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The Unintended Consequences of ECB's Asset Purchases. How Excess Reserves Shape Bank Lending[*]

Philipp Roderweis[†] Jamel Saadaoui[‡] Francisco Serranito[§]

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Abstract. An unintended by-product of asset purchases by the European Central Bank (ECB) has been a huge increase in excess reserves, leading to a structural liquidity surplus in the banking sector of the euro area. These exogenously imposed excess reserves imply higher balance sheet costs, forcing banks to offset these costs by changing their lending behavior. We observe this effect particularly in periods of low-interest rates. Thus, we identify a shock that represents an exogenous imposition of excess reserves on banks. We then employ linear and nonlinear local projection methods to analyze how lending changes in the context of unconventional monetary policy. We find that excess reserves injected by the ECB crowd out certain types of credit. An increase in excess liquidity does not stimulate lending to non-financial corporations in the euro area. On the contrary, it tends to discourage it while amplifying household credit for consumption and housing, as well as loans to financial corporations. Impulse response analysis via smooth local projection methods highly confirms these findings.

Keywords: excess reserves, bank lending channel, bank balance sheet costs, local projection, smooth local projection

JEL Classification: C32, E44, E51, E52, E85

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1. Introduction

After the global financial crisis in 2008, the European Central Bank (ECB) started to use unconventional monetary policy measures. In fact, the ECB expanded its balance sheet to address risks to macroeconomic and financial stability, thus increasing the supply of liquidity to commercial banks at a specific interest rate and subject to certain collateral provisions. Over time, the pool of eligible collateral accepted for refinancing operations has expanded and liquidity has been made available to banks with maturities longer than in the precrisis period. In particular, the two three-year longer-term refinancing operations (LTROs) conducted in December 2011 and March 2012 marked the ECB's turn towards the so-called quantitative easing (QE) measures. The introduction of the Asset Purchase Program (APP)[1] in 2015 represented the flagship of these unconventional instruments.

Under this program, medium- and long-term government and corporate bonds were purchased almost exclusively from commercial banks to lower corresponding yields and stimulate economic activity. In return, banks received new central bank liquidity in the form of reserves. Banks domiciled in the euro area keep these central bank reserves in interest-bearing accounts at their corresponding national bank, thus creating a special interest-bearing asset that can only be held within the banking system. Ultimately, the supply of reserves is determined by the Eurosystem and depends on the current monetary policy. Consequently, individual banks cannot simply reduce or increase reserves; they can only distribute them via the interbank market. Reserves leaving one bank's balance sheet will increase another bank's balance sheet.

Since the beginning of the ECB's asset purchases, the subsequently created reserves have exceeded the banking sector's structural liquidity need. This need for reserves results from the ECB's minimum reserve requirements and other autonomous factors. When the interbank market is not functioning properly, banks with a liquidity deficit have to resort to the central bank's credit facility. To avoid the relatively costly use of this facility, there may be a demand for reserves above the structural demand created by minimum reserve requirements and other autonomous factors (Horst & Neyer 2020).

For example, during the financial crisis and the subsequent sovereign debt crisis, the aggregate demand for banks' reserves increased significantly. Increased distrust and perceptions of risk, as well as growing information asymmetries, led to financial stress in the banking sector. Banks wanted to have more reserves than the minimum reserve requirements and cope with autonomous factors. They started to hold the liquidity for precautionary reasons. The Eurosystem fully met the surging demand for reserves, subject to the availability of collateral.

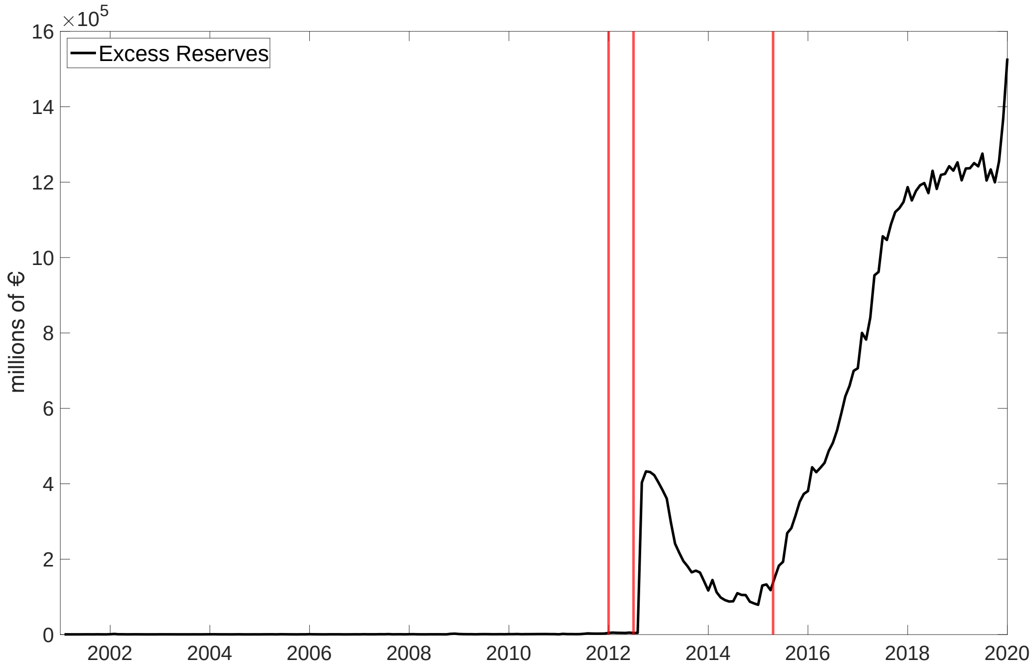
However, further asset purchases, especially those under QE, then unintentionally overcompensated for the structural liquidity needs of the banking sector, thereby increasing the level of aggregate excess liquidity, i.e., all deposits of the central bank exceeding the reserve requirement.[2]

[1] For more information about the APP, see `https://www.ecb.europa.eu/mopo/implement/app/html/index.en.html`.

[2] Excess liquidity is usually a different concept from excess reserves. For simplicity, however, we use the terms excess liquidity and excess reserves interchangeably.

Although the ECB's purchases were primarily aimed at stabilizing long-term interest rates, they also entailed, as a by-product, a simultaneous increase in liquidity unneeded by banks. Consequently, the banking sector was no longer able to fully eliminate excess liquidity by reducing its borrowing from the ECB. As can be seen in Figure 1, QE increased the amount of excess reserves held by banks in the euro area from €0.97 billion at the end of 2007 to €1.53 trillion at the end of 2019. The euro area banking sector has been operating in an environment characterized by a structural liquidity surplus. Thus, after the financial crisis and the European debt crisis, the quantity of reserves in the banking system was determined almost exclusively and exogenously by the actions of the ECB. The provision of excess liquidity was necessarily driven by supply (Baldo et al. 2017).

Figure 1: Excess reserves subject to reserve requirements



Note: Red vertical bars correspond to the two LTROs (end of 2011 / beginning 2012) and the APP in 2015, respectively. Data is provided by the EC, where excess reserves are defined as the amount of reserves held by banks at their central bank in excess of the reserve requirements.

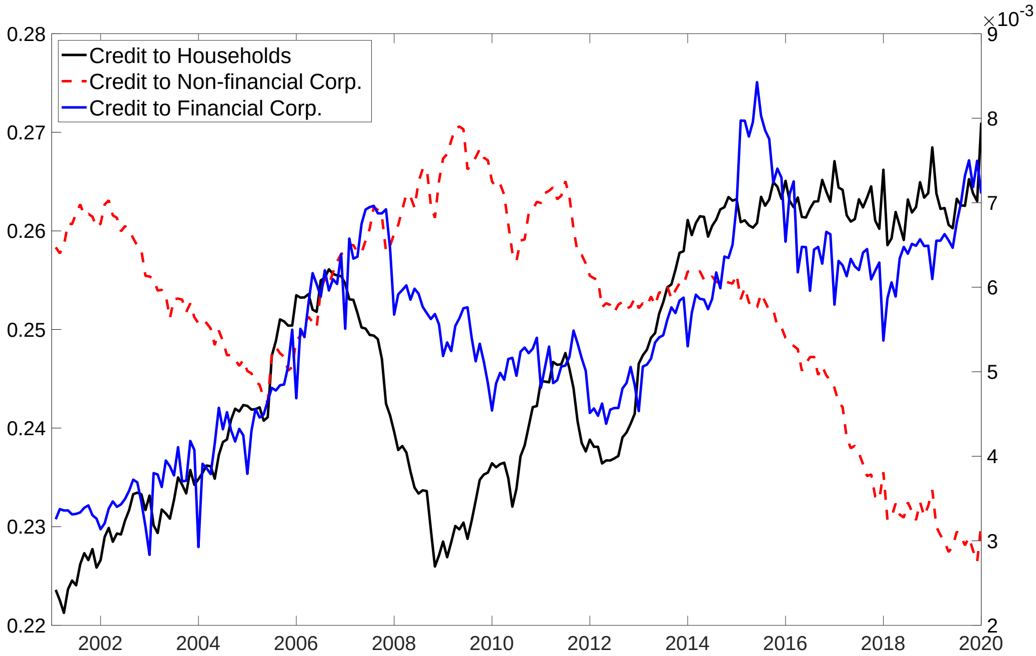
However, holding excess liquidity is costly for banks. Since June 2014, excess liquidity holdings have been remunerated at a negative rate.[3] Furthermore, increases in excess reserves imply higher costs in the size of their balance sheets due to agency costs or regulatory requirements for capital and leverage ratios. Following Martin et al. (2016), we consider these heightened balance sheet costs to be a consequence of the ECB's large-scale asset purchases.[4] This has triggered a debate about whether the unintended spur in excess reserves influences banks' lending behavior in the context of unconventional monetary policy, see, among others, Keister & McAndrews (2009) and Ryan & Whelan (2021).

[3]The deposit facility rate was -0.5% until July 2022. This rate must be paid regardless of whether liquidity is held in the Eurosystem's deposit facility or in a current account within the Eurosystem.

[4]For more information on balance sheet costs, see the theoretical models of Williamson (2019), Kumhof & Wang (2021).

For example, Figure 2 shows the evolution of bank loans to the private sector over different periods. The time series depicted are ratios of MFI loans[5] to households and to financial and non-financial corporations (NFCs), normalized by total domestic MFI loans. Although total lending appears to be highly sensitive to macroeconomic events and monetary policy measures, not all types of credit behave in the same way. In particular, loans to households and financial corporations show strong downward movements after the 2008 financial crisis. Both increased shortly after the European sovereign debt crisis and with the start of the first unconventional asset purchase programs around 2012. With the introduction of QE in 2015, these loans first increased considerably before stabilizing. NFC loans show very different trends. Although they did not start to fall sharply until a few years after the financial crisis, the downward trend has continued steadily. Especially with the introduction of QE, an extreme decline can be observed.

