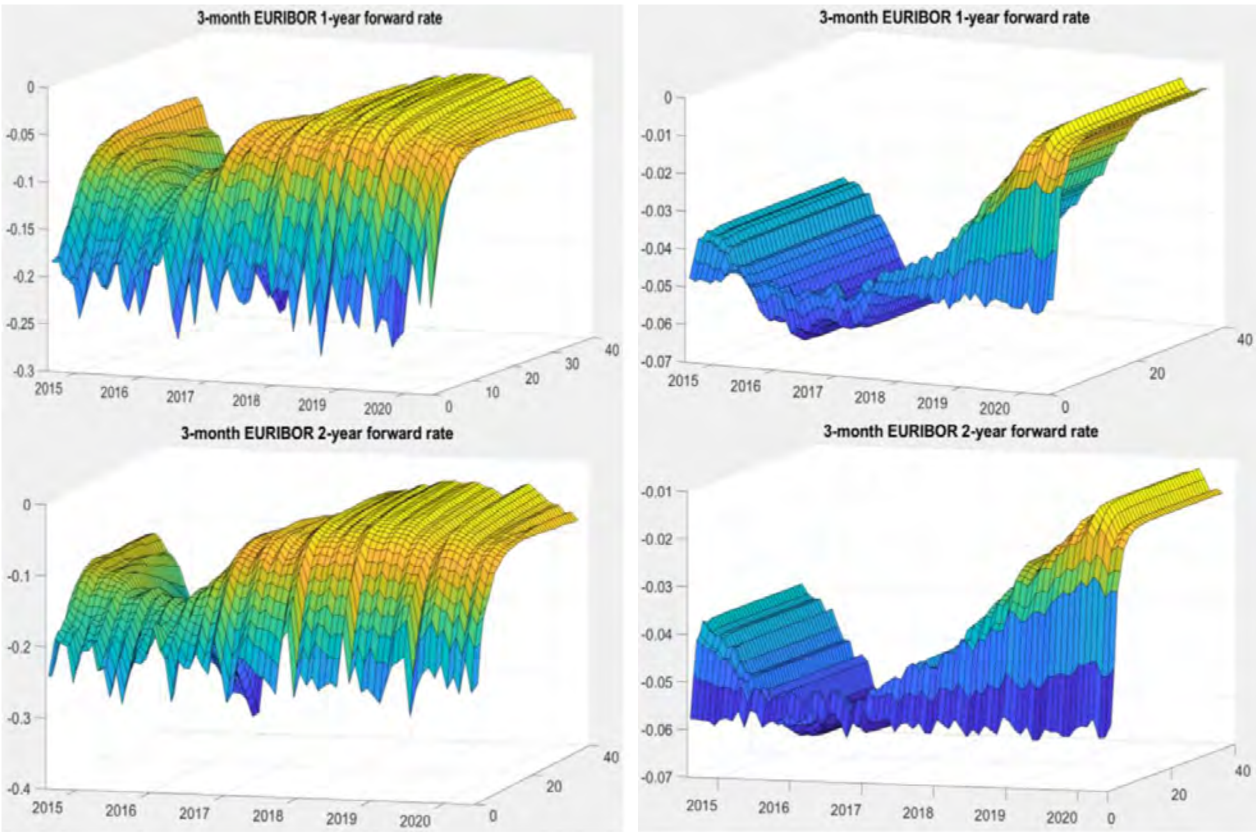
Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

The reanchoring channel is related to one of the key transmission channels of asset purchases – the signalling channel (Eggertsson and Woodford (2003), Bauer and Rudebusch (2014), Bhattarai et al. (2015)) as both convey information about the future path of nominal interest rates. As argued in Andrade et al. (2016), the reanchoring channel pushes down short- and medium-term interest rate expectations because, by embarking on a large-scale asset purchases, the central bank lifts the perceived inflation target, requiring lower policy rates. This, in turn, lifts long-term interest rate expectations as agents also anticipate higher long-term inflation. The signalling channel, on the other hand, is silent about the impact of QE on interest rate expectations in the long run; it primarily reinforces the central bank's commitment to keep policy rates at low levels, thereby lowering agents' interest rate expectations in short to medium run. Therefore, QE reinforces the overall policy stance and simultaneously complements the effectiveness of both a policy rate cut into negative territory

(Rostagno et al. (2019)) and enhances the credibility of forward guidance (Zlobins (2020b)). Our

Figure 6: **Signalling channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions



Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

findings in Figure 6 document that the signalling channel has remained broadly unimpaired since the launch of the APP in 2015, particularly when looking at impact effects, although the impulse responses of interest rate expectations appear to be less persistent towards the end of the sample, especially when the shock is identified via the HFI approach. Overall, it seems though that asset purchases are still able convey useful information about the future interest rate path to financial market participants and strengthen the overall policy stance, in line with the findings of Geiger and Schupp (2018).

However, Lemke and Werner (2020) argue that the ECB's asset purchases are primarily transmitted to the yield curve via the compression in the term premia component instead of lowering the expectations, thus suggesting that they primarily operate through the portfolio rebalancing effect with the signalling channel having only a limited role in the transmission of asset purchases in the euro area[9]. Arguably the most important transmission channel of QE – portfolio rebalancing (Vayanos and Vila (2009), Krishnamurthy and Vissing-Jorgensen (2011), D'Amico et al. (2012)) – is set in motion both through the direct impact of QE on bond markets ("local supply channel") and duration extraction, pushing down long-term interest rates as a result. Figure 7 shows that ECB's ability to compress both the sovereign and risk-free yield curve via the portfolio rebalancing channel of asset purchases has remained largely intact over time, but similarly to the signalling channel, the impulse responses appear to be slightly less persistent towards the end of the sample.

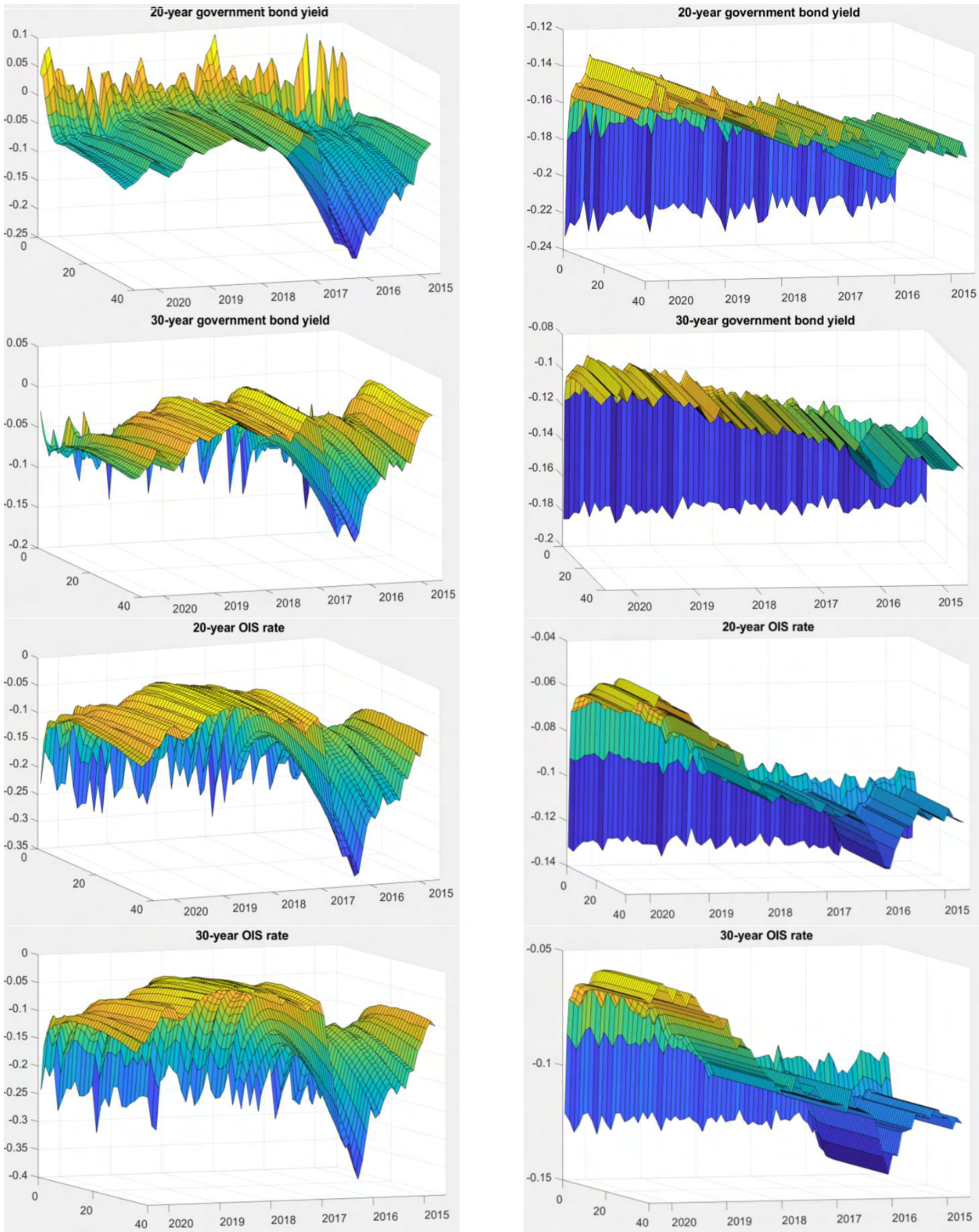
Another feature of the portfolio rebalancing mechanism is that it also relieves bank funding constraints as the central bank, by purchasing assets from financial intermediaries, provides them with funds, giving rise to the bank lending channel (Gertler and Karadi (2011), Karadi and Nakov (2021)). Thus, QE-induced compression of the term premia trickles down to borrowing costs of firms and households, resulting in a broad-based easing of financial conditions. Our evidence in Figure 8 indicates that central bank asset purchases in the euro area have indeed been an effective measure for alleviating balance-sheet constraints of banks and increasing the credit supply to firms and households. The ECB's asset purchases have also contributed to lower financing costs and the effects on all lending-related variables are rather stable over the sample.

However, cheaper financing does not necessarily lead to higher inflation as argued in the seminal papers on the cost channel of monetary policy (Barth III and Ramey (2002), Christiano et al. (2005), Ravenna and Walsh (2006)). The intuition behind the cost channel is straightforward – lower financing costs lead to a decrease in firms' marginal costs which can then be passed on to the consumer prices in order to gain a market share. This aspect is particularly relevant in the presence of a increasing competition in international markets, which has been highlighted as a major factor contributing to the Phillips curve flattening in the euro area in Eser et al. (2020). Additional explanation for the interaction between the Phillips curve flattening and borrowing costs is put forth in Boehl and Lieberknecht (2021) who argue that, at the ZLB, the costs of external financing can dominate firms' price setting, because the ZLB is binding in a situation when the output gap is significantly negative and the costs of other production factors are already compressed. To provide empirical evidence for the existence of cost channel in the transmission of asset purchases, we employ the producer price index as proxy of firms' costs. The results in Figure 9 indeed suggest that lower funding costs for firms, induced by the central bank asset purchases, have enabled them to lower

[9] A caveat of their study though is that they only consider transmission of the ECB's asset purchases to the German Bunds while Geiger and Schupp (2018) look at the euro area OIS curve.

Figure 7: **Portfolio rebalancing channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions



Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

their prices. Regarding the time profile, the cost channel was particularly active in 2015 and 2016, when the APP was initially launched, but the effects have tailed off slightly towards the end of the sample, largely mimicking the dynamics of lending rate to non-financial corporations in Figure 8. The existence of the cost channel in the euro area thus serves as one of the factors contributing to a more muted reaction of price pressures to the ECB's asset purchases and raises some questions on its recent focus on preserving "favourable financing conditions" (Lane (2021)) as predominant means to an end – ensuring the price stability. Moreover, Abbate et al. (2020) provide empirical evidence that expansionary financial shocks (i.e. which drive down credit spreads) in the US have deflationary effects, suggesting the dominance of aggregate supply channels (via the cost channel mechanism) over the demand-side induced price pressures in response to the drop in the cost of external finance. This has important implications for monetary policy since it affects funding costs and can therefore be considered as a specific type of financial shock. As a result, monetary policy actions aimed at lowering borrowing costs can be counterproductive in central banks' pursuit to lift inflation towards the target.

