Monetary policy transmission in Denmark*

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We provide estimates of the transmission of monetary policy shocks from the European Central Bank to Denmark, utilizing high-frequency changes in asset prices during policy announcements that isolate pure monetary policy shocks. Contractionary monetary policy significantly reduces both activity and inflation in Denmark. We elaborate on the consumer price response by highlighting two additional findings: a contractionary monetary policy shock leads to *i*) a significant appreciation of the effective Danish krone rate caused by an appreciation of the euro and *ii*) a significant drop in tradeable goods prices but an insignificant decline in non-tradeable goods prices.

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1. Introduction

Monetary policy takes center stage in most economies' pursuit of maintaining stable output and price developments. Key to the success of using monetary policy in this pursuit is the knowledge of how monetary policy works and at what strength it delivers its goals. Questions such as what the peak effect of monetary policy shocks is, what the lags in monetary policy are and what channels it works through, are often raised. Although decades of research have formed some long-held views on the answers to these questions, a quantitative statement is tied to the specific country that is under study. While larger economies benefit from a vast amount of empirical studies that are up to date with recent advances both in estimation techniques and identification strategies, evidence specific to smaller economies are, if any exists, more scarce.

The aim of this paper is to empirically investigate how the Danish macroeconomy responds to ECB monetary policy shocks. Danish monetary policy rates closely track those of the ECB because Denmark conducts a fixed exchange rate policy against the euro. Thus, our estimates do not only capture the effects from a change in Danish interest rates but also contractionary spillover effects stemming from the impact of ECB monetary policy on the euro area economy itself. Our main finding is that a monetary policy tightening effectively brings down real economic activity and inflation in Denmark. We find that a 100 basis points increase in the three-month money market rate, induced by a monetary policy shock, brings down consumer prices by around one percent and industrial production by eight percent after one year. Furthermore, after around one and a half year the unemployment rate is up by 1.3 percentage points.

Any empirical analysis of the transmission of monetary policy faces a significant challenge: separating monetary policy changes from those driven by economic conditions. This is a complex endeavor because central banks typically react to prevailing economic conditions when crafting monetary policies. To address this issue, we employ a, by now, well-established approach in which we analyze minute-by-minute asset price movements around monetary policy announcements by the ECB. The core idea in this identification strategy is to exploit the reaction of financial markets as a signal of the disparity between the expectations of monetary policy given the economic situation and the actual policy outcome – essentially, the high-frequency reaction of financial markets conveys a monetary policy shock. Because the identification approach uses movements in asset prices in a narrow window around policy announcements, it plausibly rules out reverse causality.

The use of financial market responses introduces two concerns. Firstly, financial markets react to both conventional and unconventional monetary policy measures. This paper's specific focus is on the effects of conventional monetary policy, necessitating the isolation of these policies from unconventional ones. We achieve this by identifying unexpected shifts in monetary policy that impact the short end of the yield curve. This isolation is carried out through a factor model, as detailed by Gürkaynak, Sack and Swanson (2005), which is estimated on changes in overnight index swap (OIS) yields across various maturities from the Euro Area Monetary Policy Event-Study Database (EA-MPD) constructed by Altavilla et al. (2019). Consequently, we select the factor that captures movements in the short end of the yield curve as our conventional monetary policy shock.

The second concern is that financial markets react not only to changes in monetary policy but also to the release of the ECB's non-public assessments of the economic outlook. This so-called 'information effect' works in the opposite direction of the monetary policy shock. For instance, while a tightening of monetary policy may suggest an intention to cool off the economy, it may also signal a stronger economic outlook than previously assessed. Research designs that do not control for information effects tend to produce biased estimates plagued by wrong-signed price responses (i.e. a price puzzle) and attenuation of the true effect on activity (Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023a). To mitigate potential biases from these information effects, we examine the simultaneous movements between stock prices and the monetary policy shock, as proposed by Jarociński and Karadi (2020). In this approach, the information component is identified as those monetary policy shocks that lead to positively correlated stock price movements. The information component is then finally removed from our series of monetary policy shocks by only retaining those shocks that are negatively correlated with stock prices.

We first estimate daily impulse responses of several financial variables. We do so to assess the validity of our monetary policy shock series and to investigate the financial channel of monetary transmission in Denmark. The financial variables include money market rates, sovereign yields, mortgage bond rates, stock prices, oil prices, and exchange rates. Our estimates firstly show that ECB monetary policy fully passes through to Danish money market rates. Secondly, we find that a monetary tightening *i*) increases yields on Danish government and mortgage bonds, *ii*) induces a short-lived but economically and statistically significant fall in oil and stock prices, and *iii*) causes the Danish krone to appreciate against the currencies of all major non-Euro trading partners. These findings lead us to conclude that our monetary policy shock series is both relevant in a Danish context and works as expected.

We then carry out our main empirical analysis, where we estimate how Danish macroeconomic variables respond to monetary policy shocks. Our baseline specification includes monthly data on industrial production, the unemployment rate, consumer prices, an energy price index, the three-month money market rate, and the US BAA corporate bond spread. We use the monetary policy shock as an instrument for the three-month money market rate.

Estimating impulse responses is nontrivial, and it is well-known that the two most commonly used approaches, Vector Autoregressions (VARs) and Local Projections (LPs), can yield significantly different estimates (Miranda-Agrippino and Ricco, 2021; Li, Plagborg-Møller and Wolf, 2024). Discrepancies arise because the two methods balance bias and variance differently, a particular issue when working with few observations. Given that our sample only spans the period from January 2002 to February 2023, the bias-variance trade-off is a concern for us. To address this issue, we employ the Bayesian Local Projections (BLP) approach proposed by Miranda-Agrippino and Ricco (2021) and Ferreira, Miranda-Agrippino and Ricco (2023). In this approach, we use estimated VAR impulse responses as priors for posterior Local Projection estimates. This allows for a data-driven method to optimally balance the trade-off between bias and variance.

Our main finding – that monetary policy shocks lead to significant contractions in the Danish economy – echoes the findings of a long list of studies on other countries.[1] In terms of magnitude, our estimates are in line with studies on other European countries by Cesa-Bianchi, Thwaites and Vicondoa (2020), Laséen (2020) and Jarociński and Karadi (2020) who employ a similar identification method. It is also important to consider that all response estimates are relative to a trend. Thus, a monetary policy contraction does not necessarily imply an actual drop in activity and prices but instead a slowdown in the economy compared to what would have occurred without the contraction. This counterfactual is particularly important to keep in mind when assessing how the economy is expected to behave during cycles of monetary policy easing or tightening, which are typically reactions to other shocks affecting the economy.

We conduct a range of robustness checks, including using the one-year money market rate instead of the three-month money market rate, excluding the pharmaceutical industry from the measure of industrial production, using an interpolated monthly measure of Danish GDP as a measure of economic activity instead of industrial production and excluding the years after the Covid-19 outbreak. Our main findings are robust to these checks.

Our results stand out in one way: we find that the effects of monetary policy shocks come with both long and short lags. While the long lags of monetary policy confirm the common wisdom from decades of empirical research, the presence of short lags is a more recent finding, often found in analyses employing high-frequency identified shocks. Jarociński and Karadi (2020), Miranda-Agrippino and

1. The scope of this paper is too narrow to do justice to the extensive list of papers that belong to the empirical literature on the effects of monetary policy. Ramey (2016) is an often cited paper for an overview of the literature. Recent related studies to ours include Cesa-Bianchi, Thwaites and Vicondoa (2020), Jarociński and Karadi (2020), Miranda-Agrippino and Ricco (2021), and Bauer and Swanson (2023a) who analyze monetary policy transmission and effects in the US, the euro area and the UK, respectively.

Ricco (2021) and Bauer and Swanson (2023a) find similar short lags for the US economy and Cesa-Bianchi, Thwaites and Vicondoa (2020) find it for the UK. Our results suggest that this is also the case for Denmark.