Figure 2: Credits to total domestic MFI credits



Note: Left axis corresponds to credits to households and NFC relative to total domestic credit; right axis corresponds to credits to financial corporations to total domestic credit. Data is taken from the ECB.

In this context, we examine the extent to which excess reserves, i.e. the consequence of the ECB's asset purchases, could at least partly explain these different credit developments. In fact, the idea that central bank reserves have an impact on bank lending is not new. The origins of this discussion include Bernanke & Blinder (1988), Bernanke & Gertler (1995) and Kashyap & Stein (1995) who show that monetary policy innovations can lead to changes in bank lending schedules through the so-called bank lending channel (BLC). Bernanke & Gertler (1995) argue that, because of information asymmetry in the credit market and costly enforcement, agency problems arise in the financial market and create an external finance premium.[6] The change in monetary policy should then affect the external finance premium through changes in the supply of intermediated credit, particularly the quantity of loans supplied by banking institutions to the credit markets.

[5]Loans from monetary financial institutions (MFIs) excluding the ESCB.

[6]The external finance premium is defined as the difference in cost between funds raised externally (by issuing equity or debt) and the opportunity cost of funds generated internally (by retaining earnings).

The recent literature revisits the BLC by focusing on high excess reserves due to unconventional monetary policy (UMP); see, for example, Rodnyansky & Darmouni (2017).[7] However, the first theoretical papers mostly argue against a positive impact of the ECB's increase in excess reserves through the BLC (Martin et al. 2016, Heider et al. 2019, Diamond et al. 2023, Horst & Neyer 2020). In particular, Diamond et al. (2023) find for the US that each newly created dollar of central bank reserves under QE crowds out 13 cents of bank lending due to high balance sheet costs. Horst & Neyer (2020) even speak of a "reverse bank lending channel". The Eurosystem's large-scale asset purchases increase excess reserves, and thus deposits on bank balance sheets. Due to the cost of the balance sheet, having more reserves than needed led to higher marginal costs of holding deposits. Since banks also create deposits when they lend, further lending would not be profitable. Consequently, the positive effects of QE in the euro area are offset by the costly excess reserves held by individual countries, according to Neyer et al. (2022). In this context, Heider et al. (2019) show that increased reliance on deposits when the policy rate is low for a long period harms the net worth of banks, leading to increased risk-taking strategies for banks with high deposit volumes.

Although there is an emerging theoretical literature on the adverse effects of reserves on bank lending, our paper is the first to empirically analyze the unintended consequences of forcing the euro area banking system to hold billions of euros of excess reserves. We thereby rely on recent literature that has illustrated the negative effects of low- and negative-rate environments on banks' profitability, see Claessens et al. (2018), Abadi et al. (2023). However, to our knowledge, no similar studies included the costs of excess reserves.

To fill the gap in the empirical literature, we show that not only low interest rates but also high excess reserves can affect the transmission of monetary policy. Unlike Diamond et al. (2023), we find that higher balance sheet costs due to the exogenous increase in excess reserves lead banks not to decrease but to shift lending into specific sectors. This pattern is consistent with the "search for yield" behavior, in which banks accumulate riskier assets to meet nominal profitability targets (Borio & Zhu 2012). As masses of low-yielding, even negative-yielding, reserves accumulate on bank balance sheets. Thus, banks will seek additional returns, thereby increasing their risk tolerance and potentially disrupting the fragility of the financial system in the long run.

Our analysis of the impact of excess reserves on the banking system differs from other empirical works in several aspects. First, we identify exogenous shocks on excess reserves within a zero and sign restriction framework. However, instead of analyzing the direct effect of the unconventional monetary policy of the ECB (Baumeister & Benati 2013, Gambacorta et al. 2014, Boeckx et al. 2017), we focus on its consequences in the form of an unintended and simultaneously exogenous increase in excess reserves (i.e., as a by-product of the ECB's asset purchases).

[7] Rodnyansky & Darmouni (2017) argue that the Fed's asset purchases stimulate lending by US banks with large holdings of mortgage-backed securities (MBS). Using a difference-in-differences identification strategy, they find that QE-affected banks lent more after the first and third rounds of quantitative easing than banks not directly affected by the program. Two relevant channels are investigated. In addition to the "net worth channel", where asset purchases have a positive impact on banks' net worth, they also find that QE works through a "liquidity channel". The authors argue that as excess MBS holdings became more liquid, banks were able to exchange them for reserves and thus expand their lending.

Second, we implement these shocks as external series in Local Projections (LP) to then perform impulse response analyses. Although LPs may suffer from higher variance, they have the advantage of a lower bias compared to VAR estimators and are more accurate for increasingly distant horizons, according to Ramey (2016). We find that, contrary to what traditional BLC predicts following Bernanke & Blinder (1988) in conventional times, higher reserves do not lead to an increase but rather to a change in the composition of total credit. In particular, household loans for housing and consumption and loans to financial corporations such as pension and insurance funds benefit from higher excess reserves in the banking sector. Booms in this type of household debt are particularly associated with strong negative effects on the real economy in the long run, and are therefore of particular risk (see, among others, Schularick & Taylor (2012), Jordà et al. (2015), Mian & Sufi (2018) and Grimm et al. (2023). On the other hand, we estimate that loans to non-financial corporations react significantly and negatively to excess reserve shocks.

Third, we investigate the existence of nonlinear dynamics by applying nonlinear Local Projections (NL-LP) methods. We show that the effects of the identified excess reserve shock are state dependent. We find that the effects identified in the linear model are more pronounced when the euro area bank lending rate is below a certain threshold. As banks' profitability declines with falling interest rates, a further imposition of costly excess reserves may induce banks to search for yield. These effects are more pronounced than they would be in a high interest rate environment.

Fourth, we use a Penalized (Smooth) Local Projections (SLP) approach, which helps to control for possible excessive variability in least-square LP estimations. Together with different identification schemes for the excess reserve shock found in the recent literature, we can confirm the robustness of the baseline results for the euro area.

Our findings have strong policy implications, especially for central banks. We find that in periods of unconventional monetary policy, the consequences of higher balance sheet costs due to excess liquidity may imply that the BLC no longer describes monetary transmission. Accordingly, analyzing the role of excess reserves in monetary transmission is not only important in times of monetary easing but also needs to be considered in monetary policy decisions in times of monetary tightening.

The remainder of the paper is structured as follows. Section 2 reviews the literature on the bank lending channel in the context of large asset purchases and, consequently, high excess reserves. Section 3 specifies the baseline VAR model and identifies the exogenous shock of excess reserves. In Section 4, the impulse response analysis is estimated in LP and NL-LP models. In addition, Section 5 contains several robustness checks, including the estimation of SLP and LP estimates using different identified shocks found in the literature. Finally, Section 6 concludes.

2. Literature Review

The literature has long developed the concept of the BLC, with the importance of the balance sheet structure and the net worth of intermediaries for the transmission of monetary policy (Bernanke & Blinder 1988, Bernanke & Gertler 1995). The idea of the bank lending channel is rooted within the theory of the credit channel. This theory argues that frictions in the credit market, particularly in the form of asymmetric information between lenders and borrowers, amplify traditional interest rate effects. The credit channel theory offers two explanations for this amplification: the balance sheet channel and the bank lending channel (Horst & Neyer 2020). In the context of large asset purchases, there is a range of literature that focuses primarily on the transmission of monetary policy to bank lending in general (Peersman 2011, Bowman et al. 2015, Rodnyansky & Darmouni 2017), and through the BLC in particular (Butt et al. 2014, Ryan & Whelan 2021, Giansante et al. 2022).[8]

In our paper, however, we focus specifically on the consequences of high excess reserves as a by-product of the ECB's unconventional monetary policy asset purchases, their transmission to banks' lending behavior, and the role of the BLC within. In this context, we relate to the literature that focuses on the effects of high excess reserves on bank profitability. Bank reserves consist of deposits on banks' current accounts with the central bank. They play an important role in the banking sector as they are required to meet banks' needs for reserve requirements, cash withdrawals, and precautionary liquidity holdings (Bucher et al. 2020). Under the ECB's unconventional monetary policy, the supply of reserves exceeded banks' structural liquidity needs, leading to structural excess reserve holdings. Here, excess reserves are defined as the amount of current account balances of commercial banks in their national central bank that exceed the reserve requirements (Horst & Neyer 2020). Since the purchases of the ECB were primarily intended to control long-term interest rates, the oversupply of liquidity must be viewed as a simple by-product of unconventional monetary policy, rather than its objective.

The increase in excess reserves as the by-product of the ECB's may be associated with higher balance sheet costs for banks, e.g. in the form of agency or regulatory costs. As a result, the marginal cost of holding deposits increases, decreasing the banks' profitability, see Martin et al. (2016). At the same time, as banks are forced to hold higher supply of reserves than structurally required, the marginal utility of reserves in banks' asset portfolios declines. The magnitude of this cost increases with the amount of externally imposed liquidity held by banks. For more detailed information, see Diamond et al. (2023).

In this regard, our paper also builds on the literature that shows how bank profitability affects their lending activities, and thus the level of intermediation in the economy. Theoretical literature, such as Martin et al. (2016), Diamond et al. (2023), finds that bank lending is dampened as a result of high excess reserves. Horst & Neyer (2020) even speak of a "reverse bank lending channel". They find that the positive effects of QE in the euro area are offset by the cost of holding excess reserves. When banks lend, they credit the corresponding amount to their customers' deposit accounts. That is, by lending, banks create deposits with new money (Jakab & Kumhof 2015). In this context, Horst & Neyer (2020) argue that large-scale asset purchases by the Eurosystem increase excess reserves and thus deposits. These excess reserves raise the marginal cost of holding deposits for banks (i.e., balance sheet cost). If banks continued to lend in an environment of high excess liquidity, these same marginal costs would rise even more. Further lending would not be profitable. As a result, banks avoid or even reduce lending. Therefore, this effect is more pronounced in countries with higher excess liquidity (Neyer et al. 2022).

[8]For more details on the transmission of monetary policy through the BLC, see Albertazzi et al. (2021).

However, the costs of high reserve holdings appear not only to affect bank credit growth in general, but also to make the traditional banking business of lending to the real economy less lucrative. For example, Kandrac & Schlusche (2021) argue that the imposed increase in reserves disrupts the bank's optimal portfolio allocation by simultaneously altering its net interest margin. Banks are induced to reallocate their portfolios toward riskier, higher-yielding loans. They increase their risk tolerance to meet their nominal profitability targets in times of low interest rates. This pattern is consistent with the idea of a yield search, in which banks accumulate riskier assets to achieve greater profitability (Borio & Zhu 2012). Costly reserves and declining interest margins may push banks into higher yielding asset classes.

Similarly, Gambacorta & Marques-Ibanez (2011) argue that the cost of reserves and the decline in marginal lending rates may increase the incentive to take on more risk. This would lead to a disproportionate increase in banks' demand for non-interest income or loans with higher expected returns. According to Borio et al. (2017), very low interest rates could affect the profitability of lending activities by eroding persistently low interest margins. Simultaneously, banks would be less likely to limit, and possibly even increase, the profitability of activities that are more similar to investment banking, such as securities underwriting, trading, or mergers and acquisitions.

