Measuring Monetary Policy in the Euro Area Using SVARs with Residual Restrictions

By Harald Badinger and Stefan Schiman*

This study measures the effects of monetary policy in the euro area using a small number of sign and magnitude restrictions on the residuals of a SVAR. We derive the dates and directions of these shocks from high-frequency financial market data around official ECB policy announcements. Based on an in-depth narrative analysis and a comparison of the results with those of a standard high-frequency approach, we argue that our approach is purged from central bank information effects. Despite our rather agnostic identification strategy, we find clear and conclusive effects of monetary policy shocks on a wide range of macroeconomic variables.
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The measurement of monetary policy has been subject to numerous studies over the last decades. For the estimation of its causal effects, structural vector autoregressions (SVARs), using alternative identification strategies, have developed as predominant econometric approach.[1]

The present study on monetary policy in the euro area roots methodologically in a strand of this literature, which uses high-frequency data to uncover financial market surprises around central bank announcements for identification (e.g., Gertler and Karadi, 2015). While it is widely agreed that such an approach, exploiting unexpected variation in monetary policy, convincingly addresses endogeneity concerns, a potential drawback is that central banks' announcements of interest rate decisions also reveal central bank information on the economic outlook, an issue that features prominently in recent studies (e.g., Jarociński and Karadi, 2020; Andrade and Ferroni, 2021).

In order to measure the effects of the ECB's 'conventional' monetary policy, we propose an identification strategy that focuses on a few pronounced interest rate surprises and combines the virtues of high-frequency identification with those of

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[1]Surveys of the comprehensive literature are provided by Christiano, Eichenbaum and Evans (1999) and Ramey (2016).

a narrative approach.

Specifically, we build on the identification strategy put forth by Antolín-Díaz and Rubio-Ramírez (2018), which imposes sign and magnitude restrictions on a few residuals of an SVAR, the dates and directions of which we infer from financial market responses to official ECB interest rate announcements. Based on a narrative analysis of these (in total four) events and their preceding macroeconomic developments, we argue that these interest rate surprises constitute conventional monetary policy shocks and that the estimates of their effects are hence purged from information effects.

The estimation period ranges from the launch of the euro in 1999 to 2019. We set residual sign restrictions in those four months, in which financial markets were most surprised by the ECB's interest rate announcements as reflected in changes in overnight interest rate swaps: October and November 2008 and October and November 2011. In October 2008 the ECB joined a world-wide coordinated rate cut and moved from a corridor to a floor system (expansive shock). One month later, the ECB failed to meet market expectations fueled by a sharp rate cut by the Bank of England (restrictive shock). In October 2011, interest rates remained unchanged despite the unresolved sovereign debt crisis and weakening economic activity (restrictive shock). Again, one month later, rates were cut despite an essentially unchanged economic environment and in contrast to forward guidance (expansive shock). Interestingly, the latter two shocks occurred around the change of presidency from Jean-Claude Trichet to Mario Draghi, who assumed office in November 2011.

A magnitude restriction completes our set of identifying assumptions. It states that the residual of the interest rate equation, i.e., the unexplained part of the interest rate decrease in November 2011, was predominantly due to the monetary policy shock. This restriction is substantiated by the fact that the money market rate moved only on the day the new, lowered policy rates came into effect, indicating that other macroeconomic shocks did not play a material role in that month.

Despite its parsimony and rather agnostic nature our approach achieves strong identification. Specifically, we find that a restrictive interest rate decision by the ECB leads to an increase of short-term and long-term interest rates, a decline of the narrow money stock, a decline in expected and realized consumer prices, an appreciation of the euro against the U.S. dollar, an increase of the corporate bond spread, and a gradual negative response of real output, which reaches its trough one and a half to two years after the shock. We also find that the impulse responses are more conclusive than those obtained from a standard high-frequency approach. This supports the view that our identification strategy cleans the estimated effects of monetary policy from central bank information shocks.

Related Literature. — Methodologically, our paper contributes to the literature that seeks identification of monetary policy shocks in VARs by means of known past policy events. In their pioneering work, Romer and Romer (1989, 1994) select (restrictive) monetary policy shocks on the basis of written central bank material and introduce them into monetary VARs as a dummy variable. Romer and Romer (2004) address the endogeneity problem present in their early studies and pointed out by Shapiro (1994) and Leeper (1997) by controlling for the Fed's own macroeconomic projections.

An alternative approach, which has gained increased popularity in recent years, is the use of high-frequency financial market data sufficiently close to monetary policy announcements (e.g., Gürkaynak, Sack and Swanson, 2005). In such a setting the direction of causality can be credibly assumed to run from policy measures to market developments, not vice-versa.

Barakchian and Crowe (2013) for the first time incorporate a high-frequency indicator directly into an SVAR. Gertler and Karadi (2015) introduce high-frequency information into a proxy SVAR framework (Stock and Watson, 2012; Mertens and Ravn, 2013), making use of the fed funds futures as an 'external instrument'. Jarociński and Karadi (2020), invoking results by Plagborg-Møller and Wolf (2021), argue that (asymptotically) equivalent impulse responses can be obtained by including the shock series directly into the SVAR, ordered first, and using triangular identification. In the following, we refer to these approaches, which use the full high-frequency series for identification of monetary policy shocks as 'standard high-frequency approach' or 'standard high-frequency identification'.

The central bank announcement of its interest rate decision may, however, not only entail a monetary policy surprise but it may also reveal the bank's assessment about the state of the economy, i.e., an information effect (Romer and Romer, 2000). In models of central bank information effects, agents filter out the central bank's assessment of the economic situation from the observed interest rate decision alone (Melosi, 2017; Nakamura and Steinsson, 2018). For example, an unexpected rate hike will often represent a restrictive monetary policy shock, but it could also be a response of the central bank to an improvement of the economic outlook.[2]

Observed financial market responses may therefore conflate the effects of the two shocks—conventional monetary policy shocks and information shocks—which have potentially opposite effects on many macroeconomic variables. Recent studies have proposed different ways to separate the information content from the pure policy content in central bank announcements, several of them on monetary policy in the euro area:

Using sign restrictions, Cieslak and Schrimpf (2019) and Jarociński and Karadi (2020) exploit the different comovement between interest rates and stock prices to isolate monetary policy shocks from information shocks. The latter find that, in the euro area, the standard high-frequency approach does not only underestimate the effects of monetary policy, but that it also produces results that are

[2]See Bauer and Swanson (2021) for an alternative interpretation of the information effect that does not rely on superior central bank information.

inconsistent with standard theory. Eminidou and Zachariadis (2022) analyze the effects of ECB shocks on firms' selling prices and production expectations and confirm that information effects play an important role.

Hafemann and Tillmann (2020) perform a principal component analysis with interest rates and stock prices and find that it delivers two factors that are clearly interpretable as information shocks and pure monetary policy shocks. Andrade and Ferroni (2021) take yet another view on these two components by focusing on the ECB's forward guidance. They invoke the different comovement between interest rates and expected inflation to separate surprises about future monetary policy from news about the expected economic development.

We suggest an alternative approach that focuses on a small subset of policy surprises for which we show by means of a narrative analysis that they are pure monetary policy shocks. In doing so, our paper is methodologically close to Antolín-Díaz and Rubio-Ramírez (2018), who use the dates and directions of monetary policy shocks proposed by Romer and Romer (2004) and Gürkaynak, Sack and Swanson (2005) to identify a monetary VAR for the US by residual sign and magnitude restrictions.

A number of other recent papers adopt restrictions on the residuals of SVARs to identify a wide variety of macroeconomic shocks: Ludvigson, Ma and Ng (2021) and Redl (2020) use them to examine uncertainty shocks, Zhou (2020) and Kilian and Zhou (2020) investigate oil market shocks, Laumer (2020) government spending shocks, Furlanetto and Robstad (2019) labor market shocks, Ben Zeev (2018) investment-specific technology shocks, and Ludvigson, Ma and Ng (2017) oil market, monetary policy, and house price shocks. Our paper is the first to use residual sign and magnitude restrictions[3] to identify the effects of conventional monetary policy shocks by the ECB.

