A Reserve-Focused Assessment of Quantitative Easing and Bank Balance Sheets

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Abstract

During the financial crisis and the pandemic, the Federal Reserve created vast amounts of bank reserves to finance purchases of long-term securities and drive down their yields. I investigate how bank balance sheets react to this reserve creation. I identify a reserve supply shock using agnostic identification of structural vector autoregressive (SVAR) models developed by Arias et al. (2019). Banks react to an unexpected influx of reserves by decreasing loans and increasing holdings of liquid assets – mostly the reserves themselves, but also federally-backed debt securities. I find evidence that banks are actually willing to lend and sell the loans to issuers of asset-backed securities, but they are limited by loan demand.

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JEL Codes: E31, E32, E44, E51, E52, E58, G21, G28

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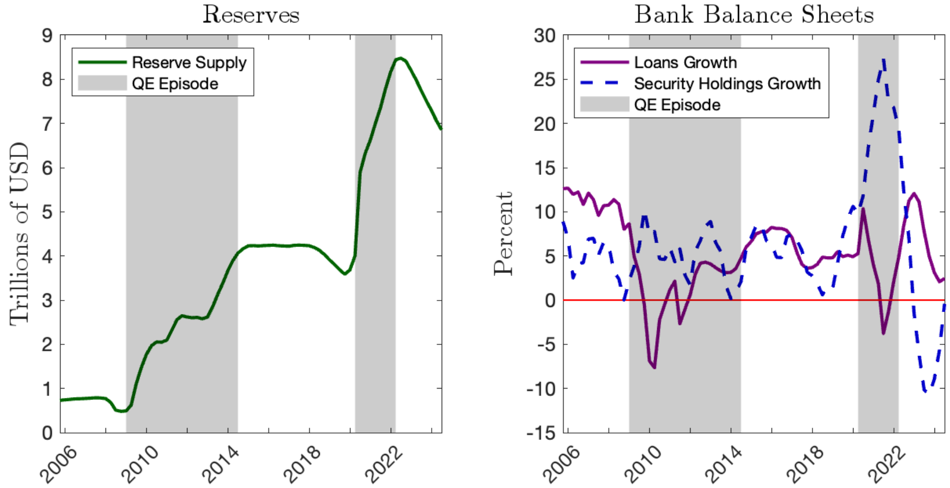
1 Introduction

On March 15, 2020, the Federal Reserve released a statement saying that it is "prepared to use its full range of tools to support the flow of credit to households and businesses." One of these tools is the Fed's purchase of long-term debt securities while short-term interest rates are low, commonly referred to as quantitative easing (QE). On a large scale, purchasing these securities eases conditions for borrowers by driving up demand for their debt and lowering yields. At the same time, the Fed finances these purchases by crediting the sellers with reserves, which are risk-free, nominal assets that can only be held by the sellers (called primary dealers), the government, and depository institutions (hereafter "banks"). The left panel of Figure 1 shows that the Fed drastically increased the supply of reserves during two asset purchasing sprees: 2008-14 and 2020-22. The right panel demonstrates a striking shift on bank balance sheets. During these sprees, the growth rate in bank security holdings far outpaces that of loans. Is this shift the result of reserve creation? Is the contraction in loans due to an unwillingness of banks to issue new ones? Or is the culprit something else like dampened loan demand from the coinciding recessions?

In this paper, I ask how the influx of reserves from QE affects bank balance sheets on aggregate. I use structural vector autoregression (SVAR) to find that banks decrease aggregate loan holdings roughly half a year after a positive reserve supply shock. I find strong evidence that banks instead prefer to hold safe, liquid assets – mostly the reserves themselves and federally-backed debt securities to a lesser extent. The idea is that injecting risk-free (and often interest-bearing) reserves into the banking system should impact the trade-off between high-yield, illiquid loans and low-yield, liquid assets. Following Diamond et al. (2024), I call this the "reserve supply channel" of QE. Bianchi and Bigio (2022) provide a theoretical backdrop that

Figure 1: Bank Balance Sheets during QE



Monthly data taken from FRED (see Section 2.1 for details). The left panel displays a level, the right panel year-over-year growth rates. Both are averaged to quarterly frequency. Dates for QE are inferred from the website of the Federal Reserve Bank of New York.

connects monetary policy to this trade-off. While the decrease in loans is somewhat *unintended*, I also document that a positive reserve supply shock elicits the *intended* positive responses from real GDP and prices. Although, it is not my objective to attribute these responses to a particular channel of QE.

Asset markets receive the most attention surrounding QE, but monetary policy is ultimately implemented through banks. The effectiveness of QE through declining yields and rising asset prices could be amplified by bank asset purchases or counteracted if loan origination slows. Of course, an individual bank can avoid both loans and securities and hoard the reserves themselves. Thus, the quantity of aggregate reserves supplied *and* the allocation of these reserves across banks can impact aggregate holdings of loans and securities. It is important that policymakers understand the factors that determine how banks orient their balance sheets around reserves. These factors can help gauge under which circumstances amplification or counteraction wins and how banks stand to gain or lose.

To this point, I investigate the mechanism of the results in Section 4. After controlling for potential explanatory variables, I show that banks are indifferent between holding loans or securities when responding to a reserve supply shock. Among these variables, I find that banks hold on to liquid assets due to a lack of loan demand, not supply. The results are actually consistent with increased lending activity when loan demand, the default rate, and Treasury spreads improve during Fed asset purchases. Total MBSs outstanding is another important factor suggesting that banks likely sell off loans for the issuance of securities. I find little evidence that the mechanism behind the decrease in loans can be traced back to the influx of reserves. Rather, it is more likely that QE plays a role in determining which liquid assets banks hold while waiting for loan demand to recover.

The literature on the transmission of QE through the reserve supply channel is small compared to through asset markets.[1] However, I do not view my research question as a novel one. Diamond et al. (2024) ask the same question and determine that QE reduces lending (driven by commercial loans) by increasing its marginal cost. My paper differs from theirs in three key ways. First, I feature bank security holdings more prominently in my discussion. Second, I use a dynamic, macroeconomic model whereas Diamond et al. (2024) conduct cross-sectional demand and supply estimation. Beyond the obvious contribution of time-dependent responses, dynamics are crucial because QE is determined in concert with the macroeconomic environment. Diamond et al. (2024) assume QE to be exogenous. Third, and somewhat related, I use monthly data while Diamond et al. (2024) aggregate to the annual frequency.

[1]Prominent and/or recent papers studying the asset market channels of QE include Krishnamurthy and Vissing-Jorgensen (2011); Fabo et al. (2021); Swanson (2021); Bauer and Swanson (2023); and, Swanson (2024). Also, Bernanke (2020) surveys monetary policy tools considered "unconventional," including QE.

Other papers in this area take a more focused approach. Kandrac and Schlushe (2021) and Delis et al. (2024) study lending around a 2011 FDIC policy change that (1) determines fees by assets, not deposits, and (2) exempts banks from fees based on reserve holdings. Both find that lending increases (for fee exempt banks and syndicate loans respectively). Despite the opposite results, these papers are actually consistent with my finding that banks' preference for liquidity is correlated with low loan demand. Couaillier (2022), finds that bank capital targets are procyclical, which is related to increased holdings of liquid assets during QE. Christensen and Krogstrup (2019) attribute declining long-term yields on Swiss debt to bank portfolio rebalancing in response to QE there. Generalizing these results to the U.S. is difficult because the Fed purchased long-term debt whereas the Swiss National Bank stuck to short maturities. My results suggest that U.S. banks are more inclined to replace loans with reserves than securities, at least on aggregate. More distantly, Buchak et al. (2024) investigate the secular decline of lending. They attribute this trend in large part to improvements in securitization technology, akin to my findings. I uncover a possible connection between this secular decline and reserve creation.

It is worth noting that, prior to the QE era, empirical papers studying conventional policy often included reserves in VAR systems (e.g. Bernanke and Blinder, 1992; Christiano et al., 1996; Uhlig, 2005; Arias et al., 2019). Bernanke and Blinder (1992) are the first to present evidence that conventional monetary policy works in part through bank balance sheets. Like me, they find a delayed response from bank security holdings and loans. However, in their case, the response from loans is more prolonged.[2] If the reserve supply channel spills over to the macroeconomy, then it will likely take at least half a year to materialize.

The paper proceeds as follows. Section 2 outlines the data, SVAR identification, and sampling algorithm. Section 3 reports the main results and their immediate consequences. Section 4 uncovers potential mechanisms and discusses their policy implications before a concluding summary in Section 5.

2 Empirical Approach

I identify only a reserve supply shock in a SVAR using methods developed in Arias et al. (2019). I see a couple advantages of this so-called "agnostic identification" for my application. It leverages the basic elements of monetary policy determination to impose uncontroversial sign and zero restrictions that specify a policy rule. This policy-rule emphasis leaves the impulse responses untouched. Additionally, it permits clear interpretation of the structural shock corresponding to the policy rule – the reserve supply shock in my case. The downside is that partially identified SVARs under sign and zero restrictions can suffer from heightened identification uncertainty.

In this section, I first describe the data, including the construction of reserve supply. Then, I derive the monetary policy rule and impose the identifying restrictions. Lastly, I discuss the details of the Bayesian sampling algorithm.

[2] One possible reason why loans respond quicker in my setup is the increased prevalence of securitization since the 80s and 90s (Fuster et al., 2022; Buchak et al., 2024), which is consistent with my results.