Claessens et al. (2018) provide empirical support to these theoretical perspectives. For a sample of 3385 banks in 47 countries, they find that a 1 percent policy rate drop implies a net interest margin decline of 8 basis points, adversely affecting bank profitability. If interest rates remain low for too long, the continued drag on bank profitability will outweigh bank capital gains, which could lead to a contraction in credit supply; see Abadi et al. (2023). Also, Heider et al. (2019) notes that when the policy rate becomes negative, greater reliance on deposits can adversely affect banks' net worth. Consequently, banks with high deposits will lend less. Similarly, Grimm et al. (2023) find that when interest rates remain below the natural rate for an extended period, there is an increase in asset prices, such as house prices, and in the growth of certain loans, both of which have been shown to be associated with greater financial fragility; see, among others, Schularick & Taylor (2012), Jordà et al. (2015).

In our paper, we draw on this recent literature to illustrate the effects of monetary policy on banks' activities. We argue that holding high levels of excess reserves imposes costs on banks' balance sheets. In addition to the negative effects of low interest rates, as seen in Claessens et al. (2018), Abadi et al. (2023), Grimm et al. (2023), the costs imposed by excess liquidity reduce banks' profitability and may lead to changes in their lending behavior.

Specifically, we find that household credits for housing and consumption in particular are driven by excess reserve shocks, while credit to non-financial corporations responds negatively — especially in a low interest rate environment. The danger of this trend is that a rapid expansion of domestic housing credit may be more closely related to crises than lending to non-financial firms; see Büyükkarabacak & Valev (2010), Mian & Sufi (2010), Beck et al. (2012), Jordà et al. (2014). For example, Mian & Sufi (2018) show that booms in household debt in particular (i.e., consumption and housing loans) are associated with a temporary increase in real activity. However, this boost is short-lived and eventually reverses. Looser financial conditions boost the left tail of the projected GDP growth distribution in the short run at the expense of strong negative effects in the medium run, without affecting the growth path of the economy.

Finally, our paper relates to the literature that deals with the quantification of the macroeconomic effects of unconventional monetary policy in the euro area using structural vector autoregressive models (SVAR) identified with zero and sign restrictions; see, e.g., Peersman (2011), Baumeister & Benati (2013), Gambacorta et al. (2014), Wieladek & Garcia Pascual (2016), Boeckx et al. (2017), Debortoli et al. (2020). Intentionally, we deviate from this literature in at least one respect: instead of analyzing the direct effects of the ECB's unconventional monetary policy, we focus on its consequences in the form of an unintended and simultaneously exogenous increase in excess reserves (i.e., a by-product of the ECB's asset purchases). Restrictions are imposed on the SVAR in such a way that an excess reserve shock (at a given policy rate), exogenously imposed by the ECB's unconventional monetary policy measures, can be disentangled from other shocks.

By identifying an excess reserve shock in this way, we deliberately deviate from the identification schemes for interest rate surprises following monetary policy announcements, as seen, among others, in Jarociński & Karadi (2020).[9] For one, we do not explicitly model the ECB's asset purchases or monetary policy actions as a whole, but consider the resulting by-product of an increase in banks' excess reserve holdings. For another, as outlined in Boeckx et al. (2019), Jarociński & Karadi (2020)'s shocks reflect the ECB's announcements on conventional interest rate policy, including actual changes in the ECB's policy rate or adjustments to forward guidance. Our excess reserve shock, however, is orthogonal to changes in the policy rate and focuses on changes in the structure of banks' balance sheets, as we impose a zero restriction on the response. These two shocks are fundamentally different.

Furthermore, our paper differs from the SVAR literature in that impulse responses are estimated using LP and NL-LP methods according to Jordà (2005, 2023). LP methods are designed to allow for the computation of impulse response functions without specifying and estimating the underlying multivariate dynamic systems. Although LPs may suffer from higher variance, they have a lower bias than VAR estimators. LPs have been widely used to analyze the transmission of monetary policy, especially when the shock has already been identified exogenously; see, among others, Hafemann & Tillmann (2020). In an LP framework, we find that high exogenously imposed excess reserves alter banks' lending behavior. LPs also have the advantage over VARs of being able to account for nonlinearities more easily; see Ramey (2016), Ramey & Zubairy (2018), Ahmed & Cassou (2021). Using NL-LP methods, the effects are amplified when specifically considering a low interest rate regime.

The results are confirmed by using an SLP methodology (Barnichon & Brownlees 2019). Although still very recent and therefore not often applied, SLP is gaining attention in macroeconomic research. In the context of the monetary policy literature, Funashima (2022) applies SLP to US data from 1985 to 2007 and attempts to estimate the effects of loose and restrictive monetary policy shocks on the uncertainty of monetary policy. Further applications of SLP can be found in Franta & Gambacorta (2020) or Stolbov & Shchepeleva (2021). The SLP approach can control for the high variance of LP estimators and is therefore ideally suited for the robustness exercise.

[9] In this approach, changes in interest rates (such as indexed overnight swaps) in a short window around ECB Governing Council press releases and press conferences are used as proxies for monetary policy shocks; see, among others, Altavilla et al. (2019), Jarociński & Karadi (2020), Kerssenfischer (2022).

3. Identification and estimation of excess reserve shocks

3.1. Data and methodology

To identify an unintended and forced shock to excess reserves that is orthogonal to conventional monetary policy and exogenous to banks' demand for liquidity, we apply VAR models. A linear vector autoregressive data generating process (DGP) of finite order p can be expressed as,

$$y_t = \Pi_1 y_{t-1} + \dots + \Pi_p y_{t-p} + u_t, \tag{1}$$

where the intercept is suppressed for convenience and $y_t = (y_{1t}, \dots, y_{Kt})'$ is a $(K \times 1)$ vector of endogenous variables for $t = p+1, \dots, T$. $\Pi_i, i = 1, \dots, p$, are $(K \times K)$ coefficient matrices, and $u_t = (u_{1t}, \dots, u_{Kt})'$ is a $(K \times 1)$ vector of independent and identically distributed white noise residuals, being the unpredictable component of y_t. The VAR process can be written in his *structural form* as,

$$A_0 y_t = \Gamma_1 y_{t-1} + \dots + \Gamma_p y_{t-p} + \varepsilon_t. \tag{2}$$

Here, the $(K \times 1)$ vector of zero mean structural shocks, ε_t, is serially uncorrelated with a diagonal variance covariance matrix $\Sigma_\varepsilon = E(\varepsilon\varepsilon')$ of full rank such that the number of shocks coincides with the number of variables, see Kilian & Lütkepohl (2017). Therefore, ε_t is assumed to be white noise. The coefficients A_0 and Γ are the parameters of interest. Therefore, Γ is a $(K \times K)$ matrix of autoregressive slope coefficients and the $(K \times K)$ matrix A_0^{-1} reflects the structural impact matrix, which contains the contemporaneous effects of the increase of each endogenous variable on the other. It captures the impact effects of each of the structural shocks on each of the model variables. The Equation (2) is structural in that the shocks are postulated to be mutually uncorrelated with each element of ε_t having a distinct economic interpretation. This fact allows one to interpret movements in the data caused by any one element of ε_t as being caused by a shock, see Kilian & Lütkepohl (2017).

In the benchmark specification, the vector of endogenous variables y_t includes seven monthly variables for the euro area coming from the databases of the ECB, Eurostat and the OECD: the log of excess reserves subject to reserve requirements (Excess Reserves); the log of the industrial producer index (Output); the log of the Harmonized Index of Consumer Prices (HICP) excluding energy and unprocessed food (Prices); the level of financial stress, as measured by the Composite Indicator of Systemic Stress (CISS); the spread between euro overnight index average (EONIA) and the main refinancing operations (MRO) rate (Spread); the long-term nominal interest rate, as measured by the yield on 10-year government bonds (10-year yields); and the main refinancing operations rate (Policy Rate).[10]

The VAR is estimated over the period 2001m1-2019m12.[11] The period covers both the conventional and unconventional monetary policy phases, as well as the European financial

[10]Data sources and description can be found are available upon request to the authors. In the choice of the variables, we are mostly guided by Boeckx et al. (2017).

[11]The VAR and the associated impulse response analysis were also conducted for periods that exclude both the financial crisis (2011m1-2019m12) and the asset purchases under the LTROs in late 2011 and early 2012 (2013m1-2019m12). The IRFs for the shortened period show similar results to those for the full sample (see Figure 8 in Section 5).

and sovereign debt crisis, in order to observe the extent to which banks' lending behavior changed under these two policy regimes. We distinguish between the two policy regimes by imposing appropriate restrictions in the identification of the VAR. When choosing this period, we are guided, among others, by Burriel & Galesi (2018). Furthermore, since we are primarily interested in an analysis of impulse response, we exclude the Covid-19 crisis, as these observations could significantly affect the estimation of parameters (Lenza & Primiceri 2022).

We view excess reserves held by banks as our key indicator of the consequence, rather than the cause, of a policy that imposed more liquidity onto banks' balance sheets than they needed. Moreover, using excess reserves allows us to bypass the difficulty of distinguishing between demand and supply innovations when using monetary aggregates as a shock. Since we do not want to identify an unconventional monetary policy shock but rather the exogenous oversupply of liquidity to banks, we believe we can show that a shift in lending behavior occurs when reserves exceed banks' liquidity needs. Following Avalos & Mamatzakis (2018), we can distinguish supply-driven excess reserves from endogenous movements in liquidity provision.

Furthermore, the benchmark specification should capture key macroeconomic, financial, and monetary interactions. To approximate the output at a monthly frequency, we use the industrial production index commonly used in empirical studies; see, among others, Peersman (2011) and Schenkelberg & Watzka (2013). Prices are represented by the HICP, excluding food and energy prices. To capture both conventional and unconventional monetary policy regimes, the MRO and 10-year government bond yields are included in the set of variables. These are crucial to avoid the confounding effects of shocks under different policy regimes. Following the selection of the variables Boeckx et al. (2017), we include the CISS index of Hollo et al. (2012) in the baseline VAR to capture financial stress and economic risk in the market. Finally, the model includes a measure of liquidity in the interbank market, represented by the spread between the EONIA and the MRO rate. The inclusion of this proxy is crucial, as it allows us to control for the fact that excess reserve holdings were supply driven rather than demanded by the banking sector.

Here, we explicitly refrain from differentiating the data. Differentiating these time series would result in the loss of important information about the data and their relationship, see Sims et al. (1990).[12] In our specification, no unit roots fall outside the unit circle, indicating the stationarity of the VAR and the corresponding stability of the system. The choice of lags acts as a filter that allows for the transformation of the given data into a white noise time series. Therefore, a lag choice of $p = 2$ throughout the paper seems appropriate. With this number of lags, the residuals are uncorrelated and the system is stable. The likelihood ratio test confirms this choice.