From a thematic point of view, this paper contributes to the literature on monetary policy in the euro area more generally in providing an in-depth narrative analysis of the largest policy surprises by the ECB since its inception. These events are inferred from a publicly available database by Altavilla et al. (2019*a*) which contains a wide range of high-frequency asset price responses to ECB policy announcements. Therewith, we connect to the extensive studies by Hartmann and Smets (2018) and Rostagno et al. (2019) that provide a general historical record of the ECB's monetary policy.

The analysis proceeds as follows: Section I presents the results from uncovering monetary shocks in the euro area using high-frequency data and provides a narrative analysis. Section II introduces the VAR model, the data used and the identification and estimation procedure. Section III presents the results on the effects of monetary policy shocks and Section IV concludes.

[3]In the literature, these type of restrictions—or inequality restrictions on structural residuals more generally—are also referred to as 'narrative' restrictions (Giacomini, Kitagawa and Read, 2021).

I. Interest Rate Surprises by the ECB

In this section, we outline our approach to uncover monetary policy shocks in the euro area from high-frequency financial market data. We then provide a narrative analysis of the four interest rate decisions by the ECB to which financial markets responded the most and argue that these surprises were due to conventional monetary policy shocks.

A. High-Frequency Data

The identification of monetary policy shocks over the time period from 1999 to 2019 makes use of Altavilla et al. (2019*a*), who collect high-frequency data on financial market variables around monetary policy decisions of the ECB (Altavilla et al., 2019*b*). They differentiate between two time slots on days of monetary policy decisions. The first, from 1:25 to 2:10 p.m., involves the publication of a press release at 1:45 p.m., which includes the ECB's decision on its three policy rates without any further comment.[4] The second time window, from 2:15 to 3:50 p.m., covers the subsequent press conference, in which the president comments the interest rate decision and provides further information on monetary policy and the state of the economy.

A key finding from a factor analysis by Altavilla et al. (2019*a*) is that 'target surprises', i.e., surprises related to current interest rates, are confined to the press release window. The conference window, instead, is characterized by news about the future evolution of interest rates (timing of interest rate decisions and forward guidance) and about other monetary policy measures like asset purchases. Given this clear separation and our focus on the effects of conventional monetary policy, we base our analysis on financial market reactions in the press release window.

For a quantitative assessment of interest rate surprises, we construct an indicator based on changes in EONIA[5] swap rates with maturities of 1 week, 1 month, 3 months and 6 months during the press release window (1:25 to 2:10 p.m.) on days of monetary policy decisions. As the ECB Governing Council typically meets once a month, this intra-day information on interest rate surprises is easily transformed into monthly observations to match the frequency at which the variables of our SVAR are observed. In the few months, where more than one meeting took place (e.g., October 2008), we consider the cumulative change of the swap rates in the respective month. In months without a meeting of the Governing Council, the indicator is set to zero.

All four resulting time series of swap rate changes are highly leptokurtic. In 81% – 86% of the cases, swap rates do not change at all or at most by one

[4] Two such exemplary press releases are given in online Appendix A. Starting in 2016, the press releases also include forward guidance and information about asset purchases.

[5] The 'European Overnight Index Average' (EONIA) is the average of interest rates on overnight unsecured lending in the euro area interbank market, see also `https://www.emmi-benchmarks.eu/benchmarks/eonia`.

basis point, yet the standard deviation of the series ranges from 1.7 to 2.6 basis points. This means, first, that most interest rate decisions were anticipated and financial markets hardly reacted to the press releases; and second, that there were some significant unexpected decisions, i.e., interest rate surprises. We direct our attention to these events.

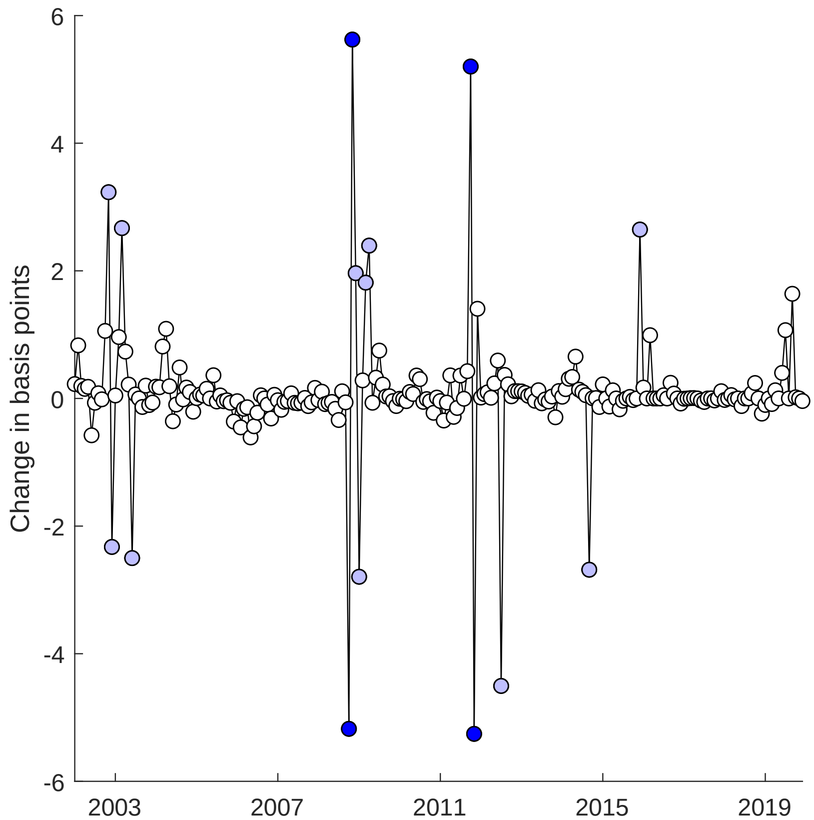

Figure 1. Monetary Policy Decisions and Financial Market Reactions

Note: Realizations of the high-frequency interest rate surprise indicator, i.e., the average of the standardized 1-week, 1-month, 3-months, and 6-months EONIA swap rate changes in basis points. Colored dots mark particularly large surprises. The four largest realizations used for identification of the baseline model are dark shaded (October 2008, November 2008, October 2011, November 2011).

In the identification of our SVAR, we will focus on a few dates of ECB policy announcements that were accompanied by particularly sharp financial market responses. To identify such events, we first standardize the time series of the changes in the four swap rates and consider the average of them at each date. The resulting synthetic series of standardized average changes is presented in Figure 1.

In our baseline scenario, we focus on the four largest surprises between 2002 and 2019:[6] October 2008 (expansive), November 2008 (restrictive), October 2011 (restrictive) and November 2011 (expansive). They are marked with dark blue shaded dots in Figure 1. We use these surprises to identify the effects of monetary policy shocks in the baseline estimation. Moreover, in Section III.D, we will also consider further interest rate surprises that are next in size; for later reference, they are marked with light blue shaded dots in Figure 1.

Our identification strategy requires that these four financial market surprises were mainly driven by monetary policy shocks and not by information shocks. In the subsequent narrative analysis in Section I.B, we argue that this was indeed the case.[7] As a quantitative, suggestive preview to our narrative arguments, note that the interest rate surprise indicator and stock prices (measured by the EuroStoxx50, also taken from Altavilla et al., 2019*a*) moved in opposite directions during the press release window at all four dates—a criterion that Jarociński and Karadi (2020) use to differentiate between monetary policy shocks and information shocks.

B. *Narrative Analysis*

We next provide a detailed narrative analysis of the four largest interest rate surprises, which we have identified with high-frequency data in the previous section. We use ECB materials, magazines, and newspaper articles to describe and interpret the public reactions conveyed and discussed in the media. In particular, we elaborate and argue that these four interest rate surprises were the result of conventional monetary policy shocks. Table 1 gives abstracts of the narratives for the four events, each of which we consider in detail in the following.

October 2008 (–). The collapse of Lehman Brothers in September 2008 severely aggravated the crisis of financial markets. Central banks all over the world took measures to counteract the freezing of interbank lending. Nonetheless, the ECB left interest rates unchanged in its regular meeting on October 2 (ECB Governing Council, 2008*a*).

[6] As Altavilla et al. (2019*a*), we use data from 2002 to 2019, because the sparsity (and, hence, increased volatility) of quotes between 1999 and 2002 impedes separating noise from true policy surprises in this period.