2.1 Data

My sample runs from July 2004 to June 2024 capturing both QE for the financial crisis and the pandemic at the monthly frequency (240 months total). I begin in 2004 because aggregate bank data is not available before then; but, I also prefer to include several years prior to the initial round of QE. I collect data from FRED ('FRED code') for the aggregate level of loans held by all commercial banks ('LOANS'), the aggregate level of security holdings by all commercial banks ('INVEST'), and the federal funds effective rate ('FEDFUNDS'). For consistency with Arias et al. (2019), I collect quarterly data for real GDP ('GDPC1') and the GDP deflator ('GDPDEF') and obtain monthly interpolations using industrial production ('INDPRO') and the CPI ('CPIAUCSL') respectively.[3]

I construct reserve supply by summing the last Wednesday of the month Fed holdings of U.S. government debt (Treasuries), mortgage-backed securities (MBSs), and federal agency debt.[4] According to "the Desk" at the New York Fed, these are the three assets targeted by QE. Taking the last value of the month ensures that reserve supply captures all the assets purchased within the month. The constructed series includes holdings of varied maturities, but reserves are supplied regardless of the purchased asset's maturity. MBSs are those backed by U.S. government-sponsored enterprises (GSEs) like Fannie Mae. Federal agency debt refers to debt of the GSEs. Treasuries account for the vast majority of reserves supplied (100% before 2008). However, MBSs and federal agency debt are together important (peaking at 62% of

[3]Specifically, I use a method developed by Chow and Lin (1971), which uses weighted least squares to infer the relationship between the quarterly and monthly data. Beyond my baseline specification, I replace the interpolations with their monthly cousins (industrial production or consumption expenditures and the CPI or the PCE price index).

[4]Reserves encompass both federal funds (cash held in accounts at the Fed) and vault cash. In more precise terms, the constructed series for reserve supply reflects the quantity of federal funds.

reserve supply in June 2010 and falling to 34% in June 2024). The initial rounds of QE were comprised entirely of MBSs and agency debt reflecting the collapse in the housing market. Fed purchases of long-term Treasuries were delayed by several months. Thus, I believe it is important to consider all three assets when studying QE. I discuss the composition of Fed asset purchases again in Section 4.3.

In general, bank assets are either loans, securities, or reserves held at the Fed. Other assets are negligible within the available aggregate bank data. Loans are of the commercial, consumer, commercial real estate, and residential real estate types, each of which is roughly equal in size. Bank security holdings refers only to Treasuries, GSE-backed MBSs, and non-U.S. government securities.[5] Banks have been decreasing their relative holdings of the latter, comprising 37% of all securities in January 2010 and only 20% in January 2024. Bank reserve holdings increased dramatically with reserve supply beginning in 2008. The two series fluctuate together (with a correlation of 0.95), but they are distinct. The difference comes from the non-depository institution holders of federal funds, which are the U.S. Treasury, GSEs, and the primary dealers.

In my baseline specification, I let the vector of endogenous variables y_t contain monthly real GDP (gdp_t), the GDP deflator (dfl_t), loans (lns_t), bank security holdings (sec_t), the fed funds rate (ffr_t), and reserve supply (res_t). All variables are seasonally adjusted except the FFR and reserve supply. All variables are in billions of USD except the deflator and the FFR. All variables are in log levels except the FFR for ease of interpretation. I utilize other data throughout the paper. See Appendix A for a description of all the data used.

[5]Non-U.S. government securities include non-GSE-backed MBSs, other asset-backed securities, state and municipal debt, mutual funds, foreign debt, and other equity securities. Details can be found in the Fed's H.8 data release.

2.2 SVAR Identification

Following the notation in Arias et al. (2019), I specify the following SVAR:

$$y_t' A_0 = c' + \sum_{l=1}^{L} y_{t-l}' A_l + \varepsilon_t', \tag{1}$$

where y_t is a $n \times 1$ vector containing the endogenous variables, A_l is a $n \times n$ matrix containing the structural parameters for $0 \leq l \leq L$, c is a $n \times 1$ vector containing additional parameters, and ε_t is a $n \times 1$ vector containing normally-distributed structural shocks with zero means and a covariance matrix given by the $n \times n$ identity matrix. In my specification, the number of endogenous variables, n, is six, and the lag length, L, is twelve. Assuming A_0 is nonsingular, the corresponding reduced-form VAR (RFVAR) is

$$y_t' = c_+' + X_t' B + u_t', \tag{2}$$

where $c_+' = c' A_0^{-1}$, $X_t' = [y_{t-1}' \cdots y_{t-L}']$, $B' = [A_1 A_0^{-1} \cdots A_l A_0^{-1}]$, and $u_t' = \varepsilon_t' A_0^{-1}$. The reduced-form errors, u_t, are evidently normally distributed with zero means and a covariance matrix given by $\Sigma = (A_0 A_0')^{-1}$.

It is well-known that restrictions must be imposed to identify the structural parameters, A_0, and therefore also the structural shocks, ε_t. Again following Arias et al. (2019), I impose these restrictions so as to specify a monetary policy rule. The first equation of the SVAR is given by

$$y_t' a_{0,1} = c_1 + \sum_{l=1}^{12} y_{t-l}' a_{l,1} + \varepsilon_{t,1}, \tag{3}$$

where $a_{0,1}$ and $a_{l,1}$ are the first columns of their respective matrices and c_1 and $\varepsilon_{t,1}$ the first entries of their respective vectors. Without loss of generality, let this be the monetary policy rule determining how reserve supply is set. Arias et al. (2019) assert that specifying a monetary policy rule is enough to interpret the corresponding shock as the monetary policy shock (Leeper et al., 1996; Leeper and Zha, 2003; Sims and Zha, 2006). Thus, I interpret $\varepsilon_{t,1}$ as the reserve supply shock.

After carrying out the products in Equation 3 and isolating reserve supply on the left-hand side, we have

$$\begin{aligned} res_t = \underbrace{a_{0,61}^{-1}c_1}_{=\alpha} + \underbrace{(-a_{0,61}^{-1}a_{0,11})}_{=\gamma^{gdp}} gdp_t + \underbrace{(-a_{0,61}^{-1}a_{0,21})}_{=\gamma^{dfl}} dfl_t + \underbrace{(-a_{0,61}^{-1}a_{0,31})}_{=\gamma^{lns}} lns_t \\ + \underbrace{(-a_{0,61}^{-1}a_{0,41})}_{=\gamma^{sec}} sec_t + \underbrace{(-a_{0,61}^{-1}a_{0,51})}_{=\gamma^{ffr}} ffr_t + \cdots + \underbrace{a_{0,61}^{-1}}_{=\sigma} \varepsilon_{t,1}. \end{aligned} \tag{4}$$

This is what I call the "unconventional monetary policy rule" (in contrast to the conventional interest rate rule specified in Arias et al., 2019). QE is meant to decrease yields of long-term debt securities, but it also creates reserves. Thus, this rule can be viewed as one side of the "QE coin." It is arguably better to specify a reserve-focused rule since the Fed has sole control over how many assets it purchases. The coefficients can consequently be interpreted as the Fed's contemporaneous response to the respective variables when purchasing assets.

I begin by restricting the relationship between conventional contractionary policy (increasing the FFR) and unconventional expansionary policy (asset purchases).

Restrictions 1 & 2:

$\gamma^{ffr} < 0$, and ffr_t does not react contemporaneously to res_t.

The first restriction states that the Fed relies more on asset purchases as the short-term FFR declines (and vice versa). The second restriction imposes that the FFR does *not* react on impact to reserve supply. The justification is that the Fed will keep the policy rate steady while it pursues QE. Only at the next FOMC meeting can it switch back to conventional contractionary policy. This is the only restriction I impose on the impulse responses.

A natural and interesting extension of my work might impose time-varying restrictions acknowledging that reserve supply increases sharply only when the FFR is at the zero lower bound (ZLB). However, I do not consider these restrictions necessary. Asset purchases create reserves regardless of the level of the FFR. Furthermore, since late 2008, the FFR is maneuvered using rates explicitly set by the Fed like interest on reserve balances (IORB), not open market operations (OMOs). Instead, OMOs (i.e. asset purchases) are now used to ensure that the Fed supplies an "ample" amount of reserves, which implies that the Fed's asset purchases are not directly tied to the ZLB.

Next, I restrict how QE is conducted in response to the macroeconomy.

Restrictions 3 & 4:

$$\gamma^{gdp}, \gamma^{dfl} < 0 \textit{ such that QE is conducted during contractions}$$
$$\textit{(and quantitative tightening, QT, during expansions).}$$

Together, these restrictions impose that the Fed attempts to stimulate aggregate demand by purchasing assets while prices remain below its target or real economic activity is stifled.[6] This is the same goal as conventional policy. *Restrictions 1 & 2*

[6]I implicitly make the same timing assumption as Arias et al. (2019): the Fed has enough available data to react to real GDP and prices contemporaneously. Although some data are not available at high frequencies, the FOMC uses forecasts, weekly indicators, surveys, and more to gauge economic activity in real time.

are important because they ensure that conventional and unconventional tools are *together* contractionary or expansionary.

Output and prices are essential in a standard Taylor-like monetary policy rule. However, my policy rule also contains loans and bank security holdings because they are central to my research question. In the following restrictions, I assume that the Fed reacts to the macroeconomy only, not bank balance sheets.

Restrictions 5 & 6:

$$\gamma^{lns}, \gamma^{sec} = 0 \textit{ such that reserve supply}$$
$$\textit{is not set according to bank balance sheets.}$$

It is likely that the Fed *does* consider banks when setting monetary policy. So, I must clarify that I assume the Fed is more concerned with the banking sector's influence on real output and prices. Thus, it may nest banks within its response to the macroeconomy using bank data and surveys.[7]

2.3 Sampling & Priors

Of course, it is generally not feasible to draw the structural parameters directly. So, I use code provided by Arias et al. (2019) that draws the reduced-form parameters in Equation 2 under a sampling algorithm developed by Arias et al. (2018). Note, to restrict the coefficients in the policy rule (Equation 4) is to restrict the structural parameters. Arias et al. (2018) show that drawing the reduced-form parameters from a posterior with the Normal-inverse-Wishart (NIW) distribution is equivalent

[7] To my knowledge, a reserve-based monetary policy rule has not been used in the literature. I further justify my restrictions by regressing first-differenced log reserve supply on the other endogenous variables. All the estimates have the expected signs to match my restrictions (Table 4 in Appendix C). These results are largely robust to specifications with one lag, twelve lags, excluding loans and bank security holdings, and using different data for output and prices.

to drawing the structural parameters from a so-called Normal-generalized-Normal density, which is simply the NIW density scaled by a term coming from a change of variable. In short, the algorithm is a type of importance sampler that forces the zero restrictions to hold, then resamples from draws satisfying the sign restrictions in the structural parameterization. I use the conjugate NIW prior and set the usual hyper-parameters to the case of the uninformative prior, as in common in the literature. I provide more details about sampling in Appendix B.