To uncover the drivers behind the short lag of the inflation response, we conclude by first showing that contractionary monetary policy shocks lead to a sizeable and immediate appreciation of the Danish krone against the USD, as well as a trade-weighted average of non-Euro currencies. Since Denmark is a very open economy with imports constituting over half of GDP, this result suggests that exchange rate movements are potentially important in shaping consumer price developments through their effects on import prices. We find support for this hypothesis by calculating the non-Euro area import share of each consumption category in the aggregate consumer price index and showing that the price responses of products with high import shares tend to be larger and react significantly to monetary policy shocks, in contrast to the price response of products with lower import shares.

The rest of this paper is organized as follows. Section 2 reviews previous studies related to our work, focusing specifically on providing an extensive overview of the existing evidence on the effects of monetary policy shocks in Denmark and the critical gaps in this case – the gaps that we try to fill. Section 3 examines the fundamental identification problem inherent in analyzing monetary policy effects and details our methodological approach to overcome these challenges. Section 4 presents our first set of results, demonstrating how Danish financial markets respond to our identified monetary policy shocks. These findings serve dual purposes: they offer valuable insights into financial market reactions, while validating the credibility of our shock series as relevant and well-identified exogenous changes in monetary policy. Furthermore, since financial market responses constitute a critical transmission channel, this section provides an important background for Section 5, where we analyze the broader responses of the Danish macroeconomy. Section 6 offers a series of robustness checks and extended discussions to verify the reliability of our findings. Finally, Section 7 summarizes our contributions and discusses their implications.

2. Related literature

Our paper aligns with the literature that uses high-frequency financial market surprises around monetary policy announcements to estimate the effects of monetary policy. A non-exhaustive list of studies includes Cochrane and Piazzesi (2002), Gürkaynak, Sack and Swanson (2005), Cesa-Bianchi, Thwaites and Vicondoa (2020), Jarociński and Karadi (2020), Miranda-Agrippino and Ricco (2021), and Bauer and Swanson (2023a). To our knowledge, no previous studies have used this approach to analyze monetary policy transmission in Denmark. Nonetheless, papers employing other identification approaches do exist: Beier and Storgaard

(2006) estimate the effects of changes in the Danish monetary policy rate, orthogonal to ECB/Bundesbank monetary policy rates, using a monthly Structural Vector Autoregression (SVAR) model. That is, they estimate the effects of shocks to the spread between the Danish monetary policy rate and that of the ECB/Bundesbank. This model encompasses industrial production, consumer prices, the Danish Central Bank lending rate, the ECB/Bundesbank lending rate, and the D-mark/krone exchange rate. Danish monetary policy shocks are identified through a Cholesky decomposition where real variables cannot react contemporaneously to financial variables, imposing a lag in the reactions of output and inflation to monetary policy. Not surprisingly, Beier and Storgaard (2006) find that exogenous Danish monetary policy shocks have short-lived effects on interest rates but persistent effects on the EUR-DKK exchange rate. The impulse responses for industrial production and prices are less precisely estimated, with the only statistically significant response being an increase in industrial production above trend one year after an interest rate hike.

Mikkelsen, Jensen and Spange (2017) analyze the spillover effects from the ECB's large-scale asset purchase program, using a Bayesian SVAR model of the euro area. This model incorporates industrial production, inflation, and the shadow rate at the monthly frequency. Monetary policy shocks are identified through a Cholesky decomposition, with the shadow rate ordered last, imposing a lag in the reactions of output and inflation to monetary policy. In contrast to our analysis, their focus is solely on financial spillovers to Denmark from unconventional monetary policy. Specifically, they find that the Danish term spread increases immediately following an unconventional monetary policy shock, while the effects on the EUR-DKK exchange rate are neutralized by the FX interventions of Danmarks Nationalbank.

Jensen and Pedersen (2019) study macro-financial linkages in a Bayesian SVAR model at the quarterly frequency identified using a Cholesky decomposition. They estimate relatively small and imprecise effects on inflation from an exogenous change in the Danish interest rate but find that the peak response on GDP and inflation occurs after two quarters. As in the two analyses listed above, their ordering of variables in the Cholesky decomposition entails that GDP and inflation only react to interest rate shocks with a lag.

Kronborg (2021) combines sign and short-run restrictions in a quarterly VAR model to estimate the transmission of foreign shocks, including ECB monetary policy, to the Danish economy. His estimates of impulse responses to monetary policy shocks are relatively imprecise, with only marginally significant effects on GDP and prices at the 68% level. Nevertheless, peak effects on GDP and prices occur at the one-year horizon. The estimated price level response for both Denmark and the foreign economy, however, reverts back to the trend, which is difficult to reconcile with the ECB's inflation target. The zero restrictions impose a dynamic structure on the impulse response estimates by assuming that foreign GDP reacts to ECB monetary policy shocks with a lag, while a sign restriction imposes that foreign prices fall following a contractionary monetary policy shock.

All things considered, our analysis of monetary policy transmission in Denmark differs from the above by *i*) having a narrow focus on conventional monetary policy; *ii*) relying on a state-of-the-art identification approach, where impulse responses are estimated without any restrictions on either the sign or dynamic structure; and *iii*) using the BLP estimation framework to balance off bias and variance in a data-driven approach.

In the context of other small open Nordic economies, a limited number of studies have explored high-frequency monetary policy shocks. ter Ellen, Jansen and Midthjell (2020) investigate financial spillovers from ECB monetary policy to Denmark, Sweden and Norway. However, their analysis does not control for information effects. On a parallel note, Laséen (2020) constructs a series of monetary policy shocks for Sweden, utilizing the reaction of the Swedish one-month OIS around Riksbanken's repo rate decisions and incorporating controls for information effects. Analogous to our findings for Denmark, his results indicate that contractionary monetary policy in Sweden significantly impacts the real economy by dampening economic activity, reducing prices and elevating the unemployment rate.

3. Identifying monetary policy shocks

Central banks respond to economic conditions, potentially introducing bias when regressing output and prices on changes in monetary policy rates. Exogenous changes in policy rates are hence not directly observable in the data. A well-established identification method involves inferring revisions of expected policy decisions from financial markets, specifically by examining changes in risk-free market rates within a narrow intra-day window surrounding monetary policy decisions (e.g. Kuttner, 2001; Cochrane and Piazzesi, 2002; Gürkaynak, Sack and Swanson, 2005; Gertler and Karadi, 2015). A change in market rates signifies an unexpected policy decision according to financial market participants. Conversely, when market rates remain stable, the policy decision aligns with market expectations.

To measure changes in market rates, we use market rate data from the EA-MPD database developed by Altavilla et al. (2019). This database provides asset prices within 10-minute event windows surrounding all monetary policy announcements made by the ECB's Governing Council and is continuously updated. The EA-MPD features three event windows related to the release of ECB policy decisions due to the two-step announcement process. Initially, a concise press release containing policy decisions is issued. During most of our sample period, these press releases were brief and lacked explanations for the policy decisions. However, over time, the releases have become more comprehensive, now encompassing both explanations of policy decisions and ECB staff projections.[2] The press release is typically followed by a press conference held half an hour later. During the conference, the ECB President presents the Introductory Statement and engages in a Q&A session with journalists. As shown by Altavilla et al. (2019), surprise changes to current policy rates are captured from the 10-minute window before the press release to the 10-minute window after the press release (referred to as the »press release window« in the EA-MPD). This is because no additional information on current monetary policy rates is revealed during the press conference. Hence, we focus on this narrow window in our analysis. Since the high-frequency approach is quite standard we present its main points here and relegate the technical details to Online Appendix A.

3.1. Estimating ECB monetary policy surprises

Monetary policy communications encompass multiple dimensions. One dimension involves announcing immediate changes to policy rates, impacting the short end of the yield curve. Other dimensions involve conveying information about intentions to adjust policy rates in the future, i.e. forward guidance, or intentions to undertake asset purchase programmes. These factors influence the yield on longer-term debt securities. Each of these dimensions can have diverse effects on the economy, necessitating a nuanced approach to analyzing monetary policy.

To assess the impact of immediate policy rate changes, we isolate shifts in the short end of the yield curve. We adopt the approach outlined by Gürkaynak, Sack and Swanson (2005) in constructing these ECB policy surprises. In this approach, we extract two principal components from a factor model that considers yields of one-month, three-month, six-month, one-year, two-year, five-year, and ten-year OIS instruments. We derive these yield components from data surrounding 223 ECB monetary policy decisions within the sample period spanning the period from January 2002 to June 2023.