3.2. Shock identification

The relationship between structural shocks, ε_t, and reduced form shocks, u_t, is given by,

$$A_0 u_t = \varepsilon_t. \tag{3}$$

[12]The preference for VARs in levels can be explained, at least in part, by a reluctance to impose potentially spurious restrictions on the model. This is particularly true for VAR estimations with macroeconomic series.

Normalizing the covariance matrix of structural errors $E(\varepsilon\varepsilon') \equiv \Sigma_\varepsilon = I$, the reduced-form variance-covariance matrix is $\Sigma_u = A_0^{-1}\Sigma_\varepsilon A_0^{-1'} = E(uu')$. Given an estimate of this reduced form, all that is required to recover the structural model of Equation (3) is knowledge of the structural impact multiplier matrix A_0 (or, equivalently, of its inverse A_0^{-1}). Given that $u_t = A_0^{-1}\varepsilon_t$, the matrix A_0 allows us to express the typically mutually correlated reduced-form innovations (u_t) as weighted averages of the mutually uncorrelated structural innovations (ε_t), with the elements A_0^{-1} serving as weights (Kilian & Lütkepohl 2017).

Isolating an exogenous excess reserve shock on the banks' balance sheet requires making identification assumptions.[13] As in Canova & De Nicolo (2002) or Uhlig (2005), we use a mixture of zero and sign restrictions on the contemporaneous matrix A_0^{-1}, which can be found in Table 1. This approach presents an identification scheme in which determining the order of causality in the model is not necessary. The intuition of an identification scheme with sign restrictions is to consider all possible permutations of SVAR models that satisfy the reduced form, but at the same time to keep only those that yield "economically meaningful" impulse responses.[14]

Our identification is based on the schemes of Baumeister & Benati (2013), Gambacorta et al. (2014), Boeckx et al. (2017), and Burriel & Galesi (2018). First, the shock has no immediate impact on output and consumer prices. This assumption, which is plausible for monthly estimates, makes it possible to disentangle the excess reserve shock from real economic disturbances such as supply and demand shocks.[15] We also impose a negative restriction on the sign of the CISS index. We assume that an excess reserve shock, which appears to increase excess reserves in the market, does not increase financial stress. This restriction embodies the notion that exogenous innovations in the stock of excess reserves have a mitigating effect on financial stress. It is necessary to disentangle the innovation from the ECB's endogenous response to financial turmoil. The expected endogenous expansion of excess reserves, which we rule out, occurs when increased financial distress causes banks to increase their demand for liquidity (Burriel & Galesi 2018). However, with the negative sign restrictions, we allow for excess reserves to be a simple by-product of the ECB's unconventional monetary policy, which is exogenously imposed on banks' balance sheets.

To further control for the fact that the increase in excess reserves was not driven by bank demand, we do not allow the shock to increase the EONIA-MRO spread (Boeckx et al. 2017).[16] The increase in excess liquidity reduces the EONIA and thus its spread to the policy rate. By postulating these restrictions, we allow supply-driven changes in banks' balance sheets to be decoupled from endogenous demand for central bank liquidity. An endogenous liquidity expansion, which we rule out here, arises when higher financial distress induces banks to increase their demand for liquidity, putting pressure on the EONIA spread (Linzert & Schmidt 2011).

[13]Here, the excess reserve shock is the only shock of interest in the model. No attempt is made to interpret the other structural shocks.

[14]The model is estimated using Bayesian methods with non-informative Normal-Wishart priors for estimation and inference. For details, see Uhlig (2005).

[15]This is an assumption made in most VAR studies analyzing the effects of monetary policy, see Bernanke & Blinder (1992), Gambacorta et al. (2014), Burriel & Galesi (2018).

[16]As of October 2019 EONIA is calculated with a reformed methodology tracking the euro short-term rate.

Table 1: Identification of excess reserve shock

Output	Prices	Excess Reserves	CISS	Spread	10-year yields	Policy Rate
0	0	≥ 0	≤ 0	≤ 0	≤ 0	0

Note: $\geq$ indicates that the response is restricted to be non-negative, $\leq$ to be non-positive, and 0 to be 0. All sign restrictions are imposed on impact.

Finally, the objective is to estimate the impact of innovations in the banks' balance sheet that are orthogonal to shifts in the policy rate. This restriction ensures that the identified shock to excess reserves does not distort conventional interest rate shocks. Rather, the excess supply of central bank reserves lowers long-term yields (Lenza et al. 2010). To illustrate this effect, we allow 10-year government bond yields to respond negatively to an excess reserve shock; see, among others, Weale & Wieladek (2016) or Wieladek & Garcia Pascual (2016).

In order to verify our strategies and to compare them with more "traditional" identification schemes, we identify excess reserve shocks inspired by Peersman (2011) and Wieladek & Garcia Pascual (2016), whereby both articles are limited to the euro area, and each proposes different identification methods. Furthermore, we construct a recursive ordering of the VAR, by implementing a Cholesky decomposition of the variance-covariance matrix of the residuals in the reduced form (see Figure 7 in Section 5). This should help us verify the baseline identification and serve as a robustness check regarding the results of the subsequent estimations.

4. LP impulse response analyses

VARs are intended to be an approximation of the ideal DGP. Thus, this type of modeling is optimal for forecasts one period ahead. However, as we are interested in estimating impulse responses, these response functions (IRFs) of the forecasts are usually specified for increasingly distant horizons. This means that the use of VAR may not be ideal for longer horizons, with misspecification errors increasing as the forecast horizon lengthens (Ramey 2016).

Jordà (2005) developed an alternative to impulse responses for VAR, namely the local projection (LP) method. The purpose of this method is to allow IRFs to be computed without having to specify and estimate the underlying multivariate dynamical system, as is required for VARs. In its basic formulation, the LP approach consists of running a sequence of predictive regressions of a variable of interest on a structural shock for different prediction horizons. The IRF is then given by the sequence of regression coefficients of the structural shock (Barnichon & Brownlees 2019).

Since the LP method, in its theoretical interpretation, is semi-parametric in nature and does not impose any underlying dynamics on the variables in the system, this leads to a number of advantages. For example, LPs can be estimated by a single equation, they are more robust to misspecification[17] of the DGP (Jordà 2005, Ramey 2016, Nakamura & Steinsson 2018), and can

[17]Misspecification is likely to arise along a number of dimensions, such as lag order, omitted variables, missing moving average components, time-varying parameters, heteroscedasticity in residuals, and nonlinearities (Ferreira et al. 2023).

be easily adapted to a nonlinear framework (Auerbach & Gorodnichenko 2016). Furthermore, while the LP estimator makes flexible use of sample autocovariances by directly projecting an outcome at the future horizon h onto the current covariates, a VAR estimator instead extrapolates longer-term impulse responses from the first p sample autocovariances.[18]

Consequently, it could be conjectured that VARs, unlike LPs, suffer from greater bias. Montiel Olea & Plagborg-Møller (2021) and Plagborg-Møller & Wolf (2021) show that LPs are more robust than SVAR approaches, especially when the data set is highly persistent. Furthermore, they find that both methods lead to the same median impulse responses in the short and medium term but behave conversely in longer horizons.

Due to their advantages over VARs, local projections are attracting increasing interest in macroeconomic research. For example, Auerbach & Gorodnichenko (2016), and Ramey & Zubairy (2018) use LPs to estimate state-dependent fiscal multipliers, while Hamilton (2011) and Cai et al. (2022) employ impulse responses from LPs to assess the dynamics of oil shocks. In the context of monetary policy, Ferreira et al. (2023), among others, use LP estimators to observe the transmission of monetary policy to the real economy.

4.1. Linear LP framework

Applying the linear local projections of Jordà (2005), one runs the following regressions,

$$y_{t+h} = \alpha^h + F_1^{h+1} y_t + F_2^{h+1} y_2 + \dots + F_p^{h+1} y_{t-p} + u_{t+h}^h, \qquad \text{for } h = 1, \dots, H, \tag{4}$$

where y_t is the endogenous variable of interest and the residuals u_{t+h}^h are a moving average of the forecast errors and may be serially uncorrelated with the regressors, see Jordà (2005). As seen, the LP estimator utilizes the sample autocovariances flexibly by directly projecting an outcome at the future horizon h on the current covariates.

By construction, the slope F_1^{h+1} can be interpreted as the response of y_{t+h} to a reduced-form disturbance in period t:

$$\Phi_h^{LP} = F_i^{h+1} = E(y_{t+h}|u_t = a_i; X_t) - E(y_{t+h}|u_t = 0_k; X_t), \tag{5}$$

with $\Phi_0^{LP} = I$, where 0_k is a $(K \times 1)$ zero column vector and the impulse response are a function of time t, horizons h and a $(K \times 1)$ column vector of the impact matrix A_0^{-1} (namely a_i). $E(.|.)$ denotes the best mean squared error predictor, y_t is a $(K \times 1)$ vector, and X_t denotes the lags of y_t $(y_{t-1}, \dots, y_{t-p})$.

The corresponding structural impulse responses functions of y_{t+h} are as follows:

$$IRF = \hat{\Phi}_h^{LP} a_i, \tag{6}$$

[18] This flexibility comes at the cost of higher variance of the estimator, relative to VARs.

where $\hat{\Phi}_h^{LP}$ estimates are obtained from a sequence of least-square regressions. a_i corresponds to the i^{th} column of the matrix A_0^{-1} and hence to the identified shock obtained in Section 3. Although Jordà (2005) does not explicitly discuss the distinction between structural and reduced-form impulse responses, Kilian & Kim (2011) shows that structural impulse responses are constructed using the VAR estimate of A_0^{-1}.

As seen in Section 3, we first identified an exogenous excess reserve shock to the matrix A_0^{-1}. Now, as it is a great advantage of local projections that once this exogenous shock has been identified, we can estimate impulse responses directly using LP methods Ramey (2016), using OLS regressions:

$$x_{t+h} = a^h + b^h shock_t + \gamma w_t + \varepsilon_{t+h}, \tag{7}$$

where x_t represents the variable of interest, w_t a vector of control variables and $shock_t$ represents the identified exogenous shock.[19] The impulse response of $shock_t$ on x_t corresponds to the series of coefficients b^h for each horizon h.

As mentioned above, higher balance sheet costs due to the increase in excess reserves might change the banks' lending behavior in the euro area. Comparing the evolutions of different types of credit allows us to identify a preference in bank lending behavior once the bank balance sheet experiences a supply-driven shock of excess reserves. Following Schularick & Taylor (2012), Jordà et al. (2015), Mian & Sufi (2018), Grimm et al. (2023), loans for (i) housing and consumption purchases, as well as loans to (ii) non-financial and (iii) financial corporations seem to be of specific interest, as they can capture heterogeneous macroeconomic trends in the economy. x_t therefore takes the form of euro area monetary financial institution (MFI) loans, that is, loans from the banking sector[20], to non-financial corporations, to domestic households (for consumption and housing), or MFI loans to financial corporations (insurance and pension funds), as shown in Figure 2 in Section 2.