[7] In other words: In our sample, the four largest interest rate surprises turn out to be monetary policy shocks. This will not necessarily be the case in general. If our narrative analysis had indicated that one (or more) of these interest rate surprises contained significant information shocks, our identification approach would have involved considering the next largest interest rate surprise(s) and selecting the one(s) that qualify as monetary policy shock according to the narrative analysis.

TABLE 1—MAIN INTEREST RATE SURPRISES IN THE EURO AREA

Date	*Sign*	*Description*
Oct. 8, 2008	−	Coordinated rate cut and change of the allotment procedure from a corridor to a floor system.
Nov. 6, 2008	+	ECB does not meet expectations raised by BoE's sharp rate cut immediately preceding it.
Oct. 6, 2011	+	Unchanged rates despite unresolved sovereign debt crisis and weakening economic activity.
Nov. 3, 2011	−	President Draghi's first meeting; rate cut despite an essentially unchanged economic environment.

Note: A negative sign denotes an expansive shock, a positive sign a restrictive shock.

Assuming that inflation would remain too high due to inflation-indexed wage-setting (*"nominal increases which are abnormal in our view,"* ECB, 2008*a*), the Governing Council stressed the crucial importance of keeping inflation expectations firmly anchored. This was perceived restrictive by financial markets, the short-term swap rates increased by up to 2.4 basis points. Ho wever, the Financial Times (2008*b*) noted that *"Mr. Trichet carefully left room for manoeuvre and did not rule out possibly co-ordinating a cut in interest rates with the US Federal Reserve—if consistent with combating inflation."*

This coordinated rate cut was orchestrated less than a week later. The monetary policy committees of the main central banks in the world met on October 8 and collectively cut policy rates by 50 basis points (ECB Governing Council, 2008*b*). This surprised financial markets, given the ECB's dogmatic position on price stability. The Financial Times (2008*c*) cited the then Chief European Economist at Goldman Sachs, Erik Nielson, who described as *"breath-taking the U-turn in ECB thinking."* The ECB might have *"had little choice but to fall into line with action taken by other central banks."*

While the magnitude of the rate cut from 4.25% to 3.75% was not extraordinary, another measure, announced in a separate press release the same day (ECB Governing Council, 2008*c*), enhanced the expansive shock: The procedure for providing liquidity to the banking system was changed from a variable-rate bidding to a fixed-rate full allotment procedure. Excess liquidity started to build up and pushed EONIA from the middle of the policy rate corridor (i.e., from close to the main refinancing rate) to the bottom (the deposit facility rate), making the deposit facility rate the effective policy rate (Hartmann and Smets, 2018, p. 54).

In the same press release, the ECB announced that it would decrease the corridor of standing facilities from 200 to 100 basis points, implying a re-increase of the deposit rate by 50 basis points and, hence, to its previous level of 3.25%. This means that the change of the allotment procedure constituted a policy rate cut of 50 basis points, from 3.75% (the main refinancing rate) to 3.25% (the deposit facility rate). Hence, the overall measures taken on October 8 amounted to a monetary easing of 100 basis points, half of which is attributable to the collective rate cut and half to the change in the allotment procedure.

The swap rate decline following the October 8 meeting was much larger in size than the corresponding increase on October 2, such that the cumulative interest rate surprise in October 2008 was clearly negative. While this would in principle fit the notion of a negative information shock given the escalating recession at that time, several important aspects speak against it. First, the increase of swap rates in response to the decision of leaving interest rates unchanged from October 2 implies that, in the run-up to the rate cut, financial markets already had a gloomier assessment of the economic situation than the ECB. Second, the relaxation of the allotment procedure had the purpose, and most likely the effect, of reducing financial market tensions. This measure is therefore unlikely to have been understood as further bad news about the economic situation, but rather as a way of alleviating it. Third, the stock market moved in the other direction than swap rates during both press releases individually and overall; i.e., the share price index slipped after the interest rate announcement on October 2 and it increased (more markedly) on October 8.

In their analysis of monetary policy in the euro area, Soenen and Vennet (2021, p. 6) confirm this reading. They argue that monetary policy was initially perceived to be not sufficiently expansionary when the financial crisis hit. However, *"once the ECB stepped up its policy actions with substantial repo rate decreases and the launch of longer-term refinancing operations, the monetary policy stance reverted to expansionary."*

November 2008 (+). The Bank of England (BoE) heralded the day of November 6, 2008, with a massive interest rate cut. It slashed its policy rate, the 'bank rate', by 150 basis points from 4.5% to 3%, which amounted to the biggest rate reduction since 1981 and resulted in the lowest rate since 1954. According to the New York Times (2008), analysts had expected a far more modest decrease: *"The Bank of England took the lead by aggressively cutting its benchmark interest rate by 1.5 percentage points—triple what most analysts had expected."* The day before the meeting, the Financial Times (2008*a*) only conjectured that *"traders will be grievously disappointed (...) if the Bank does not cut by 75 basis points,"* not speaking of a rate cut double this size. The Economist (2008) summarized that *"it is hard to spring a surprise when everyone is expecting one, but the Bank of England has managed it."*

To the extent that this interest rate decision constituted a negative information shock, it led to a downward correction in the assessment of the world economic outlook and, hence, placed high expectations on the ECB regarding monetary easing. *"On the financial markets, the interest rate step in the UK was taken as* *a signal that the European Central Bank (ECB) might also decide to cut interest rates significantly more. But they were disappointed,"* the Handelsblatt (2008) commented the ECB's interest rate decision (translation by the authors). The Governing Council lowered the interest rates by only 50 basis points, although it had considered a 75 basis points cut in the debate (ECB, 2008*b*). *"Set against the Bank of England's derring-do, however, the Frankfurt-based central bank looks like it is not taking the recent sea-change seriously enough,"* The Economist (2008) noted.

Regarding the nature of the interest rate surprise in November 2008, the economic situation at that time clearly speaks against an optimistic information shock and thus in favor of a restrictive monetary policy shock. According to the ECB, *"the intensification and broadening of the financial market turmoil is likely to dampen global and euro area demand for a rather protracted period of time. (...) The world economy as a whole is feeling the adverse effects, as tensions increasingly spill over from the financial sector to the real economy. (...) In the case of the euro area, the latest survey data confirm that momentum in economic activity has weakened significantly."* (ECB, 2008*b*)

October 2011 (+). In October 2011, the ECB was struggling with a conflicting economic situation. On the one hand, inflation was at 3 percent and hence clearly above its target level. On the other hand, economic growth was decelerating due to, among others, *"unfavourable effects on financing conditions resulting from ongoing tensions in a number of euro area sovereign debt markets"* (ECB, 2011*a*), i.e., the intensifying euro area crisis.

This monetary policy dilemma made the outcome of the Governing Council meeting on October 6, 2011, particularly uncertain. The ECB decided to leave interest rates unchanged, which *"was in line with the results of a Reuters poll of economists in which 56 of the 76 economists questioned saw rates being left unchanged while 20 expected a decrease"* (Financial Mirror, 2011). Chris Williamson, the chief economist at Markit, was instead quoted by the British Broadcasting Corporation (2011) as saying that *"the ECB's decision to focus on inflation (...) is a surprise, as a rate cut appears to have been warranted, according to the recent downward trend in business surveys."*

Financial markets appear to have predominantly echoed this view, given the significant increase in interest swap rates after the announcement of the interest rate decision. It might have been reinforced by certain statements of Governing Council members. Yves Mersch from Luxemburg said that *"should there be, compared with current data, a significant worsening of the dynamics of the economy in the euro zone, we do have room to move."* (Reuters, 2011). Erkki Liikanen from Finland confirmed that *"we said (in the last meeting) risks to inflation are balanced and risks to growth are to the downside. And my personal opinion is that the risks to growth are substantially to the downside."* Other Governing Council members, however, were less downbeat.

A few months earlier (in April and in July 2011), interest rates had been increased due to heightened inflation, although at the same time Greece, Ireland, and Portugal faced record-high debt refinancing costs. This monetary policy stance, which was highly controversial, was perpetuated in October 2011, Trichet's last meeting as president of the ECB, in spite of a worsening economic situation and the yet unresolved and even mounting refinancing problems of several euro area member states. Therefore, similarly to November 2008, the interest rate surprise in October 2011 was unlikely to be driven by a positive information shock, but rather by a policy decision perceived as overly restrictive.