I must note that the sampling algorithm utilizes the orthogonal reduced-form parameterization, which is convenient under sign and zero restrictions. The use of an orthogonal matrix has been criticized because it introduces information beyond the data and identifying restrictions that favors some parameter values over others. To be more specific, a uniform prior on the set of orthogonal matrices translates to a non-uniform prior on the set of individual parameters under the identifying restrictions (Baumeister and Hamilton, 2015). Arias et al. (2025) ease this concern when the object of interest is the entire vector of impulse responses. However, their absolution does not apply to under-identified systems. For the time being, I posit that the advantages of agnostic identification outweigh the disadvantages.

In practice, I augment the RFVAR in Equation 2 with dummies covering six months during the coronavirus pandemic beginning in March 2020. Failing to control for the break from historical trends during the pandemic could bias my results. I employ priors on these dummies proposed by Cascaldi-Garcia (2024). The innovation is a prior parameter that controls the informativeness of the pandemic observations. Following Cascaldi-Garcia (2024), I choose this parameter by maximizing the marginal data density.

3 Results

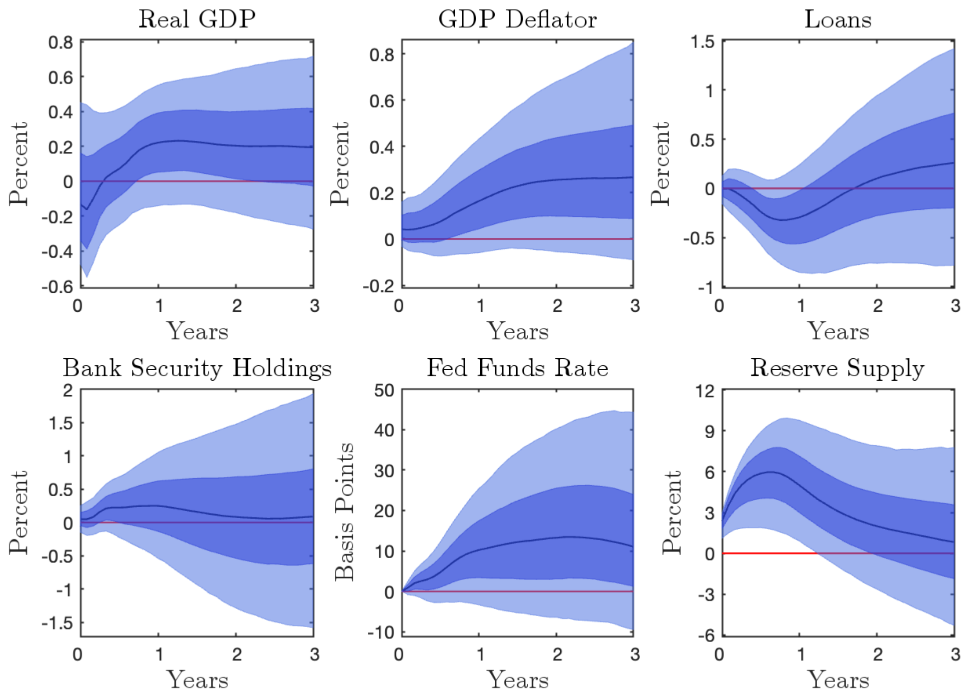
For all impulse response functions (IRFs) posted hereafter, I plot the pointwise median path and 68% and 95% probability bands based on ten thousand draws from the posterior distribution. Recall that the strength of agnostic sign and zero restrictions is confidence in the signs of the IRFs. Later in this section, I also briefly discuss robustness.

Figure 2 shows the baseline responses to a positive reserve supply shock, which represents an unexpected increase in Fed asset purchases (an expansionary shock). The responses from loans and bank security holdings are most relevant to my research question. Loans respond negatively with high posterior probability from roughly six to twelve months after the shock. The negative response is consistent with Diamond et al. (2024). It is important not to conflate loan holdings with loan issuance. Selling off loans and letting existing loans expire without issuing new ones are observationally equivalent here. The latter appears to be more consistent with the delayed response. However, it takes time for reserves to reach commercial banks after Fed asset purchases.[8] Thus, it may also take time for banks to sell loans. Forming a consistent story about these results is the topic of Section 4. Bank security holdings respond positively with most posterior probability roughly three to six months before loans. Despite the wider probability bands, the median responses of both loans and bank security holdings peak at about the same magnitude. Again, bank security holdings are comprised mostly of federally-backed debt securities, of which U.S. Treasury debt is the *most likely* driver of the increase. Consider that Treasury bonds doubled as a percent of total bank security holdings across my sample (32%

[8] Recall that reserves are initially credited to the primary dealers, which are most often not depository institutions.

in June 2024). Overall, it appears that banks prefer safe, liquid assets over loans in response to an increase in reserve supply.

Figure 2: Impulse Responses to an Expansionary Reserve Supply Shock



IRFs to a one standard deviation positive reserve supply shock identified under *Restrictions 1-6*. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands. All IRFs are based on ten thousand draws from the posterior distribution.

Real GDP and the GDP deflator both respond positively with high posterior probability to the expansionary shock – as expected. These responses are incredibly robust to other specifications, which I discuss below. In this paper, I do not determine whether the expansionary outcome is driven by the reserve supply channel or other channels of QE. Although, the macroeconomy looks to react *more* slowly than banks. So, it is plausible that banks are feeding into these responses. Bassett et al. (2014)

and Boyarchenko et al. (2024) find that bank capital and lending practices have a meaningful impact on real GDP.

The responses from the Fed are consistent with the switch from unconventional expansionary to conventional contractionary policy. Specifically, the Fed initially increases reserve supply greatly. After it observes an increase in output and prices, there is upward pressure on the FFR and the response from reserve supply (asset purchases) returns to zero. As mentioned in Section 2.1, an increase in reserve supply is highly correlated with an increase in bank reserve holdings. Based on the response from reserve supply, we can infer that the most drastic change on bank balance sheets is not loans or security holdings, but reserve holdings. Banks hold on to large quantities of reserves when the supply unexpectedly increases.

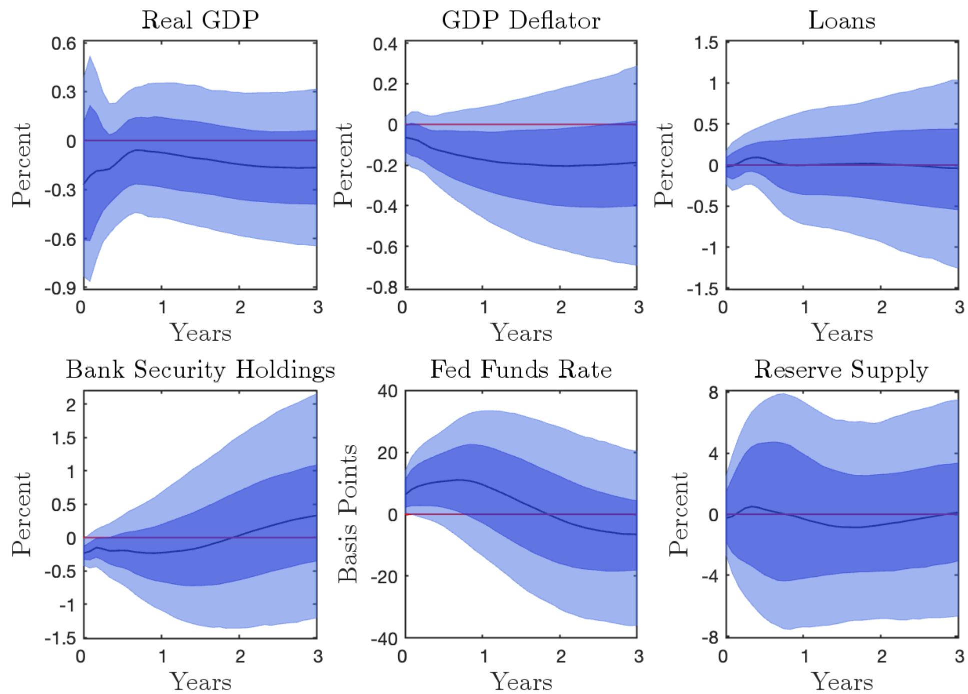
For perspective, I also *separately* identify a traditional FFR shock. I plot the responses in Figure 3.[9] All responses are either imprecise or attenuated compared to the responses to the reserve supply shock, which is weak evidence supporting the use of asset purchases while conventional policy is constrained.[10] Real GDP and the GDP deflator react negatively as expected (consistent with Arias et al., 2019, and conventional wisdom). Loans and reserves have no discernible response. The most interesting takeaway comes from bank security holdings. Banks likely want to avoid losses from an unexpected rise in interest rates. So, they sell debt securities on impact. Thereafter, there is no response from bank security holdings.

Focusing again on reserve supply, Table 1 contains percentiles of the posterior draws of the contemporaneous coefficients in Equation 4. These estimates represent the Fed's sensitivity to the other endogenous variables when determining how many

[9] In Appendix C, I also report the coefficients for the conventional fed funds rate policy rule when identifying this shock.

[10] Stronger evidence exists in the literature (e.g. Gagnon et al., 2010; Sims and Wu, 2020).

