European University Institute
DEPARTMENT OF ECONOMICS

Three Essays in Monetary and Macroprudential Policies

Benedikt Mario Kolb

Thesis submitted for assessment with a view to obtaining the degree of Doctor of Economics of the European University Institute

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European University Institute
Department of Economics

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I confirm that Chapter 1, "Monetary Policy Communication Shocks and the Macro-economy", was jointly co-authored with Mr Robert Goodhead from EUI and that I contributed 50% of the work. Moreover, I confirm that Chapter 2, "The Macroeconomic Effects of Bank Capital Requirement Changes: Evidence from a Narrative Approach", was jointly co-authored with Ms Sandra Eickmeier and Mr Esteban Prieto from Bundesbank and that I contributed 33% of the work.

Signature and Date:

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Abstract

This thesis focuses on recent monetary and macroprudential policies addressing the Financial Crisis.

Chapter1 stresses the role of central-bank communication. In particular, shocks derived from movements in federal funds futures prices during monetary policy announcement days have become popular for analysing U.S. monetary policy. While the literature often considers only surprise changes in the policy rate ("action" shocks), we distinguish between action and "communication" shocks (surprise announcements about future rates), using a novel decomposition of futures price movements. Our results indicate that communication shocks are the main driver of U.S. monetary policy shocks and that they explain a substantial share of variation in production.

Chapter 2 turns to a macroprudential topic: How will a tightening in aggregate bank capital requirements affect the real economy? We investigate this using a narrative index of regulatory US bank capital requirement changes for the period 1980M1 to 2016M8. Our results robustly suggest that a tightening in capital requirements leads to a temporary drop in lending and economic activity. The aggregate capital ratio and the level of bank capital increase permanently. Our results suggest that permanently higher capital requirements have no lasting negative effect on the real economy.

Finally, Chapter3 looks at asset purchases by the ECB. Their declared goal is to revive inflation, but purchases of which asset will be best suited for this? I address this question in a DSGE model with a role for three different asset classes: Government bonds, securitised financial assets and corporate sector bonds, which affect the economy via different channels. I investigate the impact of asset purchases in an environment of low inflation and a policy rate at the zero lower bound. Purchases of government bonds appear most effective in countering disinflationary episodes, while those of securitised assets have less impact.

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1 Monetary Policy Communication Shocks and the Macroeconomy

(joint with Robert Goodhead)[1]

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1.1 Introduction

On December 16, 2015, the Board of Governors of the Federal Reserve decided to increase the federal funds target rate range for the first time since June 2006. The move came as little surprise to financial markets, however. While in the previous Federal Open Market Committee (FOMC) meeting of October the target rate had been held constant, policymakers had indicated that a rate rise was likely, subject to a continuation of recent positive macroeconomic developments.[2]

Although this rate hike officially marked the end of the zero-lower bound (ZLB) period of monetary policy for the United States, it was the October FOMC meeting that saw a revival in trading of near maturity federal funds futures contracts, which are used by market participants to bet on future Fed target rates. The market for federal funds futures, which began operating in 1988 and quickly became deep and liquid, has been used extensively to identify surprises in U.S. monetary policy and analyse their effect on financial markets and the real economy. The idea is simple: given that the prices of such contracts incorporate all information available to markets, they ought to embody the market expectation of future policy rates. Changes in the futures rate during the course of FOMC meeting days can thus be credibly interpreted as policy surprises, or monetary policy shocks. Data from futures markets therefore provide the econometrician with a means to separate the effects of changes in monetary policy from the underlying changes in macroeconomic conditions to which policy makers respond.

Such a high-frequency identification approach has been used in several recent VAR studies to examine the effects of changes in monetary policy rates on macroeconomic and financial variables (e.g. Barakchian and Crowe, 2013, Gertler and Karadi, 2015). Moreover, we expect interest by economic researchers in the federal funds futures market to increase in the near future, with the resumption of the use of conventional monetary policy tools by the FOMC. However, we argue that the majority of existing VAR research has not employed the informational

[2] The press release of the October meeting states that "[t]he Committee anticipates that it will be appropriate to raise the target range for the federal funds rate when it has seen some further improvement in the labor market and is reasonably confident that inflation will move back to its 2 percent objective over the medium term". See http://www.federalreserve.gov/newsevents/press/monetary/20151028a.htm.

content of futures data to the fullest: Given that the maturity spectrum of federal funds rates spans the known dates of several future policy meetings, one can use differences in futures price reactions across the maturity spectrum to discern market expectations about future monetary policy moves. We argue that these changes in expectations are a response to communication by the FOMC and show that they are powerful drivers of economic activity. In a recent contribution, Barakchian and Crowe (2013, BC in the following) rightly point to the increased importance of forward-looking elements in monetary policy, insofar as the Federal Reserve (and other central banks) have made increasing use of forecasting when designing policy. However, we argue that by aggregating futures rates movements across maturities into a single factor, the authors neglect a fruitful opportunity to precisely identify also the forward-looking component of the announcements as received by financial markets. If financial markets are similarly forward-looking in their judgment of FOMC communication, and given that Federal Reserve communication has become more detailed about its future policy course, markets should react to announcements in a way that is reflected systematically over the spectrum of federal fund future maturities.

We propose a novel measure to obtain shocks from futures rates of different maturities, using a linear decomposition of daily futures price movements in combination with an institutional arrangement: Since 1994, the FOMC has published its meeting days well in advance, so that market participants know the dates of the future meetings that make up the routine functioning of the FOMC.[3] This allows us to resolve the dating discrepancy resulting from the fact that futures prices defined over calendar months represent expectations about meetings that are not themselves monthly. We therefore transform the differing maturities of monthly federal funds funds rates (reflecting anticipated average target rates in future months) into anticipated rates between any two future FOMC meetings covered by the usable maturity range.

Since changes in the target rate tend to persist, surprise rate changes today are likely to also affect higher-maturity futures rates. However, additional information

[3]The effect of unscheduled meetings (in five out of 181 months with meetings in our sample) is discussed in Subsection 1.3.1.

about potential policy changes in future meetings should affect only future rates, and not current ones. We are therefore able to employ a simple yet credible recursive scheme to orthogonalise monetary policy "action shocks" (surprises about the actual target rate decision communicated at an FOMC meeting) from monetary policy "communication shocks" (information about potential future target rate decisions taken at later FOMC meetings). Monetary policy communication shocks are the linear component of observed variation that does not affect preceding maturities.[4] Importantly, the action shock is based on central bank actions that are directly observable, whereas the other shocks are based on central bank communication and related expectation shifts regarding future policy actions.

In this sense our approach is in the spirit of Gürkaynak, Sack, and Swanson (2005, GSS in the following), who offer a two-factor interpretation of monetary policy surprises and convincingly argue that a "target factor" (an effect similar across all maturities) and a "path factor" (increasing over maturities) are sufficient to explain futures rate movements on announcement days. They also orthogonalise their shocks by placing restrictions on the first maturity of the contracts. Indeed, BC also find that two factors explain most of the variation, but use only the first one (a "levels effect" similar to the "target factor" in GSS), reasoning that "[s]ince the transmission of monetary policy is generally thought to occur via the impact of short rate changes on longer term (real) rates, it is this portion of the new information on rates that corresponds most closely to the relevant policy shock." (BC, p. 959). We argue that this interpretation may not be justified, since some maturities react more strongly and consistently during FOMC meetings; these are generally the ones at the upper end of the spectrum. This cannot be aligned with the "levels effect" interpretation of BC, which seems to leave out important information about how monetary policy shocks affect the economy. Instead, we argue that communication shocks are at least as important as the actual level surprise. While this is in line with the interpretation of GSS, our novel method of obtaining the shocks allows for identification of more precisely defined monetary policy

[4] As these shocks represent changes in expectations that may or may not be accurate *ex post* (i.e., news and noise shocks), and specifically relate to Federal Reserve communication on FOMC meeting days throughout our sample from 1994, we choose to label them "communication shocks".

communication shocks that pertain to given dates in the future, since we do not apply a factor structure to the data. We are also able to extract monetary policy communication shocks across multiple horizons. Additionally, our approach lends itself to a hybrid VAR study, since within our Romer and Romer (2004) type specification, we need to be able to cumulate shocks meaningfully, and it is unclear how to achieve this with the GSS path factor.