These two components collectively explain a substantial 94 percent of the variation in yields. However, these factors do not provide a straightforward economic interpretation. To address this issue, we apply the rotation technique introduced by Gürkaynak, Sack and Swanson (2005). Specifically, we impose a condition that the second factor does not load on the one-month yield and simultaneously ensure that both factors remain orthogonal and maintain unit variance.

By implementing this rotation, we identify the different roles of these factors. The first rotated factor primarily drives unexpected changes in the ECB's current interest rate target. Hereafter we will refer to the first factor as the 'target factor', in line with the nomenclature of Gürkaynak, Sack and Swanson (2005). The second

2. Non-standard policy measures are included in the press release from March 2016, forward guidance is included from July 2016, and macroeconomic projections are included from July 2019.

factor, referred to as the ’path factor’, provides insights into alterations in the expected trajectory of future monetary policy or other policy operations that impact the longer end of the yield curve, such as asset purchase programmes.

Table 1 displays the outcome of the rotation procedure, emphasizing the two distinct facets of monetary policy. The table provides estimates obtained from individual regressions of the factors against OIS yield changes. These estimates reflect the factor loadings following the rotation procedure. The target factor mainly loads on maturities of one year or less while exhibiting minimal explanatory power beyond the two-year maturity. This pattern aligns with the target factor primarily capturing immediate adjustments in ECB policy rates. In contrast, the path factor exerts a lesser influence on short maturities, with no effect on one-month rates by design, but it exerts the most significant impact on rates on the two-year horizon and beyond.

Table 1: Rotated factor loadings

	Target factor		**Path factor**	
	Loading	R^2	Loading	R^2
OIS 1M	1.0	0.867	0.0	0.0
	(0.092)		(0.186)	
OIS 3M	0.892	0.913	0.172	0.025
	(0.054)		(0.18)	
OIS 6M	0.747	0.808	0.37	0.144
	(0.063)		(0.148)	
OIS 1Y	0.556	0.415	0.729	0.517
	(0.112)		(0.111)	
OIS 2Y	0.313	0.119	0.967	0.821
	(0.145)		(0.059)	
OIS 5Y	0.095	0.012	1.0	0.961
	(0.122)		(0.029)	
OIS 10Y	-0.066	0.01	0.719	0.881
	(0.082)		(0.036)	

Notes: The table presents the rotated factor loadings obtained from one-by-one regressions of the factors on OIS rates. Factors are scaled such that the target factor has a one basis point effect on the one-month OIS rate and the path factor has a one basis point effect on the 5Y OIS rate. Heteroskedasticity-robust standard errors are shown in parentheses.

3.2. Removing information effects

Our estimates of ECB monetary policy surprises capture changes in monetary policy relative to market expectations prior to the release of ECB Governing Council decisions. These surprises may capture true monetary policy surprises – i.e. monetary policy shocks – but can also be contaminated by market participants contemporaneously adjusting their beliefs about the economic outlook. For example, when the ECB tightens monetary policy, while signaling that the economic outlook is strong, market participants may infer that they have asymmetric information about the economic outlook and revise their inflation expectations upward. In fact, it is well-known that monetary policy surprises identified through high-frequency responses of asset prices can be predicted ex post based on central banks' output and inflation forecasts, as well as revisions to these forecasts (Nakamura and Steinsson, 2018; Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023a). Moreover, data show that market participants do modify their forecasts in response to central banks' non-monetary signals about the economic outlook (Romer and Romer, 2000; Nakamura and Steinsson, 2018).

These observations have led to the interpretation that central banks possess non-public information about the economic outlook, known as the 'information effect'. Consequently, a portion of our estimated target factor, Z^{Target}, can be attributed to the central bank's assessment of the economic outlook:[3]

$$Z^{Target} = Z^{Target,MP} + Z^{Target,Info},$$

where $Z^{Target,MP}$ is the true monetary policy shock component of the target factor and $Z^{Target,Info}$ is the information component of the target factor. We are only interested in the true monetary policy shock component $Z^{Target,MP}$ and hence need to remove the effects from the information component.

$Z^{Target,Info}$ reflects a myriad of non-monetary shocks to which the ECB responds. As a result, it is a confounding variable that we should control for in order to obtain causal estimates of the effects of monetary policy shocks. Previous research has shown that failing to purge information effects can bias estimates when

3. An alternative perspective is offered by Bauer and Swanson (2023b), who challenge the notion that the Federal Reserve has an information advantage over private professional forecasters. They suggest that high-frequency changes in asset prices around monetary policy announcements may result from a 'Fed response to news' channel, where both the Federal Reserve and professional forecasters react to the same economic news, while financial markets have imperfect information about the Federal Reserve's response to economic developments. Sastry (2022) also finds little evidence of a Fed information effect, and Hoesch, Rossi and Sekhposyan (2023) note that while the effect has been significant historically, it has weakened notably in recent years.

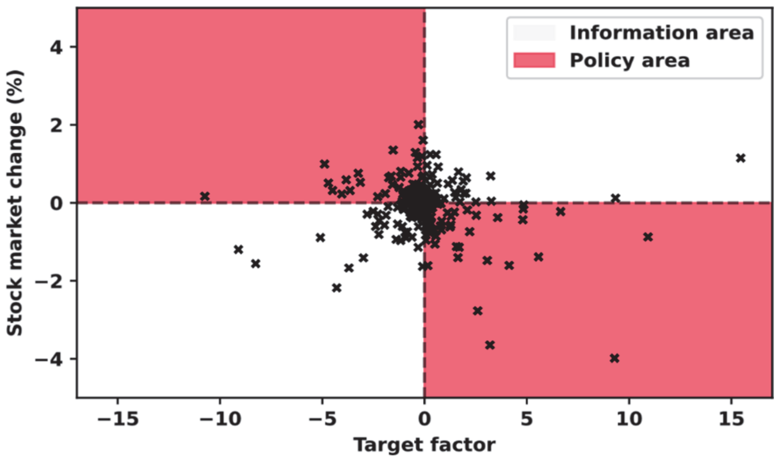
assessing the impact of monetary policy shocks (Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021). Not only are the magnitudes of the estimated impulse responses affected, but the sign of the response can also flip for some variables. We show in Online Appendix D.1 that this well-established result from studies on other countries also holds true in the Danish case, warranting our need to address this concern.

To see how and why information effects may confound our results, consider a scenario where the ECB tightens monetary policy in order to quell strong demand. If market participants interpret the tightening of monetary policy as a signal of stronger inflationary pressures than they expected prior to the policy tightening, this may lead to an upward revision of inflation expectations. In consequence, the dampening effect of the monetary tightening on inflation is counteracted by the upward revision of inflation expectations. In a severe case of this scenario where the information effect dominates the policy effect, inflation will rise despite the monetary policy tightening. In such case, failing to purge the information effect from Z^{Target} implies a price puzzle. As Online Appendix D.1 indeed shows, information effects causally imply an increase in inflation.

The discussion above demonstrates that an additional step is required if we are to isolate a pure monetary policy shock. To cleanse our monetary policy shocks from information effects, we adopt the approach proposed by Jarociński and Karadi (2020). This approach leverages the simultaneous response of stock prices during the monetary event window to derive a monetary policy shock that is orthogonal to the information component. Figure 1 visually illustrates the basic idea of the Jarociński and Karadi (2020) approach by plotting the estimated target factor against changes in the Euro Stoxx50 index during the event window.

Figure 1 shows that for approximately 45 percent of the monetary events in our dataset, stock prices move in the same direction as the target factor (shown in the white quadrants). This implies that a monetary tightening, as measured by an increase in OIS rates, is associated with an increase in stock prices, a pattern challenging the conventional understanding of the transmission of monetary policy shocks. Jarociński and Karadi (2020) interpret this positive co-movement between OIS rates and stock prices as the 'information effect'. Conversely, when stock prices display negative co-movement (red quadrants), this is interpreted as a standard monetary policy shock, i.e., a change in monetary policy rates that is unrelated to the economic outlook.