NOVEMBER 2011 (–). Interest rates were not only kept unchanged in October 2011, outgoing president Trichet also offered no indication that an interest rate move could be due in the near future (Cable News Network, 2011). Furthermore, in the run-up to the meeting on November 3, the economic situation was essentially the same as the month before. Consumer prices kept growing at the same rate, evidence from survey data remained *"unfavorable"* and *"looking forward, a number of factors seem to be dampening the underlying growth momentum in the euro area, including a moderation in the pace of global demand and unfavourable effects on overall financing conditions and on confidence resulting from ongoing tensions in a number of euro area sovereign debt markets."* (ECB, 2011*b*)

Against this backdrop, an interest rate surprise that is of the opposite sign as the month before is hard to reconcile with a shock to public information about the stance of the economy. Instead, the rate cut on November 3, 2011, of 25 basis points was likely perceived as a signal of the incoming president, Mario Draghi, to follow a more dovish policy than his predecessor given an essentially unchanged economic environment.

The Economist (2011) wrote that *"the decision came as a surprise to financial markets (...) because Mr Draghi was expected to shy away from cutting rates in his very first meeting for fear (as an Italian) of being seen as soft on inflation, especially in Germany."* The New York Times (2011) asserted that *"the move was a radical change from the stance of the bank under Mr. Draghi's predecessor, Jean-Claude Trichet, and a gutsy sign that Mr. Draghi is willing to defy inflation hawks in Germany."* The Wall Street Journal (2011) noted that *"the rate cut, which corresponded with a change in the central bank's leadership, caught financial markets off guard; the ECB's new president, Mario Draghi, an Italian, has been widely expected to maintain the bank's rigid anti-inflation stance."* All these assessments reflect the notion of an inflationary shock, i.e., an expansive policy shock, not a price-dampening negative information shock.

In the next section, we outline how these four monetary policy shocks translate into residual sign restrictions for the identification of our SVAR in order to measure the effects of the ECB's monetary policy. Moreover, we will also consider the role of further smaller, yet sizable interest rate surprises in Section III.D.

II. VAR Implementation

Point of departure is the standard reduced-form VAR

$$\boldsymbol{y}_t = \boldsymbol{c} + \sum_{i=1}^{L} \boldsymbol{A}_i \boldsymbol{y}_{t-i} + \boldsymbol{u}_t, \tag{1}$$

where $\boldsymbol{y_t}$ is the $K \times 1$ vector of observations on the endogenous variables in time period (month) t. The right-hand side includes a $K \times 1$ vector of constants, $\boldsymbol{c}$, and $i = 1, \ldots, L$ time lags of the vector of endogenous variables, $\boldsymbol{y}_{t-i}$, with corresponding $K \times K$ reduced-form parameter matrices $\boldsymbol{A}_i$. As it is standard in the literature on monetary VARs with monthly data, we set the lag length to $L = 12$. Finally, $\boldsymbol{u}_t$ is a $K \times 1$ vector of reduced-form errors (innovations), which are assumed to be independently and normally distributed, $\boldsymbol{u}_t \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{V})$.

Having set up the standard framework for our analysis, we now turn to a description of the model specification, i.e., the variables included, the data sources and the econometric implementation of our identification strategy.

A. *Variables and Data*

Our baseline VAR includes six variables: a short-term interest rate, real output, consumer prices, a corporate bond spread, narrow money, and an exchange rate.

As short-term interest rate we use *EONIA* (ECB, n.d.*a*). Real output is measured in terms of industrial production (*IP*, Eurostat, n.d.*a*). For consumer prices, we use the harmonized consumer price index (*HCPI*, ECB, n.d.*b*), which is the key indicator regarding the ECB's primary objective to maintain price stability.[8] As measure of corporate bond spreads (*CBS*), we use the same variable (and data) like Jarociński and Karadi (2020), i.e., the spread between euro-denominated bonds below investment grade and the Treasury rate (Ice Data Indices, LLC, n.d.). Narrow money, *M1*, includes overnight deposits and cash (ECB, n.d.*d*). Considering the international value of the euro, we include the nominal euro-dollar exchange rate (*EUR/USD*, ECB, n.d.*e*).

This set of variables should be rich enough to adequately capture macroeconomic relationships and the effects of monetary policy. As an extension of our baseline model, we also investigate the behavior of some further variables in Section III.C: expected inflation, long-term interest rates, and broad money.

Our data set comprises monthly data over the period from January 1999 to December 2019 (252 observations). The estimation period thus starts with the establishment of the euro area and the implementation of the ECB as its monetary policy authority. Financial market variables (the corporate bond spread, interest rates and the exchange rate) are available at higher frequencies and measured

[8] In online Appendices D.4 and D.5 we show that our results are robust to replacing industrial production by real GDP (Eurostat, n.d.*b*) and consumer prices by core consumer prices (ECB, n.d.*c*).

as monthly averages. The corporate bond spread, interest rates and expected inflation are in percent, all other variables in natural logs. Hence, in the baseline VAR, our vector of endogenous variables in Equ. (1) is of dimension 6×1 and given by

$$\boldsymbol{y_t} \equiv (EONIA_t, IP_t, HCPI_t, CBS_t, M1_t, (EUR/USD)_t)'.$$

During the sample period, a lower bound on interest rates has not been reached in the euro area. The deposit facility rate and *EONIA* became negative in 2014 and declined further thereafter. Therefore, we use the full sample in the baseline estimation. In a robustness check, we cut the sample in June 2012, one month before the deposit rate was reduced to zero (online Appendix D.1).

B. *Identification*

Our identification procedure closely follows Antolín-Díaz and Rubio-Ramírez (2018). We use external information to determine the dates, the direction (restrictive or expansive) and the relevance of a few known policy surprises and impose corresponding sign and magnitude restrictions on the structural residuals of one of the SVAR equations. In contrast to Antolín-Díaz and Rubio-Ramírez (2018), however, we do not set sign restrictions on impulse responses. Thus, none of the specific effects of monetary policy are assumed a priori, but they all arise from the estimation, which makes our identification strategy slightly more agnostic.

Having uncovered a set of monetary policy shocks from high-frequency data, we now outline how we use this information to identify the SVAR associated with the reduced form in Equ. (1). It is given by

$$\boldsymbol{B}\boldsymbol{y}_t = \boldsymbol{B}\boldsymbol{c} + \sum_{i=1}^{L} \boldsymbol{B}\boldsymbol{A}_i\boldsymbol{y}_{t-i} + \boldsymbol{w}_t, \tag{2}$$

where $\boldsymbol{w}_t = \boldsymbol{B}\boldsymbol{u}_t$ and $\boldsymbol{w}_t \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{I})$. The matrix $\boldsymbol{B}$ is the structural parameter matrix that governs the instantaneous relationships between the model variables. It is chosen such that the following restrictions are satisfied:

$$\hat{w}_{1,2008m10} < 0, \tag{SR1}$$

$$\hat{w}_{1,2008m11} > 0, \tag{SR2}$$

$$\hat{w}_{1,2011m10} > 0, \tag{SR3}$$

$$\hat{w}_{1,2011m11} < 0, \tag{SR4}$$

$$|\hat{b}_{1,1}^{(-1)} w_{1,2011m11}| > 0.5 \cdot |\hat{u}_{1,2011m11}|, \tag{MR}$$

where $\hat{w}_{1,t}$ is the structural residual of the first equation of the SVAR in Equ. (2)

and $\hat{b}_{1,1}^{(-1)}$ is the estimate of the first main diagonal element of the inverse of $\boldsymbol{B}$.[9]

The residual sign restrictions SR1 to SR4 constrain the set of eligible draws to those that identify negative shocks in October 2008 and in November 2011 (expansive monetary policy shocks) and positive shocks in November 2008 and in October 2011 (restrictive monetary policy shocks). These restrictions have been motivated and rationalized by means of high-frequency data in Section I.A and a narrative analysis in Section I.B.

The magnitude restriction, MR, deserves further discussion. It states that the monetary policy shock in November 2011 accounts for at least half of the unexplained change (decrease) in *EONIA*, i.e., the innovation in the reduced-form interest rate equation. This kind of restriction is similar to the 'Type B restriction' in Antolín-Díaz and Rubio-Ramírez (2018), which states that the contribution of a particular shock to the unexplained change of a variable must be larger than the sum of the contributions of all other shocks in absolute terms.