We will show that monetary policy communication shocks create significant contractions of industrial production, while pure action shocks do not. They also explain a larger share of variation in both production and inflation at business cycle frequencies and can be better linked to narrative accounts of changes in the monetary policy stance during the period. However, neither action nor communication shocks solve the price puzzle in our VAR models, i.e. with these shocks we also observe an initial increase in prices after a contractionary monetary policy shock, as in BC. We show that our principal findings are robust to a variety of specifications. We conclude that surprises in monetary policy communication matter more for macroeconomic fluctuations than surprises in the immediate conduct of monetary policy.

We then extend our analysis to cover the ZLB period using Eurodollar futures, which are available at longer maturities than the federal funds futures contracts; importantly, the further forward contracts remain sufficiently liquid for analysis during the period. We offer a decomposition of movements in the prices of these contracts similar to the one used for the federal funds futures, and study the effects of these shocks on macro variables using a sample that includes the 2008 financial crisis and recovery. The three Eurodollar-derived shocks we employ should be understood to be communication shocks regarding short-term interest rate changes during the year-ahead period, orthogonal communication shocks during the two year-ahead period, and orthogonal communication shocks regarding the three year-ahead period. We find the effects of longer-term Eurodollar-derived shocks to be stronger for inflation than for industrial production, with a price puzzle observed only for the more short-term Eurodollar derived communication shock. These findings underline our key message that central bank communication has significant macroeconomic effects.

The paper is structured as follows: Section 1.2 discusses related literature, Section 1.3 outlines our methodology in detail, Section 1.4 presents our baseline results, Section 1.5 examines the responses of macro variables to longer-term communication using Eurodollars data, and Section 1.6 concludes.

1.2 Related literature

Our analysis relates to the high-frequency identification literature, recent research on forward guidance, and several other empirical papers on the subject of communication by monetary policymakers.

High-frequency identification literature. The literature on identification of monetary policy shocks employing high-frequency data goes back to Rudebusch (1998) and Kuttner (2001). Söderström (2001) is an early contribution arguing that movements in the federal futures rates around an FOMC meeting are a good predictor of target rate changes implemented in the following meeting. Faust, Swanson, and Wright (2004) were the first to incorporate a structural shock series identified via changes in federal funds future rates into a VAR together with financial and macro variables. GSS aggregate the informational content of the futures using factor analysis, and argue that two factors are sufficient to capture the correlation over the maturity spectrum. Analogous to the yield curve literature, they refer to these as the "current federal funds rate target factor" and "future path of policy factor". GSS argue that the "path factor" reflects soft information on future policy actions during FOMC meetings and is important for the analysis of the effects of monetary policy on asset prices. They perform an orthogonalisation of their shocks similar to ours, but do not use their shocks in a study of the macroeconomic system.

Another decomposition of the movements in futures prices can be found in Gürkaynak (2005), who identifies "timing", "level" and "slope" surprises. Like ours, his decomposition omits a factor structure, and assumes observed variation to be a linear function of three structural shocks. However, our restrictions separately identify three shocks of a different nature: each has the same interpretation, they merely apply to different future horizons. More recently, Swanson (2017) uses a factor analysis similar to GSS to distinguish between surprises in federal funds rate changes, forward guidance and LSAP effects. Three factors sufficiently describe the dynamics of underlying high-frequency changes in various returns in this sample. The factors are then identified by rotating them such that the forward guidance and LSAP factor have no influence on yields of short-term assets, and by minimising the LSAP factor before the ZLB episode. While we find this method intuitive, we argue that based on the identification, one cannot rule out an alternative interpretation of the factors as action surprise, a non-crisis communication component and a crisis-time communication component. In any case, Swanson's analysis shows the importance of monetary-policy communication for asset prices during the ZLB episode.

Most closely related to our paper is Barakchian and Crowe (2013, BC in the following), who show that for samples starting in 1988, monetary policy shocks identified via widely used recursive schemes lead to significant *increases* in output following "contractionary" monetary policy shocks. In contrast, a VAR with cumulated high-frequency shocks, computed as a single factor of the maturity spectrum, yields contractionary effects on industrial production in response to contractionary policy. BC suggest this might be due to a more forward-looking monetary policy after the 1980s, under which policy rates react contemporaneously to, or even before, changes in economic activity.[5] They estimate a two factor model of the jumps across maturities of contract, stating that "in keeping with the literature on factor models of the yield curve (...), the factors have a natural interpretation as level and slope" (BC, p. 951). Then they opt to use only the first factor (the previously mentioned "levels effect"), which explains more than 90% of the variance across maturities. We suggest, in contrast, that impulse responses to the monetary policy shock used in BC may in fact be mostly driven by a communication component.

Other related papers from this literature include Thapar (2008), who also considers only a single monetary policy shock within a novel empirical framework, and Gertler and Karadi (2015). The latter use an instrumental variable approach to safeguard against simultaneity in a VAR including both a monetary policy shock

[5] For a similar argument, see Cochrane and Piazzesi (2002).

measure and credit costs. However, the authors note that in the case that no further financial variables are considered, a recursive VAR such as the one we employ is appropriate for an analysis of monetary policy shocks. Lakdawala (2016) uses their methodology in conjunction with the two GSS shocks to distinguish between federal funds rate and forward guidance shocks. The author finds the expected response of industrial production to a contractionary federal funds rate shock, but an expansionary effect for contractionary forward guidance communication, which is rendered insignificant when controlling for the information set of the Fed using Greenbook and Bluechip forecast data. The differences in the findings of Lakdawala (2016) relative to our own could be explained by the shorter horizon of our communication shocks (within six months as opposed to one year), or by the way the external instruments approach includes data from earlier periods (the sample for the external instruments begins in 1979). Finally, Miranda-Agrippino and Ricco (2017) adjust the instrument in Gertler and Karadi (2015) to account for autocorrelation and central-bank information revelation. Using a Bayesian local-projections approach, they find univocally negative effects of a contractionary monetary policy shock. However, they do not identify the effect of communication surprises.

Forward guidance. Our paper also relates to a growing literature on forward guidance, i.e. the deliberate steering of the public's expectations by central banks sharing internal forecasts or committing to longer-term policies. [6] However, in our extension using Eurodollar futures we also find an increased role of forward guidance as a driver of macroeconomic fluctuations after 2008, in particular for inflation. This strong effect, which increases in the horizon of communication, is in line with the predictions of DSGE models, as studied by Del Negro, Giannoni,

[6] See e.g. Campbell, Evans, Fisher, and Justiniano (2012), Ben Zeev, Gunn, and Khan (2015), or Nakamura and Steinsson (2016). Campbell et al. (2012) introduce a conceptual distinction between "Delphic" forward guidance, or transmission of private information, and "Odyssean" forward guidance, which represents explicit commitments to a future policy course. Our baseline communication shocks incorporate both forms of information. More closely related to our paper is Bundick and Smith (2016), who use jumps in federal funds futures rates as measures of forward guidance, employing them in a SVAR model, and find their effects to be comparable to conventional monetary policy shocks. However, they do not offer a comparative assessment of the effects of monetary policy actions and communication about future actions on macro variables, since they do not orthogonalise action and communication shocks with respect to each other, as we do in this study.

and Patterson (2016) and McKay, Nakamura, and Steinsson (2016).[7]

Other measures of central bank communication. Finally, there are two other related papers with shocks to central bank communication: Neuenkirch (2013) uses an indicator of monetary policy communication to distinguish target-rate from communication shocks in a recursively identified VAR for the euro area. Although the author's setup and sample are very different from ours, he also finds an important role for communication, in particular for the transmission of monetary policy to industrial production. Hansen and McMahon (2016) use results from computational linguistics analysis to distinguish FOMC communication regarding current economic conditions from forward guidance in a broader sense. They find no strong effect on real variables, which is in line with our Eurodollar analysis focusing on forward guidance, but not with our baseline results for the sample 1994 to 2008: The difference here might be explained by the fact that their communication shock aims to solely capture central bank revelations about the state of the economy, while we capture all central bank announcements that affect market expectations regarding future monetary policy actions.