To see whether expansionary financial shocks entail disinflationary effects also in the euro area, we expand our baseline setup with corporate credit spread of Gilchrist and Mojon (2018) and identify financial shock via the combination of sign and zero restrictions shown in Table 3. In essence, the

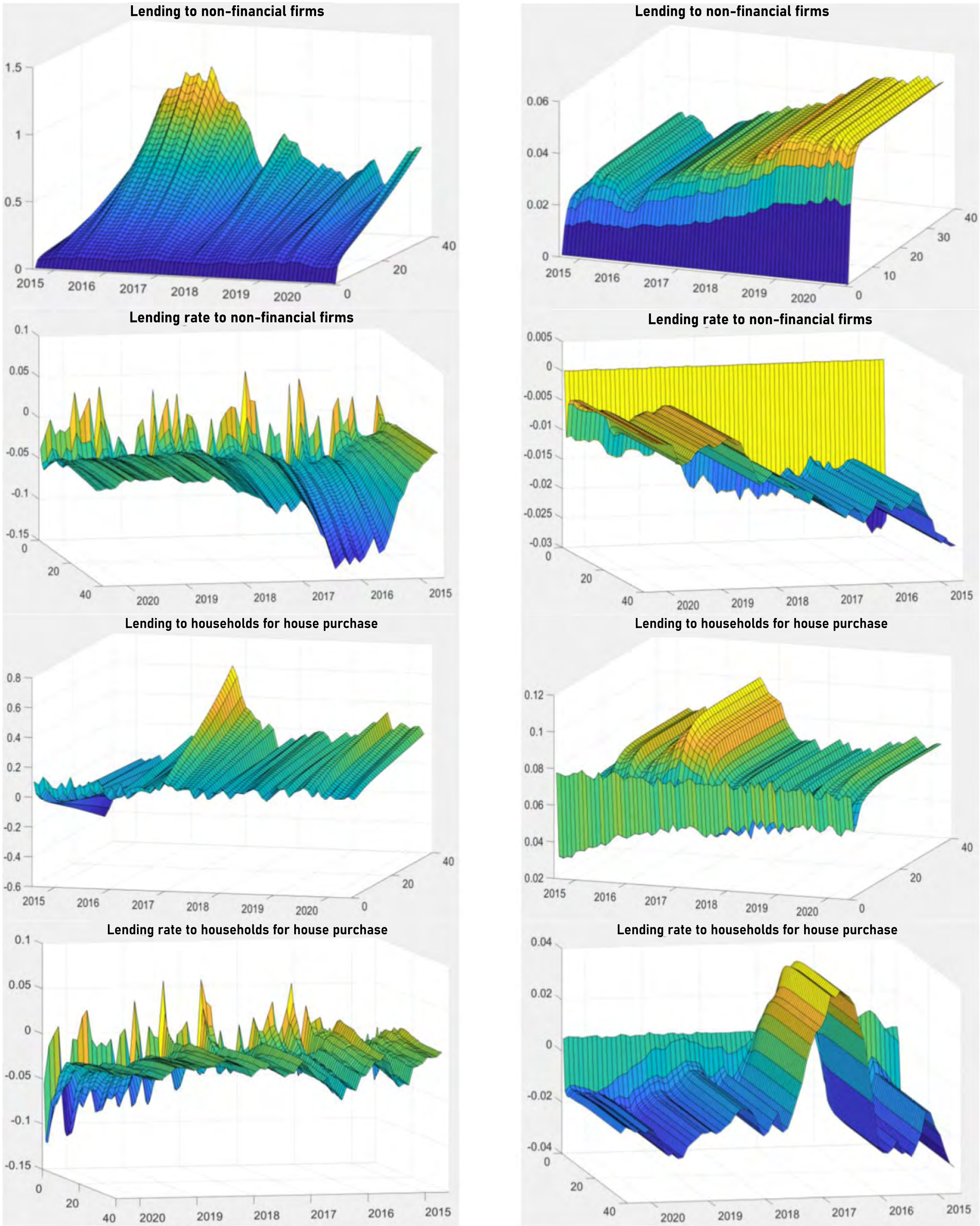
Table 3: **Identification of financial shock**

Shock	Real GDP	HICP inflation	EONIA	EUR/USD	Securities held by the Eurosystem/GDP	Corporate credit spread
Monetary policy	+	+	-	-	0	
Asset purchase	0	0	0	-	+	
Financial	+		0	-	0	-

financial shock is identified in a similar fashion to Abbate et al. (2020), assuming that it squeezes the corporate credit spread and raises output, leaving the response of inflation unrestricted to remain agnostic about the potential impact of financial shocks on price dynamics as theory stemming from the DSGE models is ambiguous about their impact on inflation. The restriction on the exchange rate to depreciate following an expansionary financial shock is motivated by the evidence from Fratzscher (2009), Gourinchas et al. (2012) and Metiu et al. (2016) suggesting that the US dollar appreciates during a credit crunch due to the flight-to-safety mechanism. Given that the euro is the second largest reserve currency (ECB (ECB)), it is very likely that this mechanism also applies to the euro area with respect to financial shocks. Finally, we impose zero restrictions on monetary

Figure 8: **Bank lending channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions

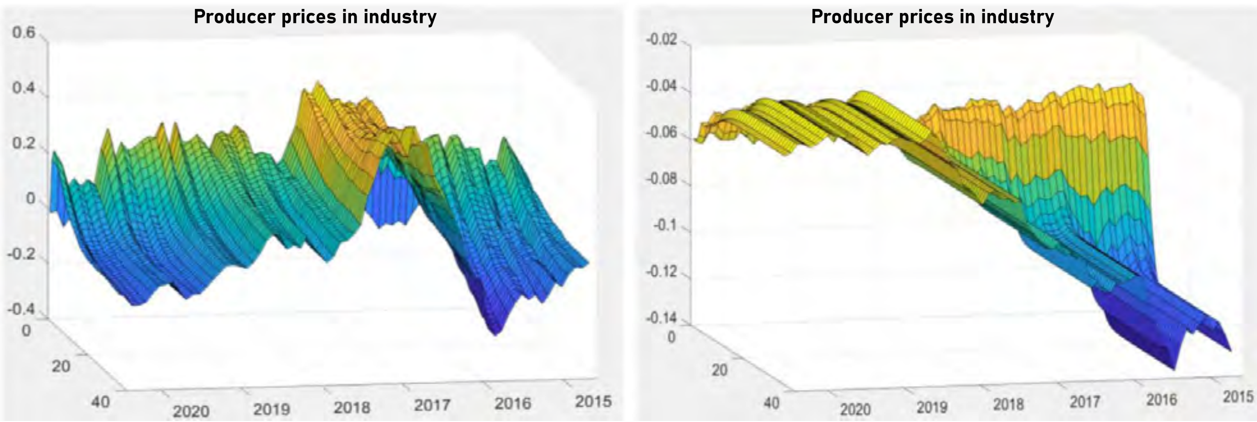


Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

policy variables to obtain orthogonality with the respective shocks and, like in the baseline sign and zero restrictions setup, all restrictions are imposed to hold on impact only. The outcome of

Figure 9: **Cost channel**

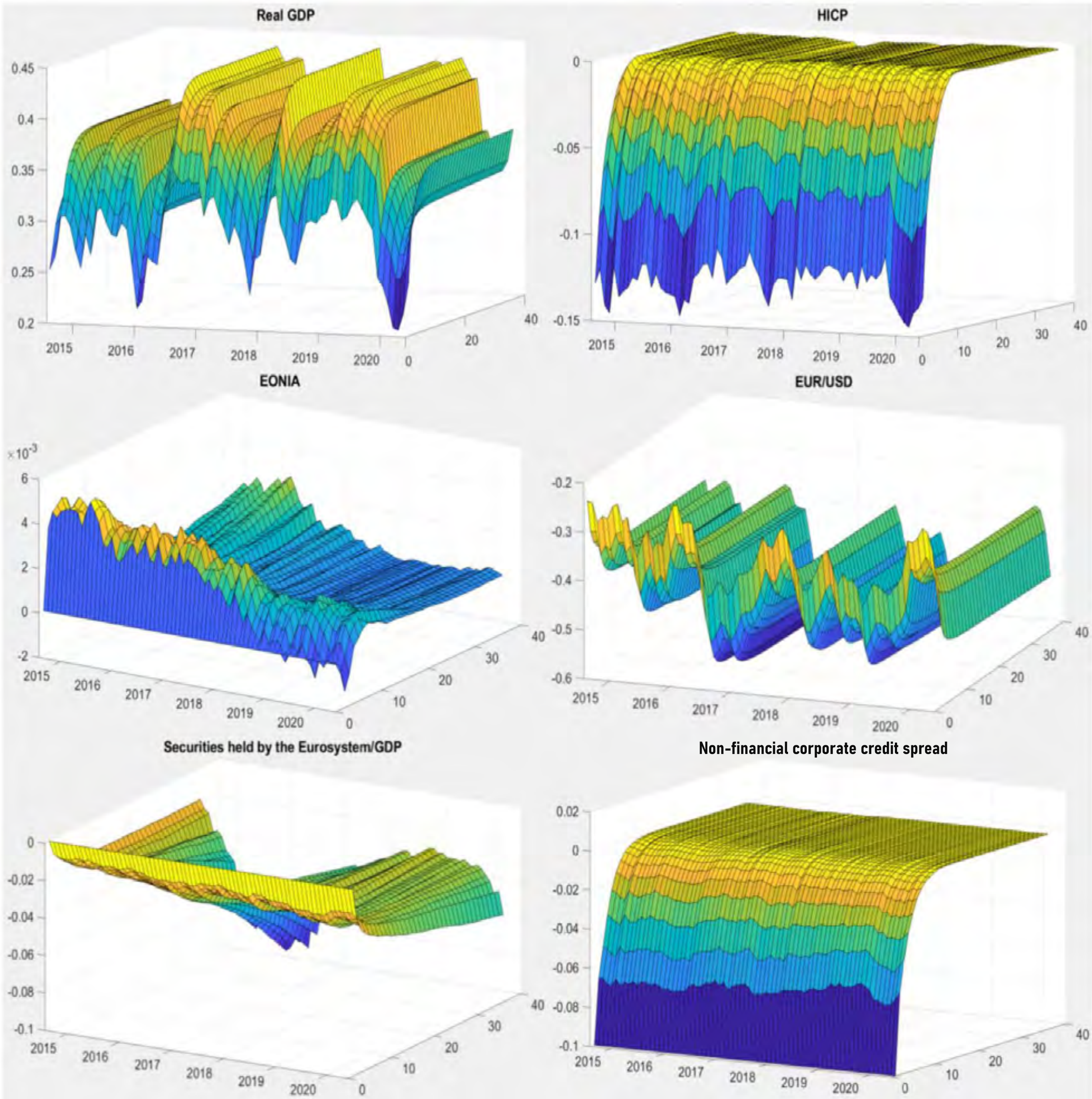
(a) Sign and zero restrictions (b) HFI + Sign restrictions



Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

this exercise in Figure 10 shows that positive financial shocks generate temporary, albeit significant downward effects on inflation in the euro area, akin to evidence of Abbate et al. (2020) from the US. Complementary to the cost channel, Boehl et al. (2020) have identified an additional mechanism through which large-scale asset purchases can have counterproductive effects on inflation due to the dominance of aggregate supply side effects. Their evidence from the US suggest that QE-induced loosening of financial conditions has predominantly boosted firm investment with little (or even negative) impact on household consumption, leading to an increase in the productive capacity of the economy and lowering aggregate price pressures. Figure 11 documents that this mechanism, which we dub the capacity utilization channel, has recently emerged also in the euro area economy, as the response of investment has remained consistent over time while the reaction of consumption has substantially declined circa 2018 (in case when the shock is identified via sign and zero restrictions) or remained negative throughout the sample (in case when the high frequency identification approach is used). Considering that the response of output has remained broadly stable over time (see Figures 3 and 4), the gradually declining reaction of capacity utilization indeed suggests that the strong response of firm investment to the ECB's asset purchases has contributed to the increase in the productive capacity of the economy, thus lowering inflationary pressures. An important question, though, remains open – why did firms invest in light of limited consumer

Figure 10: **Effects of financial shock**

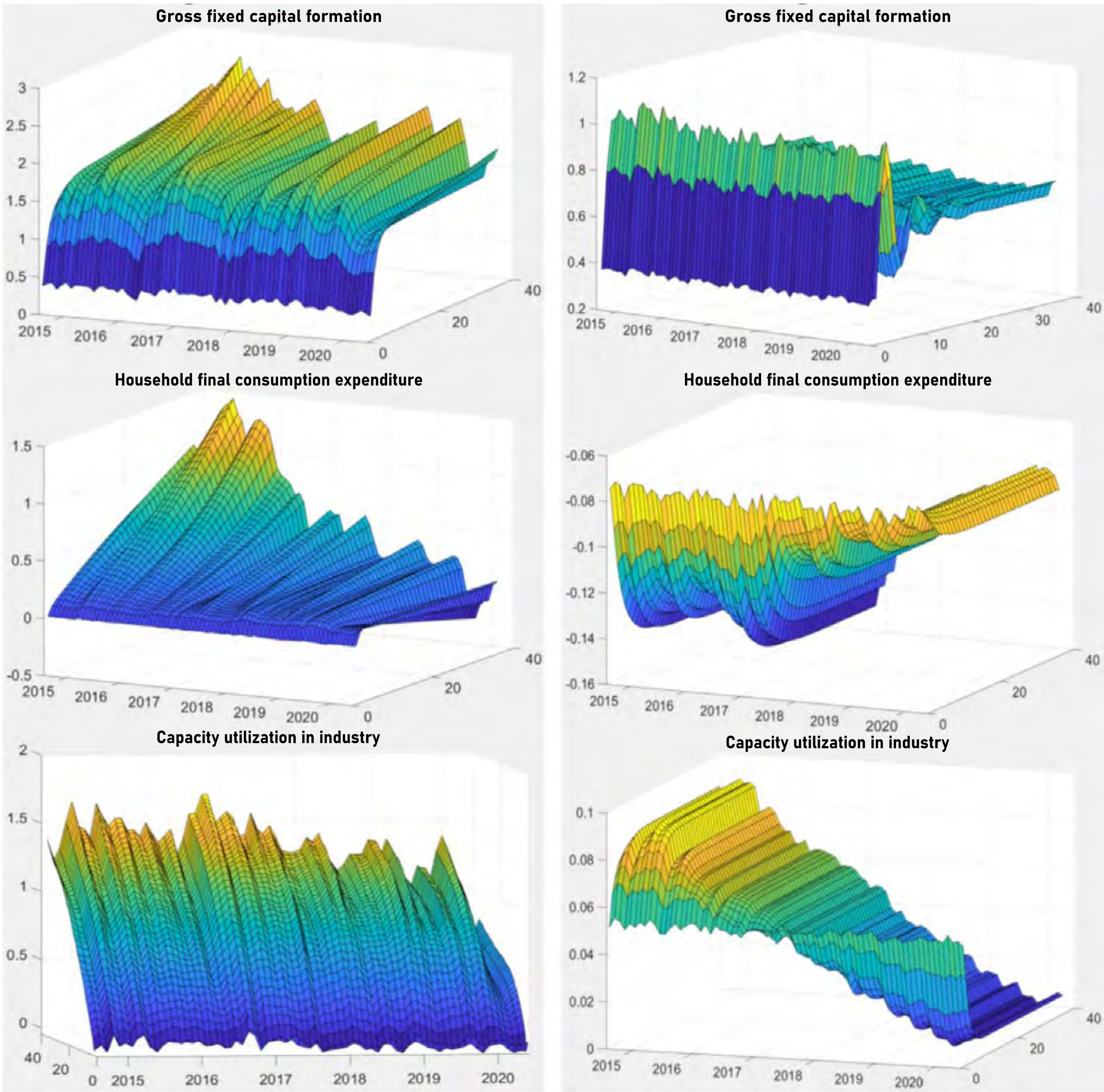


Note: Figure shows impulse response functions (cumulative for real GDP and EUR/USD) to the financial shock identified via a mixture of sign and zero restrictions. The shock has been normalized to a 10 bps drop in the euro area non-financial corporate credit spread against the German Bund (Gilchrist and Mojon (2018)).

demand? We argue that low funding costs in the QE era have created an incentive for firms to shift away from labour towards capital to reduce the wage bill, dampening private consumption and, consequently, inflationary effects. For example, Cantore et al. (2020) provide robust evidence that a standard monetary policy loosening decreases the labour income share. Given that the inverse of the labour share is often used to proxy the economy-wide markup developments (Nekarda and Ramey (2020)), the replacement of labour with capital allows firms to increase their profits.

Figure 11: **Capacity utilization channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions

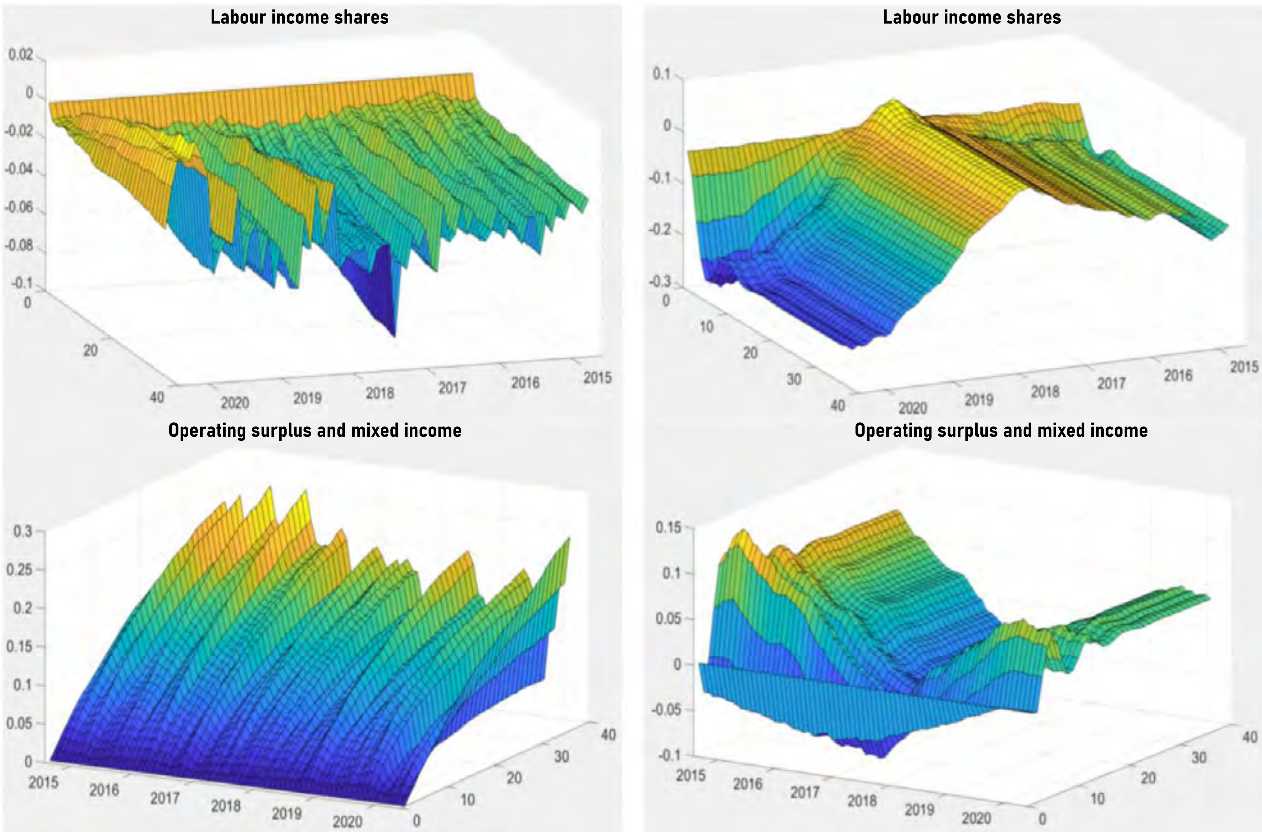


Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

Our results in Figure 12 confirm that the findings of Cantore et al. (2020) hold also for non-standard monetary policy actions, providing rationale of aggregate investment dynamics in response to the ECB's asset purchases. These findings are well in line with the observed low wage growth in the euro area, see Nickel et al. (2019), who, *inter alia*, name technology shocks as one of the driving forces behind subdued wage developments. However, while our study documents the experience with central bank asset purchases in the euro area over a relatively long sample, the long-term effects on the aggregate supply are likely yet to fully materialize.

Figure 12: **Labour income share channel**

(a) Sign and zero restrictions (b) HFI + Sign restrictions



Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

5 Robustness

Despite using alternative identification strategies in our baseline setup, we undertake a number of additional robustness checks to ensure the stability of results, including a novel approach to identify the macroeconomic effects of central bank asset purchases by merging HFI with narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018).

We start by inspecting the specification of stochastic volatility, since in our baseline setup we set the value of autoregressive parameter γ equal to 0.8, so that the shifts in volatility do not become permanent and follow random walk. For robustness, we adopt the random walk assumption of Cogley and Sargent (2005) and set it to 1. The results in Figure 13 demonstrate that the choice of

γ value has negligible impact on the estimated impulse responses as they are virtually identical to the baseline results in Figure 3 and 4, for either of identification approaches. This, however, is not surprising as also the seminal paper of Primiceri (2005) reaches a similar conclusion.

Next, we continue by performing a battery of checks to each of our identification approaches. First, we turn our attention to the sign and zero restriction approach, in particular, we make sure the response of inflation to the asset purchase shock over the sample is not driven by the oil price cycle since we use a small-scale VAR model, making it vulnerable to the omitted variable bias.

We control for the impact of oil price on our estimates by (I) using core HICP inflation instead of headline inflation as it by definition excludes the impact of energy and food prices, at least the first order effects, (II) including oil prices as exogenous variable and (III) by adding the oil price to the set of endogenous variables and identifying the oil supply shock using a similar set of restrictions to Corsetti et al. (2014) and Bobeica and Jarociński (2019), see Appendix A2. Figure 14 confirms that our time-varying estimates of the ECB's QE on inflation, emanating from a model variant with identification via mixture of sign and zero restrictions, are not driven by the observed oil price cycle over the estimation period as the impulse responses tell a largely similar story to our baseline results, i.e. that the potency of asset purchases to lift inflation has significantly declined in recent years.

Second, we focus on the robustness of our HFI setup to ensure the results obtained with this approach are not driven by misspecification in the procedure. Specifically, a potential issue with this approach is that originally we only identify a single monetary policy shock, based on the assumption that each of the three instruments employed by the ECB – asset purchases, forward guidance and negative policy rates – target different regions of the yield curve, although Altavilla et al. (2019) provides empirical backing to this assumption. To make sure that our estimates of asset purchase effectiveness, obtained via the HFI approach, are not influenced by contamination of effects stemming from other monetary policy instruments used alongside large-scale asset purchases, we (I) drop our instrument for asset purchases and replace it with the QE factor of Altavilla et al. (2019) who effectively replicate the approach of Swanson (2021) to disentangle the asset purchase surprises from other monetary policy tools. (II) we expand the literature on HFI of monetary policy shocks by simultaneously controlling for the presence of multiple monetary policy shocks in high frequency surprises via narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018).