By imposing this magnitude restriction we discard estimation outcomes that attribute a large share of the decline in *EONIA* to other than monetary policy shocks. It is motivated by the fact that in November 2011—in contrast to the other three months—*EONIA* changed only the day the new ECB interest rates came into effect. This means that no other macroeconomic shock affected *EONIA* in that month significantly. Now, given that the high-frequency data indicate a substantial interest rate surprise, it is safe to assume that the unexplained change in *EONIA* that month was predominantly triggered by the ECB's policy announcement. Online Appendix B gives more details on *EONIA* developments in the four respective months to support this view. Online Appendix D.2 highlights that the magnitude restriction plays a crucial role in narrowing down the credible sets of the impulse responses.

C. Estimation

We estimate the SVAR in Equ. (2) with standard Bayesian techniques, employing an independent Normal-Wishart prior with Minnesota-style shrinkage of the prior parameter variance-covariance matrix $\boldsymbol{V_A}$. $\boldsymbol{A} = (\boldsymbol{c}, \boldsymbol{A}_1, \ldots, \boldsymbol{A}_L)$ is of dimension $K \times (KL+1)$ and $\boldsymbol{V_A}$ is assumed diagonal, implying independent parameters. In online Appendix D.3 we check the robustness of the results to replacing the independent prior by its conjugate counterpart.

With regard to the K^2L+K diagonal elements $v_{ii,\boldsymbol{A}}$, we set a flat prior variance on intercepts, $v_{ii,\boldsymbol{A}} = 100$, and decreasing prior variances on lag parameters, $v_{ii,\boldsymbol{A}} = \kappa_1 \cdot l^{-2}$ for own lag l and $v_{ii,\boldsymbol{A}} = \kappa_2 \cdot l^{-2} \cdot \hat{\sigma}_{ii}^2/\hat{\sigma}_{jj}^2$ for lags of other variables, where the scaling parameter $\hat{\sigma}_{ii}^2/\hat{\sigma}_{jj}^2$ is the ratio of estimated error variances of univariate AR(12) models for variables i and j. The hyperparameters are set to $\kappa_1 = 0.1$ and $\kappa_2 = 0.5 \cdot \kappa_1$ to achieve sufficient shrinkage.

[9]The choice of the first equation for the identification of the monetary policy shock is arbitrary and without loss of generality.

The prior mean of AR(1) parameters in the VAR is set to one, while all other slope parameters, including the constant, are set to zero. Hence, the model estimates are shrunk towards a multivariate random walk. This is a reasonable assumption given the non-stationary nature of the variables at hand, but the results are virtually unchanged if the prior mean of the AR(1) parameters is set to zero, i.e., the estimated model is shrunk towards a multivariate white noise process.

In selecting structural parameter matrices $\boldsymbol{B}$ that satisfy the sign and magnitude restrictions we apply the well-established procedure proposed by Rubio-Ramírez, Waggoner and Zha (2010) for set-identified models (see also Kilian and Lütkepohl, 2017). Specifically, we randomly draw a square orthogonal matrix from a multivariate Normal distribution and multiply it with the Cholesky factor of $\boldsymbol{V}$ to obtain independent shocks. If a candidate draw does not satisfy the sign and magnitude restrictions on the structural residuals, it is discarded, otherwise it is retained.

In line with the recommendation by Giacomini, Kitagawa and Read (2021) in their recent work on narrative sign restrictions, we use the unconditional likelihood to construct the posterior, i.e., we abstain from importance sampling. Sampling stops when 5,000 valid draws are collected.

III. Effects of Monetary Policy Shocks

In this section, we report the estimates obtained by our residual restriction approach and compare them with those obtained by standard high-frequency identification. We then extend our baseline model to consider the effects of monetary policy shocks on other variables. Finally, we discuss the relation between the interest rate surprise indicator (see Section I.A) and the SVAR estimates of monetary policy shocks.

A. Basic Results

Estimation results for our baseline specification, which builds on the four sign and the one magnitude restriction outlined in Section II.B, are reported in Figure 2, where the blue line and the blue shaded area show the posterior median and the 68% credible set of the impulse responses of the six model variables to a restrictive monetary policy shock over a 5-year period.

Notice first that the short-run interest rate (*EONIA*) responds to a monetary policy shock within the same month. This does not come as a surprise, given that our identification strategy is related to interest rate expectations reflected in high-frequency data on overnight interest rate swaps. As a consequence, *EONIA* is a natural anchor for the scaling of monetary policy shocks to ensure comparability across different model specifications. The present and all subsequent impulse responses are to be interpreted as resulting from a restrictive monetary policy shock that leads to a median increase in *EONIA* of 25 basis points on impact.

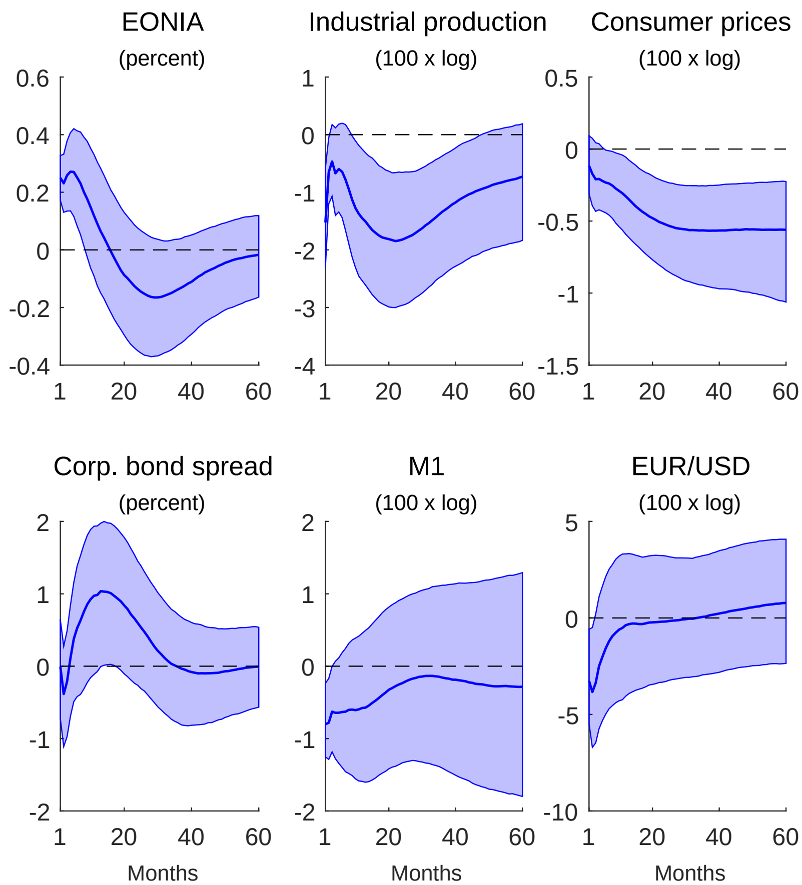

FIGURE 2. IMPULSE RESPONSES TO A RESTRICTIVE MONETARY POLICY SHOCK

Note: Blue lines are median impulse responses, blue shaded areas correspond to 68% credible sets. The monetary policy shock has been normalized to have an impact of 25 basis points on *EONIA*.

A number of interesting results emerge, all of which are consistent with standard macroeconomic theory. To begin with, there is a negative effect on output, and it intensifies gradually. The effect reaches its maximum after one and a half to two years and then levels off. The effect on consumer prices is predominantly on the negative side on impact and increases in the medium run. Both the gradual and reverting output effect and the intensifying price effect match the empirical findings of Jarociński and Karadi (2020) and Hafemann and Tillmann (2020) for monetary policy shocks by the ECB.

The corporate bond spread, which measures the tightness of financial market conditions, increases in response to a restrictive monetary policy shock. The somewhat lagged response is similar to the one found by Jarociński and Karadi (2020) for the euro area. With regard to the further variables, the stock of narrow money responds negatively on impact but the effect is less clear in the medium run. Concerning the international value of the euro, there is an unambiguous appreciation on impact and a quick reversion thereafter.