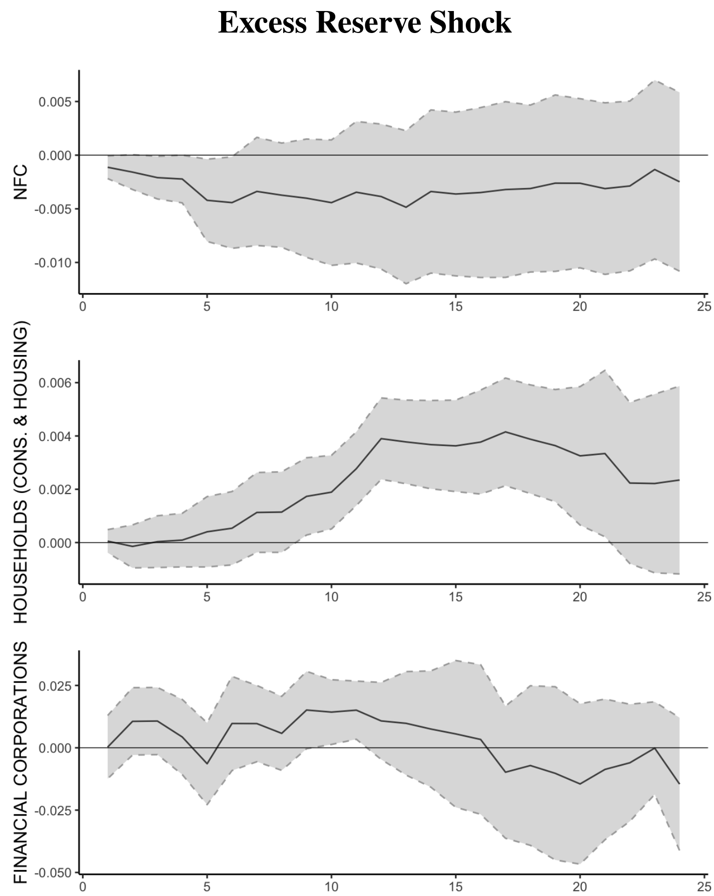
Figure 3 displays the impulse responses of the different loans to a one standard deviation to a positive excess reserve shock. The results indicate that a shock decreases lending to non-financial corporations significantly for up to half a year. Although negative, the response is not significant in the long run (upper panel). Credit to households for consumption and housing reacts positively (middle panel). This effect is significant after eight months and up to 21 months. The maximum spike is around 0.45%. Less pronounced results can be found for loans to financial corporations (bottom panel). While reacting positively to an excess reserve shock, the response is only significant after ten months for a short period of time.

We can draw several conclusions. First, the dynamics of loans to non-financial corporations show that the imposition of excess reserves due to the ECB's asset purchases forced banks to reduce their lending to non-financial corporations. Higher balance sheet costs due to the high stock of excess liquidity seem to reduce traditional bank lending to the real economy. This supports the evidence found by Kandrac & Schlusche (2021) for the US. A reverse bank lending channel as postulated by Horst & Neyer (2020) in their DSGE analysis could be suspected. However, the effects seem marginal and insignificant after a while.

[19] A lag length of $p = 2$ is chosen. However, the use of different lag lengths produces the same IRFs.

[20] Credits of the European System of Central Banks (ESCB) are excluded in the calculation of loan supply.

Figure 3: Linear impulse responses functions of credits to excess reserve shock



Notes: The solid black lines represent the median impulse response. The grey shaded areas represent the 68% confidence interval. NFC stands for non-financial corporations.

Second, impulse response analysis reveals that banks are induced to reallocate their portfolios to riskier, higher-yielding loans. In particular, household loans for housing and consumption respond positively to an excess reserve shock. This effect is significant for 14 months. Such loans are riskier in this sense, as a rapid expansion of domestic housing credit may be more closely related to crises than lending to non-financial firms; see Büyükkarabacak & Valev (2010), Mian & Sufi (2010), Beck et al. (2012), Jordà et al. (2014). Furthermore, Mian & Sufi (2018) show that booms in household debt in particular (i.e. consumption and housing loans) are associated with a temporary increase in real activity. However, this boost is short-lived and eventually reverses. A shock to excess reserves, which increases banks' balance sheet costs, gives banks an incentive to offset these costs with loans that may be riskier and more damaging to the euro area economy. Third, loans to financial corporations, such as insurance or pension funds, do not seem to respond significantly to a shock to excess reserves, at least in the linear framework.

Given the results for the full sample period, it is interesting to analyze the responses in a situation where interest rates are low. According to Abadi et al. (2023), if interest rates remain low for too long, the continued drag on bank profitability will outweigh bank capital gains, which could lead to a contraction in credit supply. Similarly, Grimm et al. (2023) find that when interest rates remain below the natural rate for an extended period, there is an increase in asset prices, such as house prices, and in the growth of certain loans, both of which have been shown to be associated with greater financial fragility; see, among others, Schularick & Taylor (2012), Jordà et al. (2015).

Therefore, we examine whether lending changes when the margin on lending rates is minimized, i.e., when the profitability of lending is generally low and an exogenous excess reserve shock additionally increases the cost of the bank's balance sheet. The state dependence of lending is analyzed using a nonlinear LP analysis.

4.2. Nonlinear LP framework

A great advantage of the local projection methodology is that it can easily be adapted to a nonlinear framework. Many works have applied local projections to study nonlinear and threshold effects; see, among others, Owyang et al. (2013), Ramey & Zubairy (2018), Ahmed & Cassou (2021).

As in the linear framework, we apply local projection to analyze an excess reserve shock, that we adopt here to a nonlinear framework such that:

$$y_{t+h} = I(z_{t-1} > \rho_1)\Omega_H^{h+1}(L)y_{t-1} + I(z_{t-1} < \rho_1)\Omega_L^{h+1}(L)y_{t-1} + \mu_t, \qquad \text{for } h = 1, ..., H, \quad (8)$$

where y_t is a vector of the same endogenous variables as in the linear framework. z_t is the switching variable, which is the bank lending interest rate. I denotes an indicator function which takes the value 1 if the bank lending rate is below the threshold ρ_1 (*low interest rate regime*). $\Omega_H(L)$ is a lag-polynomial of matrices in the *high interest rate regime*, while $\Omega_L(L)$ is a lag-polynomial of matrices in the low interest rate regime. $\mu_t isanerrorterm.$

The threshold value is extracted from a threshold VAR (TVAR) applying the euro area wide bank lending rate as the threshold variable.[21] The latter is the interest rate on loans for new businesses other than revolving loans and overdrafts, convenience, and extended credit card debt. This rate seems to be the most appropriate for our purposes, as it indicates the profitability of bank lending (Gambacorta & Marques-Ibanez 2011).

The euro area-wide lending rate is plotted in Figure 4. The horizontal red line represents the TVAR estimated threshold of 2.89%.[22] It can be seen that the bank lending rate moves in line with European monetary policy. Thus, it experienced a sharp decline after 2008, falling below the threshold for the first time, before recovering eventually. With the introduction of the first unconventional asset purchases, the lending rate fell further to be below 1.5% by the end of the APP program.

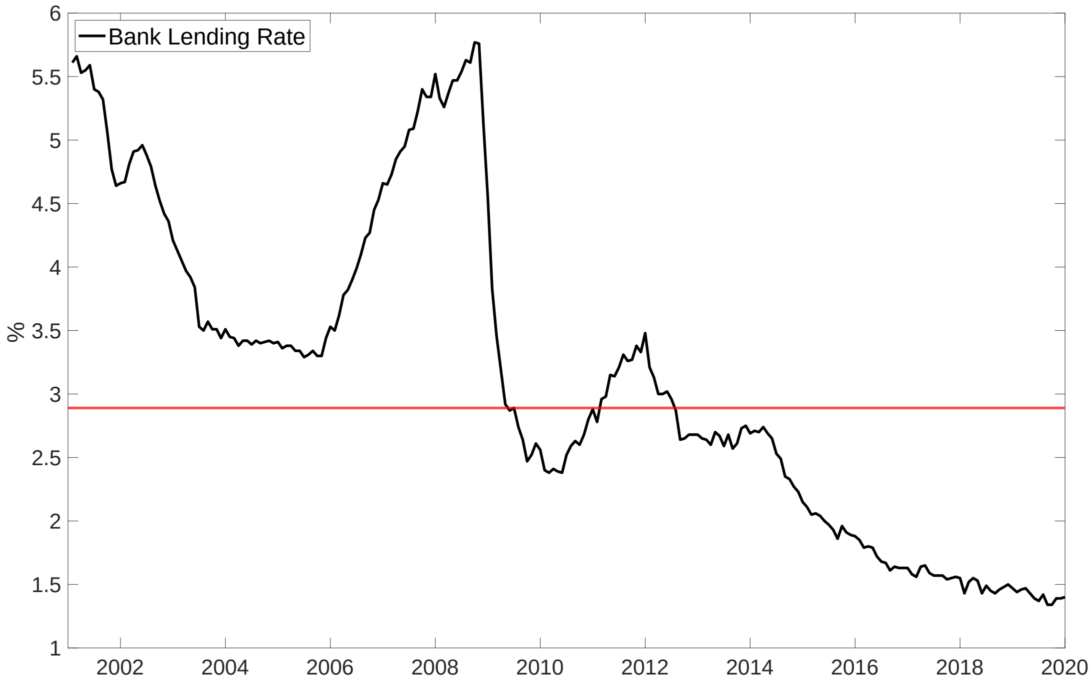
We use a likelihood ratio (LR) test to test for the presence of a threshold, which rejects the null hypothesis of linearity.[23] Furthermore, the threshold variable is orthogonal to the estimated

[21]The TVAR is estimated with the following set of endogenous variables: the consumer price index without food and energy prices, the industrial production index, excess reserves, total MFI loans to euro area residents, the CISS and the euro area wide lending rate.

[22]The threshold values of the switching variable are determined endogenously by a grid search over possible values of the switching variable. The estimation of the threshold values corresponds to the model with the smallest determinant of the covariance matrix of the error terms μ_t.

[23]The p-value of the LR-Test (Linearity vs. Two-Regimes) rejects the null at the 1 percent level. The best unique threshold is equal to 2.89.

Figure 4: Threshold of euro area wide lending rate



Note: The horizontal red line corresponds to the estimated threshold value of 2.89. Data for the bank lending rate is taken from the ECB.

shock. Therefore, a nonlinear framework seems more appropriate to analyze the impact of excess reserves on bank lending. The estimated threshold of 2.89 allows the analysis of impulse responses to excess reserve shocks in two regimes, i.e. a high interest rate regime and a low interest rate regime (Figure 4).