Figure 15 suggests that our baseline HFI setup indeed recovers the structural QE disturbance as the use of the Altavilla et al. (2019) QE factor yields very similar impulse responses, both quantitatively and qualitatively. However, to further sharpen our HFI setup, we develop a novel approach which allows us to control for the presence of multiple monetary policy shocks in policy announcements. This task, though, is not trivial as, e.g. the application of Jarociński and Karadi (2020)-style approach, to tell them apart via sign restrictions alone, is clearly not fit for purpose since pure monetary policy shocks of Odyssean nature, induced by different monetary policy tools,

Figure 13: **Setting persistence parameter γ=1**

(a) Sign and zero restrictions (b) HFI + Sign restrictions

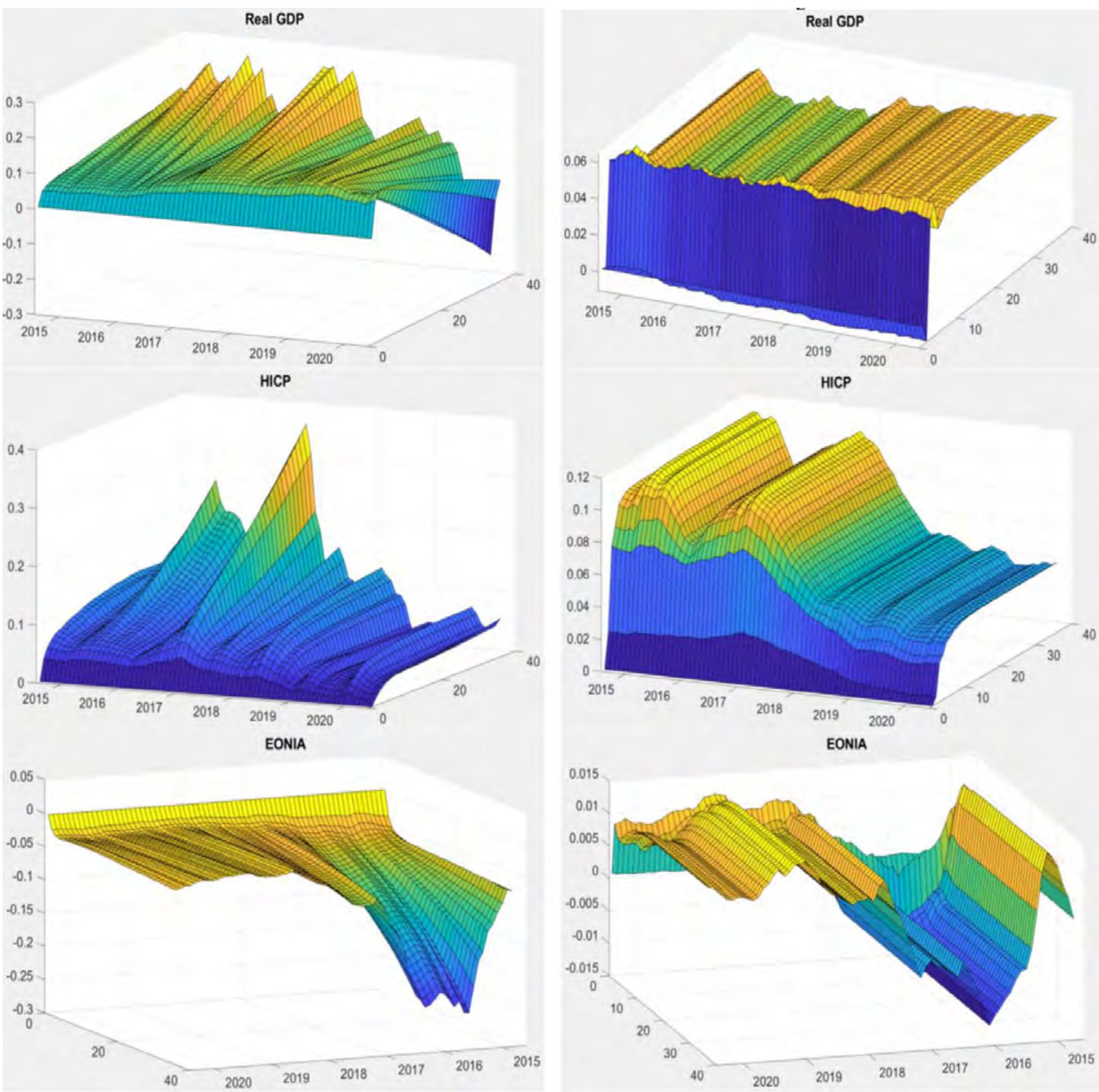
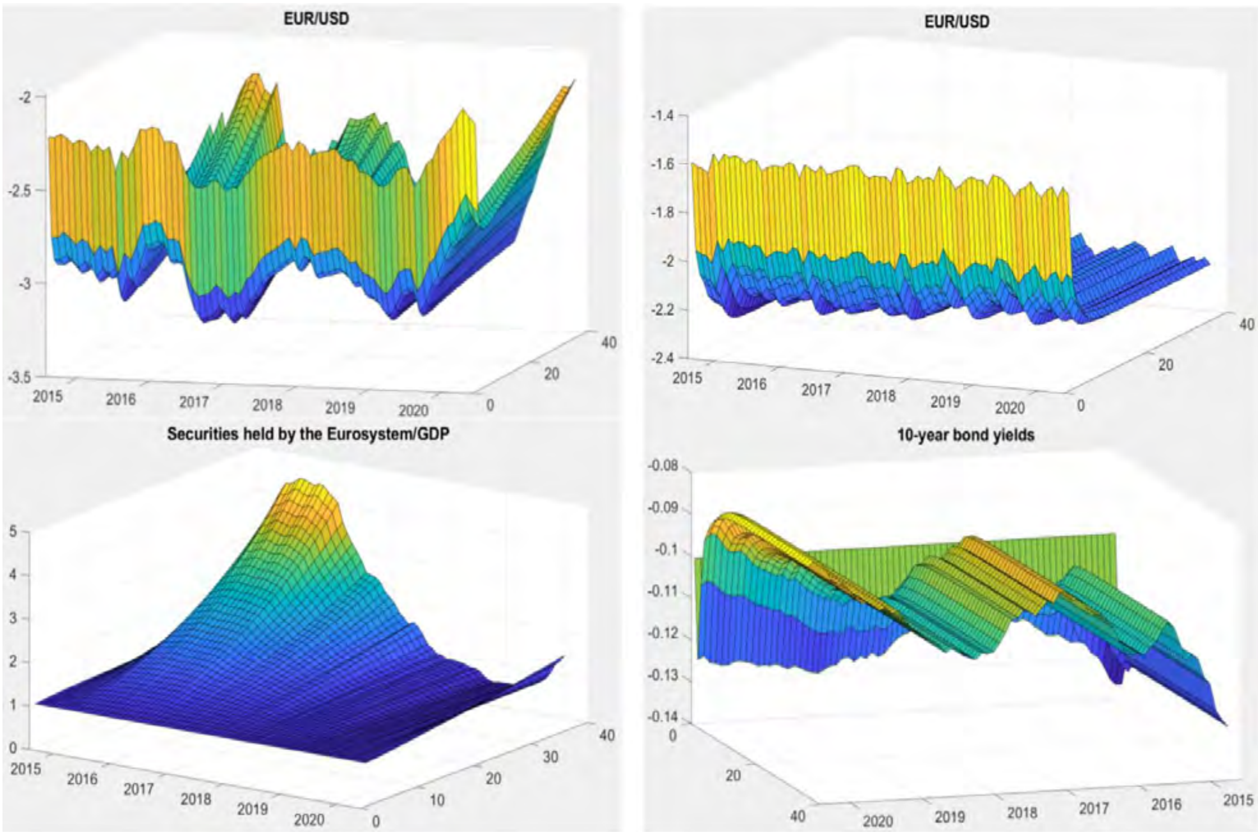


Figure 13: **Setting persistence parameter γ=1 (cont.)**

(c) Sign and zero restrictions

(d) HFI + Sign restrictions



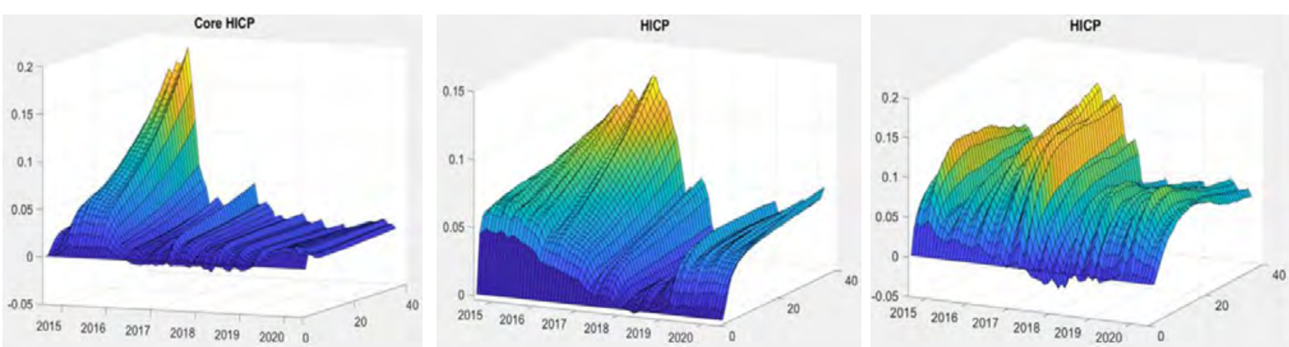
Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