1.3 Methodology

This section introduces our data, and outlines how we obtain changes in anticipated policy rates from changes in the price of futures contracts defined over calendar months. We then present a Cholesky decomposition that delivers identification of monetary policy action and communication shocks. Finally, we explain how we incorporate our shocks into a structural VAR model in order to examine their effect on macroeconomic variables.

1.3.1 Data

Federal funds futures contracts were introduced on October 3, 1988, by the Chicago Board of Trade, and are the most widely used futures contract tied to the federal

[7] These papers address the so-called "forward guidance puzzle", an observed tendency for implausibly large effects of monetary-policy news shocks in the standard New Keynesian framework.

funds rate.[8] The use of these futures limits our sample to the period before the ZLB, since trading in the shorter maturity contracts effectively ceased at the onset of this period.[9]

Federal funds futures contracts allow market participants to place a bet in month t on the average effective federal funds rate during the concurrent or future months, denoted by $\bar{r}_{t+m}$, with $m \geq 0$.[10] A buyer of the contract on day d in month t can commit to borrow federal funds at a fixed rate at the end of the month $t+m$, and we denote this futures rate by $f_{d,t}^{(m)}$. Under no arbitrage, we have that the futures rate $f_{d,t}^{(m)}$ reflects the market expectations of the average effective federal funds rate $\bar{r}_{t+m}$:

$$f_{d,t}^{(m)} = \mathbb{E}_{d,t}[\bar{r}_{t+m}] + \delta_{d,t}^{(m)}, \quad \forall m \in H,$$

where $\delta_{d,t}^{(m)}$ is a risk-premium term, and H denotes the set of available maturities of contracts. Since Kuttner (2001), authors have argued that the jumps in the federal funds futures market observed on FOMC meeting days capture a surprise component of monetary policy, and that one can use these surprises to identify monetary policy shocks. As the futures rate can be expected to incorporate all information available to the markets, a change in the futures rate over a small time window around FOMC statements should reflect changes in market expectations about future policy, i.e. policy "surprises". Assuming no change in the risk-premium $\delta_{d,t}^{(m)}$ for that short time window,[11] a policy surprise can be computed as the difference in the futures rate at the end of the FOMC meeting day from that at the end of the

[8]See Moore and Austin (2002). In principle our method can be applied to any country where futures contracts relating to monetary policy variables are traded. We follow the majority of the literature and focus on the federal funds futures market in the U.S.

[9]We examine the ZLB period using Eurodollar futures in Section 1.5. However, our short baseline sample makes the likelihood of structural breaks in the transmission of monetary policy less likely (see e.g. Boivin and Giannoni, 2006 and D'Amico and Farka, 2011).

[10]The time index t here is at monthly frequency, reflecting the definition of the underlying of the contract as a monthly average (we use a bar in our notation to emphasise this). Throughout we let t refer to the month, which is the frequency of our VAR, and we let d denote the particular day in given month t.

[11]Piazzesi and Swanson (2008) have shown that the risk-premium in the federal funds futures market is sizeable and time-varying, but only at business-cycle frequencies.

previous day,

$$\Delta f_{d,t}^{(m)} \equiv f_{d,t}^{(m)} - f_{d-1,t}^{(m)} = \Delta \mathbb{E}_{d,t}[\bar{r}_{t+m}], \quad m > 0.$$

Note that for contracts on the current month, agents will already have observed a component of the realization of $\mathbb{E}_{d,t}[\bar{r}_{t+m}]$, because $d-1$ days of that month (whose length is M days) have already elapsed. We follow Kuttner (2001) in scaling the futures rate for the concurrent month, $\Delta f_{d,t}^{(0)}$, up by the ratio of number of days in the month, M, over the number of days remaining after the meeting, $M-(d-1)$.[12] Thus we obtain a "corrected" measure $\Delta f_{d,t}^{*(0)}$:

$$\Delta f_{d,t}^{*(0)} = \frac{M}{M-(d-1)} \cdot \Delta f_{d,t}^{(0)}.$$

One issue with this correction is that the scaling factor becomes very large at the end of the month (up to 31 for $M = d = 31$). We therefore again follow Kuttner (2001) and use the change in the futures rate of next month ($\Delta f_{d,t}^{(1)}$ in place of $\Delta f_{d,t}^{*(0)}$) for meetings on the last three days of a month (see Kuttner, 2001, p. 529f).

Although federal funds funds contracts are now available for maturities as far as three years into the future, only the first six maturities of futures are considered liquid enough to be treated as efficient financial markets over our time-period (see BC, p. 959). We use daily changes in futures rates around FOMC dates for the maturities $m \in \{0, 5\}$. GSS find that using intraday or daily data makes virtually no difference for the post-1994 sample.[13]

1.3.2 From futures rate changes to expected policy rate changes

The federal funds futures prices give us changes in market expectations about policy rates on FOMC meeting days. In our analysis below, we are interested in

[12] We take into account that the overnight rate refers to the night *after* day d. See Hamilton (2008), p. 378.

[13] "[F]or samples that exclude employment report dates, or samples that begin in 1994, the surprise component of monetary policy announcements can be measured very well using just daily data." (GSS, p. 66)

changes in expectations about: 1) the current policy rate, 2) the policy rate set at the next FOMC meeting, and 3) the policy rate set at the FOMC meeting after this. To analyse surprises regarding current and future rate decisions, we first need to extract measures of the market expectation of average rates within certain intervals: between the current and the next FOMC meeting, between the next meeting and the meeting after, and so on.

However, our six usable futures maturities are defined over calendar months, while meeting days are unevenly spread out across the months in the maturity spectrum.[14] Although we are able to use six rate jumps that span the next six months into the future (and therefore always at least three future meetings), the futures contracts cannot represent six individual policy surprises, since there are at most three further meetings during this period—monetary policy can change at most another three times. To obtain average rates expected by the markets between meeting dates, we follow a linear extraction method. Similar methods are used in GSS and Gürkaynak (2005), however, we add an iterative weighted averaging procedure to reduce noise and use all available information.

Let $\Delta\rho^j_{d,t}$, $j \in \{0, I, II\}$ denote the change in the expected rate for the j^{th} future meeting, taking place in month $t+m(j)$ (here the exact month of the future meeting will vary, which is why m is a function of j).[15] Recall that the expectation revision always occurs during the contemporaneous meeting indexed by day d and month t. Thus,

$$\Delta\rho^j_{d,t} = \Delta\mathbb{E}_{d,t}[\bar{r}_{t+m(j)}].$$

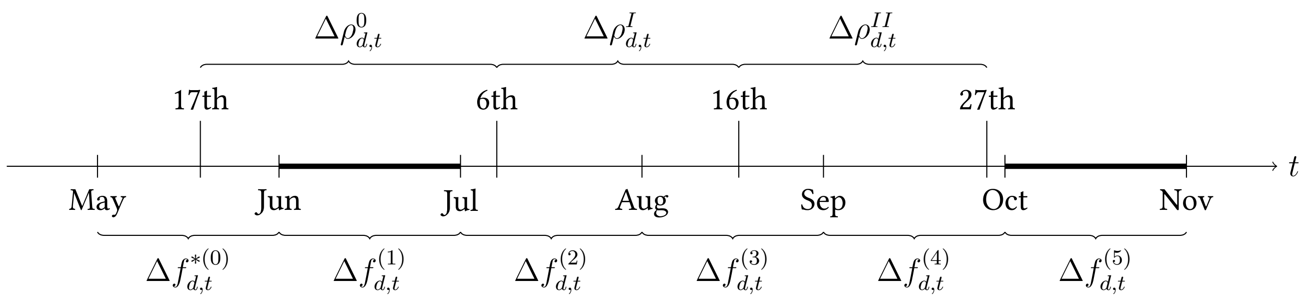
We can create up to three such anticipated rates: from the current meeting to the next, $\Delta\rho^0_{d,t}$, from the next to the one after that, $\Delta\rho^I_{d,t}$, and from this (third) meeting to the fourth, $\Delta\rho^{II}_{d,t}$ (the construction of $\Delta\rho^{III}_{d,t}$ would require longer maturities).