Figure 3: Impulse Responses to a Contractionary Fed Funds Rate Shock



IRFs to a one standard deviation positive Fed Fund Rate (FFR) shock identified by modifying Equation 4. That is, the FFR and reserve supply swap places such that the FFR is the policy tool of interest. *Restrictions 1-4* are modified such that the FFR has a contemporaneous positive response to real GDP and the GDP deflator. I do not restrict the FFR response to reserve supply or vice versa. I keep *Restrictions 5 & 6* that the FFR does not react to bank balance sheets. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands. All IRFs are based on ten thousand draws from the posterior distribution.

assets to purchases within the same month. I find that the Fed is most sensitive to prices, in line with its dual mandate. Reserve supply increases by about 4% and 1% when the GDP deflator and real GDP drop by 1% respectively. It increases by about 1.7% when the FFR drops by one hundred basis points. This estimate also tells us the pace of QT. The Fed's balance sheet shrinks by 1.7% when the FFR rises by one hundred basis points. Of course, γ^{lns} and γ^{sec} are zero by *Restrictions 2 & 3*. The left tails are rather large for all coefficients, especially for γ^{dfl}. As in Arias et al. (2019), I check my results to rejecting implausibly large draws (in absolute value).

My baseline IRFs are incredibly robust to this check. I post these responses and other selected robustness in Appendix C.

Table 1: Coefficients in the Unconventional Monetary Policy Rule

Parameter	2.5th %-tile	16th %-tile	Median	84th %-tile	97.5th %-tile
γ^{gdp}	-2.916	-1.957	-1.039	-0.331	-0.052
γ^{dfl}	-15.996	-8.613	-3.927	-1.145	-0.174
γ^{lns}			0.000		
γ^{sec}			0.000		
γ^{ffr}	-5.066	-3.350	-1.719	-0.570	-0.091

Percentiles based on ten thousand draws from the posterior distribution of the coefficients in Equation 4. Those posted here are the contemporaneous coefficients. The intercept and coefficients on the lag terms are not posted (nor restricted).

My baseline IRFs are also robust to only six lags instead of twelve, leaving the coefficient on the FFR in the policy rule unrestricted, more or less pandemic dummies, and choosing a small or large informativeness parameter on the pandemic observations (from Cascaldi-Garcia, 2024). There is some attenuation in the responses for the model with only three lags or first-differenced data instead of log levels. Although, all responses have the same signs as their baseline counterparts in Figure 2. When I drop *Restriction 2* (the FFR does not react on impact to reserve supply), the left tails of the posterior distributions of the contemporaneous coefficients are much larger than the baseline. Additionally, the FFR responds positively on impact to an unexpected increase in asset purchases. Thus, I believe *Restriction 2* is crucial for separating expansionary and contractionary policy. All other responses are largely robust (Figure 7).

My baseline results appear most sensitive to replacing endogenous variables with other data. Output and prices consistently respond positively if I substitute the monthly interpolated real GDP and GDP deflator for industrial production or consumption expenditures and the CPI or the PCE price index respectively (Figure 8).

I also add employment and bank reserve holdings separately, which have no response and a large positive response respectively. In all these specifications, the response from loans is robust while bank security holdings have no response. Thus, I re-emphasize that banks most prefer to hold the reserves. Bank purchases of debt securities likely occur on a smaller scale as they are hard to detect using agnostic SVAR identification and aggregate data.

4 Further Analysis & Discussion

Recall that the Fed aims "to support the flow of credit to households and businesses" in times of financial distress. At a glance, my baseline results imply that the reserve supply channel runs counter to this objective. After an unexpected increase in reserve supply, banks decrease loan holdings, hold on to the newly created reserves, and – to a lesser extent – purchase safe, liquid securities. There are a number of possible explanations for these results: (1) loan demand is low during QE; (2) loan supply contracts due to high risk or poor balance sheet conditions; (3) banks prefer to take advantage of rising asset prices; and, (4) banks need risk-free assets to meet regulatory capital requirements. In this section, I ask which of these reasons most likely explains the response from banks and which do not. If the story involves an unwillingness of banks to extend credit, then my results highlight an unintended consequence of QE. Instead, I find that dampened loan demand and high default risk are most consistent with banks' preference for safe, liquid assets. In fact, banks seem willing to lend because they can sell loans to issuers of asset-backed securities.

I proceed by discussing the possible mechanism in two directions. First, I uncover factors that explain the response from banks. Second, I ask whether these factors react to the reserves supply shock or not. In Section 4.3, I also discuss the differences between the financial crisis and pandemic QEs in the context of my results.

4.1 Orthogonalized Response

My strategy for explaining the baseline results is to gather data consistent with the possible mechanisms listed above, orthogonalize bank balance sheets to this data, and check the impulse response of the orthogonalized series. The orthogonalization stage involves regressing bank balance sheets on the controls and taking the residual. This process is inspired by Bauer and Swanson (2023). However, in their case, they orthogonalize a *shock* to macroeconomic news. If the controls explain the response from banks, then we would expect the residual to have no response to the reserve supply shock.

My goal is to *jointly* explain the response from loans and bank security holdings. So, I define the following series:

$$lls_t = lns_t - sec_t, \tag{5}$$

which is loans less securities. An increase (decrease) in lls_t represents a relative shift towards (away from) loans on bank balance sheets. My baseline results are characterized by a decrease in lls_t in response to a positive reserve supply shock. Of course, some information is lost when using lls_t. A decrease in lls_t comes from *either* a decrease in loans or an increase in security holdings (or both). If I repeat the analysis in this section for loans and bank security holdings separately, the results are consistent with those of loans less securities. I use lls_t for brevity and to focus on the trade-off between "risky" loans and "safe," liquid securities. I do not include reserves in this trade-off. Consider that aggregate federal fund holdings should equal federal funds supplied. If a bank issues a loan or purchases a security, then its reserves will simply end up at another bank. Research in this area requires disaggregated data (see Ihrig et al., 2019, for a start).

For orthogonalization, I run the following regression:

$$\Delta lls_t = policychange_t + pandemic_t + \beta_1 controls_t + \beta_2(controls_t \times qe_t) + v_t, \quad (6)$$

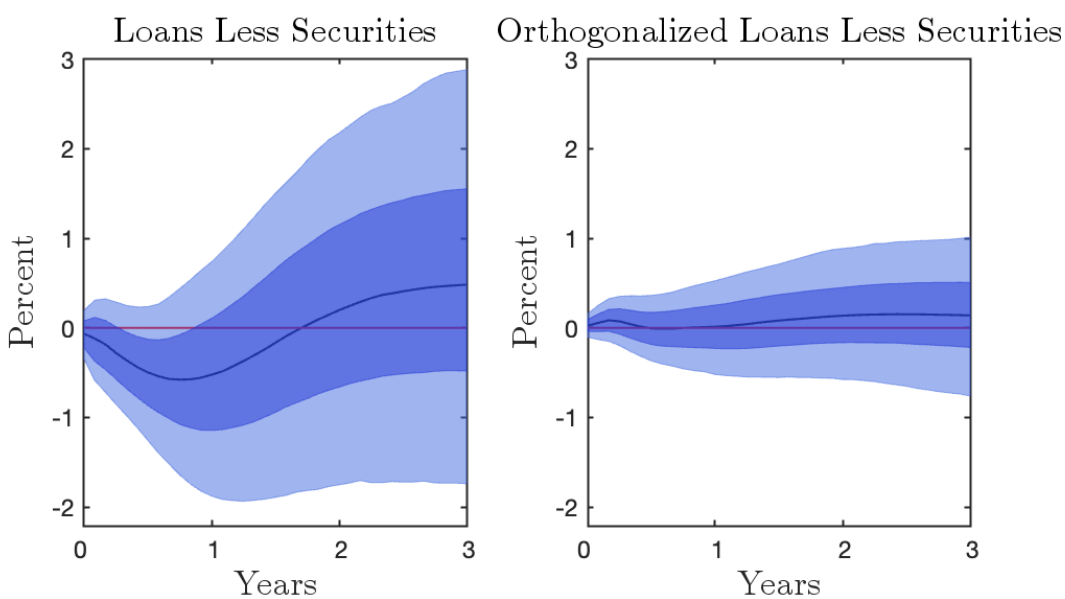
where $policychange_t$ and $pandemic_t$ are respectively indicators for the first six months of 2010 and six months during the coronavirus pandemic beginning with March 2020. These indicators cover drastic increases in loans from changes in accounting standards[11] and during pandemic lending programs (e.g. main street lending). Excluding these indicators could bias my results; though, the results below in Figure 4 are robust to their exclusion. I also define qe_t to indicate months during which QE was active: November 2008 to October 2014 and March 2020 to March 2022. The dependent variable, lls_t, is first-differenced to avoid problems of nonstationarity. The set of controls includes the net percent of banks reporting strong loan demand, the net percent of banks tightening standard for loan supply, the delinquency rate on all loans, the value of assets liquidated from failed banks (from the FDIC), a financial regulation uncertainty index (from Baker et al., 2016), the 10-year Treasury yield, the 10-year/3-month Treasury spread, the 10-year/2-year Treasury spread, first-differenced deposits, first-differenced durable goods consumption, first-differenced gross private domestic investment, first-differenced tier 1 risk based bank capital, and first-differenced total MBSs outstanding (as in Fuster et al., 2022). Ap-

[11] FAS 166 and 167 from the Financial Accounting Standards Board became effective in early 2010. During these months, banks began reporting credit card lending that was previously considered off-balance sheet. See the Federal Reserve's press release from June 12, 2009.

pendix A provides all the details of the data. I should clarify that Equation 6 is an over-simplification. I include also lags of deposits, durable goods consumption, and investment, of which the two latter are meant to be proxies for loan demand. Bank capital and MBSs outstanding are included *only* in lags since they could nest lls_t.

Figure 4 compares the cumulative responses of Δlls_t and the orthogonalized series, $\hat{v}_t$ from Equation 6, to a positive reserve supply shock. The left panel corresponds to my baseline results, that is a decrease in loans and an increase in securities.[12] The right panel shows that loans less securities does not respond when orthogonalized to the controls. The economic interpretation here is that banks are indifferent between lending and purchasing securities. Loans and securities increase or decrease in lockstep in response to an unexpected influx of reserves.

Figure 4: Orthogonalized Impulse Response



IRFs to a one standard deviation positive reserve supply shock *separately* identified in each system. The right panel comes from the VAR system that replaces Δlls_t with $\hat{v}_t$ from Equation 6. Both panels are *cumulative* IRFs. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands based on ten thousand draws from the posterior distribution.