Figure 1: Stock market response and target factor



Notes: The figure plots the estimated target factor against the percentage change in European stock prices (as measured by the Euro Stoxx50 index) during the Monetary Event Window. Sample period: January 2002 to June 2023.

We employ the so-called 'poor man's' sign restriction approach as outlined by Jarociński and Karadi (2020) to disentangle monetary policy shocks from information effects. In this approach, the monetary policy shock is set equal to the estimated target factor when the factor and stock prices exhibit opposite movements (depicted in the red areas in Figure 1), while it is set to zero when they move in the same direction (white areas).

In a robustness check, we also explore rotational sign restrictions that allow for both types of shocks to be active simultaneously, following the approach introduced by Jarociński (2022).[4]

3.3. Predictability tests

Structural shocks are often defined as uncorrelated and exogenous forces that are economically meaningful (Ramey, 2016). Hence, if the estimated monetary policy and information shocks can be predicted by publicly available information, it

4. Miranda-Agrippino and Ricco (2021) use an approach to remove the information effect from Federal Reserve monetary policy shocks by directly controlling for Federal Reserve staff (Greenbook) projections. However, this method may not be as suitable for ECB monetary policy shocks, as the ECB only publishes staff projections on a quarterly basis and not for every Governing Council meeting. We have experimented with constructing an alternative version of our shock series inspired by the methodology in Miranda-Agrippino and Ricco (2021) using ECB staff projections. However, this performed poorly since the lack of staff projections for every Governing Council meeting results in a noisy shock series.

would call into question the exogeneity of such shocks. In the case of the Federal Reserve, Miranda-Agrippino and Ricco (2021) and Bauer and Swanson (2023a, 2023b) present evidence that high-frequency shocks are indeed predictable.

We find little evidence of predictability in our estimated shocks. To test the predictability of our estimated shocks, we regressed both the monetary policy and information shocks on the most recent release of four key euro area variables available prior to the monetary policy announcement: 1) GDP growth, 2) the unemployment rate, 3) headline HICP inflation, and 4) core HICP inflation. These regressions were carried out using both the level and first-differences of the four variables. To ensure that we use the same data as that available for market participants, we use the latest data point from Eurostat available before any revisions.

The resulting R^2 values from these regressions are 0.031 for both the monetary policy shock and the information shock. Therefore, news about developments in euro area output, unemployment and prices cannot explain any significant share of the variation in our estimated shocks, which lends credibility to our estimated shocks.

4. Transmission to Danish financial markets

The first part of our results concerns the reaction of Danish financial markets to ECB monetary policy shocks. We estimate the response of different financial asset prices at the business day frequency using local projections.[5] Additionally, we estimate how Danish financial markets respond to information shocks (i.e. increases in the target factor that are positively correlated with stock prices around ECB monetary policy decisions).[6]

We investigate the response of 15 financial variables. These variables encompass a range of financial indicators, including Danish money market rates at various maturities (one, three, six and 12 months), two-year and 10-year Danish government bond yields, both short and long mortgage bond yields, the natural logarithm of the Danish krone exchange rate against major trading partner currencies (USD, GBP, JPY, SEK, and NOK), the natural logarithm of the Danish C20 stock market index, and the natural logarithm of Brent oil prices.[7]

5. We opt for local projections when estimating the financial market response because the daily frequency of financial market data yields a large sample.
6. As per the discussion above in Section 3.2, however, the term information shock is a misnomer, since it is not a structural shock. Instead, it captures different types of shocks to which the ECB responds (Ricco, Savini and Tuteja, 2024).
7. While the euro area represents Denmark's largest trading partner, the EUR-DKK exchange rate remains unaffected by monetary policy shocks due to the krone's tight peg to the euro. Attempts to estimate the response of the EUR-DKK exchange rate using OLS estimators proved numerically unstable, likely because the exchange rate remained nearly constant throughout our sample period.

The local projection impulse response estimates are obtained by regressing each of the financial variables onto the simultaneous shock variable (either the monetary policy or information shock). As controls, we include lags of the dependent variable, the shock and the 14 other financial variables. The purpose of the controls in our setting is not to ensure identification, since the shock by itself constitutes a credible, unpredicted shock. Instead, the aim is to increase efficiency by having controls that act as predictors of the dependent variable (Olea et al., 2025). In order to construct confidence bands, we follow the lag-augmentation approach of Olea and Plagborg-Møller (2021) in which we control for a conservative number of lags (30 days) in the local projections and apply heteroskedasticity-robust standard errors.[8]

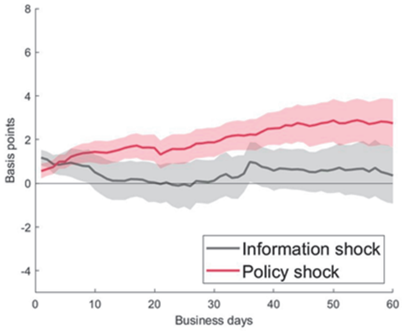
Given the high-frequency nature of our data and the tendency of asset prices to react swiftly to news, we are meticulous in considering the timing of the underlying data. Therefore, when we refer to asset prices on day *t*, we are referencing prices recorded after the window in which ECB policy decisions are typically announced (typically the closing market quote).[9]

Estimates of rate responses are shown in basis points, while the impulse-response estimates of other variables are presented in percentages. Both shocks are normalized to produce a one basis point increase in the 1M OIS during the narrow window when monetary policy is announced.

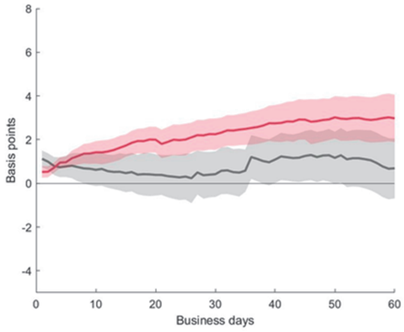
Figure 2 shows the responses of the 1M, 3M, 6M and 1Y Danish money market rates to, respectively, the monetary policy and information shock. A contractionary ECB monetary policy shock leads to a persistent increase in Danish money market rates. In contrast, an information shock only leads to short-lived and statistically insignificant responses. We suspect that this difference in the responses to information shocks is because non-monetary shocks to economic fundamentals alter the responses for two main reasons. First, Danmarks Nationalbank does not always follow the ECB by changing monetary policy rates one-for-one with ECB monetary policy rates. Second, the money market rates in our data are CIBOR rates for about the first half of our sample, after which we use CITA rates. CIBOR rates are based on unsecured loans and are not free of credit risk, which may be affected differently by information shocks compared to monetary policy shocks.[10]

8. There is yet little consensus on lag length selection in local projections. Following Olea et al. (2025) we have estimated separate *AR(p)* models with varying lag length, *p*, for each of the variables in the local projections model. The Akaike information criteria obtained from this exercise favor a short lag length ($p < 60$ days) for all variables except interest rates. Regardless, we show that our results are robust to the number of lags in Online Appendix C.3.
9. These series are available at daily frequency, except for mortgage yields, which are measured weekly and then interpolated to match the daily frequency. A detailed description of the data series and our approach to addressing timing issues can be found in Online Appendix B.
10. See Abildgren (2023) chapters 3 and 4 for a description of credit risk in the Danish money market and the monetary policy interest rate spread between Denmark and the euro area.

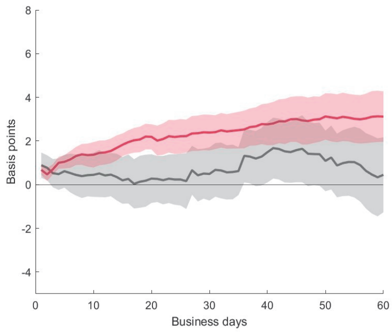
Figure 2: Money market rate responses to monetary policy and information shocks



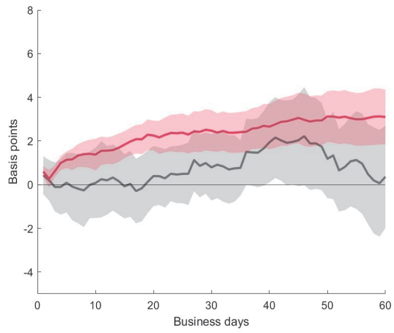
(a) One-month money market rate



(b) Three-month money market rate



(c) Six-month money market rate



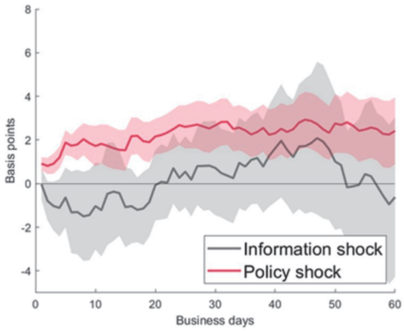
(d) One-year money market rate

Notes: The figure shows the estimated impulse-response function to a monetary policy shock (red) and an information shock (grey) on a daily horizon. Estimates are obtained from local projections with 30 lags. Bands indicate 10% confidence intervals constructed using heteroskedasticity-robust standard errors.