Impulse responses in a high interest rate regime are computed according to:

$$IRF = \hat{\Omega}^h_{1,H} a_i, \tag{9}$$

Similarly, impulse responses in a low interest rate regime are computed according to:

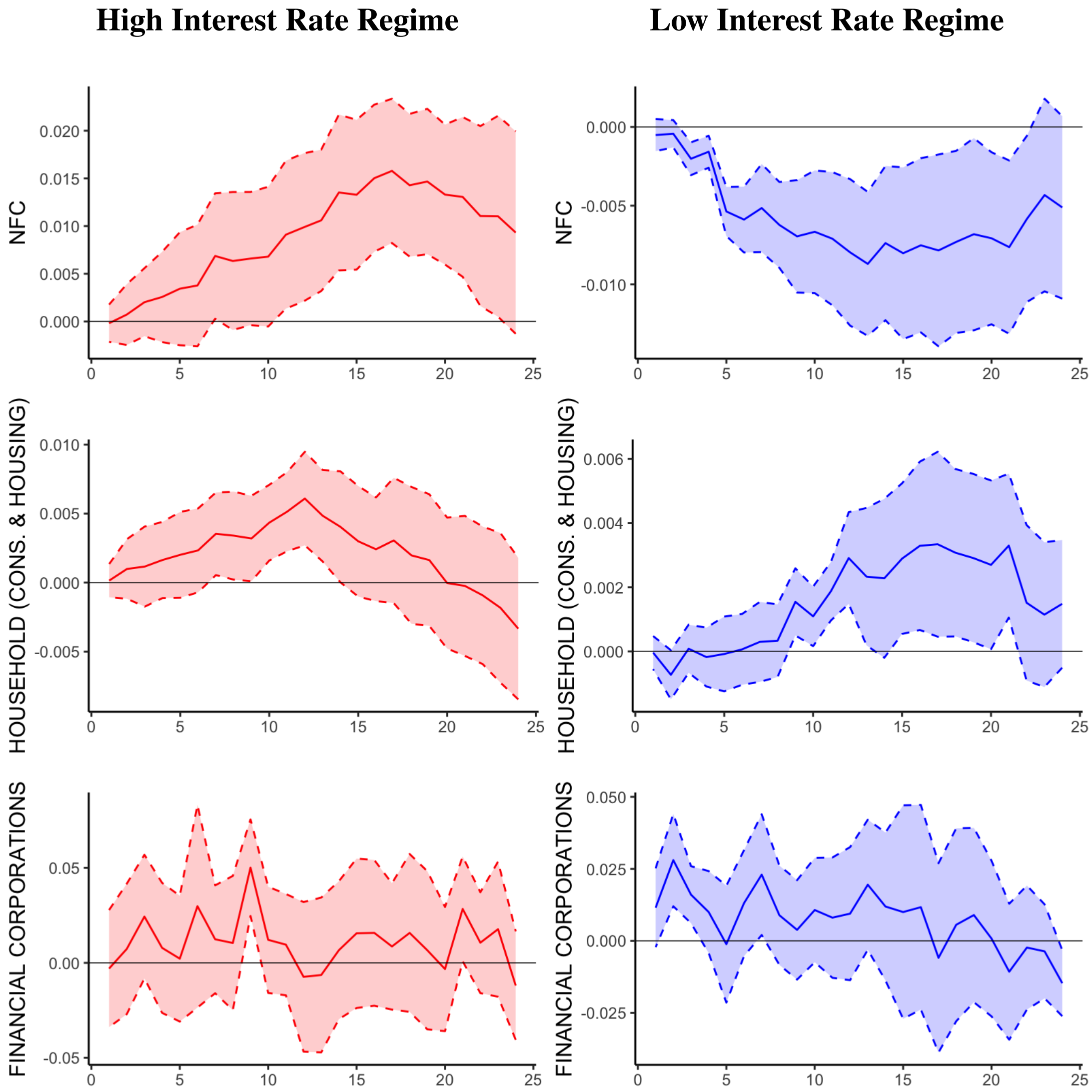
$$IRF = \hat{\Omega}^h_{1,L} a_i. \tag{10}$$

where a_i corresponds to the i^{th} column of the matrix A_0^{-1}, which has been identified by the means of zero and sign restrictions in Section 3.

The impulse response analyses are shown in Figure 5, with the IRFs on the left responding to a shock when interest rates are high (red) and the IRFs on the right responding to a shock when interest rates are low (blue).

The results of the impulse response analysis are consistent with our theoretical expectations. Loans to non-financial corporations respond positively to a one standard deviation to a positive excess reserve shock when interest rates are high. This effect is significant between 10 and 24 months. The maximum spike is around 1.6%. However, loans to NFC show a strong negative response when bank lending rates are low. The effects are significant over nearly all horizons, while having a maximum drop of 0.8%. It appears that costly reserves reduce real-economy credit once lending rates are already low. While the linear IRF analysis shows only a marginally significant negative response of NFC lending, the nonlinear analysis produces a highly significant and long-lasting response. It is also interesting to note that banks were more willing to lend to the non-financial corporate sector at a time when the ECB provided reserves only on demand — and not in excess.

Figure 5: Nonlinear impulse responses functions of credits to excess reserve shock



Notes: Authors' own calculations. The panel on the left-hand side describes IRFs in a regime where the lending rate is above 2.89%. The panel on the right-hand side shows IRFs in a regime where the lending rate is below 2.89%. The respective solid lines represent the median impulse response. Shaded areas represent the 68% confidence interval. NFC stands for non-financial corporations.

Nonlinear effects are also evident in the IRFs of household loans. Household loans respond positively to an excess reserve shock in the high interest rate regime, though only being significant for a short time. The maximum spike can be found around 0.6%. In contrast, the significant response in a low interest rate regime is more persistent. Significance also occurs earlier than in the high-interest rate environment.

Finally, as in the linear LP, loans to financial corporations do not respond significantly to an excess reserve shock when interest rates are high. This is different in the low interest rate regime. Here, we see that an exogenous supply of excess reserves to banks has a positive and significant effect of more than 2.5% lasting around 4 months.

The nonlinear impulse response analysis reinforces the linear context conjecture that bank behavior changed as a result of the exogenously imposed increase in excess reserves due to the ECB's asset purchases. These excess reserves imply higher balance sheet costs, forcing banks to offset the costs by changing their lending behavior. We observe this effect particularly in periods of low interest rates.[24]

To our best knowledge, this analysis is the first empirical work in the euro area to confirm that the consequences of high excess reserves as an unintended by-product of monetary policy have an impact on banks' lending behavior. First, the IRFs confirm the existence of a reverse bank lending channel, as found in Horst & Neyer (2020). The cost of excess reserves increases the marginal cost of holding deposits (Martin et al. 2016) and reduces the total lending to non-financial corporations. Furthermore, banks appear to direct credit to sectors that are more risky for the economy.

Second, we find that the results are amplified when interest rates, in the form of marginal lending rates, are low. This supports the theory of Borio & Zhu (2012), Gambacorta & Marques-Ibanez (2011) and Kandrac & Schlusche (2021). Banks increase their risk tolerance to meet their nominal profitability targets in times of low interest rates. Costly excess reserves contribute to further losses in profitability and may push banks into higher-yielding asset classes.

5. Robustness exercises

5.1. Smooth local projection (SLP)

As was seen, least-square LPs have several advantages compared to VARs (see Section 4). However, when comparing LP and VAR estimations, one could find a bias/variance trade-off between least-squares LP and VAR estimators. For example, Li et al. (2022) conducted a simulation study of LP and VAR estimators of structural impulse responses across thousands of data generating processes. The analysis considers various identification schemes and several variants of LP and VAR estimators. According to their findings, LP estimators have lower bias than VAR estimators but do have a substantially higher variance.

To reduce the variance of least squares LP, Barnichon & Brownlees (2019) propose a penalized regression of LP, thus introducing an IRF estimation methodology called smooth local projection that builds upon penalized B-splines. While sharing the advantages of least squares LPs, SLPs could overcome their major drawback, that is, a large variability of the impulse responses functions (IRF) estimator (Stolbov & Shchepeleva 2021).

[24]Similar results are obtained when estimating IRFs to an excess reserve shock according to Peersman (2011) and Wieladek & Garcia Pascual (2016) in a nonlinear framework.

The logic behind this method consists in modeling the sequence of IRF coefficients as a linear combination of B-splines basis functions and estimating the coefficients of this linear combination using a shrinkage estimator that shrinks the IRF towards a smooth quadratic function of the horizon. More simply, the estimator minimizes the sum of squared forecast residuals (across both horizons and time) and includes a penalty term that encourages the estimation of smooth impulse responses. Li et al. (2022) argue that this kind of penalized LP is especially attractive at short horizons.

According to Barnichon & Brownlees (2019), this SLP method could have a number of advantages. First, the methodology can substantially increase the accuracy of LP estimation while preserving flexibility. Second, the SLP estimation is executed by standard ridge regressions, whose implementation is simple and straightforward. Third, SLP, like standard LP, can be used to recover structural IRFs with a number of identification schemes. Although still very recent and therefore not frequently applied, SLP is gaining attention; see Franta & Gambacorta (2020), Stolbov & Shchepeleva (2021), Funashima (2022).

We consider the following predictive equation for each horizon h,

$$y_{t+h} = \alpha^h + \varphi^h x_t + \sum_{i=1}^{p} \gamma_i^h w_{it} + \varepsilon_{t+h}^h, \tag{11}$$

where x_t is the excess reserve shock at time t, and ε_{t+h}^h is a prediction error term with $Var(u_{t+h}^h) = \sigma^2$. The shock variable is implemented in the SLP by simply ordering it first, see Ramey (2016). y_t are the different credit variables. We are interested in the dynamic multiplier φ^h, which denotes the causal effect of the shock at horizon h. w contains a set of control variables. Since we are particularly interested in verifying banks' responses to an excess reserve shock when interest rates are low, it seems reasonable to estimate the impulse response function for a period between 2013m1-2019m12.

As mentioned above, to overcome the issue of LP estimation via least squares and its suffering from excessive variability, Barnichon & Brownlees (2019) applies an SLP estimation based on B-splines. B-splines are frequently used to approach the so-called splines, a function that is composed in a piecewise way of polynomials with maximum degree n. This method of convergence is conducted by approximating given points with the help of weight functions, where the first and last point can be the start and end point of the curve. The givens are the $q + 1$ points chosen by the researcher, the so-called control points. Then, a smooth curve is sought, which runs in the vicinity of these control points and can be changed locally by shifting them. B-splines are a basis of hump-shaped functions indexed by a set of knots and composed of $q + 1$ polynomial pieces of order q. All B-spline basis functions of order q can be obtained recursively from basis functions of order $q - 1$. For more information on SLP, see Barnichon & Brownlees (2019).