[12] The IRFs of the other variables are largely unchanged when using Δlls_t.

So, which data are most responsible for the difference in responses in the left and right panels? Table 2 reports the OLS estimates from Equation 6. I standardize all the data so that we can easily compare the estimated coefficients. I also use HAC standard errors to account for autocorrelation in the error. The third column is of most interest. It posts the total effect *during QE*, $\hat{\beta}_1 + \hat{\beta}_2$. Positive (negative) coefficients indicate a shift towards (away from) loans.

Banks' preference for safe, liquid assets is most likely explained by a lack of lending opportunities, not a contraction in credit supply. The coefficient with the largest magnitude is that on assets liquidated from failed banks, though it is not statistically significant. The sign is positive – the opposite of what we would expect – indicating that poor health in the banking sector is not a reason for the contraction in loan holdings. Consider also that loan demand has a much larger coefficient than loan supply (0.341 v -0.053). Banks shift balance sheets towards loans when reporting stronger demand. This effect is especially strong during QE (0.341 v 0.067). Adding to this, the coefficients on the 10-year/3-month Treasury spread – a weak proxy for the profit margin on loans – and deposits are 1.235 and 0.280 respectively. During QE, an increase in the spread and deposits are highly correlated with a shift towards loans. This suggests that banks are willing to lend and hold liquid assets while waiting for opportunities.

The most striking result is the coefficient on total MBSs outstanding (-1.076). This coefficient is both large and significant. It indicates that a rise in mortgage holdings by issuers of MBSs is highly correlated with a shift away from loans in the next period *only during QE*.[13] Perhaps banks are willing to lend because they can easily sell loans for securitization. The negative coefficients on durable consumption

[13]The coefficient remains large and significant (-1.393) when total MBSs oustanding is included as a lead, not lag.

Table 2: Orthogonalization Estimates

Dep. Var.: First-Differenced (FD) Loans Less Securities			
Variable	Alone	Interacted	Sum
Loan Demand	0.067	0.275	0.341**
	(0.076)	(0.175)	(0.158)
Loan Supply	0.075	-0.127	-0.053
	(0.122)	(0.204)	(0.163)
Delinquency	-0.341**	-0.515**	-0.856***
	(0.145)	(0.251)	(0.205)
Assets Liquidated	-0.059	1.467	1.408
	(0.049)	(1.207)	(1.206)
Finreg Uncertainty	0.222**	-0.196	0.026
	(0.100)	(0.173)	(0.141)
10Y Treasury Yield	0.170**	0.302	0.472***
	(0.074)	(0.195)	(0.181)
10Y/3M Treasury Spread	0.770***	0.465	1.235***
	(0.192)	(0.501)	(0.467)
10Y/2Y Treasury Spread	-0.755***	-0.597	-1.352***
	(0.231)	(0.497)	(0.445)
FD Deposits	-0.146*	0.426***	0.280***
	(0.085)	(0.118)	(0.081)
Lag FD Deposits	-0.158**	0.005	-0.153
	(0.074)	(0.137)	(0.115)
FD Durable Consumption	0.001	-0.194*	-0.193***
	(0.086)	(0.103)	(0.057)
Lag FD Durable Consumption	-0.092	-0.112	-0.203***
	(0.074)	(0.094)	(0.057)
FD Investment	-0.412***	0.364**	-0.048
	(0.146)	(0.164)	(0.074)
Lag FD Investment	0.083	-0.067	0.016
	(0.127)	(0.142)	(0.065)
Lag FD Bank Capital	0.091*	-0.075	0.016
	(0.052)	(0.118)	(0.106)
Lag FD MBSs Outstanding	0.031	-1.106***	-1.076***
	(0.091)	(0.267)	(0.251)
Adjusted R-Squared: 0.604			

OLS estimates from Equation 6. FD stands for "first-differenced." The first, second, and third columns report $\hat{\beta}_1$, $\hat{\beta}_2$, and $\hat{\beta}_1 + \hat{\beta}_2$ respectively. All variables are standardized except indicators. HAC standard errors are reported small in parentheses. Standard errors for $\hat{\beta}_1 + \hat{\beta}_2$ are computed using $var(\beta_1 + \beta_2) = var(\beta_1) + var(\beta_2) + 2cov(\beta_1, \beta_2)$. Asterisks indicate statistical significance at the 1% (***), 5% (**), and 10% (*) levels.

are consistent with this story.[14] A rise in durable consumption during QE is associated with a shift away from loans, not towards. If banks issue more loans when durable consumption rises, then they could be selling these loans. The data is also consistent with this. Banks reported weak loan demand and faced declines in durable consumption during the financial crisis and the pandemic. However, both recovered *while* QE was still occurring in both cases.

Treasury yields and spreads are also important in explaining the response from banks. The coefficients on the 10-year Treasury yield and the 10-year/2-year Treasury spread are 0.472 and -1.352 respectively. Banks shift away from loans when yields fall (and prices rise) and the 10-year/2-year spread rises. At the same time, banks are inclined to increase loans if yields rise during QE, which is consistent with the story described above. Considering that loan demand is more important than supply, the Treasury markets are likely a factor in determining which liquidity banks hold, not whether they are willing to lend or not.

4.2 Policy Implications

Now, we might wonder if we can trace these important factors back to the Fed. Do the variables that explain the response from banks react to the reserve supply shock? I take the six most important and significant explanatory variables from Table 2 and separately add them to the set of endogenous variables in the SVAR. Their responses are displayed in Figure 5. I avoid adding them all to the system at once since this would play into the weakness of agnostic sign and zero restrictions: identification uncertainty. I keep *Restrictions 1-6*, but I must add an additional restriction in each

[14] Note that I cannot rule out capital requirements as a player in the mechanism. Beyond low loan demand, banks may want to sell loans because they are relatively risky, which would lower capital thresholds.

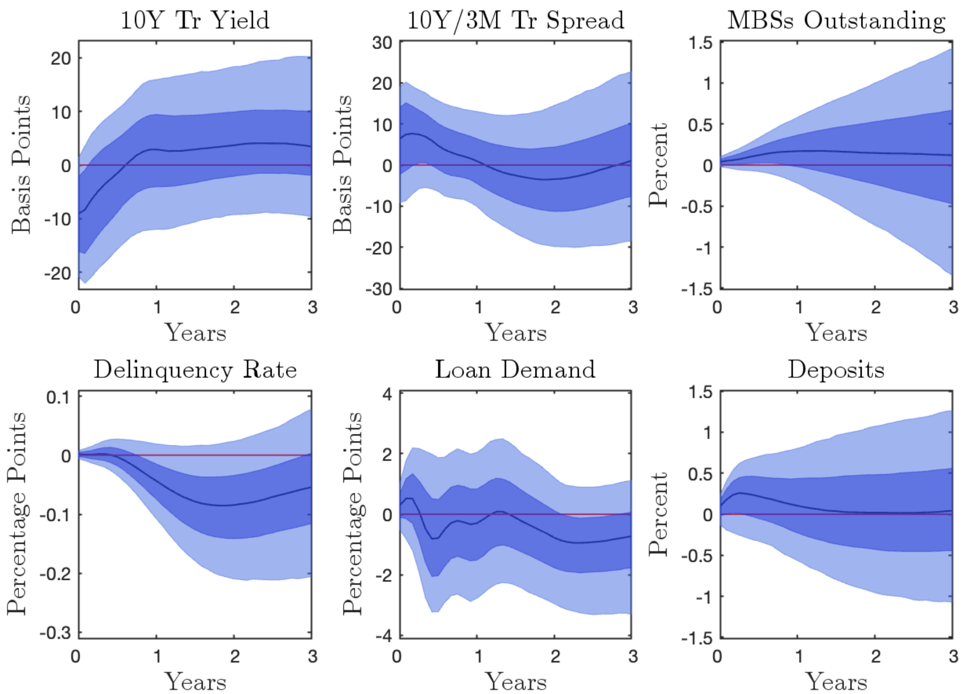
specification. In general, I impose that the Fed does not react contemporaneously to the new variables when conducting QE. However, I restrict that the Fed will purchase more assets when the 10-year Treasury yield rises. Also, I do not restrict the Fed's reaction to the 10-year/3-month Treasury spread. I justify these restrictions by first running the models with an unrestricted coefficient on the new variable.

I must first acknowledge some data discrepancies. MBSs outstanding, the delinquency rate, and loan demand are available only at the quarterly frequency. Averaging all the data to quarterly gives inconclusive results since there are only eighty quarters for which all the data is available. So, I again employ the monthly interpolation method used in Arias et al. (2019), which I describe in Appendix A. I use mortgage loans, the unemployment rate, and the University of Michigan consumer sentiment index respectively. When averaged to the quarterly frequency, these variables are highly correlated with their respective series.

As expected, a positive reserve supply shock elicits a negative response on impact from the 10-year Treasury yield with high posterior probability (median of 10 basis points). This implies that the Fed is partially responsible for the shift of bank balance sheets away from loans. Similarly to above, the shift on bank balance sheets *due to the Fed's actions* is likely more about a choice between holding reserves or safe securities than issuing loans or not because loan demand appears more important than supply.

In light of the prevalence of securitization, the response from MBSs outstanding is of great interest. Fed purchases of large quantities of MBSs could incentivize securitization, preference towards mortgage origination, and risk-taking. The Fed looks to be aware of this potential channel. Concerning the pandemic QE, Fed Governor Michelle Bowman stated, "the FOMC intends to hold primarily Treasury securities

Figure 5: Responses from Important Explanatory Variables



IRFs to a one standard deviation positive reserve supply shock identified *separately* when adding each variable to the system. See the main text for details about the identifying restrictions. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands based on ten thousand draws from the posterior distribution.

in the longer run to minimize the effects [...] on the allocation of credit."[15] Since I find no response (or a very small response) from MBSs outstanding to the reserve supply shock, QE is likely not responsible for bank behavior with respect to securitization.[16] This is not to say that the Fed should ignore this behavior. Securitization remains an important factor when determining how banks utilize new reserves. Similarly, there is little discernible response from the 10-year/3-month Treasury spread and loan demand. Although, the Fed should still watch these indicators when conducting QE.