Table 2—Forecast Error Variance Decomposition

	EONIA	*IP*	*HCPI*	*CBS*	*M1*	*EUR/USD*
Impact	0.26	0.19	0.06	0.02	0.16	0.14
(t=1)	[0.1–0.4]	[0.0–0.4]	[0.0–0.2]	[0.0–0.1]	[0.0–0.4]	[0.0–0.4]
Long-term	0.14	0.24	0.30	0.12	0.08	0.10
(t=60)	[0.1–0.3]	[0.1–0.4]	[0.1–0.5]	[0.0–0.3]	[0.0–0.2]	[0.0–0.3]

Note: Contribution of monetary policy shocks to forecast error variance (median estimates; 68% credible sets in brackets).

The contribution of monetary policy shocks to forecast error variances is shown in Table 2. Two results stand out: The short-term interest rate *EONIA* is affected most strongly by monetary policy shocks on impact, which account for 10 to 40 percent of its unexplained short-run variation. In contrast, the role of monetary policy shocks for consumer prices increases over time: Shocks that occurred up to several years in the past account for 10 to 50 percent of its unexplained variation.

B. Comparison with Standard High-Frequency Identification

Standard approaches that rely on high-frequency financial market responses around policy announcements typically use the full shock series to instrument monetary policy shocks (e.g., Gertler and Karadi, 2015). Since interest rate surprises alone are not informative on whether these shocks are conventional monetary policy shocks (the type we aim to identify) or information shocks or both, standard high-frequency identification is prone to conflate these two sources of financial market responses.

Comparing our results with those obtained by standard high-frequency identification therefore allows us to assess how well our approach identifies the effects of monetary policy shocks and cleans their estimated effects from those of central bank information shocks. Regarding the estimation we follow Jarociński and Karadi (2020) by including the full shock series—here, our interest rate surprise indicator—ordered first in the VAR, which is then identified recursively and estimated using the same Bayesian framework as outlined in Section II.C.[10]

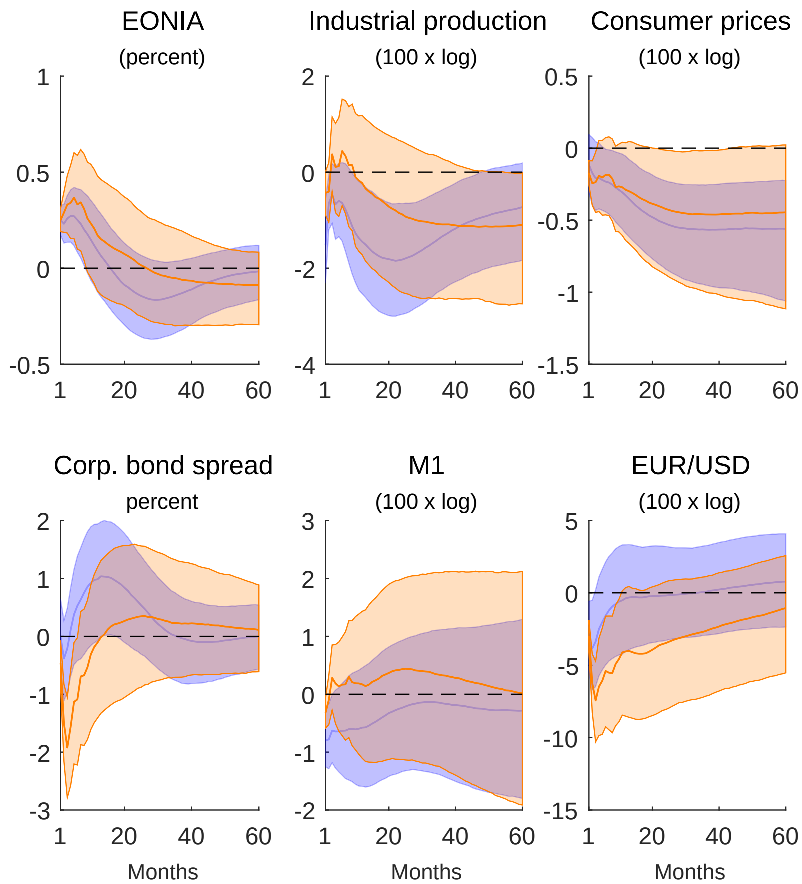

Figure 3. Impulse Responses, Standard High-Frequency Approach

Note: Impulse responses obtained with the standard high-frequency approach in orange, impulse responses from our baseline model with residual sign and magnitude restrictions in blue. Solid lines are median estimates, shaded areas correspond to 68% credible sets. The monetary policy shock has been normalized to have an impact of 25 basis points on *EONIA*.

[10]In using a Bayesian VAR framework with the same prior, this approach comes methodologically closest to the one used in the estimation of the baseline model. All parameters in the interest rate surprise equation are shrunk towards zero, which can be easily implemented by means of an independent prior. The zero restrictions ensure that the indicator series is fully captured by the residual and, hence, feeds one-to-one as a shock into the model.

Figure 3 compares the estimation results of the two approaches. Impulse responses obtained from our baseline model with residual sign and magnitude restrictions are in blue, impulse responses obtained with the standard high-frequency approach are in orange. The solid lines are median estimates, the shaded areas correspond to 68% credible sets.

While *EONIA* responds rather similarly, the effects on output, consumer prices, and money are less clear with the standard high-frequency approach and partly ambiguous. The standard high-frequency approach cannot uncover a meaningful response of output or money in the short-run and the negative effect on consumer prices is less pronounced than the one found with the baseline model. On the other hand, regarding the exchange rate, we observe larger and more sustained effects with the standard high-frequency approach compared with the baseline model.

These findings lend support to the view that the standard high-frequency approach picks up information shocks that our residual restriction approach does not: A positive information shock, i.e., one that is accompanied by rising interest rates, induces an increase in output, prices and money demand, attenuating the effects of a restrictive monetary policy shock, as in Jarociński and Karadi (2020). On the other hand, both shocks, if they raise the short-term interest rate, also lead to an appreciation of the exchange rate and, thus, reinforce each other (Brubakk et al., 2022).

Furthermore, the standard high-frequency approach yields a reduction of the corporate bond spread in response to a restrictive monetary policy shock, a result that is also found by Jarociński and Karadi (2020). The implication would be that a restrictive monetary policy shock eases financial conditions, which is at odds with standard theory. Alternatively, this finding can be interpreted as evidence for the presence of information shocks, which, if positive, would indeed elicit an improvement of financial conditions.

C. *Responses of Other Variables*

In this section, we extend our VAR model to analyze the effects of monetary policy shocks on other variables, specifically, expected inflation, long term interest rate, and broad money, which we add one by one to the baseline specification given by Equ. (1). We continue to compare our results with those from a standard high-frequency VAR.

As the left panel in Figure 4 shows, expected inflation, measured by the one-year ahead consumer price inflation forecast of the ECB Survey of Professional Forecasters (ECB, n.d.*f*), decreases systematically in response to a restrictive monetary policy shock according to our baseline model. The standard high-frequency VAR, instead, delivers a largely uninformative response. Again, this is evidence for information shocks and their absence in our approach.

Moreover, like Hafemann and Tillmann (2020) we find that the risk-free long-term interest rate as measured by the 10-year German government bond yield

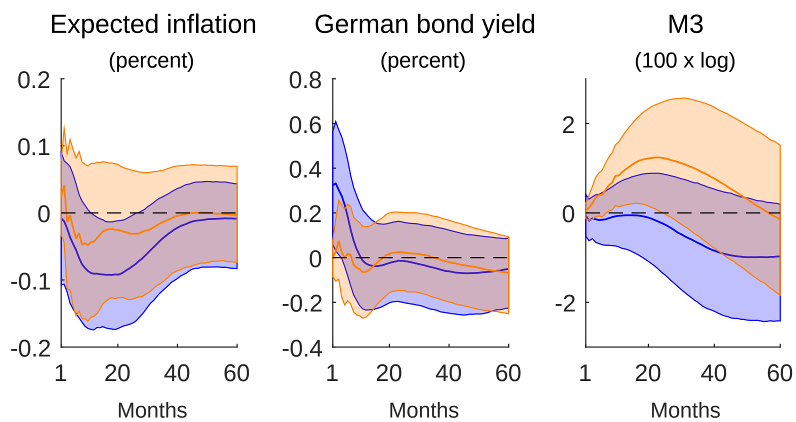

Figure 4. Impulse Responses of Other Variables

Note: Impulse responses obtained from our baseline model with residual sign and magnitude restrictions in blue, impulse responses obtained with standard high-frequency approach in orange. Solid lines are median estimates, shaded areas correspond to 68% credible sets. The monetary policy shock has been normalized to have an impact of 25 basis points on *EONIA*.

