MASTER

APPLIED ECONOMETRICS AND FORECASTING

MASTER´S FINAL WORK

DISSERTATION

A NOVEL APPROACH TO IDENTIFY MONETARY POLICY SURPRISES FOR LOCAL PROJECTION IN THE EUROZONE

STEFANO ROSSI

SUPERVISION:

ADRIANA CORNEA MADEIRA

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Abstract

This paper investigates the dynamic causal effects of monetary policy in the Eurozone by proposing a novel framework that combines Principal Components Analysis (PCA) and Local Projection–Instrumental Variables (LP-IV). PCA is applied to high-frequency changes in Euro Overnight Index Average (Eonia) rates at different maturities around ECB announcements, with the scope of identifying a measure of monetary policy surprises that capture both short and medium-term market reactions. These surprises serve as an instrument for the LP-IV regression to estimate the impulse response functions of three macroeconomic indicators to interest rates shocks. The empirical analysis reveals that monetary policy surprises around ECB press conferences are a strong instrument for monetary policy shocks. Positive monetary shocks are shown to reduce the sovereign stress indicator, suggesting that contractionary monetary policy may alleviate financial stress by reducing inflation expectations. The responses of industrial production and price levels are less informative, suggesting the need for further investigation. By adopting these methodologies, this research proposes a new framework for estimating the transmission mechanism of monetary policy in the Eurozone.

Resumo

Este trabalho investiga os efeitos causais dinâmicos da política monetária na Zona Euro, propondo um novo quadro que combina Análise de Componentes Principais (PCA) e Projeção Local–Variáveis Instrumentais (LP-IV). A PCA é aplicada às mudanças de alta frequência nas taxas Eonia em diferentes maturidades em torno dos anúncios do BCE, com o objetivo de identificar uma medida de surpresas da política monetária que capture reações de mercado de curto e médio prazo. Essas surpresas servem como instrumento para a regressão LP-IV estimar as funções de resposta ao impulso de três indicadores macroeconômicos a choques nas taxas de juros. A análise empírica revela que as surpresas da política monetária em torno das conferências de imprensa do BCE são um instrumento forte para choques de política monetária. Choques monetários positivos são mostrados para reduzir o indicador de estresse soberano, sugerindo que a política monetária contracionista pode aliviar o estresse financeiro ao reduzir as expectativas de inflação. As respostas da produção industrial e dos níveis de preços são menos informativas, sugerindo a necessidade de investigações adicionais. Ao adotar essas metodologias, esta pesquisa propõe um novo quadro para estimar o mecanismo de transmissão da política monetária na Zona Euro.

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Glossary

OIS - Overnight Index Swap

PCA - Principal Components Analysis

PCA1 - First Principal Component

ECB - European Central Banks

LP - Local Projections

LP-IV - Local Projections Instrumental Variables

mps - Monetary Policy Surprises

IR - Impulse Response

ADF - Augmented Dickey-Fuller

R - Euro 1-year Government Bonds Yield

P - Harmonized Index of Consumer Price

IP - Industrial Production Index

SovCISS - Sovereign Stress Indicator

VAR - Vector Autoregression

Eonia - Euro Overnight Index Average

FOMC - Federal Open Market Committee

ESI - European Sentiment Indicator

Contents

1 Introduction

Monetary policy is a key instrument governed by the ECB to achieve growth and stability targets in the Eurozone. Through its impacts on interest rates, the effects of monetary policy propagate throughout the entire economy, from industrial production to inflation. As such, understanding the impacts of central banks' decisions has become a central theme in the macroeconomic literature. Isolating the pure effects of such decisions on the economic activity, however, remains a significant challenge.

The aim of this research is to estimate the transmission mechanism of monetary policy in the Eurozone using the most advanced methodologies from the American literature. Indeed, while for the U.S. there are numerous studies in this field, the literature for the Eurozone is still limited.

This work illustrates a new framework for estimating the dynamic causal effects of monetary policy in the Eurozone. The novelty of the approach consists in combining the Principal Components Analysis (PCA) for identifying monetary policy surprises, following Bauer and Swanson (2023), with the Local Projections - Instrumental Variables (LP-IV) method by Plagborg-Møller and Wolf (2021) and Stock and Watson (2018).

Specifically, this research analyzes the reaction over time of three key macroeconomic indicators, industrial production index (IP), Harmonized Index of Consumer Prices (P) and Sovereign Stress Index (SovCISS), to changes in monetary policy. The goal of the employed methodologies is to obtain consistent estimates of these reactions by isolating the pure effect of monetary policy shocks from other influencing factors.

By applying for the first time for the Eurozone the methodology in Bauer and Swanson (2023) (for building a monetary policy shock) with the dynamic causal effect estimation methods of Plagborg-Møller and Wolf (2021) and Stock and Watson (2018) used in U.S. research, this case-study represents a new proposal for estimating monetary policy transmission mechanism in the Euro area that can be used as a framework for future researches in the topic.

Moreover, obtaining more accurate estimates of monetary policy impacts can contribute to the understanding of macroeconomic dynamics in the Eurozone.

This dissertation is structured as follows. Firstly, the application of the methodology from Bauer and Swanson (2023) is described for the Eurozone, namely the Principal Component Analysis (PCA) of changes in the Overnight Index Swap (OIS) rates across different maturities is calculated to build the monetary policy surprises around the ECB announcements. Utilizing PCA allows to create a measure of monetary policy surprise that captures both the short-term effect of the monetary policy decision and the medium-term effect of the assessment of the economic outlook presented in the ECB's press conference. Since both components have an impact on the economy, it is fundamental to combine them to obtain meaningful estimates. Secondly, Local Projections (LP) are used to estimate the dynamic causal effects of these monetary policy surprises.

Plagborg-Møller et al. (2024) demonstrated that, assuming unrestricted lag structures and weakly stationary data, LP and Vector Autoregressions (VAR) estimate the same impulse response functions. However, LP are preferred over VAR because according to Olea et al. (2024), they are more robust to model misspecification.

The empirical analysis revealed the that Sovereign Stress Index decrease following a positive monetary policy shock. This reduction could be explained by a lowering of inflation expectation, which contributes to stabilize the markets. Price levels and Industrial Production, after an initial slight decline, exhibit an unstable pattern. This is partially coherent with economic theory, as prices and industrial production are expected to decrease following a rise in interest rates, but not for six months only.

Section 2 contains a review of the predominant literature about monetary policy surprises identification and about the estimation methods of dynamic causal effects. Subsequently, in Section 3, the procedure for constructing the monetary policy surprises measure used in the empirical analysis is presented, explaining how they are calculated around ECB announcements using principal component analysis. Section 4 illustrates the theoretical and econometric foundation of LP-IV methodology, including a detailed overview of the data used in the analysis. These descriptive chapters are followed by an empirical analysis chapter, Section 5, where the results of the work are reported. Ultimately, the conclusion summarizes the outcome of the research, underlining its limitations and suggesting cues for further studies in the field.

2 Literature Review

Understanding the transmission mechanism of monetary policy is a key issue for central banks, which manipulate interest rates to achieve the growth and inflation targets of their mandates. Their decisions can impact all aspects of the economy such as inflation, bank lending and production levels. The importance of this subject has led economists to develop numerous studies over the years. However, isolating the pure effects of monetary policy shocks is not straightforward and remains a subject of debate. Output variables are influenced by multiple factors, so it is fundamental to avoid endogeneity when estimating the impact of monetary policy.