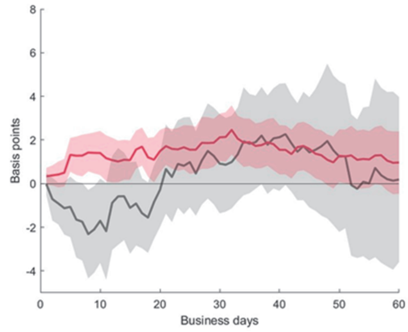
Figure 3 shows the responses of government and mortgage bond yields. Government and mortgage bond yields increase following a contractionary monetary policy shock with less significant responses for bonds with longer maturities, which is to be expected for conventional monetary policy shocks. Information shocks, on the other hand, do not lead to significant responses.[11]

11. Keep in mind that the response of mortgage bond yields should be interpreted with caution, as we rely on interpolated weekly time series.

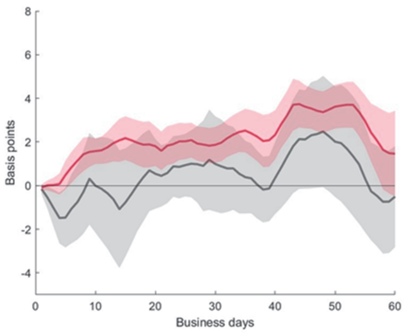
Figure 3: Government and mortgage bond yield responses to monetary policy and information shocks



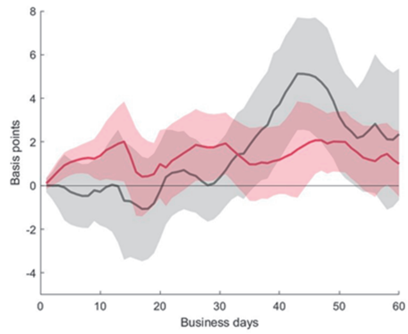
(a) Two-year government bond yield



(b) 10-year government bond yield



(c) Short mortgage bond yield

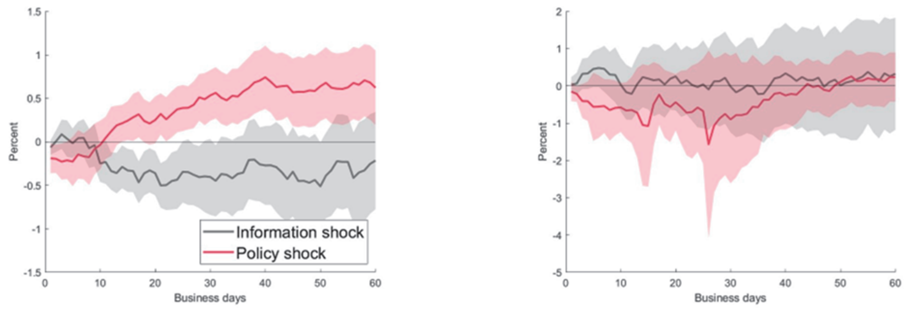


(d) Long mortgage bond yield

Notes: The figure shows the estimated impulse-response function to a monetary policy shock (red) and an information shock (grey) on a daily horizon. The long mortgage yield refers to an average of the yield on 30-year callable mortgage bonds, while the short mortgage yield refers to the yield on non-callable mortgage bonds with a maturity of less than two years. Estimates are obtained from local projections with 30 lags. Bands indicate 10% confidence intervals constructed using heteroskedasticity-robust standard errors. currency).

Figure 4 shows the reactions of Danish stock prices and oil prices (in US dollars). Despite the identification procedure implying a decline in European stock prices within the narrow policy announcement window, it may appear surprising that Danish stock prices only exhibit a short-lived and relatively insignificant drop immediately after a monetary policy shock.[12] However, it is worth noting that Jarociński (2022) also only estimates a statistically significant fall in European stock prices on impact using an identical identification approach but insignificant effects afterwards. On the other hand, the reactions of oil prices are more intuitive, showing a decline following a monetary policy shock, although the effect is not highly significant.

Figure 4: Stock market and oil price responses to monetary policy and information shocks



(a) Stock prices (b) Oil prices

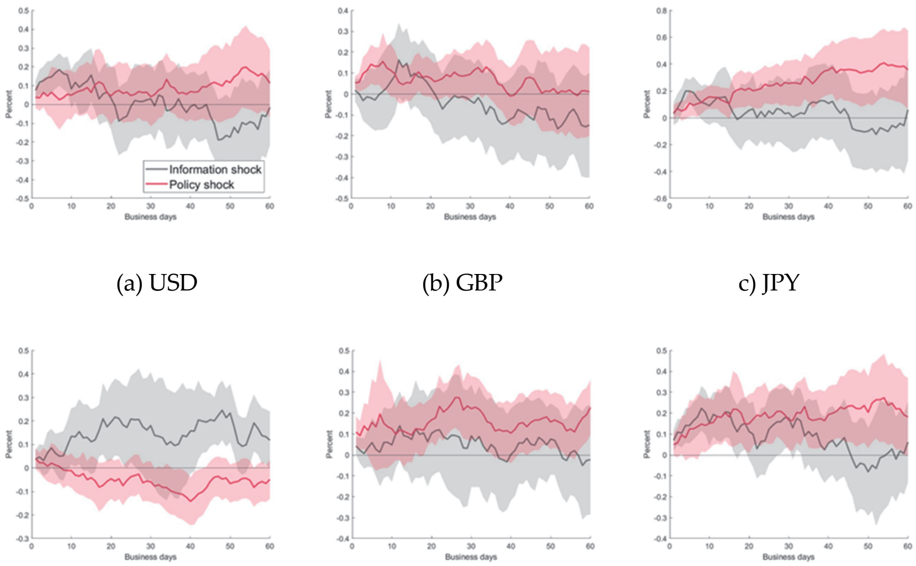
Notes: The figure shows the estimated impulse-response function to a monetary policy shock (red) and an information shock (grey) on a daily horizon. Estimates are obtained from local projections with 30 lags. Bands indicate 10% confidence intervals constructed using heteroskedasticity-robust standard errors.

4.1. Responses of exchanges rates

Next, we show that exchange rates against the Danish krone respond heterogeneously to ECB monetary policy shocks.[13] Figure 5 shows the impulse response estimates of individual currencies' exchange rate vis-á-vis the Danish krone to policy and information shocks. In addition to the currencies in our baseline local projections, we also show the response of the Chinese renminbi in the subsample after August 2005.[14] All responses are reported in 100 times the log exchange rate of foreign currency per Danish krone (a positive response is a depreciation of the foreign currency).

12. We explored whether the stock price response is affected by specific sectors by conducting estimations on Nasdaq OMX supersector equity indices. However, the results from this exercise align with our baseline estimates.
13. Of course, these responses are in fact how currencies move against the euro because of the Danish krone's tight peg to the euro.
14. The renminbi was pegged to the US dollar prior to 21 July 2005.

Figure 5: Nominal DKK exchange rate response vis-á-vis individual currencies to ECB monetary policy shocks



(a) USD (b) GBP c) JPY

(d) SEK (e) NOK (f) CNY

Notes: The figure shows the estimated impulse-response function at a daily horizon to a monetary policy shock (red) and an information shock (grey). Estimates are obtained from local projections with 30 lags. Bands indicate 10% confidence intervals constructed using heteroskedasticity-robust standard errors.