[15]Stated in May 2024 during a speech at the Bank of Japan.

[16]I also find no response from MBSs outstanding when I consider only reserves supplied from the Fed's MBS purchases.

There is a slight positive response from deposits consistent with Diamond et al. (2024). They argue that an influx of reserves decreases the marginal cost of deposits. I add to this, asserting that the crowding-in of deposits would encourage lending. Lastly, there is a small negative response from the delinquency rate at long horizons, which is associated with a shift towards lending.

4.3 Decomposing Reserve Supply

As noted in Section 2.1, Fed holdings of MBSs and agency debt peaked at 62% of the Fed's balance sheet during the initial wave of the financial crisis QE, commonly called QE1. During the second wave (QE2), the Fed actually decreased its holdings of these securities by reinvesting them upon maturity into Treasuries. Only during the final wave and the pandemic QE did the Fed increase its holdings of MBSs and Treasuries together. In response to the pandemic, the Fed prioritized Treasury purchases over MBSs. From March 2020 to March 2022, Fed holdings of Treasuries increased by roughly $2.8 trillion compared to $1.3 trillion in acquired MBSs. Do banks care which assets are attached to reserve creation? Do banks respond differently in each QE episode? Unfortunately, empirical work on QE can be inconclusive since there is a relatively short history – especially considering that QE was not conducted uniformly. In this section, I discuss differences between the financial crisis and the pandemic using facts from the data and my results thus far. However, Figure 9 in Appendix C plots IRFs when considering reserves supplied from Treasury and MBS purchases separately.

Table 3 posts the correlation of Fed and bank asset components over the entire sample, the financial crisis only, and the pandemic only. The bank components are offset by six months since this is the approximate time it takes them to respond in my baseline results. As described above, Fed Treasury and MBS holdings are negatively correlated during the financial crisis and strongly positively correlated during the pandemic. This highlights the primary difference between the two QE episodes.[17]

Fed holdings of both Treasuries and MBSs are strongly negatively correlated with loans of all types during the pandemic only, but mostly commercial loans. Considering the unprecedented contraction of aggregate demand during pandemic lockdowns, the negative relationship is consistent with loan demand driving the decrease in loans, not banks (abstracting from programs like the Paycheck Protection Program). This suggests that the composition of the Fed's purchases was not a major factor for banks during the pandemic. On the other hand, Fed purchases of MBSs are actually correlated with an increase in consumer loans during the financial crisis, which could represent credit card borrowing during its early stages; but, there remains a negative relationship with all other loans. Again, the relationship is strongest with commercial loans, which supports several papers that find QE leads to a contraction in commercial lending (Supera, 2021; Greenwald et al., 2023; Diamond et al., 2024). I hesitate to conclude that the composition of Fed purchases makes any difference during the financial crisis, like the pandemic, because the relationship with real estate loans is consistent across. It is just as likely that the timing of Fed purchases confounds the composition of them.

Reserve supply is related to a decrease in bank security holdings during the financial crisis, but an increase during the pandemic. Banks associate an increase in reserve supply with purchasing MBSs and selling Treasuries. Interestingly, this relationship is largely consistent across the entire sample, except for one instance: Fed MBS holdings during the financial crisis. Here, reserve supply corresponds to a

[17] I exclude Fed holdings of agency debt securities from this analysis because they were only purchased for a short period during QE1.

Table 3: Correlation of Fed and Bank Holdings

	Full Sample		Financial Crisis QE		Pandemic QE	
	Fed Treasuries	Fed MBSs	Fed Treasuries	Fed MBSs	Fed Treasuries	Fed MBSs
Fed Treasuries	1.000	0.306	1.000	-0.185	1.000	0.713
Fed MBSs	0.306	1.000	-0.185	1.000	0.713	1.000
All Loans	-0.169	-0.026	-0.074	0.155	-0.470	-0.510
Commercial Loans	-0.102	-0.240	0.042	-0.612	-0.413	-0.503
Consumer Loans	-0.030	0.304	-0.028	0.381	-0.330	-0.370
Commercial Real Estate Loans	-0.219	-0.147	-0.187	-0.023	-0.336	-0.359
Residential Real Estate Loans	-0.264	-0.269	-0.100	-0.215	-0.339	-0.438
All Bank Security Holdings	0.191	0.056	-0.167	-0.132	0.193	0.239
Bank Treasuries	-0.031	0.139	-0.391	0.396	-0.326	-0.315
Bank MBSs	0.235	0.060	0.123	-0.214	0.409	0.487

The table entries are correlation coefficients of Fed Treasury and mortgage-backed security (MBS) holdings and bank balance sheet components offset by six months. The columns corresponds to the entire sample (2004-24), only the financial crisis QE (November 2008-October 2014), and only the pandemic QE (March 2020-March 2022).

decrease in bank MBS holdings perhaps because of the fallout in the housing market when QE was dominated by purchases of MBS. Again, timing confounds making any inference about the implications of the composition of Fed purchases. Researchers should closely examine patterns during a third QE episode – if or when it happens.

5 Conclusion

This paper examines changes on bank balance sheets in response to reserves created by the Federal Reserve when purchasing assets. I identify a reserve supply shock by specifying a policy rule and imposing sign and zero restrictions on the parameters. In response to an unexpected influx of reserves, banks decrease loans and increase their holdings of liquid assets roughly half a year after the shock. These findings are largely consistent with other papers in this area (Diamond et al., 2024; Greenwald et al., 2023, 2024). Banks hold liquidity mostly in the form of the reserves themselves. I also document an increase in holdings of federally-backed debt securities, but this result fails robustness.

One of my contributions to the literature involves explaining the mechanism of bank responses. Diamond et al. (2024) find that loans decrease because their marginal cost increases. They hypothesize that regulatory capital thresholds might be more expensive to meet if banks were to hold on to risky loans. I find that banks are limited by loan demand, not by their willingness to hold loans. However, I provide evidence that banks decrease their loan holdings by selling them to issuers of asset-backed securities whether they are able to issue new loans or not, which is still consistent with their capital requirement hypothesis.

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Appendix A Data Sources

Data is gathered from July 2004 to June 2024 for the monthly frequency and Q2 2004 to Q2 2024 for the quarterly frequency. Whenever mentioned below, I use the Chow-Lin method (Chow and Lin, 1971) to obtain monthly interpolations of quarterly data (also used by Bernanke and Mihov, 1998; Mönch and Uhlig, 2005; Arias et al., 2019). In short, the interpolation of the low frequency data is inferred from regressing it on the high frequency data (averaged to the low). I use weighted least squares where the weights are the variance-covariance matrix of the errors assuming they follow an AR(1) process. In practice, I use log levels for applicable time series. I gather the following data for my baseline specification.

- Quarterly real gross domestic product, seasonally adjusted annual rate, billions of chained 2017 U.S. dollars from FRED ('GDPC1'). I interpolate to the monthly frequency using industrial production (see next).

- Monthly total industrial production, seasonally adjusted, index (2017 base) from FRED ('INDPRO').

- Quarterly gross domestic product implicit price deflator, seasonally adjusted, index (2017 base) from FRED ('GDPDEF'). I interpolate to monthly frequency using the CPI (see next).

- Monthly consumer price index (CPI) for all urban consumers, all items in the U.S. city average, seasonally adjusted, index (1982-4 base) from FRED ('CPIAUCSL').

- Monthly loans and leases in bank credit for all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED ('LOANS').

- Monthly securities in bank credit for all commercial banks, seasonally adjusted, billion of U.S. dollars from FRED (‘INVEST’).
- Monthly federal funds effective rate, percent from FRED (‘FEDFUNDS’).

I construct a time series for the Federal Reserve’s total holdings of the assets targeted by QE (reserve supply) by summing the following series.

- Weekly Wednesday level U.S. Treasury securities held outright by the Federal Reserve, millions of U.S. dollars from FRED (‘TREAST’). I scale to billions of U.S. dollars and take the last value of the month.
- Weekly Wednesday level mortgage-backed securities held outright by the Federal Reserve, millions of U.S. dollars from FRED (‘WSHOMCB’). I scale to billions of U.S. dollars and take the last value of the month.
- Weekly Wednesday level federal agency debt securities held outright by the Federal Reserve, millions of U.S. dollars from FRED (‘FEDDT’). I scale to billions of U.S. dollars and take the last value of the month.

The following time series are bank loans and securities broken down by category.

- Monthly residential real estate loans at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED (‘RREACBM027SBOG’).
- Monthly commercial real estate loans at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED (‘CREACBM027SBOG’).
- Monthly consumer loans at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED (‘CONSUMER’).

- Monthly commercial and industrial loans at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED ('BUSLOANS').
- Monthly Treasury and agency securities at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED ('USGSEC').
- Monthly other securities at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED ('OTHSEC').

Additionally, I gather the following data for robustness.

- Monthly personal consumption expenditures, seasonally adjusted annual rate, billions of U.S. dollars from FRED ('PCE').
- Monthly personal consumption expenditures chain-type price index, seasonally adjusted, index (2017 base) from FRED ('PCEPI').
- Monthly all nonfarm employees, seasonally adjusted, thousand of persons from FRED ('PAYEMS'). I scale to millions of persons.
- Monthly total reserves of depository institutions, billions of U.S. dollars from FRED ('TOTRESNS').

I gather the following data for further analysis in Section 4.

- Quarterly net percent of domestic banks reporting stronger demand across loan categories, weighted by banks' outstanding loan balances, percent, from the Federal Reserve's Senior Loan Office Opinion Survey posted on FRED ('SUBLPDMODXWBNQ'). For use in VAR, I interpolate to the monthly frequency using consumer sentiment (see below).