A crucial step in these causal dynamic estimations is defining a way to measure monetary policy shocks that can be used in econometric analysis. Since exact shocks are difficult to identify, it is necessary to find a proxy to estimate their effects. To obtain consistent estimates of dynamic causal effects, this measure must be exogenous to the economic variables to which monetary policy naturally responds to.

A common measure of monetary policy surprises correlated with the shock and exogenous to other variables is the change in high-frequency interest rates around the central bank's announcements. As explained by Altavilla et al. (2019), this is motivated by the assumption that monetary policy does not respond to asset price changes or macroeconomic variables within the announcement day. Therefore, shocks to high-frequency interest rates—i.e., monetary policy surprises—are due solely to the monetary policy news. This assumption makes it possible to use monetary policy surprises as exogenous shocks in dynamic causal systems.

The use of high-frequency interest rates to measure monetary policy surprises was introduced by Kuttner (2001), and since then, it has been widely applied by many authors such as Gertler and Karadi (2015), Ramey (2016), Stock and Watson (2018), Braun et al. (2024), and Gürkaynak et al. (2004).

While the high-frequency interest rates employed in U.S. research are usually the Federal

Funds Futures Rate, studies in the Eurozone are less uniform. Some cases where high-frequency changes have been used to measure policy surprises in the Eurozone include:

Jarociński and Karadi (2020) use high-frequency responses of European swap rates based on bid and ask quotes to distinguish the effects caused by the two components of European Central Bank (ECB) monetary policy communication, namely the press release and the press conference.

Tillmann (2020) use changes in the German 10-year government bond yield on meeting days to capture the market reactions to ECB press conferences.

Kane et al. (2018) utilize the price changes of Euro area government bonds around press release and press conference windows to assess the impact of both announcements on asset prices and macroeconomic variables.

Altavilla et al. (2019) employ Overnight Index Swaps (OIS) for the Eurozone, where the index corresponds to the Euro Overnight Index Average (Eonia).

While there are numerous studies on monetary policy effects in the American literature, studies for the Eurozone are still limited. A significant contribution to help fill this gap has been made by Altavilla et al. (2019), who constructed a database of high-frequency intraday data for asset classes similar to those employed in American studies. They further contributed to understanding ECB monetary policy communication by identifying two different components of monetary policy surprises: the first one related to short-term interest rates, given by the sole release of the monetary policy decision, and the second one linked to on interest rates at 6-month up to two-year maturities, caused by the economic outlook assessment revealed during the press conference.

From the above-mentioned studies, it is evident that incorporating both the press release and the press conference is highly relevant when assessing the impact of ECB monetary policy on the real economy. Building on this insight, this work aims to provide a more complete measure of monetary policy surprises in the Eurozone.

A novel approach for combining the two communication events comes from Bauer and Swanson (2023), who propose a new way to measure monetary policy surprises. First, they compute the principal components of the changes in Eurodollar futures contracts (ED1–ED4) around Federal Open Market Committee (FOMC) announcements, which correspond to a weighted average of the target surprise factor and the path surprise factor. Secondly, they argue that monetary policy surprises can still be predicted by some variables known prior to the announcement and, to overcome this problem, they build a new monetary policy surprise orthogonal to these variables.

The first use of principal components for building policy news indicators traces back to Nakamura and Steinsson (2018), who also used a composite measure of changes in interest rates at different maturities to capture the effects of forward guidance - the U.S. equivalent of the ECB press conference.

In this context, this work applies, for the first time in the Eurozone, Principal Component Analysis to identify a valid measure of monetary policy surprises in the Euro Area that can be used to estimate dynamic causal effects. By applying PCA to high-frequency interest rate changes around ECB announcements, it is thus possible to combine in few variables the information from multiple interest rate maturities.

To estimate the dynamic response of macroeconomic variables to a structural shock, the most commonly used methodologies are the Vector Autoregression (VAR) and Structural Vector Autoregression (SVAR). A valid alternative approach is proposed by Jordà (2005): Local Projections (LP). LP consist in a series of separate regressions of the shock on the target variables at different horizons, which allows for the estimation of impulse response functions without the need to specify the entire system dynamics. In the forecasting literature, the LP are known as direct forecasts.

Plagborg-Møller and Wolf (2021) compared the two methodologies (VAR and LP), showing that they are equivalent under certain conditions and with appropriate adjustments. The choice of LP in this analysis is thus justified by the more intuitive regression interpretation of the LP impulse response estimators and their robustness to model misspecification, see Plagborg-Møller et al. (2024).

Other authors have also already used LP to estimate impulse response functions to macroeconomic shocks in the Eurozone. End et al. (2021) use LP to estimate the impulse response of aggregate demand to monetary policy shocks under different regimes. Colavecchio and Rubene (2019) use LP to estimate state-dependent impulse response functions, showing how the effects of shocks can differ based on the state of the economy. It is once again interesting to notice how the number of studies in the Eurozone employing LP is limited compared to the extensive literature in the U.S.

The framework followed in this analysis is the Local Projection–Instrumental Variables (LP-IV) approach proposed by Plagborg-Møller and Wolf (2021) and Stock and Watson (2018), which estimates LP using instrumental variables to overcome the problem of endogeneity of interest rates. More exactly, the changes in the interest rates do not reflect the pure monetary shock only, but also changes in other macroeconomic variables, hence they are correlated with the error term in the LP. To overcome the endogeneity problem, a strong instrument needs to be built. This is one of the main contributions of this dissertation, leveraging on Bauer and Swanson (2023).

3 Monetary Policy Shock

Monetary policy shocks are defined as the unanticipated component of monetary policy action. Naturally, the more unexpected the shock, the stronger the response of financial markets to central bank monetary policy's announcements. How to determine the exact amount of shock is widely debated in the literature, as the chosen measure must be uncorrelated with other shocks in order to obtain consistent estimates of the impulse responses. A common technique that satisfies this requirement is the use of monetary policy surprises, defined as the changes in high frequency interest rates around central banks' announcements. In this way, the shock is assumed to be caused solely by the announcement itself, as other factors are unlikely to have a significant impact within such a narrow time window.

This chapter proposes a new approach for identifying monetary policy surprises in the Eurozone, inspired by the most advanced methods applied in the American literature Bauer and Swanson (2023). Its novelty consists in identifying monetary policy surprises as the first principal component of the changes in the OIS rates around three different windows around the ECB announcements. These changes reflect the unexpected component of the monetary policy announcement.

The ECB announces its monetary policy in two steps: a press release and a subsequent press conference. Both windows are usually followed by strong reactions in financial markets. The two announcements plus their combination represent the three time intervals around which the monetary policy surprises are calculated. This allows to study the impact of each announcement and of the total monetary event separately.

Principal Components Analysis is a statistical technique that reduces large datasets by identifying the components that capture the most of variability. Each component is a different linear combination of the variables. In this analysis, PCA is applied to OIS rate changes across six maturities following ECB announcements. The rates are standardized, and the principal components are calculated from the correlation matrix. The first component, which explains the largest part of variability, represents the monetary policy surprise used for the empirical analysis.