As an approach to approximating the coefficient φ^h, we use a linear expansion of the B-spline basis function expansion in the forecast horizon h, so that the curve representation is,

$$\varphi^h \approx \sum_{k=1}^{K} f_k B_k(h), \tag{12}$$

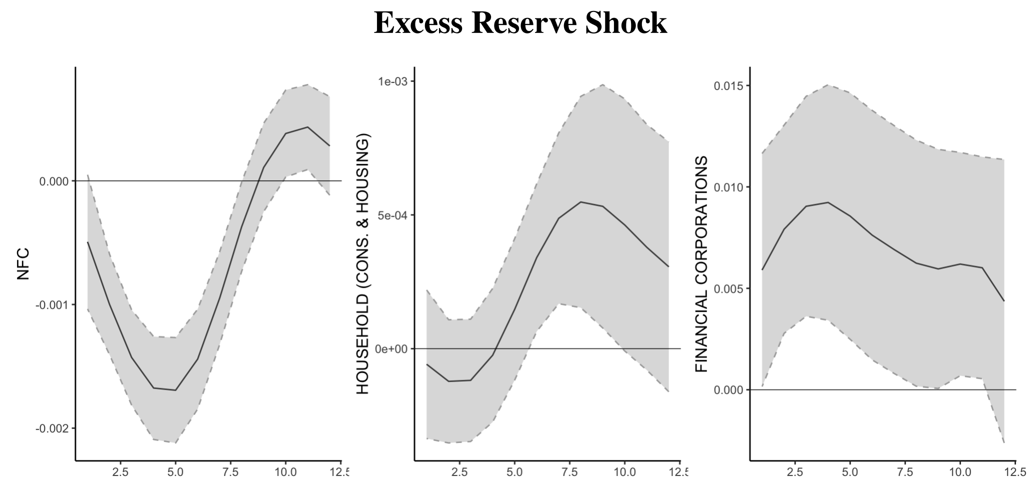
where $B_k : \Rightarrow \mathbf{R}$ for $k = 1, ..., K$ is a set of B-spline basis functions and f_k is a set of scalar parameters for $k = 1, ..., K$. For each horizon, h, φ^h is the weighted sum of the control points. The procedure for the terms α^h and γ_i^h is analogous, so that Equation (11) can be approximated as,

$$y_{t+h} \approx \sum_{k=1}^{K} a_k B_k(h) + \sum_{k=1}^{K} f_k B_k(h) x_t + \sum_{i=1}^{p} \sum_{k=1}^{K} c_k B_k(h) w_{it} + \varepsilon_{t+h}^h. \tag{13}$$

An attractive feature of the model is that it retains linearity in regard to the parameters, which are further examined using a generalized ridge estimation to obtain the values of the dynamic multiplier φ^h. For a more detailed explanation, see Barnichon & Brownlees (2019).

In the case of SLP, if the shock is identified, then the IRF can be estimated by running Equation (13). We set y_t equal to the corresponding endogenous variables, i.e. MFI loans to non-financial corporations, households, and financial corporations. The coefficient φ^h captures the causal effect of the structural shock and the IRF is given by $\varphi^h a_i$, which can be estimated as $\widehat{\text{IRF}}(h, a) = \hat{\varphi}^h a_i$.[25]

Figure 6: Smooth LP impulse responses of credits to excess reserve shock



Notes: Authors' own calculations. The solid black lines represent the median impulse response. The grey shaded areas represent the 95% confidence interval. A horizon of $h = 12$ was chosen, as SLP are more valid in the short run. NFC stands for non-financial corporations.

The results of the impulse response analysis can be seen in Figure 6. 95% confidence intervals are used for SLP estimations. The impulse responses confirm the results shown in the linear local projection impulse response analysis. While credit to non-financial corporations shows a strong and significant negative response, household credit for consumption and housing indicates a strong, significant positive response to an excess reserve shock. In contrast to linear LP analysis, credit to financial corporations also shows a strong positive and long-term significant response. This provides strong evidence to support the findings in the nonlinear LP estimations.

[25] A lag length of $p = 2$ is chosen. However, using different lag lengths produces the same IRFs.

5.2. Alternative identification schemes

To verify our baseline identification strategy and compare it with widely used specification schemes, we identify an excess reserve shock with the variables and restrictions used in Peersman (2011) and Wieladek & Garcia Pascual (2016). Both investigations are limited to the euro area and propose different identification schemes, as can be seen in Table 2 and Table 3, respectively.

We replace the monetary policy variables used in Peersman (2011) and Wieladek & Garcia Pascual (2016) with excess reserves to allow comparison with our model. For the same reason, we apply the identification to a data set with the same observation period as our baseline identification. In addition, we identify the shock using a simple Cholesky decomposition. For this, we use the same variables as in the original benchmark specification.[26] Our objective is to show that similar identification strategies of an unconventional monetary policy shock from the literature are close to, yet conceptually different from, the identification of an excess reserve shock as in our baseline model.

Table 2: Shock identification *à la* Peersman (2011)

Output	Prices	Excess Reserves	Credit	LRate	Policy Rate	Spread	Credit-Base
0	0	≥ 0	≥ 0	≤ 0	0	≥ 0	?

Note: Output: log industrial production, Prices: log HICP index, Excess Reserves: log excess reserves subject to minimum reserve requirement, Credit: log total MFI loans to euro area residents, LRate: euro area wide lending rate to new businesses, Policy Rate: main refinancing rate (MRO), Spread: spread between 12 month and 1 month Euribor, Credit-Base: log spread between total MFI credit and monetary base. The question mark symbol "?" indicates that no restriction has been included for the variable.

For example, Peersman (2011) attempts to identify a conventional and an unconventional monetary policy shock. He defines unconventional policy shocks as positive innovations in credit supply caused by monetary policy actions that are orthogonal to the policy rate and the money market term spread.[27] The identification scheme is shown in Table 2. Similar restrictions to Peersman (2011) have been made in our baseline identification scheme. For example, we include a similar spread between longer-term and shorter-term Euribor to control for banks' demand for liquidity. In addition, our shock is also defined to be orthogonal to the policy rate and thus is constrained to 0.

However, our baseline identification differs from Peersman (2011) in several respects: in addition to the policy rate, we include 10-year government bond yields, which are negatively constrained. This helps us to distinguish between conventional and unconventional monetary policy. Peersman does not make a similar distinction. Moreover, he may neglect the effects of monetary policy on financial markets. For this purpose, we include the CISS index, which is restricted to be non-positive.

Among the papers that only identify an unconventional monetary policy shock, Wieladek & Garcia Pascual (2016) use 10-year government bond yields for the euro area. By choosing a

[26] Output and prices are ordered before excess reserves, with the rest of the variables ordered after.

[27] This is the spread between the 12-months and 1-month Euribor.

Table 3: Shock identification *à la* Wieladek & Garcia Pascual (2016)

Output	Prices	Excess Reserves	Yield	Stock
0	0	≥ 0	≤ 0	≥ 0

Note: Output: log real GDP, Prices: log HICP index, Excess reserves: log excess reserves subject to minimum reserve requirement, Yield: 10-year government bond yield euro area, Stock: log Euro Stoxx 50 index.

period when the policy rate is at its lower bound, they do not seem to have a problem identifying a shock and focus only on unconventional monetary policy. Like us, they do not allow prices and output to react in the same period, while restricting long-term interest rates to negative. In contrast to our identification scheme, they include stock prices as a financial variable instead of CISS. The sign is positive. The identification scheme is shown in Table 3.

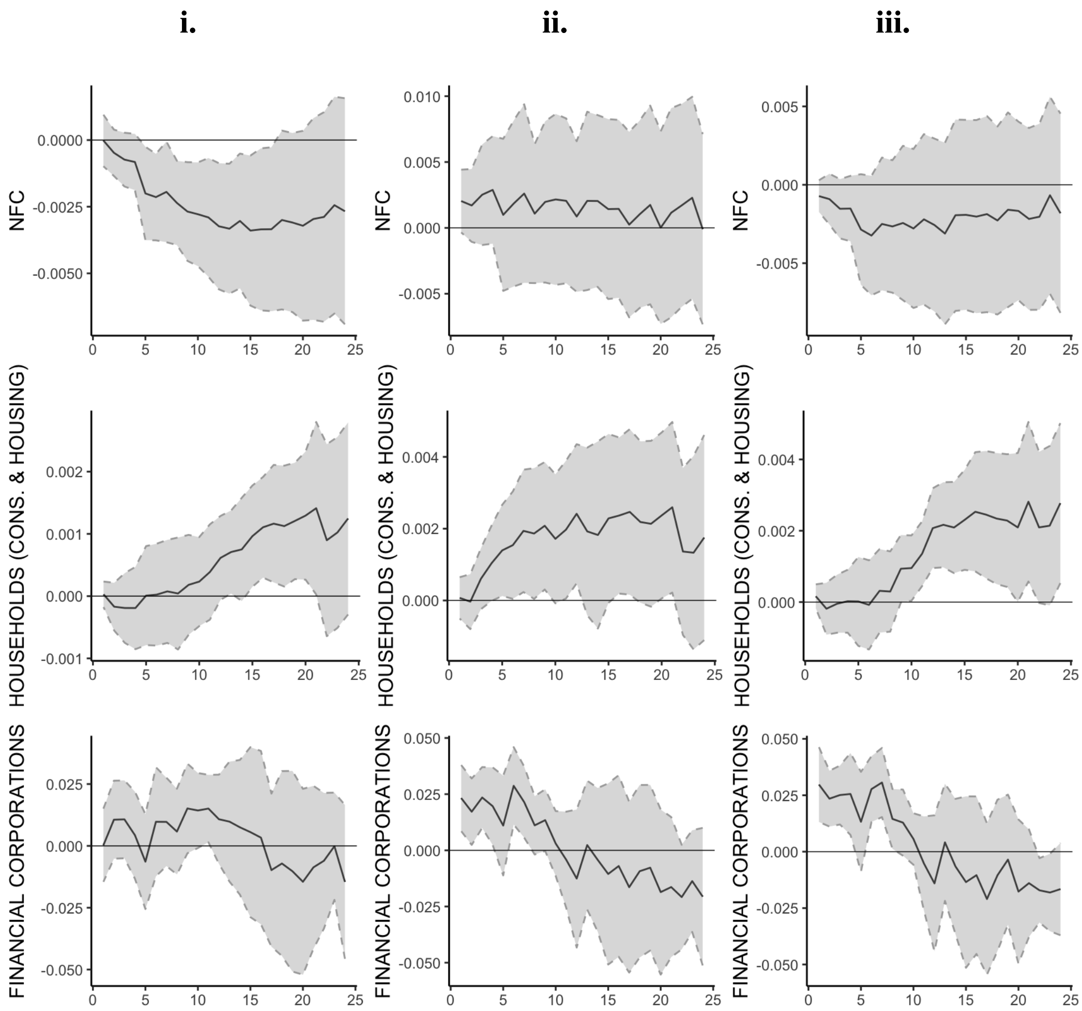
However, if one wants to identify an exogenous and supply-side imposed excess reserve shock on bank balance sheets, this identification is not sufficient. On the one hand, this identification does not control banks' demand for liquidity. On the other hand, in the case of excess reserves, it is equally important to consider conventional monetary policy, since the programs that create excess liquidity are often accompanied by policy rates that still move in positive territory.