[14] FOMC meetings take place roughly every six weeks, usually in late January, April, July and October and mid March, June, September and December. The meetings for late July and October often take place in early August and November instead.

[15] As the anticipated rate changes $\Delta\rho^j_{d,t}$ are valid for the time between two meetings (on average six weeks), we index them by Roman numerals $(0, I, II)$ to differentiate them from the monthly futures rate changes $\Delta f^{(m)}_{d,t}$. We neglect the appropriate expectations operator to ease the notational burden. Also note that our $\Delta\rho^j_{d,t}$ notation would correspond to $mp0$, $mp1$, and $mp2$ in Gürkaynak (2005).

Figure 1 illustrates the timing with an example: the FOMC meeting taking place on May 17, 1994 and the three meetings that followed (those of July 6, August 16 and September 27). The figure displays the five calendar months into the future from the month of the meeting, and the jumps in the futures rate for the contract associated with that month, $\Delta f_{d,t}^{(m)}$.

Figure 1: Illustration of the Conversion of $\Delta f_{d,t}^{(m)}$ to $\Delta \rho_{d,t}^{j}$



Notes: The timeline shows the months May to November 1994, as labelled below the axis. Above the axis are the days of FOMC meetings. The jumps in the monthly futures rates, $\Delta f_{d,t}^{(m)}$, are indicated below the axis, above it are the jumps in expected federal funds rates between meetings, $\Delta \rho_{d,t}^{j}$. Months without FOMC meetings are marked by a thick line.

To extract the anticipated policy rates changes $\Delta \rho_{d,t}^{j}$, we work iteratively forward, starting with $\Delta \tilde{\rho}_{t}^{0}$, which is simply the corrected jump[16] in the futures rate for the concurrent contract,

$$\Delta \tilde{\rho}_{d,t}^{0} = \Delta f_{d,t}^{*(0)}.$$

Since contracts are defined over average interest rates for calendar months, we know the price of the futures contract for the month of the next meeting, $f_{d-1,t}^{(I)}$, must be a weighted average of the expected interest rate carried forward from the previous meeting, and that expected to be set in the next (indexed 0 and I, respectively),

$$f_{d-1,t}^{(I)} = \frac{d_I - 1}{M_I} \mathbb{E}_{d-1,t}[r^0] + \frac{M_I - (d_I - 1)}{M_I} \mathbb{E}_{d-1,t}[r^I] + \delta_{d,t}^{(I)}. \tag{1}$$

[16] The tilde notation reflects the fact that these jumps are preliminary values and will subsequently undergo a weighted averaging procedure.

Here d_I refers to the day of the next meeting, and M_I to the number of days in the month of the next meeting. When we lead Equation 1, before differencing, we obtain the expression

$$f_{d,t}^{(I)} - f_{d-1,t}^{(I)} = \frac{d_I - 1}{M_I} \cdot \Delta\tilde{\rho}_{d,t}^{0} + \frac{M_I - (d_I - 1)}{M_I} \cdot \Delta\tilde{\rho}_{d,t}^{I},$$

where $\Delta\tilde{\rho}_{d,t}^{j} = \mathbb{E}_{d,t}[r^j] - \mathbb{E}_{d-1,t}[r^j]$, and we assume the risk premium does not change within the meeting day ($\Delta\delta_{d,t}^{(I)} = 0$). Therefore:

$$\Delta\tilde{\rho}_{d,t}^{I} = \frac{M_I}{M_I - (d_I - 1)} \left([f_{d,t}^{(I)} - f_{d-1,t}^{(I)}] - \frac{d_I - 1}{M_I} \cdot \Delta\tilde{\rho}_{d,t}^{0} \right). \tag{2}$$

We can derive a similar expression for $\Delta\tilde{\rho}_{d,t}^{II}$. Because the futures rate jumps are likely to be noisy, and since such noise could be weighted up by the scaling terms, we utilise the extra information represented by changes in futures rates for calendar months without meetings. Thus, if there is no meeting in the month following the meeting, we create a final version of $\Delta\rho_{d,t}^{0}$ by taking a weighted average of this measure with the jump in the next month's futures rate, as follows:

$$\Delta\rho_{d,t}^{0} = \frac{M_0 - (d_0 + 1)}{M_0 - (d_0 + 1) + M_1} \cdot \Delta\tilde{\rho}_{d,t}^{0} + \frac{M_1}{M_0 - (d_0 + 1) + M_1} \cdot \Delta f_{d,t}^{(1)}.$$

We are therefore using the fact that the jump in the price of next month's contract is an equally valid measure of the surprise for the case that there is no meeting next month (since a single target rate will hold over the whole period). We employ the same strategy to create $\Delta\rho_{d,t}^{I}$ and $\Delta\rho_{d,t}^{II}$, whenever there is no meeting in the month following a given meeting.[17] This approach ensures that the futures rate changes that occur towards the end of the month (with higher d) will get a smaller weighting in the convex combination.

As mentioned by Gürkaynak (2005), a potential limitation of this method is the possibility of rate changes during unscheduled meetings. The FOMC can deviate

[17] In the case that there is a meeting next month we do not perform the weighting. Further, we perform this operation during the iterative extraction, in the sense that where appropriate the weighted version of the previous surprise is used to extract the next, which then may be weighted, etc.

from its published meeting schedule if circumstances require it and has done so seven times in our sample.[18] If markets were to incorporate an endogenous probability of emergency meetings into their pricing, this could be problematic for our identification scheme. However, given that we take differences of futures prices on meeting days, the occurrence of unscheduled meetings will only bias our shock measures when the market expectations about the likelihood of an unscheduled meeting are changed on account of news delivered *during the day* of the previous (scheduled) FOMC meeting. From inspection of the minutes, the committee has never mentioned unscheduled meetings during the meetings that preceded them. Therefore, we do not believe that unscheduled meetings present a serious concern.

1.3.3 From expected policy rate changes to structural shocks

Given the surprises in the policy rates, $\Delta\rho^j_{d,t}$, we want to obtain the structural shocks that generate these changes in expectations. We know that target rate changes by the Fed are highly persistent (shown in Coibion and Gorodnichenko, 2012, for example), and therefore that any rate decision communicated during the FOMC meeting will also shift market expectations across the spectrum of maturities towards this rate. This is what GSS and BC refer to as their "target factor" and "level factor", respectively. Thus an unexpected policy rate change by the FOMC will lead to an updating of expectations about the current month's rate, but also about future rates, as the rate is likely to persist: Without any additional information about the FOMC's future course of policy action, markets can take the set policy rate to be the new *status quo*. We will call these surprise announcements of immediate policies "action shocks".

We also aim to quantify the effects of an important second component to FOMC meetings, namely communication about the future. We therefore posit the existence of orthogonal information about future policy changes contained within the announcement. The central banker may reveal surprise information about a rate change, and simultaneously deliver independent surprise information relating to future policy. Additional surprise communication about potential policy actions in these future meetings ought to affect all futures rates *after* the future meeting

[18] The dates were 01/03/2001, 08 and 17/10/2007, 01 and 22/09/2008, 03/11/2008 and 10/08/2008.