(ECB, n.d.g) increases in response to a restrictive monetary policy shock. The standard high-frequency model fails to uncover this effect, see the center panel in Figure 4.

Finally, the broad monetary aggregate (*M3*, ECB, n.d.h) seems to be hardly affected by conventional monetary policy shocks, see the right panel in Figure 4. This result is not particularly surprising given that the development of *M3* has been dominated by the effects of unconventional monetary policy measures in recent years. The standard high-frequency approach, however, yields a transitory increase in *M3*, which is at odds with standard theoretical predictions for a restrictive monetary policy shock.

D. Further Interest Rate Surprises

While we deliberately use only a few, i.e., the four largest interest rate surprises for identification, there were further events with smaller, yet sizable financial market responses to ECB announcements. We next extend the set of events considered to the fifteen largest interest rate surprises shown in Figure 1.

Table 3 gives an overview of the eleven surprises next in size to the four events already considered in Section I, online Appendix C.1 provides a more detailed narrative analysis. It confirms that all eleven unexpected interest rate decisions can be regarded as monetary policy shocks, with the exception of December 2002, which strongly features characteristics of an information shock.

Table 3—Further Interest Rate Surprises in the Euro Area

Date	*Sign*	*Description*
Nov. 7, 2002	+	Amid a worsening economic situation, the ECB does not bow to calls to cut rates.
Dec. 5, 2002	−	ECB relents in the face of the economic downturn and cuts rates by more than expected.
Mar. 6, 2003	+	Preceding statements of ECB officials misinterpreted in direction of larger rate cut.
Jun. 5, 2003	−	Markets are doubtful about a significant rate cut, so the ECB exceeds expectations.
Dec. 4, 2008	+	ECB intensifies monetary easing only cautiously and lags behind BoE's rate cut.
Jan. 15, 2009	−	Restoration of pre-crisis corridor range reduces interest rate floor disproportionately.
Mar. 5, 2009	+	Similarly to 2008, the ECB fails to meet expectations raised by preceding BoE rate cut.
Apr. 2, 2009	+	ECB cuts rates only cautiously, but stock valuations do not drop.
Jul. 5, 2012	−	Markets did not expect the deposit facility rate to be reduced to zero.
Sep. 4, 2014	−	Rate cut one month after ECB said rates would remain unchanged for longer.
Dec. 3, 2015	+	The ECB Governing Council does not follow president Draghi's push for a higher rate cut.

Note: A negative sign denotes an expansive shock, a positive sign a restrictive shock.

How does our parsimonious identification strategy with just four sign restrictions handle these events? To address this question, we consider boxplots of the structural residuals (monetary policy shocks) at the corresponding dates in Figure 5. With two exceptions (December 2002, March 2003), the median structural residuals and the interest rate surprise indicator match in sign. As the December 2002 surprise was most likely due to an information shock, our model correctly predicts the sign of monetary policy shocks in nine out of the additional ten (unrestricted) cases.

Considering the distribution of the structural residuals, in seven cases, our model clearly identifies the interest rate surprises as monetary policy shocks with the correct sign. In two instances (November 2002, April 2009), approximately half of the draws match the financial market responses. In another two instances

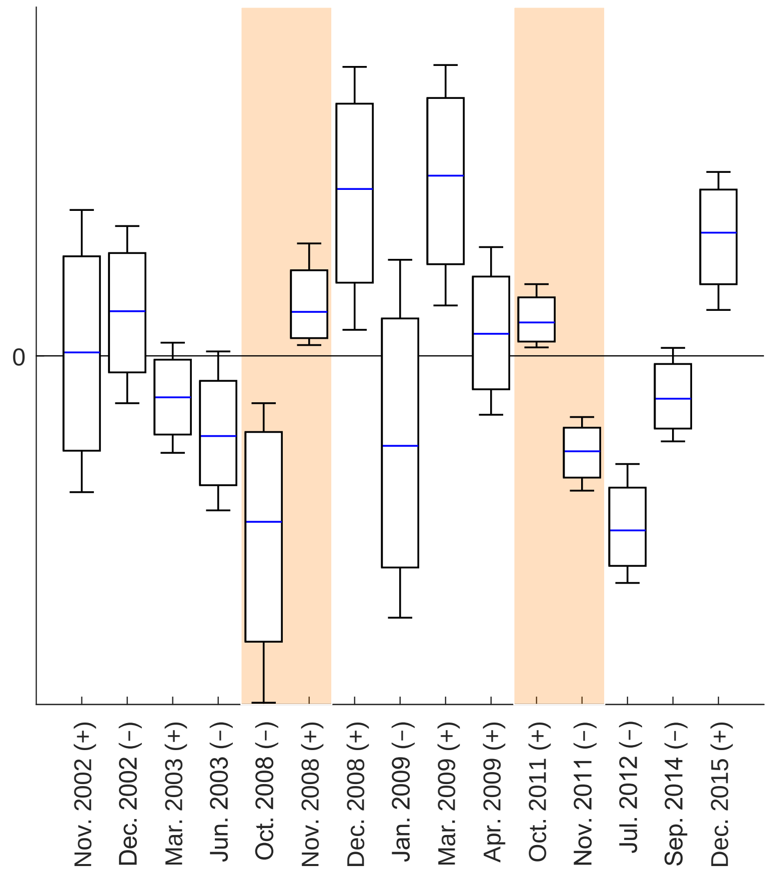

Figure 5. Structural Residuals at Dates of Sizable Interest Rate Surprises

Note: Boxplots indicating the median, 50% quantile (boxedge) and 68% quantile (whisker) of the structural residuals at dates of sizable interest surprises. The four dates used for identification, i.e., shocks where the sign is prespecified by assumption, are marked by orange shaded areas. The signs in parenthesis on the x-axis denote the direction of the interest rate surprise at the corresponding date.

(December 2002, March 2003), the majority of draws does not align with the corresponding financial market signals. Overall, we regard this result as supportive to our parsimonious approach based on just five restrictions. Nevertheless, it is of interest to consider the results from an estimation with an extended identification strategy, that uses further sign restrictions at these dates.

We opt for an identification strategy involving fourteen sign restrictions on the residuals at all dates except for December 2002 (see online Appendix C.2 for details). This extended identification leaves our estimation results largely unchanged. The result confirms that, apart from December 2002, the largest interest rate surprises in our sample were mainly driven by monetary policy shocks. Given the pronounced difference of our results compared with those from standard high-frequency identification, information shocks appear to feature predominantly in other observations with interest rate surprises of smaller magnitude.

E. Monetary Policy Shocks and Interest Rate Surprises

Figure 6 compares our interest rate surprise indicator with the median structural residuals of the monetary policy equation of our SVAR, i.e., the estimated monetary policy shocks. The latter can be interpreted as deviations from an ex-post estimated monetary policy rule as described by our model variables.[11] A first observation is that not all structural residuals and interest rate surprises match in sign and magnitude. There are also constellations, where small monetary policy shocks (policy rule deviations) have surprised financial markets, and others, where large shocks did not. We consider salient examples of all three constellations in the following.

Large Shock, Large Surprise. — There were several instances, in which large deviations from the implied policy rule came as a surprise to financial markets. Large expansive shocks include June 2003, October 2008, January 2009 November 2011 and July 2012, large restrictive shocks appear in December 2008, March 2009, and December 2015. In Figure 6, the corresponding interest rate surprises and structural shocks are marked by dark blue symbols.

A particularly notable case is July 2012, because it marks the fifth largest interest rate surprise, i.e., the next largest following the four ones used for identification. The policy measure that surprised financial markets in that month and, at the same time, constituted a significant deviation from the implied policy rule, was the reduction of the deposit facility rate to zero and not the 'Whatever it takes'-speech of Mario Draghi, which took place at the end of the same month (see online Appendix C.1). This reassures us that our identification strategy captures conventional monetary policy shocks.