In summary, both identification schemes seem to identify the main causal macroeconomic relationships. Yet, a pure excess reserve shock does not seem to be identified with these strategies. To further check the robustness of our identification, we also applied the Cholesky decomposition using the same variables used as the baseline specification. Nevertheless, the difficulty of finding an economically coherent ordering between variables makes such temporal restrictions open to criticism. In particular, disentangling conventional from unconventional monetary policy regimes, as well as identifying an excess reserve shock as supply-driven, seems impossible with the Cholesky decomposition. For this reason, shock identification using zero and sign restrictions is more accurate when analyzing unconventional monetary policy asset purchases.

The impulse response analysis is shown in Figure 7, with the Cholesky identification on the left (i), the identification strategies *à la* Peersman (2011) and *à la* Wieladek & Garcia Pascual (2016) in the middle (ii) and on the right (iii), respectively. The latter two strategies are of particular interest, as each uses different variables and restrictions to achieve shock identification. In column (ii), we see that while loans to non-financial corporations do not respond significantly to an excess reserve shock, both household loans and loans to financial corporations respond significantly positively. A one standard deviation positive excess reserve shock leads to an increase in household loans of about 0.2%. The effects are mostly significant for up to 20 months. The response of credit to financial corporations is less persistent. However, the response peaks at 2.5% and is significant for up to 7 months after the shock.

Column (iii) shows the IRFs using the identification *à la* Wieladek & Garcia Pascual (2016). Here, we assume that asset purchases affect the real economy through portfolio shifts from long-term government bonds to equities. The VAR is estimated for the period 2005m1-2019m12,

Figure 7: Alternative identification schemes



Notes: Authors' own calculations. i. shock identified with Cholesky decomposition; ii. shock identified close to Peersman (2011); iii. shock identified close to Garcia & Wieladek (2016). The solid black lines represent the median impulse response. The gray-shaded areas for the Cholesky identification represent the 95% confidence interval. The gray-shaded areas of the other two identification schemes represent the 68% confidence interval. NFC stands for the non-financial corporations.

as the Euro Stoxx 50 is not available before this period. The IRFs are very close to Peersman (2011) in column (ii).

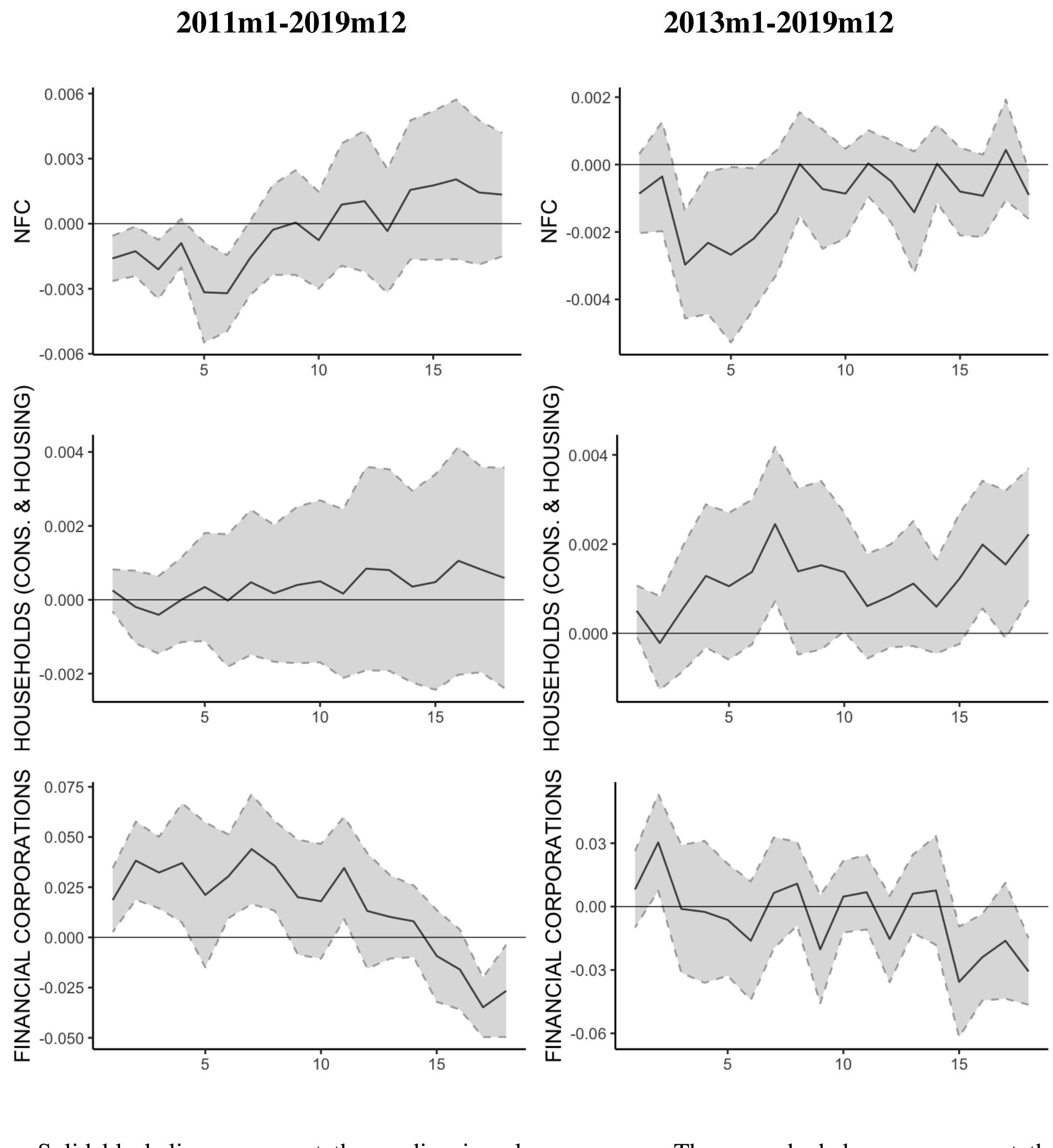
Overall, the estimated impulse response functions show a similar picture to our baseline model. Still, they differ in some respects. This is because the identification *à la* Peersman (2011) and *à la* Wieladek & Garcia Pascual (2016) was used to determine an unconventional monetary policy shock rather than an excess reserve shock.

5.3. Different Time Periods

To show that our identification holds even when periods important for monetary policy are excluded, the excess reserve shock was identified for both the 2011m1-2019m12 period and the 2013m1-2019m12 period. The choice of time frames is based on estimating the model in the absence of the financial crisis and the European sovereign debt crisis. Furthermore, we focus on a period during which unconventional monetary policy was the ECB's instrument of choice. Finally, by choosing a period between 2013m1 and 2019m12, we exclude the exceptionally large increase in the excess reserve shock in mid-2012.

For IRF analysis, the LPs are implemented on the left side of Figure 8. It shows the IRFs in a period excluding the financial crisis and the European sovereign debt crisis (2011m1-2019m12). The right side shows IRFs in a period excluding LTROs in December 2011 and March 2012 (2013m1-2019m12).

Figure 8: Impulse responses of credits to excess reserve shocks in different time periods



Notes: Solid black lines represent the median impulse response. The gray-shaded areas represent the 68% confidence interval. NFC stands for non-financial corporations.

The impulse responses in Figure 8 confirm the results of the baseline estimation. First, credit to NFCs responds significantly negatively to an excess reserve shock in both periods. Additionally, positive movements in credit to households are observed in both 2011m1-2019m12 and 2013m1-2019m12. However, the former responses do not appear to be significant. It is also interesting to note that credit to financial corporations responds significantly positively, albeit only briefly, to a shock estimated from 2013 onward.

6. Conclusion

Following the turmoil of the global financial crisis and the European sovereign debt crisis, the ECB adopted unconventional monetary policies. These measures were successful in preserving financial stability. However, high levels of excess reserves in the banking system were an important by-product of these asset purchases.

The unintended consequences of these large liquidity holdings are associated with higher balance sheet costs, such as agency or regulatory costs. As a result, the bank lending, and thus the stimulative effect of the ECB's asset purchases, may be altered. Costly excess reserves can lead banks to increase loans into higher-yield sectors to meet their profitability targets and compensate for the additional costs. Low interest rates add additional pressure on profits.

Although there is an emerging theoretical literature on the adverse effects of excess reserves on bank lending (Martin et al. 2016, Heider et al. 2019, Diamond et al. 2023, Horst & Neyer 2020), our paper is, to the best of our knowledge, the first to empirically estimate the unintended consequences of forcing the euro area banking system to hold a large amount of non-needed liquidity.

Against this background, we first identify exogenous excess reserve shocks using zero and sign restrictions. This allows us to disentangle unconventional from conventional monetary policy regimes and to model banks' excess reserve holdings as supply-driven. Then, we implement this shock as an external series in local projections and smooth local projections to then estimate impulse response functions of disaggregated loans. We find that reserve shocks do not lead to an increase in loans provided by the banking sector, but rather to a shift in the credit distribution towards the different sectors in the economy.

Specifically, our paper shows that the imposition of excess reserves due to the ECB's asset purchases forces banks to reduce their lending to non-financial corporations. Higher balance sheet costs due to the high stock of excess liquidity seem to dampen traditional bank lending to the real economy. This confirms the idea of a reverse bank lending channel, as advocated by Horst & Neyer (2020), rather than the concept of a traditional bank lending channel in conventional times, following Bernanke & Blinder (1988). Therefore, the transmission of monetary policy is different in a regime where the banking system operates under a structural liquidity surplus. Furthermore, the linear framework shows that loans to households respond significantly and negatively to an excess reserve shock, while loans to financial corporations do not.

Applying a nonlinear framework reveals that the effects of the identified excess reserve shock are more pronounced when the euro area-wide bank lending rate is below a certain threshold. We explore whether lending changes when the lending rates are low, and thus the profitability of lending is generally low. In particular, loans to non-financial corporations react strongly negatively, while loans to households react strongly and persistently positively. Unlike linear IRF analysis, loans to financial corporations now react positively when bank lending rates are low.

Although ECB asset purchases were probably necessary in the early stages of the global financial crisis (Wieladek & Garcia Pascual 2016), the bank lending channel plays a different role than theoretically expected in this context. High levels of excess reserves have serious implications for the transmission of monetary policy. Accordingly, our findings are not only important in times of monetary easing, but also need to be considered in monetary policy decisions in times of monetary tightening. Future research will examine the effect of quantitative tightening (QT) under conditions of high excess reserves as data become available. Since excess reserves will not disappear from the banking sector, liquidity holdings will also play a crucial role in the ECB's tightening cycle. Whether QT has symmetrically opposite effects to QE needs to be carefully monitored. Of particular interest are the reactions of bank lending and the overall stability of the financial sector.

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