(and associated expected policy move), but not rates *before* them. The six available futures contracts permit identification of two such monetary "communication shocks". We thus define this communication as the linear component of the expectations jump vector that does not affect the pricing of those futures preceding the meetings to which they apply. Action shocks may affect all futures rates through policy persistence, but the current rate expectations will not be affected by any communication shocks. This recursive system motivates the use of a Cholesky decomposition of the expectations jump vector.

Formally, the changes in expectations about the future monetary policy rate, $\Delta\rho^j_{d,t}$, $j \in \{0, I, II\}$, are decomposed into three orthogonal shocks: surprises about monetary decisions today (the action shock, $\varepsilon^A_{d,t}$), the decision at the next meeting (termed a "near communication shock", $\varepsilon^{NC}_{d,t}$) and the decision at the meeting after this (termed a "far communication shock", $\varepsilon^{FC}_{d,t}$) as follows:

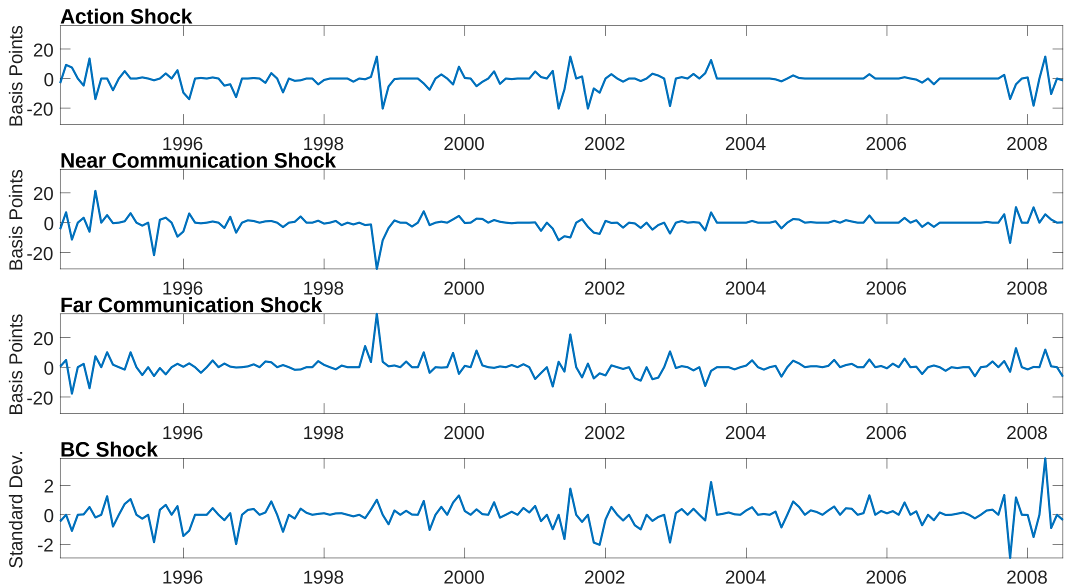
$$\mathbf{\Delta R}_{d,t} \equiv \begin{bmatrix} \Delta\rho^0_{d,t} \\ \Delta\rho^I_{d,t} \\ \Delta\rho^{II}_{d,t} \end{bmatrix} = \begin{bmatrix} m_{11} & 0 & 0 \\ m_{21} & m_{22} & 0 \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon^A_{d,t} \\ \varepsilon^{NC}_{d,t} \\ \varepsilon^{FC}_{d,t} \end{bmatrix} = \mathbf{M} \cdot \mathbf{E}_{d,t}. \tag{3}$$

The shocks $\varepsilon^j_{d,t}$, $j \in \{A,\ NC,\ FC\}$, are orthogonal to each other by construction. We obtain $\mathbf{M}$ as the lower Cholesky decomposition of $\text{var}(\mathbf{\Delta R}_{d,t})$, $\mathbf{M} = \text{chol}\left(\text{var}(\mathbf{\Delta R}_{d,t})\right)$. Rearranging, we obtain the expression for the vector of structural shocks:

$$\mathbf{E}_{d,t} = \mathbf{M}^{-1} \cdot \mathbf{\Delta R}_{d,t}.$$

Note that these operations are conducted at the frequency of the meetings, in the sense that we extract structural shocks from a jump vector with observations only on meeting days. Because we restrict our analysis to days with scheduled meetings only, there is never more than one meeting per month, meaning that we can drop the d subscript from our shock series. We enter a zero value to the shock series for the months without meetings, as in BC. Because of concerns about outliers in the series, we winsorise the expectation revisions series at 1% before extracting our shock series. The main results are qualitatively robust to not winsorising.[19]

Figure 2: Shock Series



Notes: The figure displays the three shocks $S_t^j, j \in \{A, NC, FC\}$ – dubbed "Action", "Near Communication" and "Far Communication" shock, respectively. We also display the shock series of Barakchian and Crowe (2013), formed of the first principal component of the six federal funds rate maturities, for reference. The R^2 from regressions of the BC shock on the Action, Near Communication and Far Communication shocks respectively are: 0.358, 0.144, 0.187.

Figure 2 shows the action shock series, the near and far communication shock series, as well as the BC shock series (the first factor) to serve as a basis for comparison.[20] There is evidence of increased volatility of the shock series around the

[19]The response of industrial production to the action shock differs slightly. There is an outlier on 15/10/1998, when the Federal Reserve released a statement *after* the close of the federal funds futures market, meaning that the end of the next day's futures price needs to be used. This generates a very large (10 standard deviation) action shock.

[20]For a discussion of correlations between our shock series and other series available in the literature, see Appendix Section A.1. To summarize, our action shock is significantly positively correlated with both factors in BC and the first GSS factor. Our communication shocks are positively correlated with only the first BC factor and the second GSS factor. All our shocks are positively correlated with the shock of Nakamura and Steinsson (2016), and both action and the first communication shock with an updated Romer and Romer (2004) shock series. We conclude from this investigation that our shocks capture information from all these existing shock series, but that

2001 period, after the bursting of the dotcom bubble and the events of September 11. We also see increased volatility in the run-up to the financial crisis. The relationship of the BC factor shock and our shocks varies: some BC factor shocks are simply "split" into several smaller shocks of equal sign by our decomposition (like the monetary tightening and then easing around 2001), indicating that action and communication surprises were closely aligned at that time. For other episodes, to the contrary, our shock decomposition reveals some counteracting movements in monetary policy: With the onset of the Financial Crisis in 2007, surprise action and short-term communication have an easing effect, while medium-term communication about a quarter into the future seems to have mostly underwhelmed market expectations.

Finally, we cumulate the shocks over time to form a time series of policy surprises in levels, as in BC and Romer and Romer (2004).[21] We thus attain three monthly time-series in levels, S_t^j, $j \in \{A, NC, FC\}$ where:

$$S_t^j = \sum_{i=0}^{t} \varepsilon_t^j, \quad j \in \{A, NC, FC\}.$$

1.3.4 Baseline VAR setup

We want to gauge the effect of our three measures of policy surprises on (seasonally adjusted) monthly industrial production (IP) and consumer price inflation (CPI). As we wish to understand the effect of all three shocks, we specify the fol-

they are not reducible to any of them. Furthermore, the "level factor" interpretation of BC regarding their shock may be questioned, given its significant positive correlation with our communication shocks.