All currencies depreciate following a monetary policy shock except for the Swedish krona. The depreciation follows the predictions of the uncovered interest rate condition: if the interest rate of the ECB increases, while the foreign interest rate is unchanged, then the euro must appreciate since euro bonds yield a higher return. Thus, even though the peg against the euro shields Denmark from EUR-DKK exchange rate movements, the appreciation of the euro against the currencies of Denmark's remaining trading partners affects the Danish economy. The slight, but statistically insignificant, depreciation of the Swedish krona after a contractionary monetary policy shock is consistent with the findings of Franz (2020). As documented by ter Ellen, Jansen and Midthjell (2020) and Franz (2020), ECB monetary policy shocks tend to spill over to Swedish and Norwegian interest rates, which will reduce the exchange rate response by muting these countries' interest rate differential to the euro area.

Overall, the responses to information shocks are less significant compared to those to the monetary policy shock. This may indicate that these responses are caused by other shocks to economic fundamentals than pure monetary policy shocks, which drive exchange rates. However, the US dollar depreciates on impact, while both the Swedish krona and the renminbi depreciates.

5. Macroeconomic responses to monetary policy shocks

The second part of our results concerns the reaction of the Danish macroeconomy to ECB monetary policy shocks.

Our baseline model consists of six variables: industrial production, the unemployment rate, the consumer price index, an energy price index, the three-month money market rate, and the US BAA corporate bond yield relative to the yield on the 10-year Treasury.[15] We work with monthly data from January 2002 to February 2023. Industrial production, the consumer price index and the energy price index enter the model in (natural) log-levels. For the unemployment rate, the money market rate and the corporate bond spread, we use the percentage levels. Online Appendix B.2 contains elaborate details on all the data used for our analyses of macroeconomics responses, including those used in robustness checks.

The Covid-19 period caused extreme movements, especially in industrial production and the unemployment rate. We handle this issue by including three separate, exogenous dummies in our main model for March, February and April of 2020, as proposed by Lenza and Primiceri (2022).[16]

We estimate impulse-response functions using Bayesian Local Projections (Miranda-Agrippino and Ricco, 2021; Ferreira, Miranda-Agrippino and Ricco, 2023). The baseline model of interest is an LP(p) with p = 12 lags, given by

$$y_{t+h} = c^{(h)} + B_1^{(h)} y_t + \cdots + B_{12}^{(h)} y_{t-12+1} + \varepsilon_{t+h}^{(h)}. \qquad (1)$$

15. The spread is included to capture global financial conditions and thereby the credit channel of monetary policy (Cesa-Bianchi, Thwaites and Vicondoa, 2020; Jarociński and Karadi, 2020).
16. As a robustness check, we also run the main model where we end our sample period in 2019, right before the Covid-19 outbreak. Results from this exercise are presented in Online Appendix D.5 and show that our main results still go through.

In Equation (1), y_t is our six-dimensional vector of endogenous variables, $c^{(h)}$ is a six-dimensional vector of constants, $B_i^{(h)}, i = \{1, \dots, 12\}$, are six-by-six dimensional coefficient matrices and $\varepsilon_t^{(h)}$ is a six-dimensional vector of reduced form shocks to the model economy. We use 12 lags in estimation of all h-step ahead responses.[17] The LP model gives rise to the well-known h-step ahead impulse-responses

$$IRF_h^{LP} = B^{(h)} A_0^{-1}, \tag{2}$$

where A_0^{-1} is a six-by-six dimensional identification matrix that maps the reduced form shocks in Equation (1) to structural shocks. Equation (2) makes clear that both the identification matrix A_0^{-1} and the reduced form parameter estimates $B^{(h)}$ influence our impulse response estimates. Getting both of these right is hence crucial to our analysis.

To identify monetary policy shocks, we follow Miranda-Agrippino and Ricco (2021) in employing an external instruments approach. This approach does not impose constraints on contemporaneous relationships between variables through e.g. recursive ordering.[18] Instead, we use our high-frequency identified monetary policy shock series as an external instrument for the three-month money market rate. The identification matrix A_0^{-1} is constructed such that it isolates the structural shock of interest (the monetary policy shock), while allowing for contemporaneous responses across all variables in the system. This approach follows Mertens and Ravn (2013) and Stock and Watson (2018) and allows us to focus specifically on monetary policy shocks without making assumptions about the ordering of other macroeconomic variables or their contemporaneous responses. The external instrument methodology is particularly valuable in our context as it preserves the high-frequency identification advantages while accommodating the potential for rapid transmission through financial markets.

The identification scheme requires that the usual assumptions of relevance and exogeneity of the instrument are fulfilled. That is, the instrument is correlated with monetary policy shocks and is uncorrelated with all other shocks in the system. Section 3 established the basis for these assumptions to be met. By this approach, we are able to directly answer how the Danish macroeconomy responds to an X basis points shock to the money market rate given estimates of the reduced form parameters $B^{(h)}$. The reduced form parameters can be obtained from running the LP regressions in Equation (1). Using the LP estimates of $B^{(h)}$ however poses some challenges on its own.

17. In principle, we could specify different lags for each response horizon. Although it could lead to a potential gain to work with horizon-specific lag orders (Jordà, 2005; Brugnolini, 2018), it is common practice to work with the same number of lags for each response horizon.
18. Section 5.1 discusses issues related to identification via other approaches, namely by imposing short run restrictions via the Cholesky decomposition.

It is common knowledge that when working with finite samples, LP impulse response estimates tend to suffer from high estimation variance. The consequences of this are very important (see e.g. Miranda-Agrippino and Ricco, 2021; Li, Plagborg-Møller and Wolf, 2024) and with 254 observations available for the present analysis, the loss concern regarding high sample estimation variance is particularly important. As an alternative to LP impulse-responses, researchers often consider VAR impulse-responses. VAR impulse-responses do not suffer from the same degree of sample estimation variance as the LP, as it levies parametric restrictions on the $h > 1$ responses. However, the cost of these parametric restrictions of the VAR impulse response estimates is that the estimates are prone to biases. As a result, choosing between LP and VAR impulse responses results in a trade-off between bias and variance.[19]

To address the bias-variance trade-off in a data-driven way, we consider Bayesian Local Projections. The likelihood of the BLP is determined by the LP(12) model in Equation (1). We estimate both the reduced form coefficient matrices, $B^{(h)}$, and the (HAC-corrected) variance-covariance matrix, $\Sigma_{\varepsilon}^{(h)}$. Priors on the coefficient matrix and variance-covariance matrix are specified using standard conjugate Normal-inverse Wishart distributions centered around estimates from a VAR(12) model.

The posterior mean of the h-step ahead BLP impulse response takes the form

$$B_{BLP}^{(h)} \propto \left(X'X + \left(\Omega_0^{(h)}\lambda^{(h)}\right)^{-1}\right)^{-1} \left(X'XB_{LP}^{(h)} + \left(\Omega_0^{(h)}\lambda^{(h)}\right)^{-1} B_{VAR}^{h}\right). \qquad (3)$$

In Equation (3), $X = (x_{h+2}, \dots, x_T)'$ with $x_t = (1, y_t', \dots, y_{t-12}')'$. $B_{LP}^{(h)}$ and B_{VAR}^{h} denotes, respectively, the h-step ahead impulse responses one obtains when using LP and VAR. $\Omega_0^{(h)}$ acts as a prior on the variance-covariance matrix of the h-step ahead LP regressors and $\lambda^{(h)}$ determines the tightness of the prior. Note in particular that for $\lambda^{(h)} \to \infty$, the left-hand side of Equation (3) approaches the LP estimate whereas for $\lambda^{(h)} \to 0$ it approaches the VAR estimate. The tightness of the variance-covariance prior is treated as another additional model parameter and is estimated at each horizon as the maximizer of the marginal data likelihood following Giannone, Lenza and Primiceri (2015), allowing for a data-driven approach to balance off bias and variance.