3.1 High frequency identification

The ECB announces its monetary policy decision in two steps. Firstly, it issues a press release at 14:15 CET containing only the monetary policy decision, without the rationale behind it. Secondly, at 15:00 CET, it holds a Press Conference where it explains the reasons for its decision. As demonstrated by Jarociński and Karadi (2020), both announcements convey information about monetary policy and the central bank's assessment of the economic outlook and therefore they are usually followed by strong responses in financial markets, i.e. significant movement in asset prices and interest rates.

In order to correctly estimate the dynamic causal effects of monetary policy on the economy, it is necessary that the measure chosen for identifying monetary policy shocks satisfies the *exogeneity condition*, meaning that it is not influenced by other variables in the system within each period. For this purpose, the most widespread method in the literature is the use of high frequency interest rate changes in a narrow window around the monetary policy announcement. The logic behind this choice is that, as explained by Bauer and Swanson (2023) and Gertler and Karadi (2015), since monetary policy decisions are made before their public release and interest rate changes are calculated around a very narrow window, these changes are due only to the announcement itself, i.e. the monetary policy decision, and are therefore exogenous to movements in other economic and financial variables.

For the Eurozone specifically, the most common measure of monetary policy surprise are changes of OIS rates. As described above, these measures reflect changes in market expectations of the economic outlook due to ECB announcements.

Altavilla et al. (2019) built a database that contains these OIS changes at different maturities around three windows that will serve as a base of this analysis. It is structured as follows:

- Press Release: Reflects the change in the median quote from the window 13:25-13:35 before the press release to the median quote in the window 14:00-14:10 after it.
- Press Conference: Reflects the 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.
- Monetary Event: that reflects the change in the median quote from the window 13:25-13:35 before the press release to the median quote in the window 15:40-15:50 after the press conference.

Recent literature has questioned the validity of this type of monetary policy surprise. In particular, Bauer and Swanson (2023) provide evidence that news about higher output or inflation may predict high frequency interest rates changes, potentially violating the exogeneity condition. However, as detailed further in the empirical analysis Section, this does not seem to be the case for the Eurozone, where the tested predictors were found to be non-significant.

This research applies, for the first time in the Eurozone, the most advanced research methods on dynamic causal effect of monetary policy surprises on the U.S economy. The first novelty of this approach, using PCA as guided by Bauer and Swanson (2023) , is described in the next Section.

3.2 Principal components analysis

Principal Components Analysis (PCA) is a statistical technique used to reduce the dimensionality of large datasets. Each principal component corresponds to a linear combination of the variables that explains a different proportion of variability. It is particularly useful because, by construction, the first principal component corresponds to the linear combination that explains the largest amount of variability; that is, there are no other linear combinations that explain a larger proportion of variability than the first principal component.

While the interpretation of the components can be complex, for the purpose of this analysis PCA is particularly suitable because each component corresponds to a weighted average of the reaction of rates to monetary policy across different horizons. Therefore, it allows to capture in just one or two variables the effect of ECB announcments on rates both in the short and medium term.

The PCA methodological framework used for the analysis is presented as follows:

Let $OIS = (OIS_{1W}, OIS_{1M}, OIS_{3M}, OIS_{6M}, OIS_{1Y}, OIS_{2Y})$ be the (T x 6) dataset composed of the OIS changes around ECB announcements at maturities of 1 week, 1 month, 3 months, 6 months, 1 year and 2 years, where T correspond to the number of ECB announcements selected for the analysis. Data are extracted from Euro Area Monetary Policy Event Study Database of Altavilla et al. (2019).

Steps:

1. Standardize OIS so that each column has zero mean and unit variance. This is obtained by subtracting the mean of OIS_J from each element $OIS_{J,t}$ where $t = 1, \ldots, T$ and $J = 1W, \ldots, 2Y$ and then dividing by the standard deviation σ_{OIS_J}.

$$OIS_{J,t} = \frac{OIS_{J,t} - \overline{OIS}_J}{\sigma_{OIS_J}} \quad (1)$$

   From here onward any reference to OIS will refer to OIS standardized.

2. Let $C_{J,K}$ denote the correlation matrix of OIS. The off-diagonal elements of this matrix are the Pearson correlation coefficients between OIS rates at different maturities, while diagonal elements correspond to the unit variance of OIS_J standardized.

$$C_{J,K} = = \frac{\text{Cov}(OIS_J, OIS_K)}{\sigma_{OIS_J}\sigma_{OIS_K}} \quad (2)$$

3. Compute the six eigenvalues λ_i and eigenvectors $\mathbf{v}_i$ of the correlation matrix C. The eigenvalues are the solution of the characteristic equation:

$$det(C - \lambda I) = 0 \quad (3)$$

The eigenvectors $\mathbf{v}_i$ corresponding to each eigenvalue λ_i are the solution of:

$$(C - \lambda I)\boldsymbol{v} = 0. \tag{4}$$

4. Principal components are the results of the linear combinations of $\boldsymbol{OIS}$ and $\mathbf{v}_i$. Each principal component explains a proportion of the total variance equal to the ratio of its corresponding eigenvalue to the the sum of all eigenvalues.

$$PC_i = OIS\, v_i \tag{5}$$

The first principal component calculated as described above corresponds to the monetary policy surprises caused by the ECB announcement. The sum of the monetary policy surprise within each month correspond to the measure *mps* used further in the analysis. In months where ECB didn't make announcements, *mps* is equal to zero.

4 Local Projections

LP, introduced by Jordà (2005), is a popular method in the literature to estimate dynamic causal effects in macroeconomics. Unlike traditional VARs, LP are series of regression of the outcome variable at different lags on a shock of interest, which allow to estimate the impulse response over time.

For the purpose of this analysis we are interested on the effect of monetary policy shocks on some specific macro/financial variables. To obtain consistent estimate of the impulse responses, the shock of interest must be exogenous to the system, i.e. uncorrelated with the residuals of the model. Since this is usually not the case with monetary policy shocks, LP have been integrated with the use of instrumental variables (IV). An external instrument is a variable that is correlated with the shock of interest (*relevance condition*) and that is exogenous to the outcome variables (*exogeneity condition*) (Stock and Watson, 2018). If an instrument satisfies these two conditions then the estimates of the impulse response are consistent.

The purpose of this work is to estimate the dynamical causal effects of monetary policy shocks on a set of macro/financial variables using LP-IV method by Plagborg-Møller and Wolf (2021) and Stock and Watson (2018).

While it is theoretically intuitive to justify relevance condition of *mps* by the fact that *mps* reflects unexpected changes in financial markets due monetary policy actions, the exogeneity condition is more complex. In order to be a good instrument for monetary policy shocks, mps_t must be uncorrelated with the error term of the regression at all lags. Contemporaneous exogeneity is satisfied by the fact that it is unrealistic to believe that in the narrow window around the announcements *mps* is influenced by contemporaneous shocks in the macro variables. Exogeneity with respect to future lags of the macro variables is also straightforward to demonstrate, since future shocks in macro variables can not impact previous *mps*. Diverse is the relation between past shocks in macro variables and monetary policy surprises. It is reasonable to believe that the level of *mps* might be influenced by the preceding economic environment. However, by including controlled lags of the macroeconomics variables in the LP, it is still possible to avoid endogeneity.

To the best of my knowledge, it is the first study that apply PCA of Eonia swap in a LP analysis to the Eurozone economy. The detailed methodology is explained in the next subsection of this chapter.