Figure 14: **Controlling for the impact of oil price**

(a) Core inflation

(b) Oil prices as exogenous variable

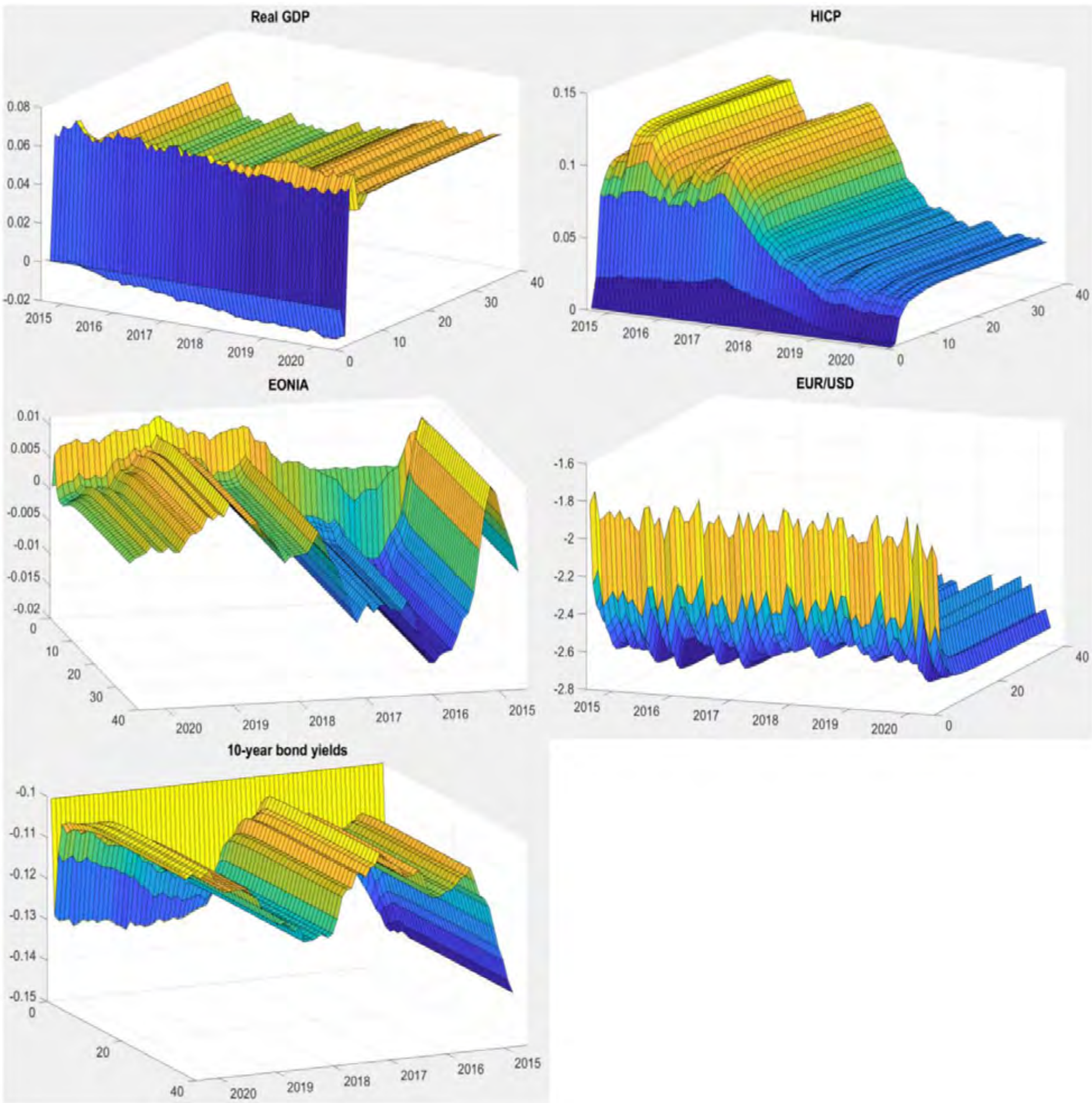
(c) Oil prices as endogeonous variable



Note: Figure shows impulse response functions to the asset purchase shock, identified via a mixture of sign and zero restrictions, which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP.

move surprises in the same direction. Also, mechanical orthogonalisation via zero restrictions is unrealistic because the ECB has often announced and/or recalibrated several instruments in its

Figure 15: **Using the QE factor of Altavilla et al. (2019) as the relevant policy instrument**



Note: Figure shows cumulative impulse response functions to the asset purchase shock, identified using the QE factor of Altavilla et al. (2019), which has been normalized to a 10 bps drop in 10-year government bond yield.

toolkit in the same meeting of the Governing Council. Therefore, to overcome this challenge, we merge the HFI approach with narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018) which, in addition to traditional sign restrictions on the impulse response functions and structural parameters, allow for placing restrictions on the structural disturbances and historical decompositions, sharpening the inference. In essence, this approach is similar to the method of Jarociński and Karadi (2020), used in our baseline HFI setup, but it differs in a sense that pure sign restrictions are augmented with narrative information about the shocks, allowing us to tell apart the effects of different monetary policy measures.

In the first step, we include high frequency surprises into the VAR model, as in our baseline HFI approach described in section 2.2[10], and further expand it with short- and medium-term OIS surprises. The addition of these variables then permits us to identify two extra monetary policy shocks – a policy rate and forward guidance, respectively. The sign restrictions depicted in Table 4

Table 4: **Sign restrictions used in case when HFI is merged with the narrative sign restrictions approach**

Shock	3-month OIS	1-year OIS	10-year OIS	Euro Stoxx 50
Policy rate	-			+
Forward guidance		-		+
Asset purchase			-	+
Central bank information			-	-

are then supplemented with additional restrictions on both the sign of the shock and the historical decomposition of the surprise, reflecting narrative information to tell apart the effects of different monetary policy measures employed by the ECB in recent years:

Narrative Sign Restriction I. *An expansionary FG shock took place in July 2013.*

Narrative Sign Restriction II. *For July 2013, the FG shock is the overwhelming driver of the unexpected movement in 1-year OIS.*

Narrative Sign Restriction III. *An expansionary policy rate shock took place in June 2014.*

Narrative Sign Restriction IV. *For June 2014, the policy rate shock is the overwhelming driver of the unexpected movement in 3-month OIS.*

Narrative Sign Restriction V. *An expansionary QE shock took place in January 2015.*

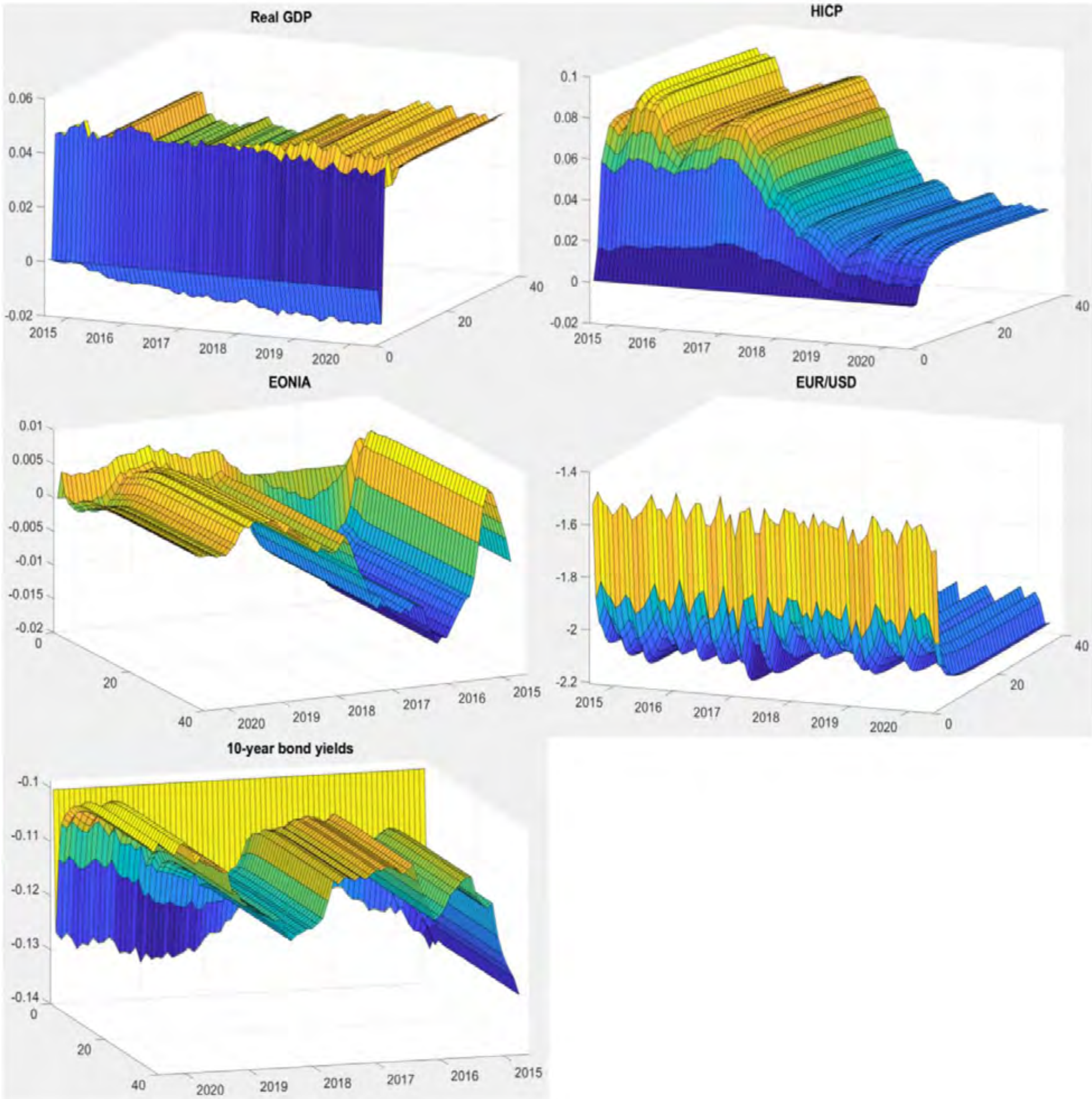
Narrative Sign Restriction VI. *For January 2015, the QE shock is the overwhelming driver of the unexpected movement in 10-year OIS.*

To sum up, for each of the three monetary policy shocks we identify, we restrict both the sign of the structural disturbance in a month when it was first announced[11] as well as the historical decomposition of the corresponding maturity OIS surprise on which the respective instrument primarily loads.

[10]The VAR model in both cases is specified identically.

[11]For the FG and QE shocks the choice of dates is straightforward as the selected Governing Council meetings are the ones in which the respective instruments were first officially announced. For a policy rate shock, our choice of the specific date is motivated by the fact that in this meeting the ECB first cut the policy rate into negative territory. Another advantage of the selected dates is that no other monetary policy actions were taken in these meetings, aiding the identification of instrument-specific effects on OIS surprises.

Figure 16: **Results derived via a mixture of HFI and narrative sign restrictions**



Note: Figure shows cumulative impulse response functions to the asset purchase shock, identified via the fusion of HFI and narrative sign restrictions approaches, which has been normalized to a 10 bps drop in 10-year government bond yield.

The figure in Appendix A7 illustrates the obtained QE shock series and confirms that the introduction of narrative information into the identification procedure indeed helps to narrow down the QE shock, at least when benchmarked against the QE factor of Altavilla et al. (2019) as the correlation coefficient between both series is $\rho = 0.91$ (using our baseline HFI procedure it was $\rho = 0.76$). Nonetheless, impulse response functions, obtained via a mixture of HFI and narrative sign restrictions, in Figure 16 are very similar to the ones derived using our baseline HFI setup as both the estimated impact of asset purchases and the time profile of responses remain largely unchanged to benchmark results in Figure 4. However, we also note that, despite the introduction of narrative information into the identification procedure, the obtained QE shock series fails to register the PEPP announcement in March 2020, as opposed to the factor rotation approach employed by Altavilla et al. (2019). Thus, we introduce two additional narrative restrictions to better capture the PEPP announcement and ensure the robustness of our findings:

Narrative Sign Restriction VII. *An expansionary QE shock took place in March 2020.*

Narrative Sign Restriction VIII. *For March 2020, the QE shock is the overwhelming driver of the unexpected movement in 10-year OIS.*

Appendix A7 shows that these restrictions further sharpen the identification of the QE shock, generating virtually identical shock series to Altavilla et al. (2019) as the correlation coefficient between both series is $\rho = 0.97$. Despite explicitly accounting for the announcement of the PEPP, the impulse responses in Appendix A8 are broadly in line with the previous results, confirming that our identification strategy effectively recovers the structural QE shock and diminishing returns of this policy measure in the euro area, at least regarding its ability to generate inflationary pressures.

The robustness checks performed in this section complement the findings from our baseline empirical setup. Namely, we show that our time-varying estimates of the ECB's asset purchases are robust with respect to the specification of stochastic volatility, after controlling for the impact of the oil price cycle and using alternative instruments for the impact of central bank asset purchases in the euro area, derived from high frequency reactions of financial variables to ECB policy announcements. Regarding the latter, we develop a novel approach in the literature to control for the presence of multiple monetary policy shocks in high frequency surprises to monetary policy announcements by merging HFI with narrative sign restrictions.

6 Conclusions

This paper documents a comprehensive empirical investigation of the effectiveness of large-scale asset purchases in the euro area over the relevant sample period, in which the ECB has actively deployed this measure to counteract deflationary pressures. It investigates the effectiveness of the ECB's asset purchases over time using a time-varying parameter structural vector autoregression with stochastic volatility and performing identification via a battery of approaches, including sign and zero restrictions of Arias et al. (2018), their fusion with the HFI approach akin to Jarociński and Karadi (2020) and a novel method which merges HFI with narrative sign restrictions of Antolin-Diaz and Rubio-Ramirez (2018).