- Quarterly delinquency rate of all loans at all commercial banks, seasonally adjusted, percent from FRED ('DRALACBS'). For use in VAR, I interpolate to the monthly frequency using the unemployment rate (see below).
- Monthly total value of assets liquidated from failed banks from the FDIC. I scale to billions of U.S. dollars.
- Quarterly net percent of domestic banks tightening standard across loan categories, weighted by banks' outstanding loan balances by category, percent from the Federal Reserve's Senior Loan Office Opinion Survey posted on FRED ('SUBLPDMOSXWBNQ').
- Monthly economic policy uncertainty index for financial regulation, index from Baker et al. (2016) posted on FRED ('EPUFINREG').
- Monthly market yield on U.S. Treasury securities at 10-year constant maturity, quoted on an investment basis, percent from FRED ('GS10').
- Monthly 10-year Treasury constant maturity minus 3-month Treasury constant maturity, percent from FRED ('T10Y3MM').
- Monthly 10-year Treasury constant maturity minus 2-year Treasury constant maturity, percent from FRED ('T10Y2YM').
- Monthly deposits at all commercial banks, seasonally adjusted, billions of U.S. dollars from FRED ('DPSACBM027SBOG').
- Monthly personal consumption expenditures on durable goods, seasonally adjusted annual rate, billions of U.S dollars from FRED ('PCEDG').

- Quarterly gross private domestic investment, seasonally adjusted annual rate, billions of U.S. dollars from FRED ('GPDI').

- Quarterly tier 1 risk based capital (PCA definition) on bank balance sheets, millions of U.S. dollars from the FDIC posted on FRED ('QBPBSRSKK'). I scale to billions of U.S. dollars.

- Monthly consumer sentiment, index (Q1 1966 base) from the University of Michigan posted on FRED ('UMCSENT').

- Monthly unemployment rate, seasonally adjusted, percent from FRED ('UNRATE').

Following Fuster et al. (2022), I construct a proxy for total mortgage-backed securities outstanding by summing the following series. Note that, for use in VAR, I obtain monthly interpolations using the sum of residential and commercial real estate loans held by all commercial banks (see above).

- Quarterly government-sponsored enterprise holdings of multifamily residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL403065405Q'). I scale to billions of U.S. dollars.

- Quarterly government-sponsored enterprise holdings of one-to-four-family residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL403065105Q'). I scale to billions of U.S. dollars.

- Quarterly agency- and GSE-backed mortgage pools of multifamily residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL413065405Q'). I scale to billions of U.S. dollars.

- Quarterly agency- and GSE-backed mortgage pools of one-to-four-family residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL413065105Q'). I scale to billions of U.S. dollars.

- Quarterly agency- and GSE-backed mortgage pools of commercial mortgages, millions of U.S. dollars from FRED ('BOGZ1FL413065505Q'). I scale to billions of U.S. dollars.

- Quarterly issuers of asset-backed securities holdings of multifamily residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL673065405Q'). I scale to billions of U.S. dollars.

- Quarterly issuers of asset-backed securities holdings of one-to-four-family residential mortgages, millions of U.S. dollars from FRED ('BOGZ1FL673065105Q'). I scale to billions of U.S. dollars.

- Quarterly issuers of asset-backed securities holdings of commercial mortgages, millions of U.S. dollars from FRED ('BOGZ1FL673065505Q'). I scale to billions of U.S. dollars.

Appendix B Sampling Details

In the Bayesian framework, we are interested in obtaining estimates of the reduced-form parameters, B and Σ from Equation 2, by drawing from their posterior distribution:

$$p(B, \Sigma | y_t) \propto p(y_t | B, \Sigma) p(B, \Sigma), \tag{7}$$

where $p(y_t|B, \Sigma)$ is the likelihood function and $p(B, \Sigma)$ is the prior distribution. I use the commonly-known conjugate Normal-inverse-Wishart (NIW) prior:

$$p(B, \Sigma) \sim NIW(\nu, \Phi, \Psi, \Omega), \tag{8}$$

which implies that the posterior is also NIW. I let the parameters ν, Φ, Ψ, and Ω be filled entirely with zero elements, which is the case of the uninformative prior. Here, the posterior has a mean given by the maximum likelihood estimate.

In practice, I let the set of variables, X_t, contain indicators for six months during the coronavirus pandemic beginning in March 2020. Cascaldi-Garcia (2024) proposes a method whereby the parameters of the posterior distribution vary with an informativeness parameter for the pandemic observations. Specifically, Cascaldi-Garcia (2024) augments y_t and X_t with dummy observations, y_d and X_d respectively. The matrix X_d contains the informativeness parameter, ϕ (see the paper for a formal definitions). As $\phi \to \infty$, the dummies shrink to zero and the pandemic observations are treated the same as all others. As $\phi \to 0$, the prior on the pandemic dummies becomes uninformative. As suggested by Cascaldi-Garcia (2024), I choose ϕ as

$$\phi^* = argmax_\phi \log p_\phi(y_t), \tag{9}$$

where $p_\phi(y_t)$ is the marginal data density with respect to ϕ obtained by integrating B and Σ out of the likelihood, which has a closed form in the NIW case (Giannone et al., 2015).

After all this, the posterior distribution has the following form:

$$p(B, \Sigma|y_t) \sim NIW(\tilde{\nu}, \tilde{\Phi}, \tilde{\Psi}, \tilde{\Omega}), \tag{10}$$

with

$$\begin{aligned} \tilde{\nu} &= T + \nu + h - m \\ \tilde{\Omega} &= (X_t^{*'} X_t^* + \Omega^{-1})^{-1} \\ \tilde{\Psi} &= \tilde{\Omega}(X_t^{*'} y_t^* + \Omega^{-1}\Psi) \\ \tilde{\Phi} &= y_t^{*'} y_t^* + \Phi + \Psi'\Omega^{-1}\Psi - \tilde{\Psi}'\tilde{\Omega}^{-1}\tilde{\Psi}, \end{aligned} \tag{11}$$

where T is the sample length, h is the number of pandemic dummies (six), m is the number of exogenous variables, $X_t^* = [X_t, X_d]$, and $y_t^* = [y_t, y_d]$.

Under the agnostic identification outlined by Arias et al. (2019), I use sign and zero restrictions on the structural parameters directly. However, it is generally not feasible to *draw* the structural parameters directly. Arias et al. (2018) reconcile these two by showing that the structural parameters follow what they call a Normal-generalized-Normal (NGN) distribution when the reduced-form parameters have the NIW distribution. This is the foundation for their importance sampler that draws from the reduced-form parameterization and ensures the restrictions on the structural parameters hold. I summarize the algorithm here:

1. Draw (B, Σ) independently from $NIW(\tilde{v}, \tilde{\Phi}, \tilde{\Psi}, \tilde{\Omega})$.

2. Construct an orthogonal matrix, Q, from the orthogonalized reduced-form parameterization, $u_t' = \varepsilon_t' Q' Ch(\Sigma)$ with $Ch(.)$ being the Cholesky decomposition, that forces the zero restrictions to hold.

3. Compute $A_0 = Ch(\Sigma)^{-1} Q$.

4. Check if the sign restrictions hold. If so, set the importance weight according to the NGN distribution. If not, set the importance weight to zero.

5. Return to step one until ten thousand draws satisfy the sign restrictions.

6. Resample with replacement according to the normalized importance weights.

See Algorithm 3 from Arias et al. (2018) for more details. Arias et al. (2018) state that the prior on the constructed orthogonal matrix, Q, *in the orthogonal reduced-form parameterization* is uniform with respect to the Haar measure.

Appendix C Additional Results & Robustness

Table 4: Policy Rule Estimates for Justifying the Identifying Restrictions

Dep. Var.: First-Differenced Reserve Supply	
Variable	
Real GDP	-1.944***
	(0.262)
GDP Deflator	-1.012
	(0.844)
Loans	-0.593***
	(0.214)
Bank Security Holdings	0.274
	(0.188)
Fed Funds Rate	-1.626*
	(0.868)

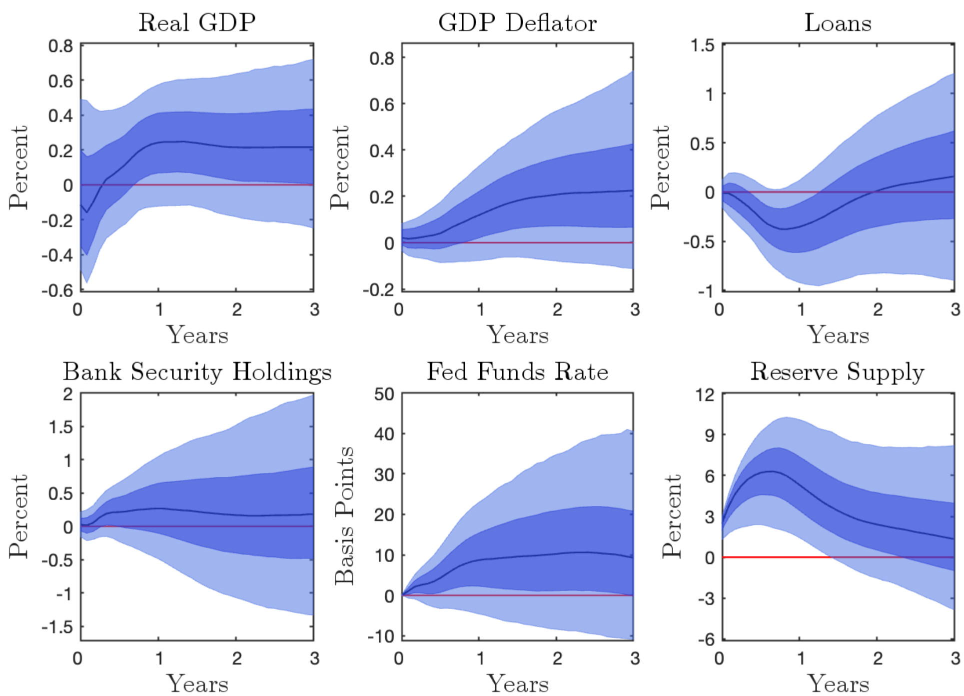
OLS estimates from $\Delta res_t = \alpha + \sum_{l=0}^{12}(\gamma_l^{gdp} gdp_{t-l} + \gamma_l^{dfl} dfl_{t-l} + \gamma_l^{lns} lns_{t-l} + \gamma_l^{sec} sec_{t-l} + \gamma_l^{ffr} ffr_{t-l}) + \varepsilon_t$. Only estimates for $l = 0$ are posted. All variables are in log levels except the fed funds rate. HAC standard errors are reported in parentheses. Asterisks indicate statistical significance at the 1% (***), 5% (**), and 10% (*) levels.