[21]Note that these series are I(1) by construction, and will be entered directly into the VAR in this form. The specification also matches the treatment of the federal funds rate and macroeconomic variables in the monetary policy shock literature, including BC, whereby all variables are commonly entered in levels. Further, the argument of Sims, Stock, and Watson (1990) should hold, insofar that "the OLS estimator is consistent whether or not the VAR contains integrated components, as long as the innovations in the VAR have enough moments and a zero mean, conditional on past values of [the vector of endogenous variables]" (p. 113).

lowing structural VAR:

$$\mathbf{Y}_t \equiv \begin{bmatrix} \log(\mathrm{IP}_t) \\ \log(\mathrm{CPI}_t) \\ S_t^A \\ S_t^{NC} \\ S_t^{FC} \end{bmatrix} = \mathbf{C}_c + \mathbf{C}_d \cdot t + \sum_{l=1}^{\text{lags}} \mathbf{C}_l \mathbf{Y}_{t-l} + \mathbf{D} \cdot \epsilon_t \tag{4}$$

We estimate the model with a constant $\mathbf{C}_c$ and a deterministic trend $\mathbf{C}_d$, using twelve lags in our baseline model.[22] As in Romer and Romer (2004) and BC, the VAR is recursive, so that monetary policy surprises cannot affect IP and CPI in the same period (but are allowed to react to them). One feature of this specification is that the unanticipated shocks are allowed to respond endogenously to variables in the VAR. This results in a loss of efficiency if the jumps are indeed orthogonal to macroeconomic variables. However, to the extent that the jumps represent endogenous information revelation on the part of the central banker, the specification allows us to control for this by orthogonalising the jumps with respect to (at least part of) their information set. We need to make the assumption that markets do not observe the monthly observations on industrial production and inflation in real time, which we find to be plausible. This argument is also made in Bundick and Smith (2016).

1.4 Results

Here we present the main findings of our VAR analysis.[23] We trace the dynamic effect of our shocks on the monthly aggregates of IP and CPI, using impulse responses as well as historical and forecast-error variance decompositions. The main conclusion we draw from our analysis is that monetary policy affects production through surprises in communication about future policy decisions, as much as sur-

[22]The Bayesian information criterion proposes one lag, and the likelihood ratio test 14. We settle for twelve lags as in Faust et al. (2004). We show that our results are robust to different numbers of lags in Section 1.4.2.

[23]For the VAR analysis, we gratefully acknowledge the use of code from the VAR toolbox of Ambrogio Cesa-Bianchi, kindly made available on his personal website: https://sites.google.com/site/ambropo/MatlabCodes.

prises regarding the decision on the target policy rate itself. Moreover, we document a price puzzle, i.e. the significant positive response of CPI to a contractionary policy surprise, for our shocks that the inclusion of commodity prices does not satisfactorily resolve. However, when the local projection approach is used instead of a VAR, we do chart a significant fall in the price level in response to a contractionary far communication shock.

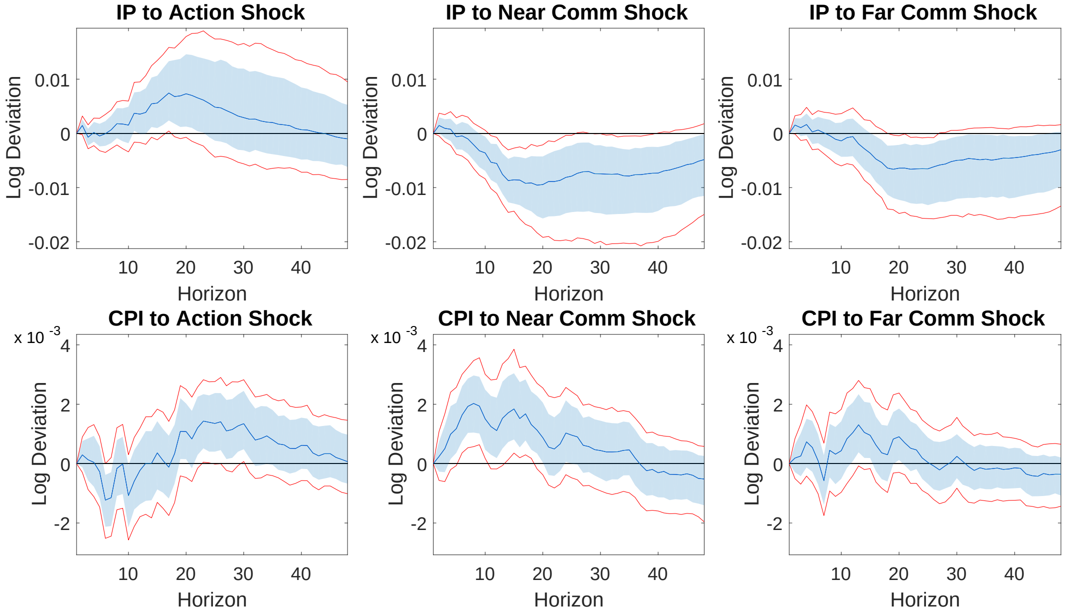
1.4.1 VAR analysis

Figure 3 shows the impulse responses to an action shock S_t^A, to a near communication shock S_t^{NC}, and to a far communication shock S_t^{FC}, respectively, on log production and consumer prices. Throughout the structural shocks are 10 basis points rate increases, unless stated otherwise (for a justification of this size see below).

We see that the reaction of production (IP) to a rise in the (expected) interest rate is negative at the 90% confidence level only for the two communication shocks. The size of the contractions is comparable, although the near communication shock displays greater significance. The action shock, on the contrary, displays a reaction of production which is instead positive with borderline significance (75% interval). The response does attain 90% significance at the 17th horizon. The reaction of inflation (CPI) depicts the price puzzle at 75% significance for the action and far communication shock, and at 90% significance for the near communication shock. For the near and far communication shocks, the median impulse response is negative at longer horizons, although insignificant.[24]

[24] We are aware that the statistical significance of our findings is rather marginal. However, the fact that significance is retained over many robustness checks below makes us confident about the results.

Figure 3: Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ to Our Shocks



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series $S_t^j, j \in \{A, NC, FC\}$ – action, near communication and far communication shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

The increase in IP after an action shock (i.e. after an unexpected interest rate increase by the central bank) and the CPI increases after all of our shock measures are both puzzling. A likely cause is that our VAR misses one important aspect of recent monetary policy: The fact that a forward-looking central bank might react to forecasts or expectations of an economic overheating by raising rates – implying the rate rise takes place simultaneously to, or shortly before, increases in IP or prices. Apparently the VAR does not pick up the dynamics caused by forward-looking monetary policy sufficiently for the action shock (a criticism that is voiced about recursively identified monetary-policy VARs in BC).[25] We will show below

[25] As might be expected from these analyses, and given the findings of BC, our near communication and far communication shocks improve upon results that can be obtained from studying the effects of contractionary shocks under the Christiano, Eichenbaum, and Evans (1996) identifi-

that including commodity prices mitigates this problem.

In magnitude the effects of our shocks are large relative to the literature. Ramey (2016) summarises existing estimates of the effects on industrial production of 100 basis points rises in the federal funds rate, and the maximum reported decrease is typically less than 5% (from BC), and usually closer to 1% (Christiano et al., 1996, find 0.7% after 24 months). Our near communication shock would deliver a negative 9.6% trough 19 months after the shock hits. However, a 100 basis point increase far exceeds the standard deviation of our shock series (7.66, 6.36, and 6.66 basis points for the action, near and far communication shock respectively).[26] Since our shock series are measures of purely unanticipated changes in the federal funds rate, they are small relative to the shock series employed in existing research that does not use high-frequency identification. The stronger effect of our shock series relative to that of BC is interesting, and could be explained by the fact that our communication shocks are seen to have stronger, negative effects relative to the action shock. To the extent the BC shock amalgamates all three shock series, it would follow that their estimated effect should be smaller than ours.

To contrast our findings with those from the existing high-frequency identification literature, we compare our shock responses to the ones from the single factor used in BC, called a "level shock" by the authors. Figure 4 plots again the responses from Figure 3, and contrasts each of them with the BC factor shock, by superimposing the results from their 3-variable VAR system on those from our 5-variable VAR system. We see that the effects of the BC shock mimic the effects of our communication shocks. While the significance of the IP contraction for the BC shock seems driven by the far communication component, the significance of the price puzzle is likely driven by the action and near communication shock components.