Our evidence shows that the ability of the ECB's asset purchases to increase economic activity has remained strong as the response of output to the asset purchase shock has been broadly stable over time, but more importantly for the ECB, their potency to lift inflation has significantly deteriorated in recent years despite the restart of purchases under the APP in September 2019 and the launch of the PEPP in March 2020. Our analysis reveals that the observed decline in the response of inflation to large-scale asset purchases cannot be completely attributed to the recent Phillips curve flattening as we find that specific transmission channels of central bank asset purchases are no longer active in the euro area. In addition, some disinflationary (side)effects have emerged from channels which have hitherto received little attention in the empirical literature on the ECB's asset purchases. In particular, the time-varying impulse responses show that their ability to influence inflation expectations has significantly weakened from 2019 onwards, leading to the dissipation of the reanchoring channel, which was particularly relevant in the transmission of purchases made under the "first round" of the APP. Furthermore, two major transmission channels of as set purchases – portfolio rebalancing and signalling – have remained broadly intact over the sample, leading to a significant compression in funding costs which, in turn, have given rise to counterproductive effects via the cost channel mechanism as firms have used lower interest rates to cut their costs. Additional evidence, pointing to the dominance of aggregate supply effects, shows that asset purchases in the euro area have predominantly boosted investment while the effects on private consumption have been limited, especially in recent years, thus increasing the productive capacity of the economy and lowering prices pressures via the capacity utilization channel. We argue that the strong response of investment has been driven by QE-induced compression of borrowing costs, creating an incentive for firms to shift away from labour towards capital to reduce the wage bill, dampening private consumption and, consequently, generating counterproductive effects on inflation.

To sum up, this paper contributes to the empirical literature on macroeconomic effects of the ECB's large-scale asset purchases by exploring their non-linear effects over time. Our evidence cautions against systematic use of this policy tool to stabilize inflation and inflation expectations in the euro area as its effectiveness has significantly deteriorated over time.

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Appendix

Table A1: **Dataset description and transformations**

Block	Variable	Description	Data source
Baseline models	Real GDP	Real GDP index. 2015=100. Monthly series are obtained by performing the Litterman temporal disaggregation procedure using the industrial production index as indicator series.	Author's calculations based on the Eurostat data
	HICP	All-items HICP. 2015=100.	ECB
	EONIA	Money market interest rate.	Eurostat
	EUR/USD	Monthly average value of the euro per US dollar.	Eurostat
	Securities held by the Eurosystem	Securities of euro area residents denominated in euro held by the Eurosystem scaled by 2015 nominal GDP.	Author's calculations based on the ECB and Eurostat data
	10-year bond yields	10-year government benchmark bond yield.	ECB
Transmission mechanism	Reanchoring channel	Survey of Professional Forecasters 1- and 2-year ahead inflation expectations.	ECB
	Signalling channel	3-month EURIBOR 1- and 2-year forward rate.	Bloomberg
	Portfolio rebalancing channel	20- and 30-year government benchmark bond yield and the OIS rate.	Bloomberg
	Bank lending channel	Annualised agreed rate/narrowly defined effective rate for loans to non-financial corporations.	ECB
		Annualised agreed rate/narrowly defined effective rate for loans to households for house purchase.	ECB
		Loans to non-financial corporations. Outstanding amounts at the end of the period (stocks), total maturity.	ECB
		Loans to households and NPISHs. Outstanding amounts at the end of the period (stocks), total maturity.	ECB
	Cost channel	Producer prices in industry (NACE B-D).	Eurostat
	Financial shock	Spread of non-financial corporations with respect to the German Bund.	Gilchrist and Mojon (2018)
	Capacity utilization channel	Real gross fixed capital formation. 2015=100. Monthly series are obtained by performing Litterman temporal disaggregation procedure using monthly real GDP index as indicator series.	Author's calculations based on the Eurostat data
		Real household and NPISH final consumption expenditure. 2015=100. Monthly series are obtained by performing the Litterman temporal disaggregation procedure using monthly real GDP index as indicator series.	Author's calculations based on the Eurostat data
		Current level of capacity utilization (%). Monthly series are obtained by performing the Litterman temporal disaggregation procedure.	Author's calculations based on the DG ECFIN data
	Labour income share channel	Labour income share is calculated as a share of compensation of employees in nominal gross value added. Monthly series are obtained by performing the Litterman temporal disaggregation procedure using monthly real GDP index as indicator series.	Author's calculations based on the Eurostat data
		Profit share is calculated as a share of gross operating surplus and mixed income in nominal gross value added. Monthly series are obtained by performing the Litterman temporal disaggregation procedure using monthly real GDP index as indicator series.	Author's calculations based on the Eurostat data
Robustness checks	Core HICP	All items excluding energy and food HICP. 2015=100.	ECB
	Oil price	Brent Spot Price FOB (US dollars per barrel).	US Energy Information Administration

Table A2: **Identification of oil supply shock**

Shock	Real GDP	HICP inflation	EONIA	EUR/USD	Securities held by the Eurosystem/GDP	Oil prices
Monetary policy	+	+	-	-	0	
Asset purchase	0	0	0	-	+	
Oil supply	+	-	0	-	0	-

Figure A3: **Exclusion of COVID-19 related dummies**

(a) Sign and zero restrictions (b) HFI + Sign restrictions

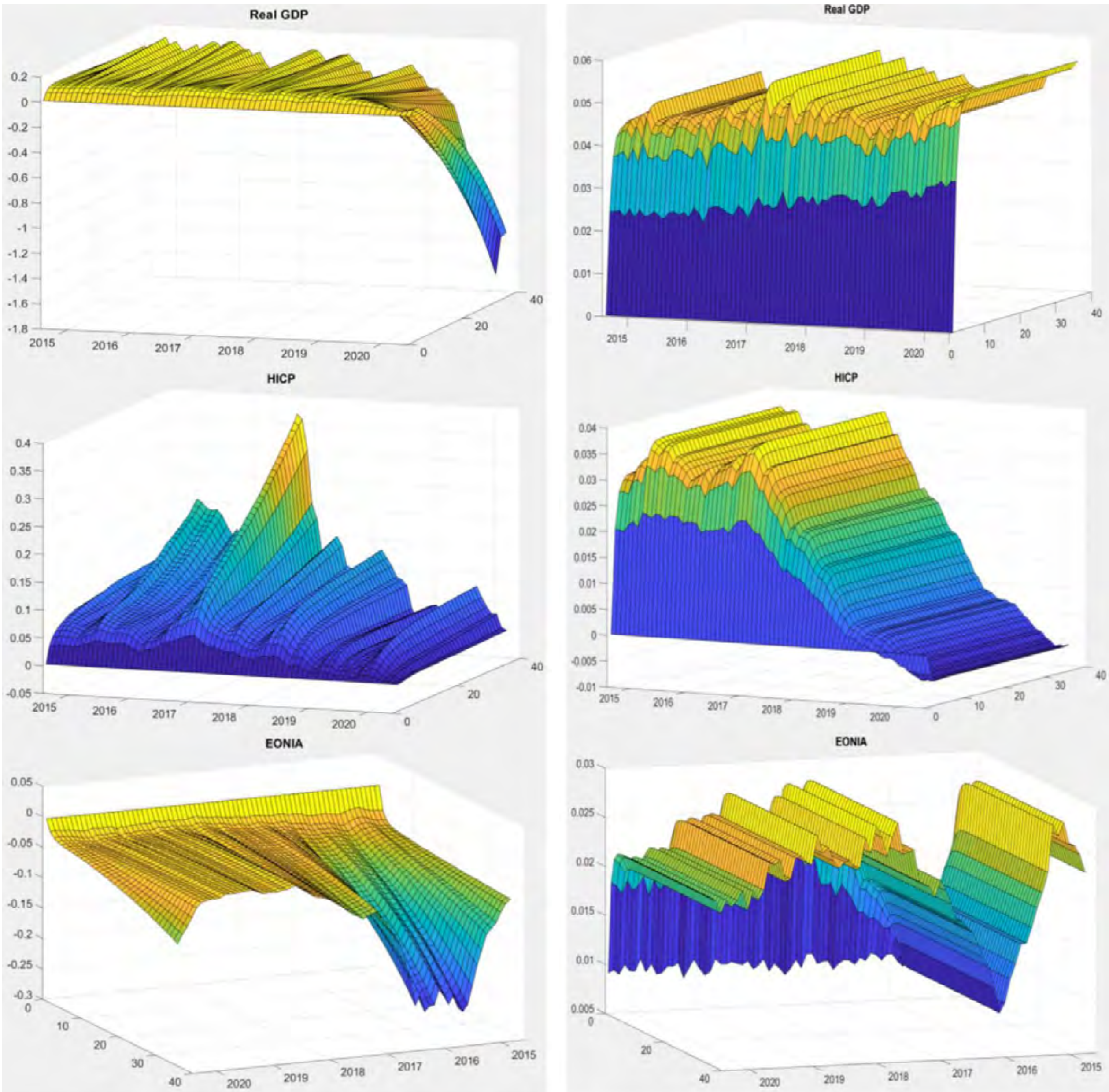
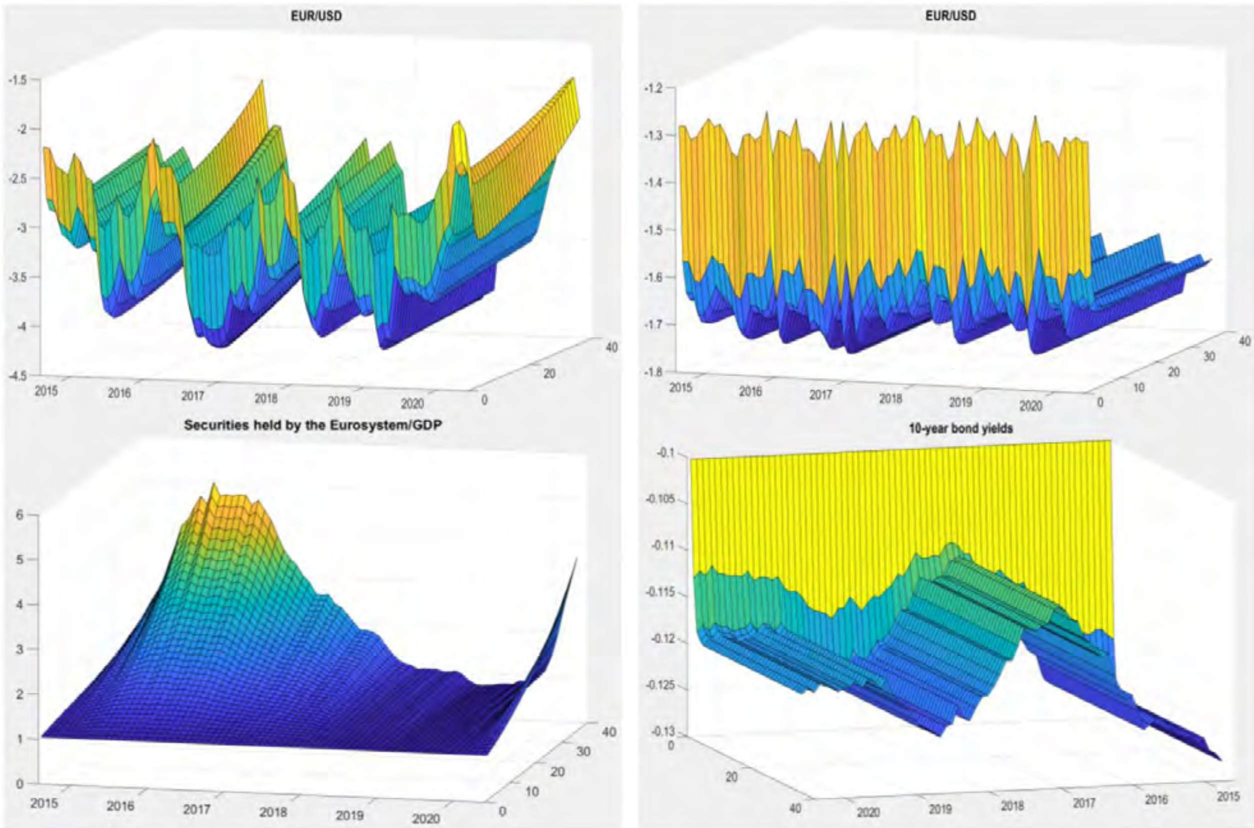