19. The bias-variance trade-off arises because LPs estimate separate regressions for each horizon, allowing flexible response shapes but resulting in higher estimation variance, particularly in smaller samples. VARs, on the other hand, impose a parametric structure, where impulse responses for longer horizons are derived from the same set of parameters used for shorter horizons. This reduces estimation variance but introduces potential specification bias if the data-generating process does not match the VAR's parametric constraints. The bias-variance trade-off is especially relevant for our sample of 254 observations, where LPs may suffer from imprecise estimates while VARs risk misspecification. BLP optimally combines both approaches according to their relative precision at each horizon, as shown in Equation (3).

We normalize all responses so that the monetary policy shock induces an increase in the Danish three-month money market rate by 100 basis points on impact. Since the monetary policy shock comes from a shift in the ECB policy rate, the reactions of the Danish economy should be interpreted in conjunction with the broader impact this policy tightening exerts on the euro area economy.

5.1. Monetary policy shocks lower economic activity in Denmark

We find that monetary policy shocks significantly affect the Danish economy and lead to expected responses. Figure 6 presents our main findings. A contractionary monetary policy shock leads to a decline in activity, measured by a drop in industrial production and an increase in the unemployment rate, as well as a decline in prices.

The peak effects of monetary policy shocks happen after one year. This is in line with the conventional notion that monetary policy shocks transmit to the real economy with a lag and gradually materialize over time. Figure 6 however also shows that although the full effects of monetary policy shocks present after one year, the Danish economy responds significantly to the shocks at shorter lags, in line with what Jarociński and Karadi (2020), Miranda-Agrippino and Ricco (2021) and Bauer and Swanson (2023a) find for the US economy and Cesa-Bianchi, Thwaites and Vicondoa (2020) find for the UK.

The short lags of monetary policy are explored in a recent study by Buda et al. (2025) who estimate the effects of ECB monetary policy shocks on daily series of consumption, retail sales and employment in Spain. Buda et al. (2025) find that although the full effects of monetary policy unravel at relatively long horizons, all variables respond to monetary policy shocks within a month. This result is confounded, however, when aggregating data to lower frequencies, which causes time aggregation bias. In particular, the authors find that when aggregating data to the quarterly frequency, the impact responses disappear and significant responses first show after three quarters. That said, the impact responses remain when aggregating at the monthly level, similar to our findings. Since the bulk of the literature on the effects of monetary policy shocks study low-frequency quarterly responses, the conventional wisdom that monetary policy shocks only have »long« lags may be based on evidence plagued by time aggregation biases.

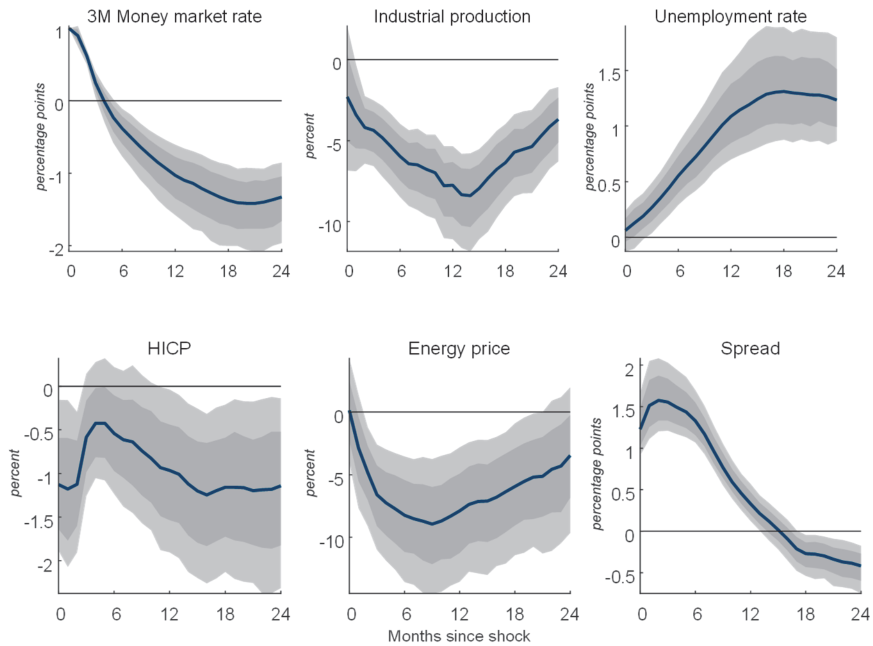
Another reason why some studies find that monetary policy does not impact the economy with short lags is that they use so-called short-run restrictions to identify monetary policy shocks.[20] In this approach, it is imposed on the dynamics of

20. Identification through short-run restrictions are also sometimes called Cholesky identification, stemming from the use of a Cholesky decomposition of the variance-covariance matrix to identify shocks. While the Cholesky decomposition can be shown to yield identification in a mathematical sense, it does not necessarily imply identification in an economic sense. The concerns for identification through short-run restrictions becomes particularly critical when the time series frequency is low.

the economy that monetary policy shocks cannot have instantaneous effects on output and prices (see e.g. Christiano, Eichenbaum and Evans, 2005). Therefore, this identification procedure rules out short lags of monetary policy by construction. With the advent of improved identification strategies, such as the approach we use, empirical studies need not impose this assumption and can allow the data to speak more freely.

Figure 6 suggests considerable quantitative effects of a monetary policy shock. In response to a 100 basis point increase in the three-month money market rate, industrial production drops by around eight percent at peak, the unemployment rate increases by around 1.3 percentage points, and consumer prices decline by approximately one percent.

Figure 6: Danish macroeconomic impulse response estimates to monetary policy shocks



Notes: The solid blue lines show the median impulse responses. Dark gray shaded areas are 68 percent posterior coverage bands. Light gray shaded areas are 90 percent posterior coverage bands.

Several considerations concerning the quantitative effects merit attention. Firstly, it is important to keep in mind that all responses are relative to a trend. Consequently, the drop in HICP of one percent, for example, does not necessarily imply a drop in the price level but rather a slowdown in price increases. Secondly, a nuanced understanding of the response of industrial production, in particular as a measure of economic activity, is crucial given its high volatility compared to GDP.[21] The GDP response (a more comprehensive measure of economic activity) to monetary policy shocks is likely to be more subdued than the observed reduction in industrial production. Indeed, as shown in Online Appendix D.2, Danish real GDP drops by around four percent at peak.[22] The drop in GDP of four percent is in line with findings from other empirical studies on European countries using a similar identification strategy. For instance, Cesa-Bianchi, Thwaites and Vicondoa (2020) find that UK GDP drops by 1.4 percent at peak, Laséen (2020) finds that Swedish GDP drops by 3 percent, and Jarociński and Karadi (2020) find that euro area GDP drops by 7-8 percent. Estimates from these studies, however, are larger than what is typically obtained from older SVAR analyses using short-run restrictions to identify monetary policy shocks (Coibion, 2012; Ramey, 2016). Finally, we have reported the effects of 100 basis point change in the interest rate, while the monetary policy shocks in our sample are relatively small; the largest shock induces an almost 19 basis point change in the three-month OIS rate within the event window. Because the model imposes a linear relationship between variables, we can simply scale estimates proportionally to obtain the response to a 100 basis points change. Effects might depend on shock size in reality but modelling such nonlinearities poses significant requirements to sample size and is beyond the scope of this paper.

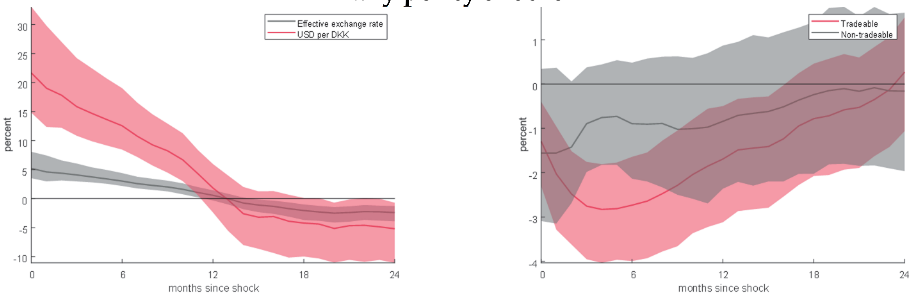
5.2. The role of imports in shaping the response of Danish consumer prices

The immediate response of Danish consumer prices to monetary policy shocks may be related to how changes in the exchange rate shape import prices. We present evidence on this specific channel in this section.