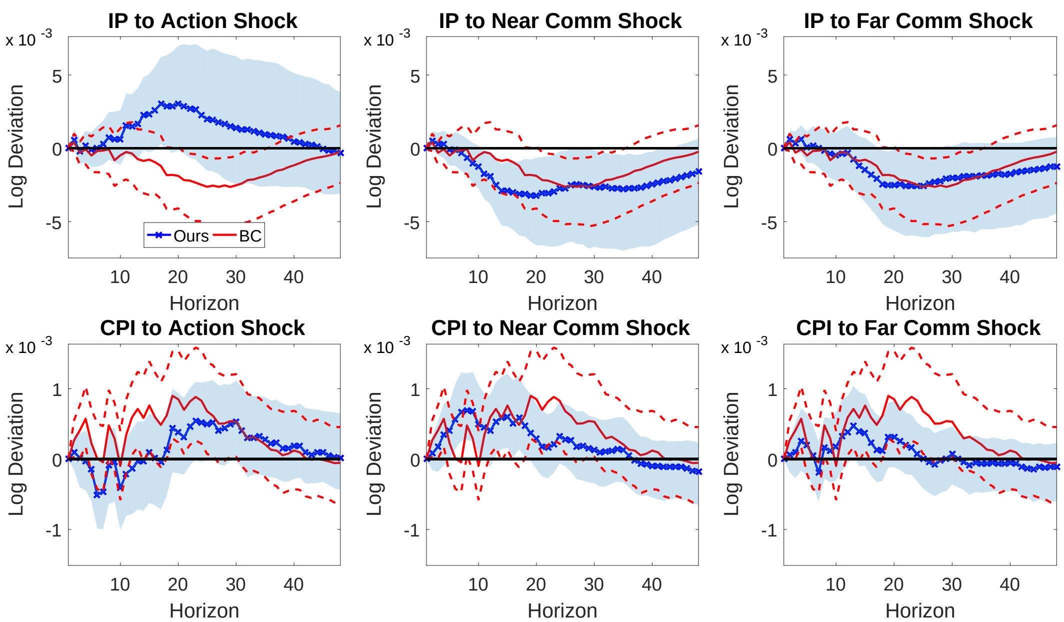
BC make a very convincing case that monetary policy in the U.S. has become more forward-looking after 1994. We believe that also central-bank communica-

cation scheme for our sample, which are plotted in Appendix Section A.2. Such a purely recursive identification scheme, within a three-variable SVAR including log industrial production, log CPI, and the federal funds rate, delivers a significantly positive response to both industrial production and CPI in response to a contractionary shock.

[26] This is why we choose to report our estimates in terms of 10 basis point rises.

tion, and its reception by the markets, has become more forward-looking during this time. This is reflected in our finding that, in post-1994 data, it is not monetary-policy surprise rate changes themselves, but rather surprise central bank communication about its future course of action that affects economic activity in the way expected from a “monetary policy shock”.

Figure 4: Comparison to Barakchian and Crowe (2013)



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series $S_t^j, j \in \{A, NC, FC\}$ – action, near communication and far communication shock respectively (all in blue), together with the responses to the factor (“level”) shock from Barakchian and Crowe (2013) in red, estimated in a 3-variable system (thus identical responses are repeated across each row). The median and confidence intervals (at 90%, blue for our VAR and dashed red for BC) were obtained from bootstrapping each VAR model 500 times. Responses are shown to a 1 standard deviation positive shock to interest rates.

Table 1 depicts the relative shares of our three shocks in a forecast error variance decomposition of both macro variables at 12, 18, 24 and 36 month horizons. As our VAR system is rather small, we are not interested in the absolute share explained by our shocks, nor the share relative to the two additional (non-identified) shocks in the system. We therefore only show the relative contribution of our three monetary-policy shocks, standardised to add up to unity.[27] The share of the near-communication shock is usually larger than that of the action shock. At any rate central bank surprise communication (understood to be the combined effect of the two communication shock series) seems to have larger effects on both production and inflation than surprise actions at business cycle frequencies—we hold that this is an interesting finding for the high-frequency identification literature.

Table 1: Forecast Error Variance Decomposition at Business Cycle Frequency

	Horizon (months)	S_t^A	S_t^{NC}	S_t^{FC}
IP_t	12	39.47	53.05	7.48
	18	40.80	44.25	14.95
	24	40.59	37.73	21.68
	36	34.58	40.02	25.40
CPI_t	12	26.85	60.26	12.89
	18	19.67	61.32	19.01
	24	15.35	61.52	23.13
	36	26.74	54.71	18.55

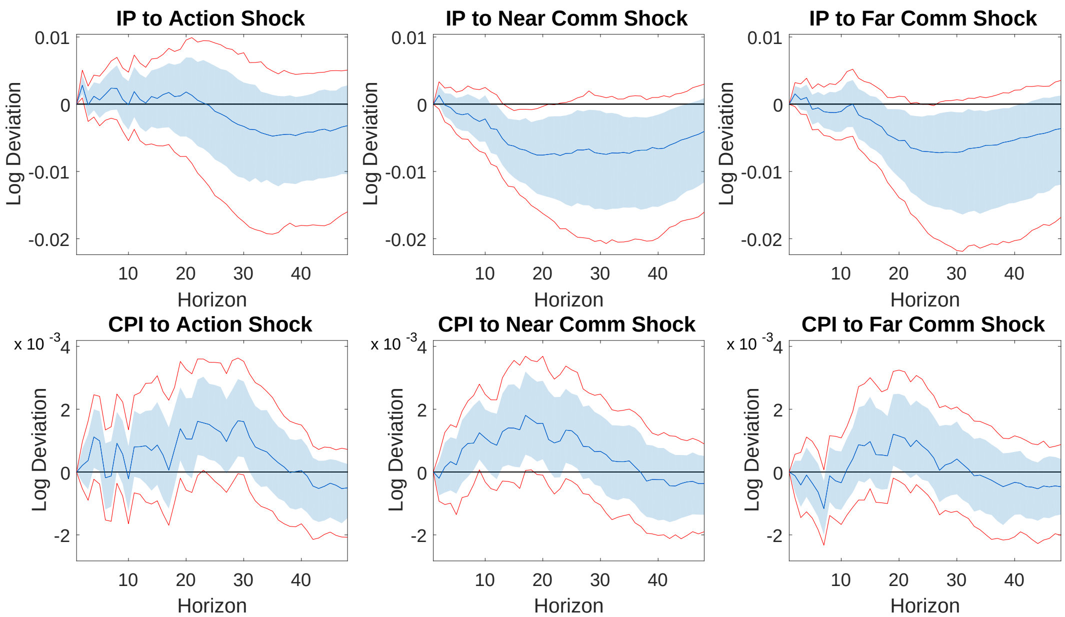
Notes: Relative contribution of our shocks to a forecast-error variance decomposition of IP and CPI at the 12, 18, 24 and 36 month horizons from our baseline 5-variable VAR. The identified three shocks are $S_{d,t}^j$, $j \in \{A, NC, FC\}$– action, near communication and far communication shock respectively. As we are only interested in the relative importance of our shocks, we present the contribution of the three shocks as a percentage of their combined contribution.

Investigating the price puzzle. We examine whether the inclusion of commodity prices is able to resolve the price puzzle, or the counter-intuitive reaction of IP to the action shock. We suspect our VAR specification above might not account sufficiently for the role of central bank forecasts in their policy-making and

[27]The absolute size of the contributions is large in general. The near communication shock explains about 29% fo the variance at a 36-month horizon. However, this is likely due to our small SVAR system, and in the same order of magnitude as in BC, who find that their shock explains around 50% of variance at a 24-month horizon.

communication. As suggested by Christiano et al. (1996), we include commodity prices in our VAR to correct this source of misspecification, since commodity prices are strong predictors of future inflation.