Figure A3: **Exclusion of COVID-19 related dummies (cont.)**

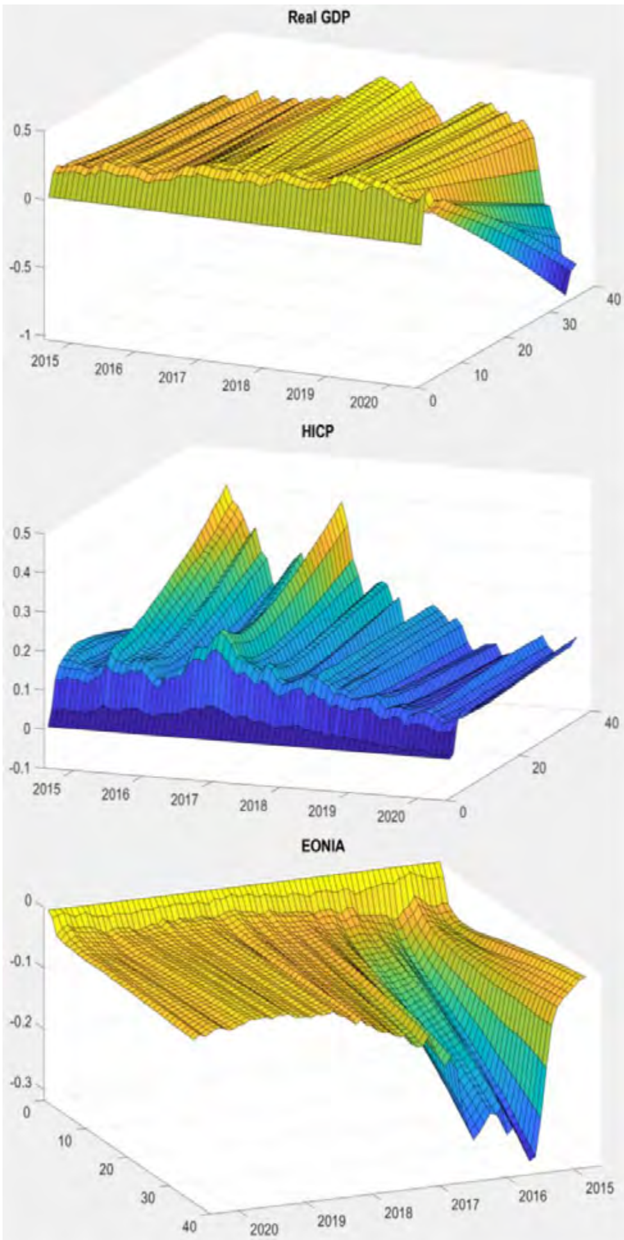
(c) Sign and zero restrictions (d) HFI + Sign restrictions



Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

Figure A4: **Setting lag order to 2**

(a) Sign and zero restrictions



(b) HFI + Sign restrictions

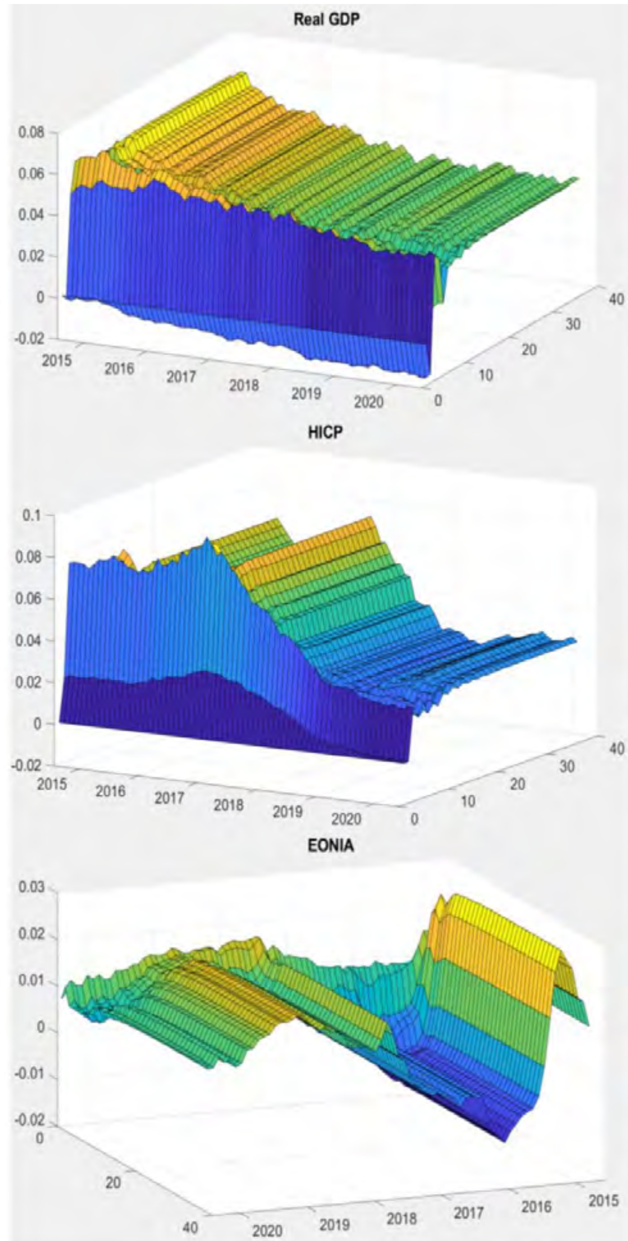
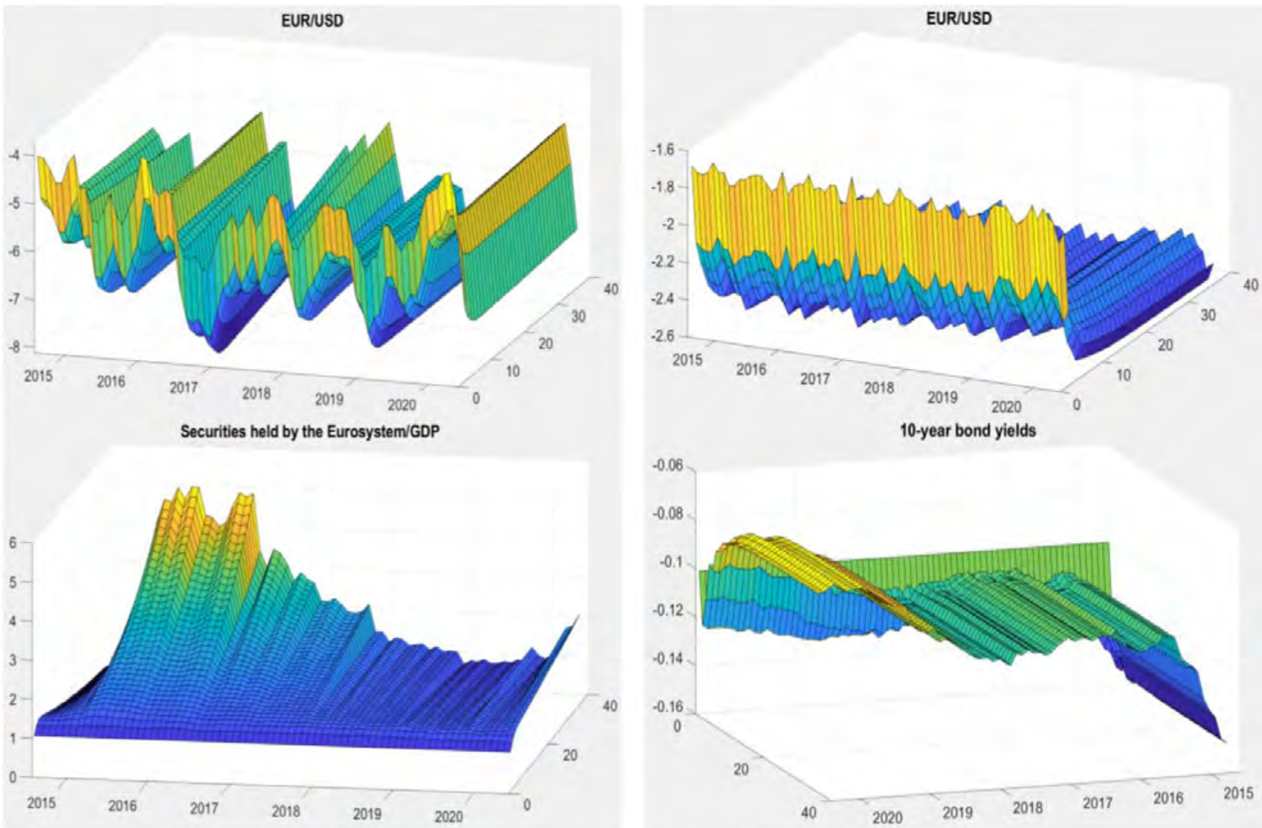


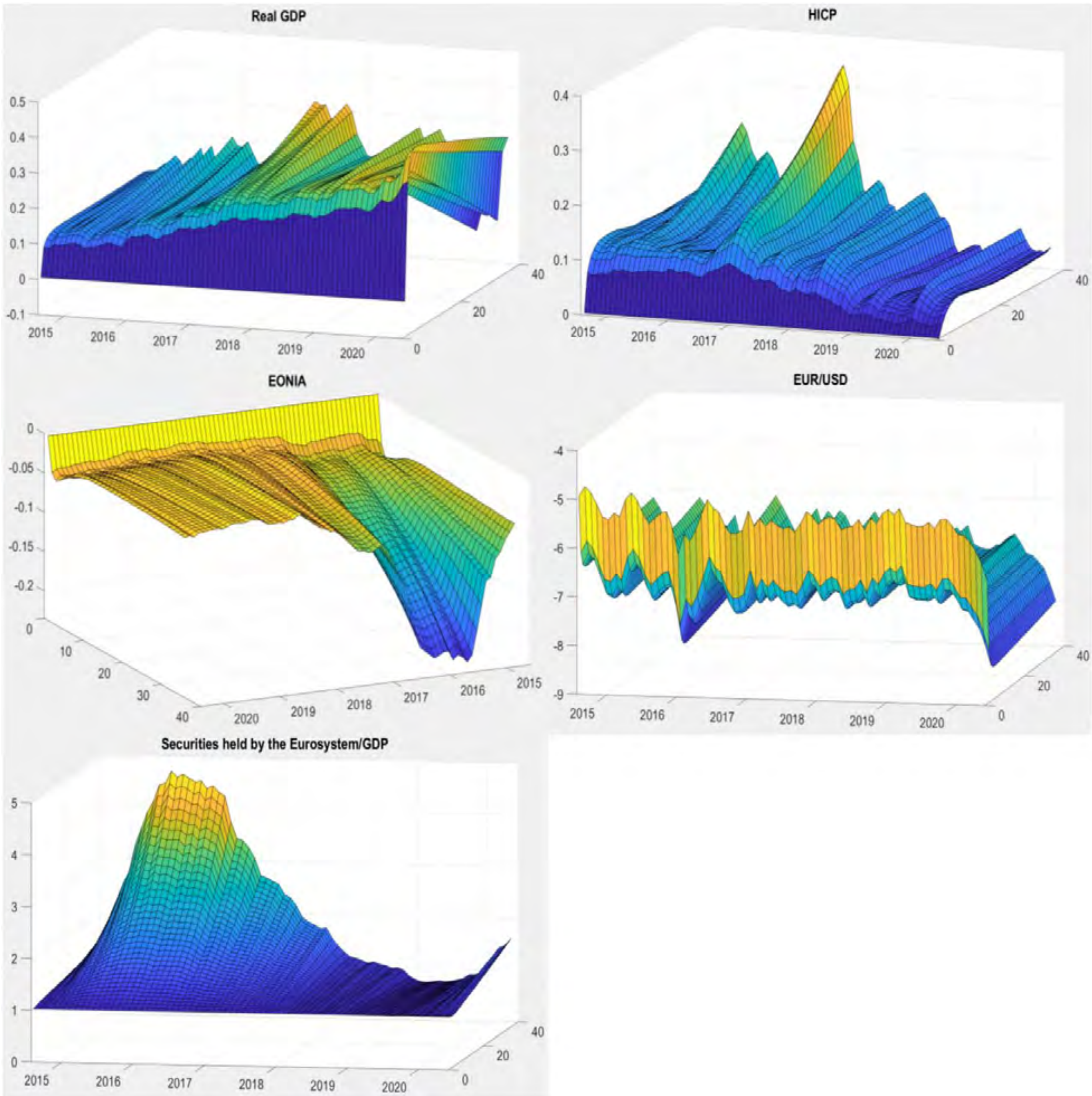
Figure A4: **Setting lag order to 2 (cont.)**