First, we add the nominal effective exchange rate and the USD-DKK exchange rate to our model. The impulse response estimates, detailed in Figure 7a, reveal an immediate and substantial appreciation of the Danish krone against both the USD and the effective exchange rate (a trade-weighted average of currencies).[23]

21. Industrial production growth rates are nearly three times more volatile than the GDP growth rate.
22. We use industrial production as a measure of economic activity in our main analysis since GDP is only available at the quarterly frequency. To use GDP, as we do in Online Appendix D.2, it is therefore necessary to interpolate the quarterly GDP series to monthly frequency. This causes some concerns but nonetheless serves as a valuable robustness check to confirm our main finding that contractionary monetary policy shocks lead to a considerable drop in economic activity in Denmark.
23. Zorzi et al. (2020) find similar impulse response estimates for the USD-EUR exchange rate.

Figure 7: Exchange rates and tradable/non-tradable price responses to monetary policy shocks



(a) Exchange rates

(b) Tradable and non-tradeable goods prices

Notes: Tradeable refers to the price index for products with an above-median extra-euro area import share, while non-tradeable refers to the price index for products with a below-median extra-euro area import share. 90 percent posterior coverage bands.

The strong and immediate appreciation of the krone suggests that exchange rate movements could be an important channel through which ECB monetary policy affects Danish consumer prices, especially at short lags. To investigate whether this is the case, we calculate the sample-average share of non-euro area imports for each product category in the HICP using the methodology of Lambertini and Proebsting (2023).[24] Using these import shares, we construct two Laspeyres price indices using 2015 HICP weights: one index for consumption categories with above-median import shares, i.e. tradeable products, and another index for those below the median import share, i.e. non-tradeable products. Lastly, both indices are seasonally adjusted.

Figure 7b shows the response of the two price indices for tradeables and non-tradeables to a monetary policy shock. As Figure 7b illustrates, the price response of tradeables is statistically significant and larger, while the response of non-tradeables is insignificant. These estimates indicate that the tradeability of products plays an important role in shaping price dynamics following monetary policy

24. The calculation of import shares is done in two steps. First, we use FIGARO input-output tables from Eurostat to calculate the total (direct and indirect) non-euro area import share for each CPA category. Second, we bridge CPA categories to HICP categories using Statistics Denmark input-output tables (Table NIO1). Sub-indices tend to be more influenced by tax changes so we use constant-taxes HICP indices.

shocks for a small open economy through exchange rate effects. This channel not only influences the size of the price response but also the speed at which effects unravel because exchange rates themselves react immediately.[25]

6. Further results and robustness checks

In this section, we present a range of robustness checks and additional analyses to assess the strength and sensitivity of our findings.

Online Appendix C presents robustness checks for the findings regarding the financial responses presented in Section 4. In Online Appendix C.1, we re-estimate the impulse responses using data from the period 2002-2019, excluding the influence of the Covid-19 pandemic. In Online Appendix C.2, we adopt the rotational sign restriction method proposed by Jarociński (2022). This approach permits both monetary policy and information shocks to be simultaneously active, as elaborated on in Online Appendix A.2. In Online Appendix C.3, we extend the lag length in the local projections from 30 to 120 days. For these three exercises, we obtain estimates that are broadly similar to our baseline results.

Online Appendix D outlines robustness checks for the findings regarding the macroeconomic responses presented in Section 5. First, we examine how our results change if we replace the monetary policy shock with the information shock when instrumenting the money market rate. The results in Online Appendix D.1 show a clear price puzzle: both HICP and energy prices increase when the money market rate increases. Moreover, the negative effect on industrial production is muted. These findings underscore the need for controlling for information effects.

Second, we examine the sensitivity of our results to using retail sales or interpolated GDP as a measure of economic activity instead of industrial production. The results presented in Online Appendix D.2 show that contractionary monetary policy lowers retail sales as well as GDP. However, the responses differ in terms of both magnitude and timing. Retail sales experiences a gradual decline to 2.8 percent below trend and its response does not peak before the end of the impulse-response horizon. Interpolated GDP falls around four percent below trend, which is consistent with GDP being about one third as volatile as industrial production. The timing of the GDP response is similar to the response of industrial production and underscores both the long and short lags of monetary policy.

25. We acknowledge that these estimates only provide indicative evidence on the importance of exchange rate fluctuations. A more conclusive investigation would require more granular price data, containing information on currency invoicing. We leave this exercise for future research.

Next, we check how our results change when we exclude pharmaceutical production from the overall index for industrial production. There are several reasons for why we make this check. First of all, the pharmaceutical sector plays a dominant role in the Danish economy. Secondly, a large fraction of pharmaceutical production happens through merchanting and processing. Thirdly, demand for Danish pharmaceutical products largely stems from abroad, in particular the US. It is hence not obvious that the pharmaceutical industry would react to our monetary policy shocks in the same way as the rest of the Danish economy. Figure D.3 in Online Appendix D.3 shows that our main results are largely unaffected by the exclusion of pharmaceutical production.

Online Appendix D.4 shows that our results are robust to including the month-on-month inflation rates of the HICP and commodity price indices instead of their log levels in our model. HICP inflation falls to 0.2 percentage points relative to trend about six months after the monetary policy shock and gradually reverts back to zero. The cumulative effect on the price level is -0.9 per cent, which is close to the effect in Figure 6. Moreover, the responses of other variables are in line with those estimated in our baseline model.

The Covid-19 period caused extreme movements, especially in industrial production and the unemployment rate. Lenza and Primiceri (2022) propose to handle the Covid-19 period by including dummies, as in our main analysis. As a robustness check, we run the main model where we end our sample period in 2019, right before the Covid-19 outbreak. Results from this exercise are presented in Online Appendix D.5. Figure D.5 shows that our main findings still go through, both qualitatively and quantitatively.

Online Appendix D.6 examines the robustness of our results by evaluating the impact of switching the policy variable from the three-month money market rate to the one-year money market rate. The one-year rate is a popular choice (e.g. Gertler and Karadi, 2015; Miranda-Agrippino and Ricco, 2021), in particular to address concerns for the period where nominal rates hit the effective lower bound. As illustrated in Figure D.6, our results remain consistent when substituting in the 1-year money market rate for the three-month rate as the policy variable.

7. Conclusion

In examining the transmission of ECB monetary policy shocks to the Danish economy, our study employs a high-frequency approach that allows us to identify conventional monetary policy shocks. Utilizing this monetary policy shock series, derived from minute-by-minute asset price movements around ECB announcements, we find substantial effects on the Danish macroeconomy. Moreover, our monetary policy shock series reveals substantial and intuitively expected effects on the Danish macroeconomy: a contractionary monetary policy shock leads to a significant drop in real economic activity, a fall in consumer and commodity prices and an appreciation of the Danish krone. We furthermore present evidence of a significant exchange rate channel by demonstrating that tradeable goods prices respond more strongly and persistently to monetary policy shocks vis-á-vis the response of non-tradable goods prices.

To set the stage and comprehend the drivers behind our findings, we conduct a thorough assessment of our monetary policy shock series, examining its impact on various financial variables. Our results confirm that ECB monetary policy has a clear pass-through to Danish money market rates. Moreover, a monetary tightening induces higher yields on government and mortgage bonds, a short-lived but significant fall in oil and stock prices, and an appreciation of the Danish krone against major non-euro trading partners.

Employing Bayesian Local Projections to address the bias-variance trade-off, we uncover a noteworthy aspect in our results — the effects of monetary policy shocks manifest with both short and long lags. This finding aligns with recent literature on the US, UK, and Euro area, emphasizing the universal nature of these dynamics. Moreover, our study suggests that exchange rate movements may play a significant role in shaping consumer prices in Denmark, particularly through their potential influence on import prices.

Comparing our work to existing literature on Danish monetary policy transmission, our analysis stands out by its exclusive focus on conventional policy, advanced identification methods, and a data-driven approach through the BLP estimation framework to balance off critical bias-variance concerns. Notably, our study contributes valuable insights to the understanding of monetary policy effects on the Danish economy, filling a gap in the literature on this subject.

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