Table 5: Coefficients in the Conventional Monetary Policy Rule

Parameter	2.5th %-tile	16th %-tile	Median	84th %-tile	97.5th %-tile
γ^{gdp}	0.005	0.037	0.132	0.353	1.049
γ^{dfl}	0.023	0.152	0.528	1.402	4.256
γ^{lns}			0.000		
γ^{sec}			0.000		
γ^{res}	-0.085	-0.023	0.027	0.126	0.544

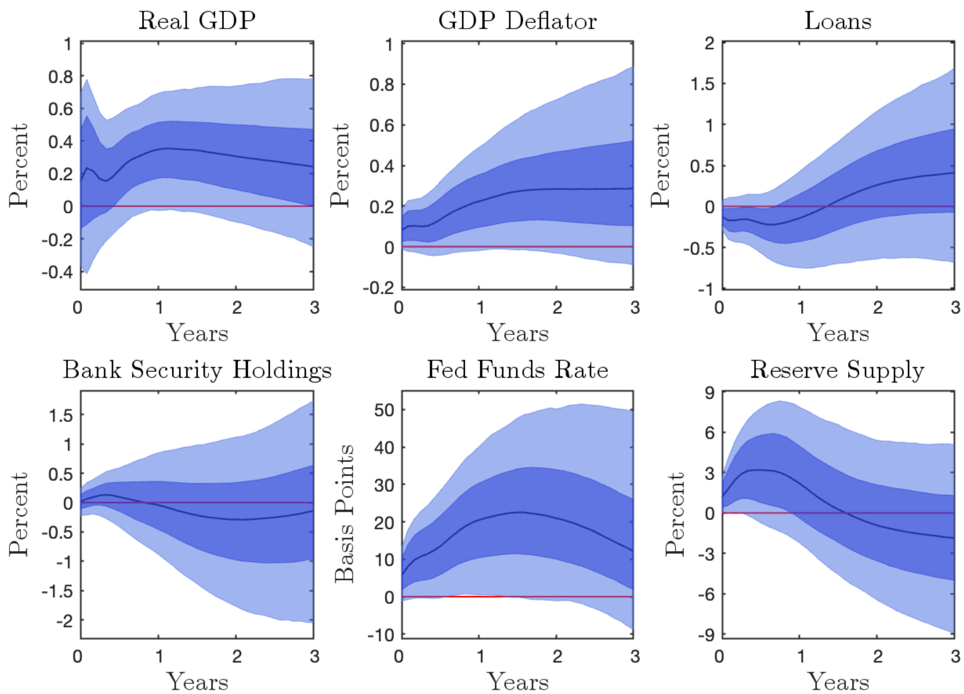
Percentiles based on ten thousand draws from the posterior distribution of the coefficients in an alternative of Equation 4 that represents a standard Taylor-type monetary policy. That is, the FFR and reserve supply swap places such that the FFR is the policy tool of interest. *Restrictions 1-4* are modified such that the FFR has a contemporaneous positive response to real GDP and the GDP deflator. I do not restrict the FFR response to reserve supply or vice versa. I keep *Restrictions 5 & 6* that the FFR does not react to bank balance sheets. Those posted here are the contemporaneous coefficients. The intercept and coefficients on the lag terms are not posted (nor restricted).

Figure 6: Impulse Responses to an Expansionary Reserve Supply Shock when Rejecting Implausibly Large Draws



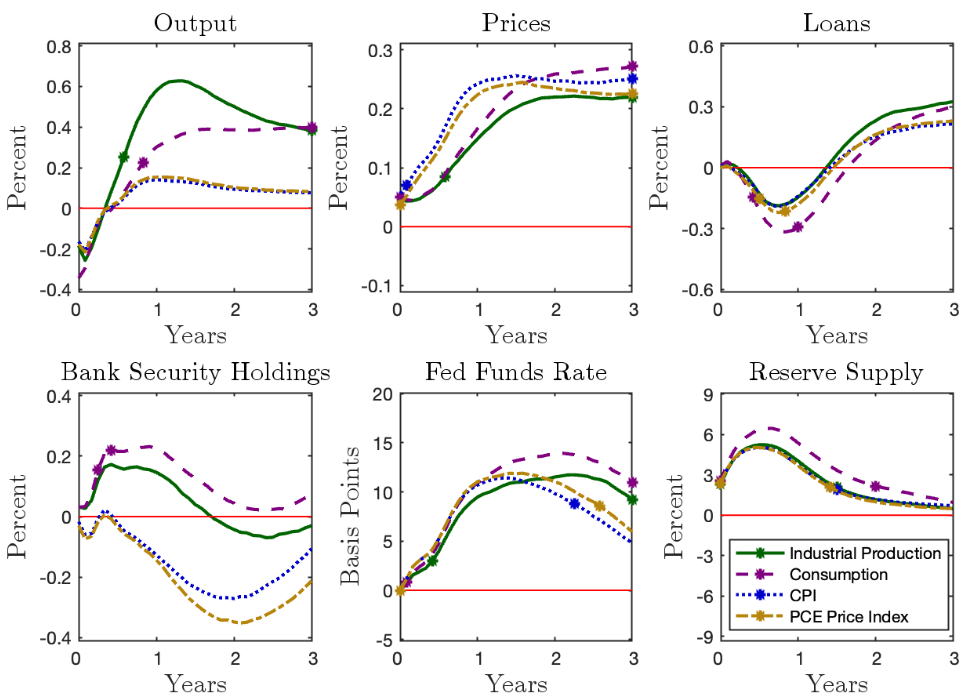
IRFs to a one standard deviation positive reserve supply shock identified under *Restrictions 1-6* when also rejecting draws greater than six in absolute value. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands. All IRFs are based on ten thousand draws from the posterior distribution.

Figure 7: Impulse Responses to an Expansionary Reserve Supply Shock
Identified Without *Restriction 2*



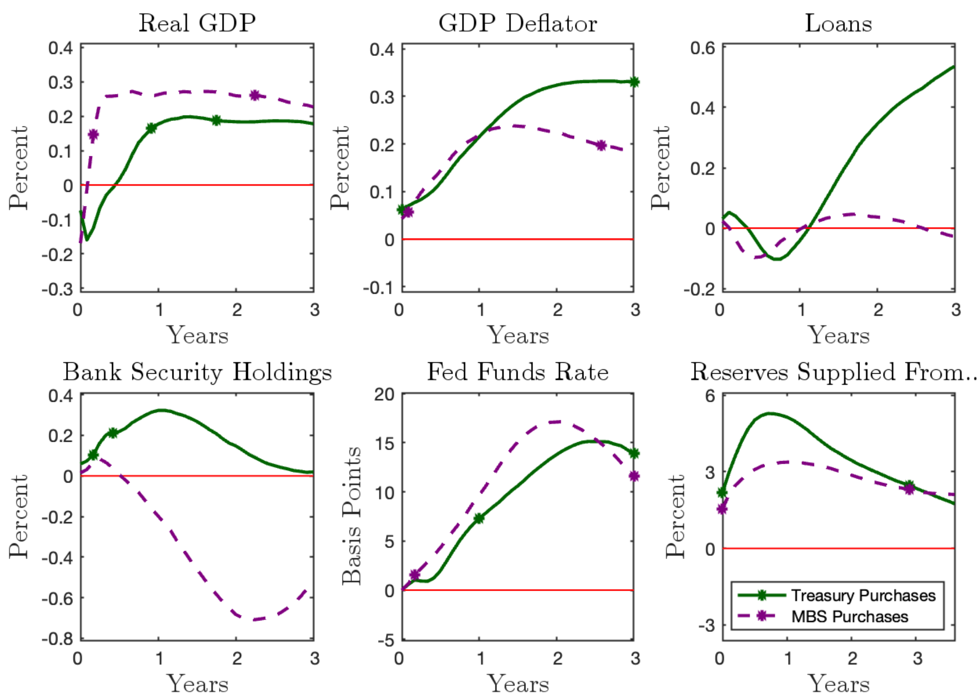
IRFs to a one standard deviation positive reserve supply shock identified under *Restrictions 1-6* without *Restriction 2*, which restricts the FFR to have no response on impact. The solid blue line represents the pointwise posterior median path straddled by 68% then 95% probability bands. All IRFs are based on ten thousand draws from the posterior distribution.

Figure 8: Impulse Responses to an Expansionary Reserve Supply Shock Identified when Replacing the Monthly Interpolated Data



IRFs to a one standard deviation positive reserve supply shock identified under *Restrictions 1-6* when *separately* replacing the monthly interpolated real GDP and GDP deflator with industrial production or consumption expenditures and the CPI or the PCE price index as indicated by the legend. The lines represent the pointwise posterior median path in response to the shock identified in each system. The asterisks indicate regions where the 68% probability bands lie entirely above or below zero. All IRFs are based on ten thousand draws from the posterior distribution.

Figure 9: Impulse Responses to an Expansionary Shock of Reserves Supplied from Fed Purchases of Treasuries v MBSs



IRFs to a one standard deviation positive reserve supply shock identified under *Restrictions 1-6*, where reserve supply is either Fed Treasury holdings only or Fed MBS holdings only as indicated by the legend. Note that the system with Fed MBS holdings begins in November 2008, as opposed to July 2004. The lines represent the pointwise posterior median path in response to the shock identified in each system. The asterisks indicate regions where the 68% probability bands lie entirely above or below zero. All IRFs are based on ten thousand draws from the posterior distribution.