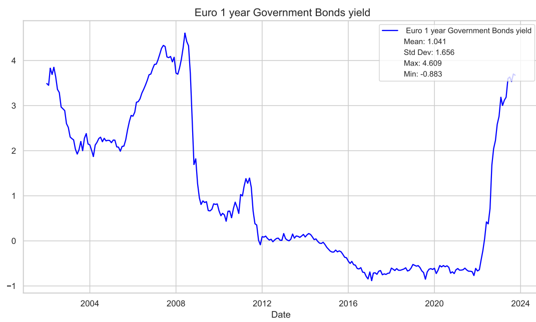
4.1 Data

This subsection describes the collection process and the features of the macro financial indicators used for this analysis: Euro 1 year government bonds yield (R), industrial production index (IP), Harmonized Index of Consumer Price (P) and sovereign stress indicator (SovCISS). The source and the construction of the monetary policy surprise (*mps*) are described in Section 3.2. All the data are monthly.

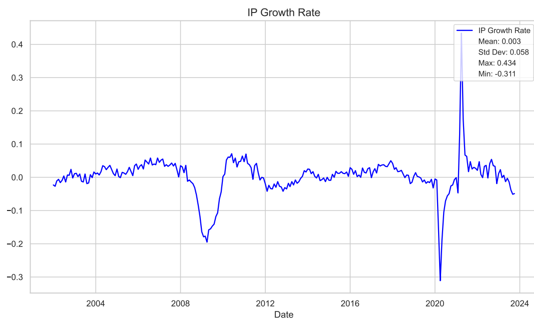
The reference database is Eurostat, from which IP, HICP and SovCISS have been extracted. R was collected from TradingView, a trading platform that stores real-time and historical market data. The industrial production index (IP) is expressed as the Eurozone industrial production growth rate. The Harmonized Index of Consumer Price (P) is first taken in logarithms, then first-differenced and multiplied by 100 to obtain growth rates. SovCISS is an indicator that measures stress in the sovereign debt market in the Euro Area.

As can be observed in Figure 1, the data covers the period from January 2002 to October 2023, counting for 262 monthly observations. R fluctuated between -0.88% and 4.61%, with an average of 1.04%, reflecting the different monetary policies of those years. IP showed extreme variability, ranging from -31% up to 43%, mainly due to spikes during the 2008 financial crisis, the COVID-19 pandemic in 2020 and the subsequent rebound. Nevertheless, its mean value remains slightly positive, at around 0.26%, indicating a general increase in industrial production over time. HICP grew on average at 0.08% per month with a moderate standard deviation of 0.2%, which is in line with the low and steady inflationary pressure typical of developed economies. Finally, SovCISS varied between 0.025 and 0.546, with an average value of 0.176, reflecting periods of financial stress inducted by economic downturns.

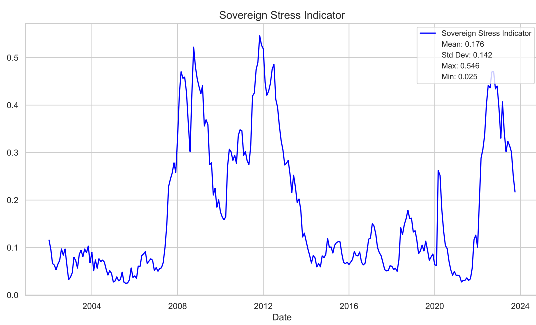
Figure 1: Macro Financial Indicators



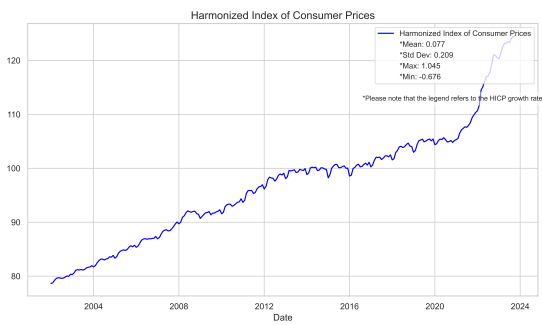
(a) Euro 1-Year Government Bonds Yield



(b) Industrial Production Index Growth Rate



(c) Sovereign Stress Indicator



(d) Harmonized Index of Consumer Prices

4.2 LP-IV Regression

This Section illustrates the LP-IV methodology by Plagborg-Møller and Wolf (2021) and Stock and Watson (2018) adopted in this work to estimate the dynamic causal effect of monetary policy shock.

Let $y_{i,t}$ denote the macro/financial variable i at time t. More exactly, $\boldsymbol{y}_t = \{R_t, 100\Delta IP_t, 100\Delta P_t, SovCISS_t\}$. The instrument is the monetary policy surprise mps_t built for the Eurozone as described in Section 3.2.

Denote by $\boldsymbol{x}_{t-1}$ the vector of controls: a constant, lags of the instrument mps_t ($mps_{t-1}, \ldots, mps_{t-p}$) and lags of $\boldsymbol{y}_t$ ($R_{t-1}, \ldots, R_{t-p}$, $100\Delta \text{IP}_{t-1}, \ldots, 100\Delta \text{IP}_{t-p}$, $100\Delta \text{P}_{t-1}, \ldots, 100\Delta \text{P}_{t-p}$, $\text{SovCISS}_{t-1}, \ldots, \text{SovCISS}_{t-p}$, $p = 6, 12$).

The objective is the estimation of the impulse responses (IR) of R_t on industrial production index, consumer price index and $SovCISS$, 2 years ahead: $h = 0, \dots, H$, $H = 25$.

In order to estimate the IRs, we have the following steps:

1. Regress mps_t on the controls $\boldsymbol{x}_{t-1}$

$$mps_t = \boldsymbol{b x}_{t-1} + u_{mps,t}, \tag{6}$$

   where $t = 1, \dots, T-25$. Save the residuals from regression (6), denoting them $mps_t^{\perp} = \hat{u}_{mps,t}$.

2. Regress R_t on the controls $\boldsymbol{x}_{t-1}$, $t = 1, \dots, T-25$. Save the residuals $R_t^{\perp}$.

3. Regress $R_t^{\perp}$ on $mps_t^{\perp}$:

$$R_t^{\perp} = \beta_R mps_t^{\perp} + \xi_{R,t}, \tag{7}$$

   where $t = 1, \dots, T-25$. Denote the OLS estimate $\hat{\beta}_R$. In this step it is important to check the F-statistic for the nullity of the parameter associated with $mps_t^{\perp}$ to verify if $mps_t^{\perp}$ is a strong instrument for R_t.

4. For $h = 0, 1, \dots, H$, $H = 24$, regress $100\Delta IP_{t+h}$, $100\Delta P_{t+h}$ and $SovCISS_{t+h}$ on the controls $\boldsymbol{x}_{t-1}$ and save the residuals $100\Delta IP_{t+h}^{\perp}$, $100\Delta P_{t+h}^{\perp}$ and $SovCISS_{t+h}^{\perp}$ respectively (there are 3 separate regressions).

4. For $h = 0, 1, \dots, H$, $H = 24$, run the following regressions

$$\begin{aligned} 100\Delta IP_{t+h}^{\perp} &= \beta_{IP,h}\, mps_t^{\perp} + \xi_{IP,t+h}^{(h)} \\ 100\Delta P_{t+h}^{\perp} &= \beta_{P,h}\, mps_t^{\perp} + \xi_{P,t+h}^{(h)} \\ SovCISS_{t+h}^{\perp} &= \beta_{S,h}\, mps_t^{\perp} + \xi_{S,t+h}^{(h)} \end{aligned}$$

   Denote by $\hat{\beta}_{IP,h}$, $\hat{\beta}_{P,h}$, $\hat{\beta}_{S,h}$ the OLS estimates.