(c) Sign and zero restrictions (d) HFI + Sign restrictions



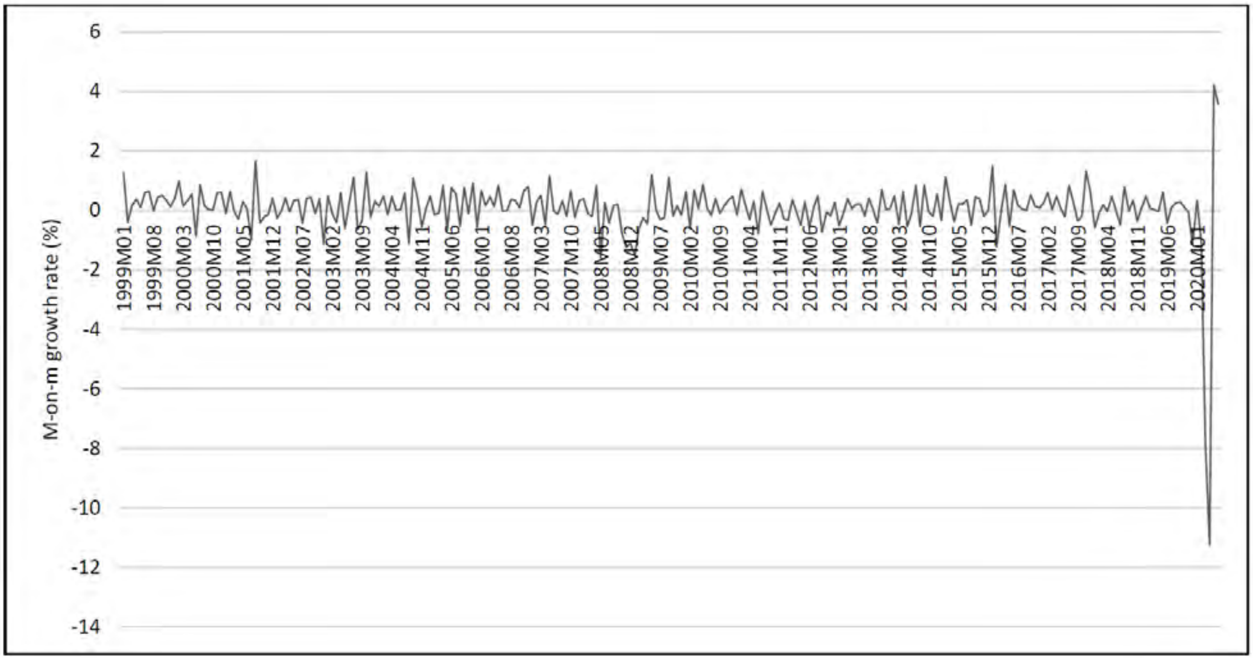
Note: Figures show impulse response functions (cumulative in case when HFI is augmented with sign restrictions) to the asset purchase shock which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP (10 bps drop in 10-year government bond yields).

Figure A5: **Imposing zero restrictions on output and inflation for a standard monetary policy shock**



Note: Figure shows impulse response functions to the asset purchase shock, identified via a mixture of sign and zero restrictions, which has been normalized to a 1 pp increase in the Eurosystem asset holdings relative to 2015 nominal GDP.

Figure A6: **Euro area monthly real GDP**



Note: Figure shows the log-difference (effectively m-on-m growth rate) of monthly real GDP obtained via the temporal disaggregation procedure of Litterman (1983) using industrial production as an indicator series.

Figure A7: **QE shock series obtained via the fusion of HFI and narrative sign restrictions**

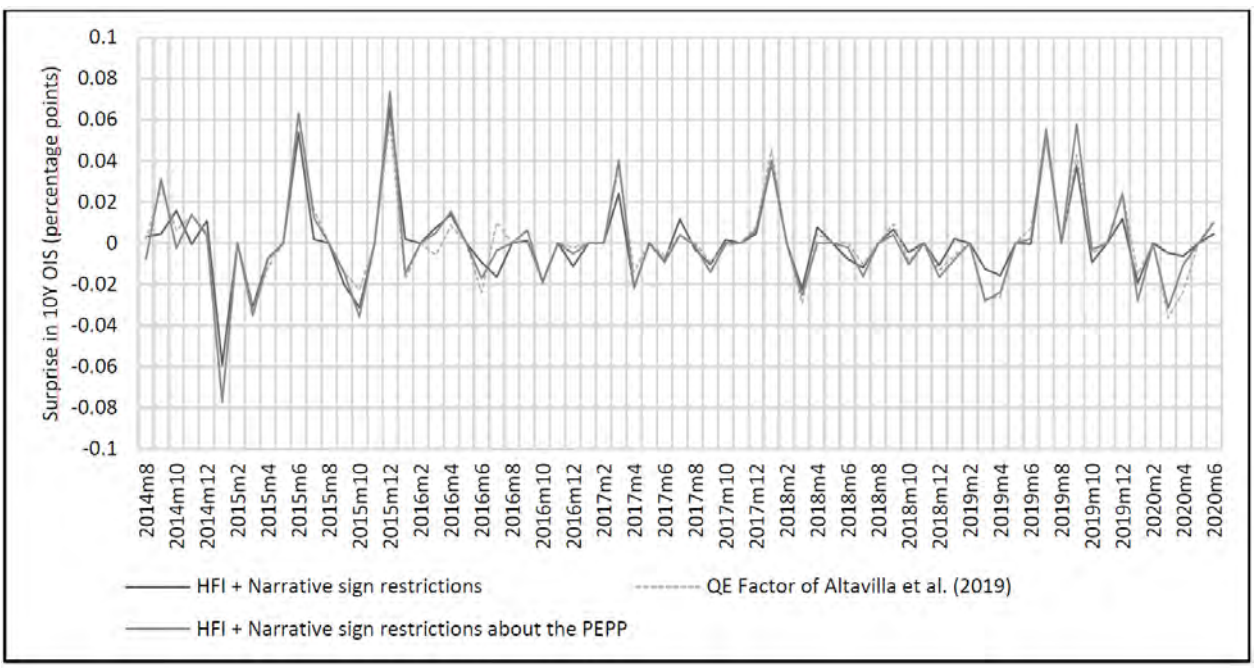
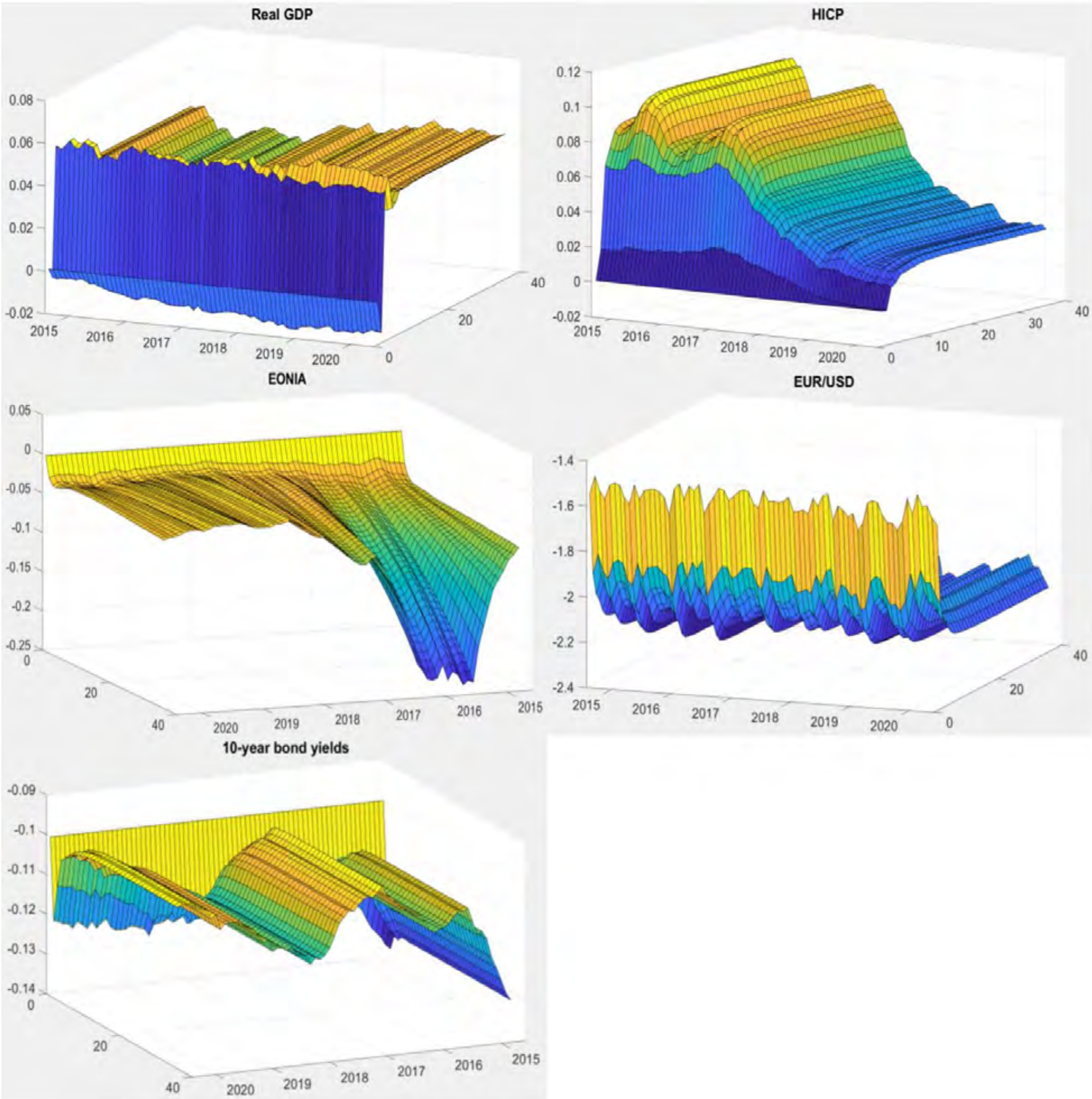


Figure A8: **Results derived via a mixture of HFI and narrative sign restrictions about the PEPP**



Note: Figure shows cumulative impulse response functions to the asset purchase shock, identified via the fusion of HFI and narrative sign restrictions approaches, which has been normalized to a 10 bps drop in 10-year government bond yield.