Small Shock, Large Surprise. — Interest rate decisions by the ECB came not only as a surprise to financial markets, when they were particularly off the implied monetary policy rule; in some cases, small structural residuals coincide with sizable financial market responses. These instances include November 2002,

[11] We stick with the standard convention to refer to the structural residuals of the SVAR as (monetary policy) shocks. These include monetary shocks in a narrow sense, i.e., rule deviations that surprised financial markets, but also rule deviations that did not come as a surprise.

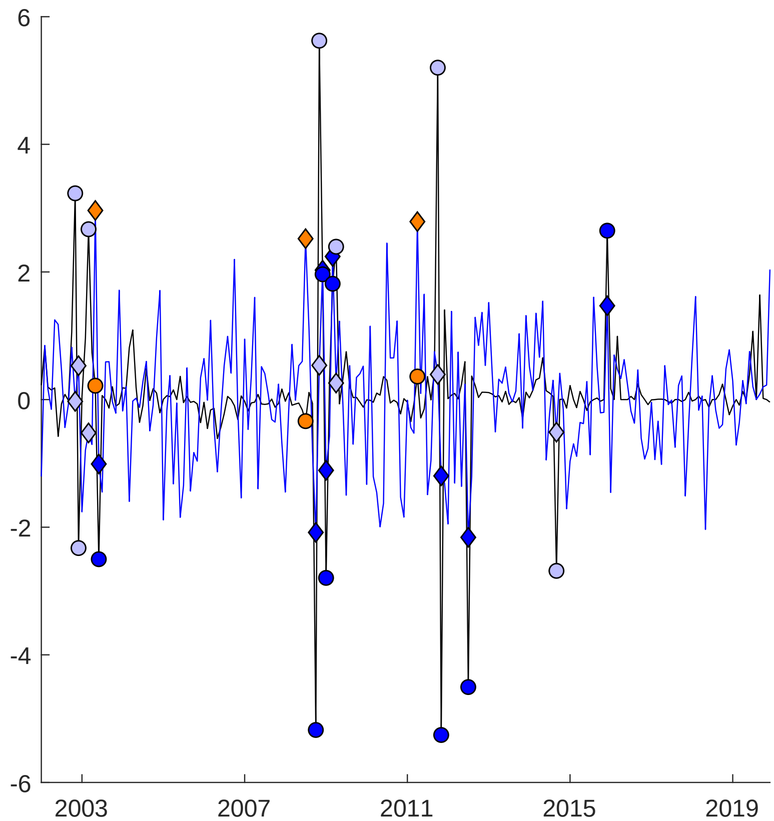

Figure 6. Structural Residuals and Interest Rate Surprises

Note: The standardized interest rate surprise indicator is marked by dots and the black line. The standardized series of point-wise median monetary policy shocks is marked by diamonds and the blue line. Dark blue symbols (dots and diamonds) indicate the coincidence of large shocks and large surprises, light blue symbols the coincidence of small shocks and large surprises, orange symbols the coincidence of large shocks and no surprises.

November 2008, April 2009, October 2011 and September 2014 (see the light blue shaded symbols in Figure 6). In two instances (December 2002, March 2003), the median structural shock has a different sign than the financial market indicator.

There are several potential reasons for such a constellation. First, all these events except for September 2014 occurred amid an economic crisis. In crisis times, financial markets may expect extraordinary (loose) policy measures, i.e., decisions that would be recorded as expansive shocks by our model. The non-occurrence of a 'bold move' then in turn leads to a (big) surprise and a corresponding jump in swap rates, even if the interest rate decision is balanced or only slightly restrictive as judged by our implied policy rule. This aligns well with the monetary policy events at hand (see online Appendix C.1).

Second, the monetary policy rule could have changed over time. Hence, what does not appear as deviation from a time-averaged ex-post rule may in fact have been a deviation from the rule in place at that time (see Gerlach and Lewis, 2014; Cour-Thimann and Jung, 2021). Third, the interest rate surprise may pertain to information effects. According to our narrative analysis, this appears to have been particularly the case in December 2002, which saw a rate cut amid a deepening recession. There is also evidence for an information shock in April 2009, as stock valuations did not drop following the interest rate announcement.

Large Shock, No Surprise. — The three largest structural residuals, however, are estimated at dates with no significant financial market responses: May 2003, July 2008, and April 2011. They are marked with orange symbols in Figure 6. Such a constellation may occur, if a deviation from the policy rule was actively aimed for by the central bank and communicated in advance.

Two of these interest rate decisions, those in July 2008 and in April 2011, were heavily debated and also criticized. In both cases, the ECB raised interest rates due to inflation concerns at a time when an economic crisis was unfolding (the global financial crisis in 2008 and the sovereign debt crisis in 2011). Hartmann and Smets (2018, p. 78-79) find that *"the interest rate increase in July 2008 does not appear to be justified by the ECB's own outlook for growth and inflation but was quickly reversed. The interest rate increases in 2011 do not show up as a major policy mistake, but seem delayed as the inflation and growth projections suggested an earlier tightening move."* While Hartmann and Smets (2018) derive their results from a policy rule estimated based on real time forecasts, we arrive at very similar conclusions.

The interest rate hike in April 2011 can indeed be interpreted as 'delayed', as our model identifies expansive monetary policy shocks in the five preceding months. Concerning the rate hike in July 2008, Corsetti, Duarte and Mann (2022, p. 523) provide evidence that it was already communicated and priced in at the press conference a month earlier: *"On 5 June 2008, (...) during the press conference, however, the president expressed concern about increased risks to price stability, setting expectations of rate hikes in the near future. In reaction to this information, the swap rate immediately jumped higher and over the afternoon increased by 27 bp."*

In contrast to these two instances, in which interest rates were raised by 25 basis points, respectively, rates were kept unchanged in May 2003, another major monetary policy shock according to our model. During this first recession in its still young history, the ECB took several unforeseen monetary policy decisions (see Table 3). One of them occurred in June 2003, when the ECB surprised the markets with an overly strong rate cut. In hindsight, this decision can hence be viewed as a correction of the decision it made one month before in May 2003, which was overly cautious according to our model though not unexpected by markets in light of the ECB's behavior since its inception.

Overall, we find the relation of interest rate surprises and structural residuals of these salient examples to fit well with our narrative analysis. Nevertheless, three qualifications shall be mentioned. First, since our parsimonious specification can only yield an approximation of the true policy rule, the structural residuals as a measure of rule deviations will contain some noise. Second, our estimates are based on final revised data and not on real-time data and forecasts available to the ECB at the time of monetary policy decisions (see, e.g., Paloviita et al., 2021). Third, while we regard the responses of interest rate expectations around policy announcements as highly informative for our identification strategy, there may have been further interesting financial market reactions to central bank decisions, especially if these decisions were communicated (or hinted at) on occasions other than official ECB Governing Council meetings.

IV. Conclusions

Official interest rate decisions by the ECB are usually well anticipated. However, in its first twenty years of existence, the ECB made several decisions that came as surprises to financial markets. Using an in-depth narrative analysis of the fifteen largest interest rate surprises, we show that the root causes of these policy shocks include, among others, resistance against outside pressure, changes in the allotment procedure, expectations raised by interest rate decisions of other central banks, and differing views among ECB Governing Council members.

Based on a subset of these large policy surprises, we measure the effects of the ECB's monetary policy, using an SVAR with residual sign and magnitude restrictions. Thereby, we combine high-frequency financial market data (to uncover interest rate surprises during official ECB policy announcements) with a narrative analysis (to make sure that the interest rate surprises used for identification are indeed monetary policy shocks).

A comparison with standard high-frequency identification shows that our approach cleans the interest rate surprises from the effects of information shocks. In line with recent studies we show that conflating monetary policy shocks with information shocks typically underestimates the effects of monetary policy.

We conclude that imposing a few well-selected sign and magnitude restrictions on the residuals of an SVAR can achieve strong identification of the effects of macroeconomic shocks. For the proper selection of these restrictions, a narrative analysis can be an adequate and attractive tool.

From a methodological perspective, an interesting question for future research relates to the conditions, under which such a rather agnostic and parsimonious identification strategy is likely to be empirically successful. One specific question pertains to the choice of the 'optimal' number of sign and magnitude restrictions. A tentative finding of this study is that magnitude restrictions appear to be crucial for the identification of SVARs with residual sign restrictions.

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