5. The estimated impulse responses are given by the Indirect Least Squares estimates (they

estimate t he same IRs as when you do a conventional LP-IV regression, see Plagborg-Møller and Wolf (2021)):

$$\begin{aligned}\hat{\gamma}_{IP,R}^{(h)} &= \frac{\hat{\beta}_{IP,h}}{\hat{\beta}_R}\\ \hat{\gamma}_{P,R}^{(h)} &= \frac{\hat{\beta}_{P,h}}{\hat{\beta}_R}\\ \hat{\gamma}_{S,R}^{(h)} &= \frac{\hat{\beta}_{S,h}}{\hat{\beta}_R}\end{aligned}$$

6. Calculate the confidence intervals at 95% for the IRs in step 5. For this, an estimate of their standard deviation is obtained as follows. Denote

$$lim_{T\to\infty} Var\left[T^{-1/2}\sum_{t=1}^{T} mps_t^{\perp}(\xi_{j,t+h}^{(h)}, \xi_{R,t})'\right] = \boldsymbol{U}_{j,R}^{(h)},$$

a positive definite matrix of constants, estimated using a HAC with Bartlett kernel (bandwidth is $\max([T^{1/3}], h+1)$), and $j = IP, P, S$, $[T^{1/3}]$ is the integer part of $T^{1/3}$ (T is the sample size). Then, for $h = 0, 1, \ldots, H$ and $H < \infty$:

$$T^{1/2}(\hat{\gamma}_{j,R}^{(h)} - \gamma_{j,R}^{(h)}) \overset{d}{\to} N(0, v_{j,h})$$

where $v_{j,h} = \boldsymbol{D}_h' \boldsymbol{U}_{j,R}^{(h)} \boldsymbol{D}_h / \sigma_{mps^{\perp}}^4$, $\boldsymbol{D}_h = \frac{1}{\beta_R}\begin{pmatrix} 1 \\ -\beta_{j,h}/\beta_R \end{pmatrix}$ and

$$\sigma_{mps^{\perp}}^2 = \lim_{T\to\infty} T^{-1}\sum_{t=1}^{T}(mps_t^{\perp})^2.$$

The formula for $v_{j,h}$ follows by applying the mean value theorem to the ratio of estimators from step 5.

5 Empirical Analysis

This chapter presents the empirical application of the methodologies described in the previous sections. The goal is to estimate the dynamic causal effects of unexpected monetary policy shock on the Eurozone economy, combining Principal Components Analysis (PCA) and LP-IV regressions.

In the first Section, PCA is utilized to identify the most significant changes in OIS rates around ECB announcements. Starting from the EA-MPD dataset by Altavilla et al. (2019), covering the period from January 2002 to October 2023, principal components of OIS rates are extracted to measure monetary policy surprises. These components capture both the short-term and medium-term shocks to interest rates resulting from monetary policy decisions, providing a complete measure of market reactions.

The second Section addresses the potential predictability of monetary policy surprises, following the critique of Bauer and Swanson (2023), who argue that these surprises can be anticipated using macro-financial variables known prior to ECB announcements. This assumption is tested to ensure the validity of *mps* as instrument in the LP-IV regressions and thus avoiding biases in estimating impulse response functions.

Finally, the impulse response functions of the Euro 1 year government bonds yield (R) on industrial production index (IP), Harmonized Index of Consumer Price (P) and sovereign stress indicator (SovCISS) are estimated through LP - IV regressions. The goal of the analysis is to understand how such shocks propagate through the economy over time.

By proposing a new approach to identify monetary policy shock, this chapter contributes to the understanding of the transmission mechanisms of monetary policy on the Eurozone economy.

5.1 Principal components analysis

This Section describes the empirical application of Principal Components Analysis (PCA) to determine monetary policy surprises. PCA is employed to identify the most important changes in OIS rates around ECB announcements. The principal components, which are linear combinations of these changes, serve as measures of monetary policy surprises that capture both short-term and medium-term shocks to interest rates resulting from monetary policy decisions.

The OIS rates for the PCA analysis are derived from EA-MPD dataset from Altavilla et al. (2019), covering the period from January 2002 to October 2023. The starting point coincides with the moment when the ECB started to follow its Press Release with a Press Conference on the economic outlook of the Eurozone. The detailed explanation of the dataset is in Section 3.1.

As outlined in Section 3.2, six principal components of Overnight Index Swap (OIS) rates at maturities of 1 week, 1 month, 3 months, 6 months, 1 year and 2 years are calculated for each window. The Augmented Dickey–Fuller, conducted to ensure the stationarity of the variables is successfully computed before proceeding with PCA. The first principal component explains roughly 70% of the series' variability across all windows, indicating that it captures the primary movements in the data. The remaining components explain progressively smaller proportion of variance, making them less significant for identify additional patterns. The variance explained by the each principal component is detailed in Table I.

Table I: Variability of the components

	PCA1	**PCA2**	**PCA3**	**PCA4**	**PCA5**	**PCA6**
Press Release	0.745	0.188	0.039	0.020	0.004	0.004
Press Conference	0.682	0.184	0.090	0.035	0.008	0.002
Monetary Event	0.722	0.215	0.036	0.021	0.004	0.002

Each principal component is a linear combination of the original variables, whose coefficients are derived from the corresponding eigenvector. This means that changes in Eonia swap at each maturity contributes to build the monetary policy surprises. Table II below presents the above mentioned coefficients of changes in OIS rates at different maturities on PCA1 across each window.

Monetary policy surprises around press conference incorporate unexpected information from the ECB's assessment of the future economic outlook, resulting in higher weights for changes in OIS rates at longer maturities. On the other hand, changes in OIS rates at shorter maturities have greater weight with regard to monetary policy surprises around ECB press releases, reflecting the immediate market reactions. Monetary policy surprises around the entire monetary event are mostly influenced by changes in OIS rates at medium-short maturity.

Table II: PCA1 loadings

	$\mathbf{OIS_{1W}}$	$\mathbf{OIS_{1M}}$	$\mathbf{OIS_{3M}}$	$\mathbf{OIS_{6M}}$	$\mathbf{OIS_{1Y}}$	$\mathbf{OIS_{2Y}}$
Press Release	-0.3814	-0.4054	-0.4476	-0.4593	-0.4179	-0.3228
Press Conference	-0.1996	-0.3242	-0.4590	-0.4793	-0.4692	-0.4411
Monetary Event	-0.3393	-0.3814	-0.4546	-0.4645	-0.4252	-0.3739

The different weights across maturities reveal that the ECB's communications influence different parts of the interest rates curve in distinct ways. These movements are captured by the first principal component. The fact that it explains about 70% of the variance makes it a valid measure of monetary policy surprises in the Eurozone and thus a potential instrument for the LP analysis.

In order to complete the serie of *mps* used furhter in the analysis, a few steps have been taken in line with Bauer and Swanson (2023). First, in those few months where the ECB made more than one announcement, the monetary policy surprises are summed to obtain the monthly *mps*. Second, *mps* is set to zero in months where ECB did not make any announcements. Figure 2 displays the monthly *mps* series around press conferences, showing that there are 40 observation, identified by the vertical red lines, where *mps* is equal to zero.

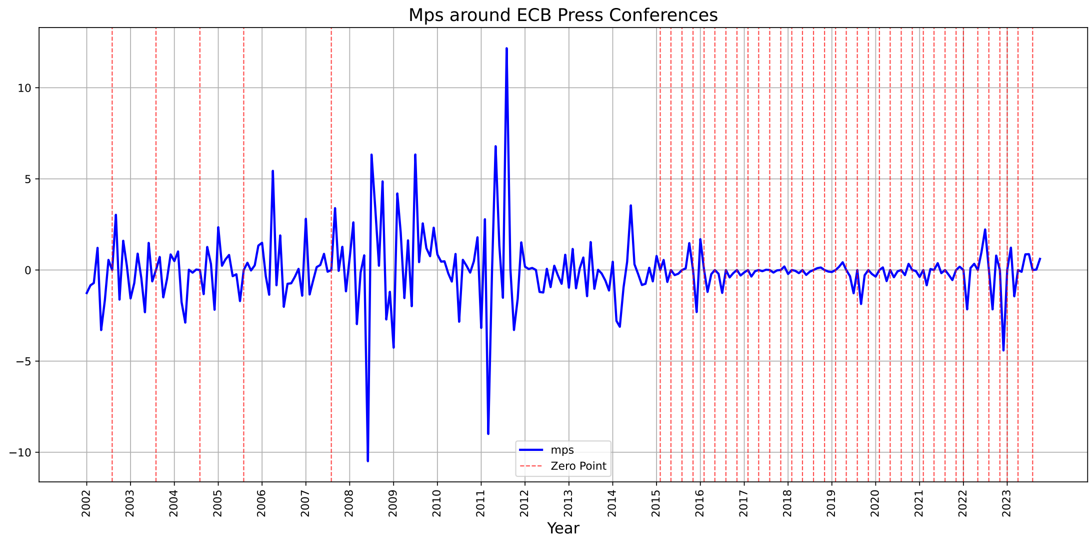


Figure 2: *mps* around ECB press conferences

5.2 Predictability of monetary policy surprises

An important criticism to the traditional identification of the dynamic causal effect of monetary policy shock is presented by Bauer and Swanson (2023). In their analysis on U.S. monetary policy, they demonstrate that *mps* can be anticipated by some macro financial variables, posing significant doubt on the validity of *mps* as an instrument. If *mps* can be predicted using variables known prior to the announcement, and these variables have an effect on y_{t+h}, the estimated impulse response would be biased. To avoid this potential bias, this assumption has been tested for each window before executing the LP-IV regressions.

These tested predictors have been chosen following Bauer and Swanson (2023) intuition and are listed below:

- STOXX log changes from one day to three months prior to ECB announcements.
- VSTOXX log changes from one day to three months prior to ECB announcements.
- Changes in the European Sentiment Index (ESI) from the announcement month to three months earlier.
- Changes in the inflation rates from one year and three months prior to one month before the announcement.

- Changes in the second principal component of the yield curve for European bonds from one day to three months prior to ECB announcements.

Linear regressions have been performed with different combinations of the predictors, using robust (to autocorrelation and heteroskedasticity) standards errors. None of the *mps* in the three windows have resulted to be predictable by any of the listed variables as none were significant at 95% confidence level and all the R^2 were below 4%. The detailed results are presented in Figures 6, 7 and 8 of Appendix A.

Unlike in the U.S., where Bauer and Swanson (2023) proved that monetary policy surprises can be predicted using variables known a priori to the announcement, the results discussed above reveal that, for the Eurozone, monetary policy surprises derived from PCA are a valid instrument for monetary policy shocks.

5.3 LP-IV Regression

This Section illustrates the results of the $LP - IV$ regressions described in Section 4.1. The objective is to estimate the impulse response functions of the Euro 1 year government bonds yield (R) on industrial production index (IP), Harmonized Index of Consumer Price (P) and sovereign stress indicator (SovCISS). Following Stock and Watson (2018) for the US case, for each monetary policy window, two impulse response functions are estimated for each variable: the first including control variables lagged up to t-6 and the second considering lags up to t-12. The results described below are relative to the strongest instrument among the six cases. Results for the other cases are detailed in the Appendix B.

A crucial step in regression with instrumental variables is to assess the relevance of the instrument, in this case *mps*. This is verified by checking that the F-statistic from the regression of R on *mps* is above 10. This threshold corresponds to the one identified by Stock and Watson (2018). The F-statistics is used to asses the significance of the parameter associated with *mps*. A low F-statistics would question the validity of *mps* as relevant instrument.

Table III summarizes the results of the F-statistics from the regression of R on *mps* controlling for 6 and 12 lags respectively. For all windows, the inclusion of more lags leads to have higher F-statistic, indicating that controlling for additional past values of the variables raise the relevance of the instrument. *mps* around press release window have demonstrated to be a weak instrument as their associated F-statistic is far below the threshold. This could be due to the fact that these monetary policy surprises incorporate less unexpected information than the press conferences. Overall, the strongest instrument is *mps* around press conference window with a F-statistic of 31.82.

Table III: F-statistic results

	6 lags	**12 lags**
Press Release	0.82	1.27
Press Conference	26.10	31.82
Monetary Event	16.61	20.14

Impulse responses of the Euro 1 year government bonds yield (R) on industrial production index (IP), Harmonized Index of Consumer Price (P) and sovereign stress indicator (SovCISS) are estimated using LP-IV methodology by Stock and Watson (2018) as described in Section 4.2, using *mps* around ECB press conference controlled for 12 lags as instrument.

Figures 3, 4 and 5 report the impulse response function of the aforementioned variables to a unit increase in interest rates, which in turn is triggered by a unit increase in monetary policy surprise. The green line represents the estimated impulse response function, while the red shaded area corresponds to the 95% confidence interval built using a HAC and the formula mentioned in Section 4.2. The horizon is expressed in months, ranging from the moment of impact (month = 0) up to two years.

Sovereign stress indicator (SovCISS) exhibits a negative reaction to a rise in interest rates. Immediately after the shock, the financial stress indicator decreases, and despite some occasional fluctuations, it continues to decline slightly over the whole horizon. A positive monetary policy shock therefore, seems to alleviate financial stress in the economy. A plausible interpretation is that a positive monetary policy shock could reduce inflation expectations and thus stabilize the financial system. In terms of statistical significance, the impulse responses are significant for the majority of the considered horizons, with the exceptions of horizon 7 and 8.

Price levels also tends to decrease following a positive monetary shock. However, the pattern becomes less clear after one year, displaying an alternation of positive and negative movements. In this case, the trajectory of prices following a tightening of monetary policy is coherent with economic theory, which predicts reduced inflation following a increase in interest rates. Nonetheless, price levels' impulse responses are not statistically significant at most horizons. Only horizons 8, 10, and 15 show responses significantly different from zero.

The industrial production index's reaction to a unit increase in interest rates is not clearly defined. There is a positive effect one month after the shock, followed by a general decrease over the next year and an increase up to two years. While it is logical that industrial production would decrease after a positive monetary policy shock, due to the expected economic contraction, the subsequent alternating positive and negative peaks are not so straightforward to interpret and require further investigation. Moreover, the responses are not statistically significant at all horizon, except for horizon 1.

All the impulse response functions' confidence intervals tend to widen as the horizon increases. This results in less precise estimates in the medium term and therefore increased uncertainty about the medium-term effects of monetary policy shock. This problem has also been highlighted by Stock and Watson (2018) for US IRs on macroeconomic variables, among others, and requires deeper examination.

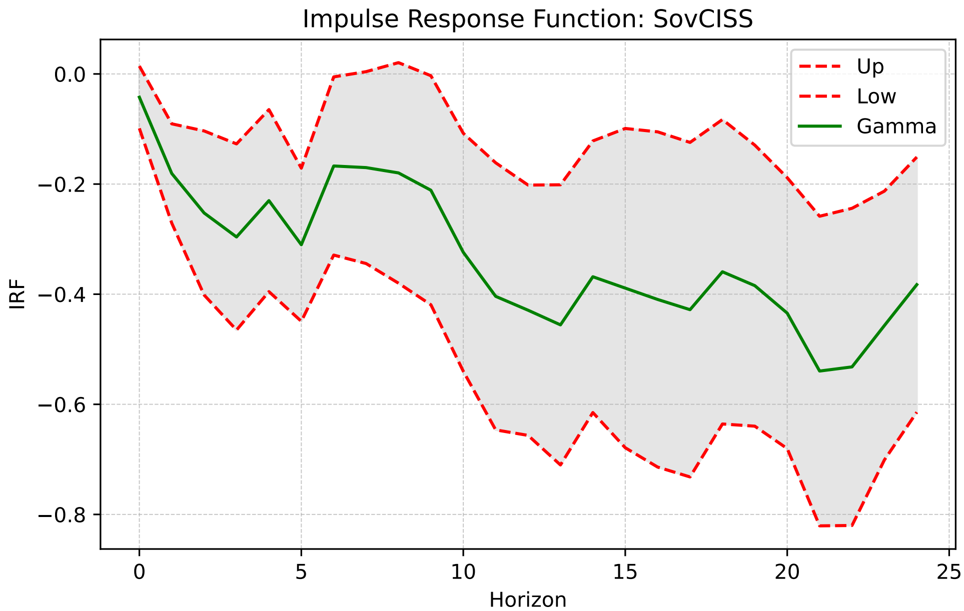


Figure 3: Impulse Response Function for *SovCISS*

Figure 4: Impulse Response Function for *IP*

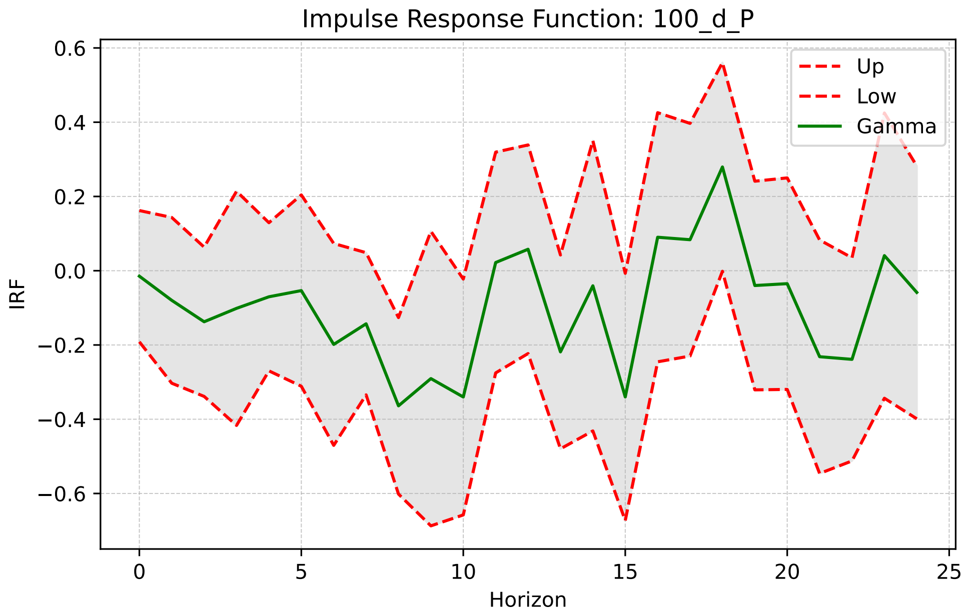


Figure 5: Impulse Response Function for P

It is interesting to compare these result to the ones obtained by Bauer and Swanson (2023), who constructed impulse responses functions for the American Economy using the same approach for identifying monetary policy surprises. For Industrial Production, the effect of a positive *mps* is a steep decline in the first ten month, followed by a persistent negative impact. For price levels, they observe a constant slight decline over the entire horizon considered after the shock, which is only in part coherent with what is observed in the Eurozone. As in this research, also in their work the variance of the impulse responses tend to increase with the horizon.

6 Conclusion

This dissertation illustrates a new framework for estimating the dynamic causal effects of monetary policy in the Eurozone by combining Principal Components Analysis (PCA) and LP-IV methodologies. Specifically, it is the first empirical application of PCA to Overnight Indexed Swap (OIS) at different maturities for identifying monetary policy surprises in the Eurozone. This approach allows to capture both the immediate and the short-medium term market reactions to ECB's monetary policy announcement. The first principal component (PCA1) accounts for roughly 70% of the variance, confirming its validity as a measure of monetary policy surprises. Monetary policy surprises have been computed for three different windows around ECB announcement to increase the set of potential instruments for the LP analysis.

Previous works have already attempted to use high frequency identification of changes in interest rates around central bank's announcement as an external instrument. However, a limitation of these approaches was the low F-statistic associated with their monetary police surprise. This research overcomes this problem by proposing a strong instrument for estimating impulse response functions.

To address concerns about the potential predictability of monetary policy surprises raised by Bauer and Swanson (2023), some macro variables have been tested for their ability to forecast monetary policy surprises. Contrary to their study on the U.S. economy, where monetary policy suprirses resulted to be predictable, for the Eurozone all the tested variables were found to be non-significant, thus satisfying the exogeneity condition required for consistent estimation of impulse response functions.

Monetary policy surprises around press conference have been demonstrated to be a strong instrument for estimating impulse response function of industrial production index (IP), Harmonized Index of Consumer Price (P), and sovereign stress indicator (SovCISS) to monetary policy shocks. The LP-IV methodology employed allowed to obtain consistent estimates of the dynamic causal effects.

The estimated impulse response functions revealed that a positive monetary policy shock leads to a decrease in the sovereign stress indicator, potentially because of the consequent decline in inflation expectation that could stabilize the market. On the other hand, the responses of the industrial production and price index were less definitive and mostly non significant. Despite observing a decline between six months and one year after the shock, these variables exhibit alternating patterns over the medium term, suggesting the need for further investigation.

To enhance a future work on this topic, several considerations are necessary. First, greater precision in quantifying impulse responses functions should be investigated. Secondly, some variance reduction techniques should be applied to reduce the variance of the forecast error, that increase along with the horizon by construction. Moreover, further investigation should be applied with respect to predictability of monetary policy surprises. More variables should be tested for their ability to predict *mps* and, in case of significant parameters, orthogonal monetary policy surprises as in Bauer and Swanson (2023) should be used. Finally it would be interesting to test the responses of financial variables that are more sensitive to monetary policy decisions, in contrast to macroeconomic variables, which tend to have a delayed reaction.

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Appendix A

This appendix contains the results of the regressions of *mps* on variables known *a priori* to the monetary policy announcement. The aim is to test the predictability of monetary policy suprises. As it is possible to notice, none of the variables result to be significantly correlated with *mps*.

Figure 6: Predictability of *mps* around press release

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                    mps   R-squared:                       0.055
Model:                            OLS   Adj. R-squared:                  0.029
Method:                 Least Squares   F-statistic:                    0.9302
Date:                Sun, 13 Oct 2024   Prob (F-statistic):              0.474
Time:                        22:53:56   Log-Likelihood:                -487.36
No. Observations:                 228   AIC:                             988.7
Df Residuals:                     221   BIC:                             1013.
Df Model:                           6
Covariance Type:                  HC2
================================================================================
                   coef    std err          z      P>|z|      [0.025      0.975]
--------------------------------------------------------------------------------
Intercept       -0.0247      0.143     -0.173      0.863      -0.305       0.256
vstoxx          -0.9001      1.252     -0.719      0.472      -3.354       1.554
stoxx            3.1108      3.172      0.981      0.327      -3.106       9.328
yields           0.1266      0.227      0.558      0.577      -0.318       0.571
infl_1y         -0.2080      0.371     -0.561      0.575      -0.934       0.519
infl_3m          0.1878      0.305      0.616      0.538      -0.409       0.785
delta_esi_3m    -0.0703      0.141     -0.500      0.617      -0.346       0.205
==============================================================================
Omnibus:                       61.595   Durbin-Watson:                   2.389
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              986.108
Skew:                          -0.493   Prob(JB):                    7.40e-215
Kurtosis:                      13.140   Cond. No.                         29.4
==============================================================================

Notes:
[1] Standard Errors are heteroscedasticity robust (HC2)
```

Figure 7: Predictability of *mps* around press conference

OLS Regression Results

Dep. Variable:	mps	R-squared:	0.011
Model:	OLS	Adj. R-squared:	-0.017
Method:	Least Squares	F-statistic:	0.4985
Date:	Sun, 13 Oct 2024	Prob (F-statistic):	0.809
Time:	22:52:24	Log-Likelihood:	-469.67
No. Observations:	222	AIC:	953.3
Df Residuals:	215	BIC:	977.2
Df Model:	6		
Covariance Type:	HC2		

	coef	std err	z	P>|z|	[0.025	0.975]
Intercept	0.0150	0.142	0.106	0.916	-0.263	0.293
vstoxx	-0.3010	0.716	-0.420	0.674	-1.705	1.103
stoxx	-3.3808	2.861	-1.182	0.237	-8.989	2.227
yields	-0.0136	0.162	-0.084	0.933	-0.332	0.305
infl_1y	-0.1412	0.161	-0.875	0.381	-0.457	0.175
infl_3m	0.0605	0.155	0.389	0.697	-0.244	0.365
delta_esi_3m	0.1110	0.112	0.992	0.321	-0.108	0.330

Omnibus:	60.956	Durbin-Watson:	2.399
Prob(Omnibus):	0.000	Jarque-Bera (JB):	997.344
Skew:	0.495	Prob(JB):	2.69e-217
Kurtosis:	13.336	Cond. No.	29.8

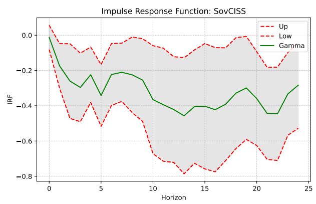
Notes:
[1] Standard Errors are heteroscedasticity robust (HC2)

Figure 8: Predictability of *mps* around monetary event

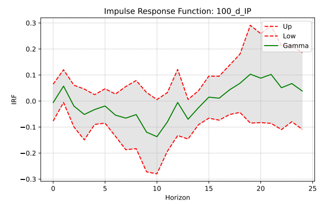
```
                            OLS Regression Results
==============================================================================
Dep. Variable:                    mps   R-squared:                       0.022
Model:                            OLS   Adj. R-squared:                 -0.004
Method:                 Least Squares   F-statistic:                    0.2387
Date:                Sun, 13 Oct 2024   Prob (F-statistic):              0.963
Time:                        22:54:35   Log-Likelihood:                -487.53
No. Observations:                 228   AIC:                             989.1
Df Residuals:                     221   BIC:                             1013.
Df Model:                           6
Covariance Type:                  HC2
================================================================================
                 coef    std err          z      P>|z|      [0.025      0.975]
--------------------------------------------------------------------------------
Intercept     -0.0076      0.143     -0.053      0.958      -0.288       0.273
vstoxx        -0.7465      1.082     -0.690      0.490      -2.867       1.374
stoxx          0.0365      3.009      0.012      0.990      -5.860       5.933
yields         0.0630      0.219      0.288      0.773      -0.365       0.491
infl_1y       -0.2636      0.300     -0.878      0.380      -0.852       0.325
infl_3m        0.1993      0.282      0.707      0.480      -0.353       0.752
delta_esi_3m  -0.0020      0.132     -0.015      0.988      -0.260       0.256
==============================================================================
Omnibus:                       31.556   Durbin-Watson:                   2.401
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              193.921
Skew:                          -0.180   Prob(JB):                     7.77e-43
Kurtosis:                       7.504   Cond. No.                         29.4
==============================================================================

Notes:
[1] Standard Errors are heteroscedasticity robust (HC2)
```

Appendix B

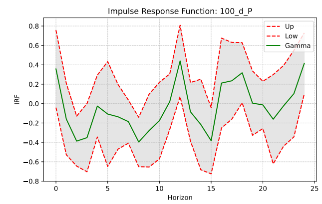
Figure 9: Impulse responses using *mps* around press conference controlled up tp 6 lags



Impulse Response Function for *SovCISS*

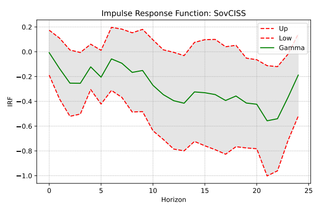


Impulse Response Function for *IP*

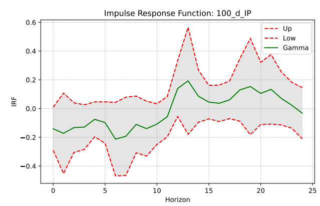


Impulse Response Function for *P*

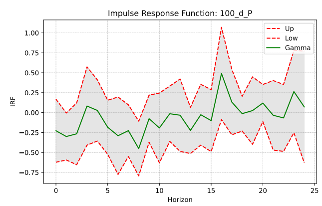
Figure 10: Impulse responses using *mps* around monetary event controlled up to 12 lags



Impulse Response Function for *SovCISS*

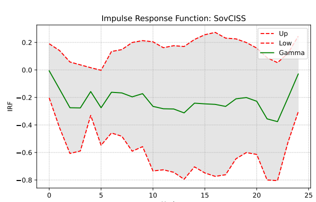


Impulse Response Function for *IP*

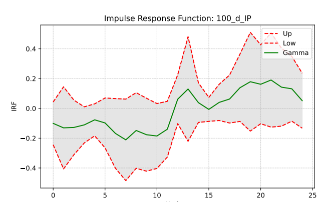


Impulse Response Function for *P*

Figure 11: Impulse responses using *mps* around monetary event controlled up tp 6 lags



Impulse Response Function for *SovCISS*



Impulse Response Function for *IP*

Impulse Response Function for *P*