Figure 5: Impulse Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ in a VAR with Commodity Prices

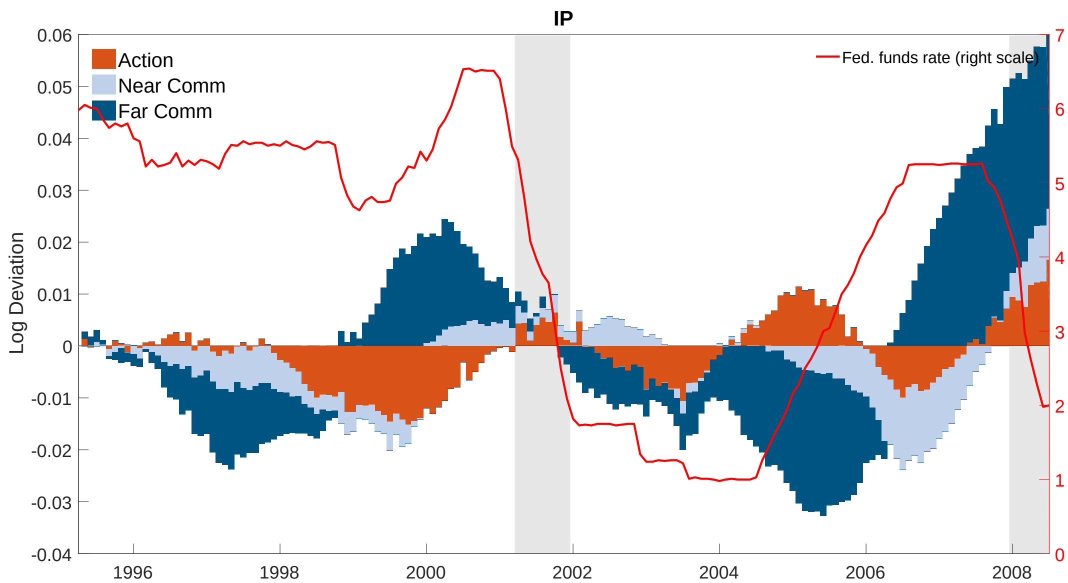


Notes: Impulse responses from our six-variable VAR, including commodity prices $\log(\text{PCOMM}_t)$, $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series $S^j_{d,t}$, $j \in \{A, NC, FC\}$ – action, near communication and far communication shock respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

We can see that the inclusion of commodity prices (ordered first in the VAR) has a notable effect on the impulse responses: the reaction of IP to the action shock is no longer significantly positive (except just after impact) and seems to become slightly contractionary, although insignificantly so, after around three years. Moreover, the price puzzle is only borderline significant, although we still do not see the expected decrease in prices. It is notable also that the long-term response of prices to the action shock does change from positive to negative, although it remains insignificant. However, it must be emphasised that the price puzzle remains a wide-spread issue in existing monetary-policy VAR research and the high-frequency identification literature, including BC and Thapar (2008).

We prefer to use the specification with commodity prices to examine the contribution of our shocks to the historical variation of industrial production, since the action shock in this case has no counter-intuitive expansionary effect. Given the puzzling responses of prices, we choose to examine only variation in industrial production.[28]

Figure 6: Historical Decomposition of $\log(\mathrm{IP}_t)$



Notes: Historical decomposition of $\log(\mathrm{IP}_t)$ in our 6-variable VAR, including the variables log commodity prices, $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ and three cumulated shock series S_t^j, $j \in \{A, NC, FC\}$ – action, near communication and far communication shock respectively. The bar plots are stacked, so their height above (below) the zero-axis represents the cumulative historical contribution of our monetary shocks to industrial production above (below) its unconditional mean. We also display the federal funds rate (right-hand scale) for reference. Grey areas denote NBER recession periods.

In the historical decomposition shown in Figure 6, we can see that the action shock has a strong counter-cyclical influence on industrial production during the boom prior to 2001. After this, however, we see that the share of production swings

[28]We discuss the decomposition of CPI for the Eurodollar case below.

associated with action shocks is small and fairly constant over time, and does not display strong systematic patterns during the Great Moderation and financial crisis period. This suggests that surprise rate announcements have become less important throughout the sample. On the other hand, the effects of the near and far communication shock, i.e. surprise announcements about potential central bank policies around one and three months into the future, seem to move in four larger cycles over the sample: two dovish, from around 1999 to 2001 and from 2006 to mid-2008, and two hawkish, from 1996 to 1998 and from 2002 to 2006.

The first expansionary episode (1999-2001) coincides with the last phase of the so-called “Greenspan put”, i.e. the conjecture that the Fed systematically eased policy in reaction to deteriorating stock market conditions during the period. The second contractionary episode (2002-06) was one of unstable growth and several corporate scandals involving American enterprises. Fed Chairman Alan Greenspan himself, in testimony to Congress, hinted at the need for improved financial regulation (see Greenspan, 2002). However, within a year his position seems to have turned into strong support for financial innovation.[29]

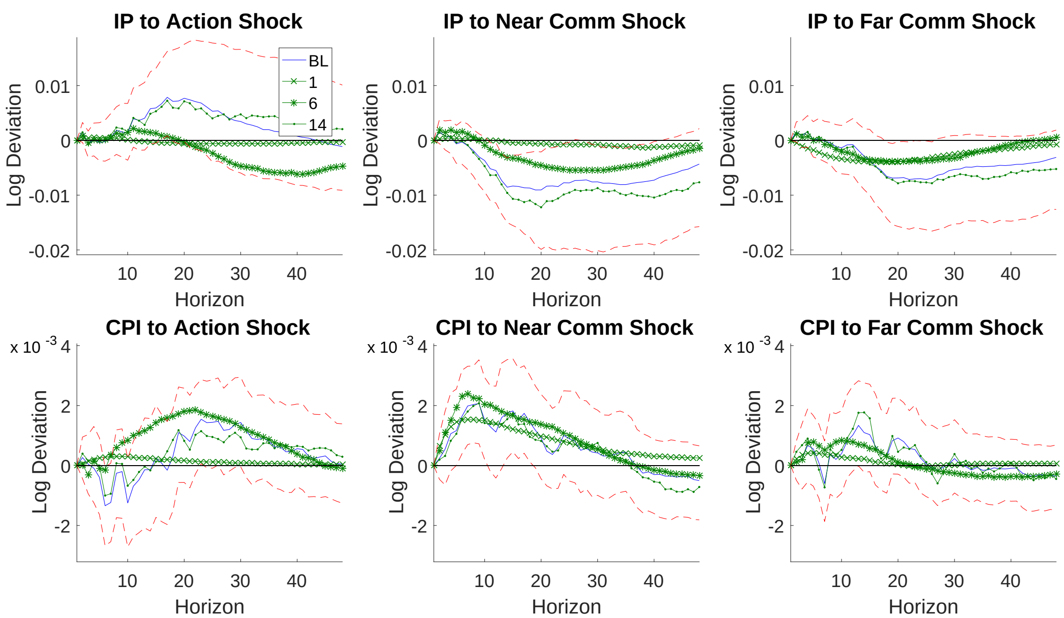
Generally we find mixed evidence for the “monetary excesses” view of John Taylor, who argues that monetary policy had remained too lax for too long and contributed to an unsustainable housing boom in the U.S. during the period preceding the financial crisis (Taylor, 2009). Between 2002 and 2006, the effects of monetary surprises are predominantly contractionary in their contribution to fluctuations in industrial production, although there is some evidence of an expansionary contribution after 2006. In the context of an emerging financial crisis, the expansionary contributions of all shocks from late 2007 capture appropriately counter-cyclical policy statements. To summarise, distinguishing between central bank action and communication shocks adds detail to our understanding of the recent monetary policy history of the U.S., and our novel monetary policy communication shocks seem well in line with common narratives.

[29]“Two years ago at this conference I argued that the growing array of derivatives and the related application of more sophisticated methods for measuring and managing risks had been key factors underlying the remarkable resilience of the banking system, which had recently shrugged off severe shocks to the economy and the financial system”, see Greenspan (2005).

1.4.2 Robustness

Figure 7 displays the impulse responses of our standard 5-variable VAR (with twelve lags), as well as responses for the same VAR with differing numbers of lags (one, six and 14, the latter being the value suggested by the likelihood ratio test).

Figure 7: Robustness Check – Different lags

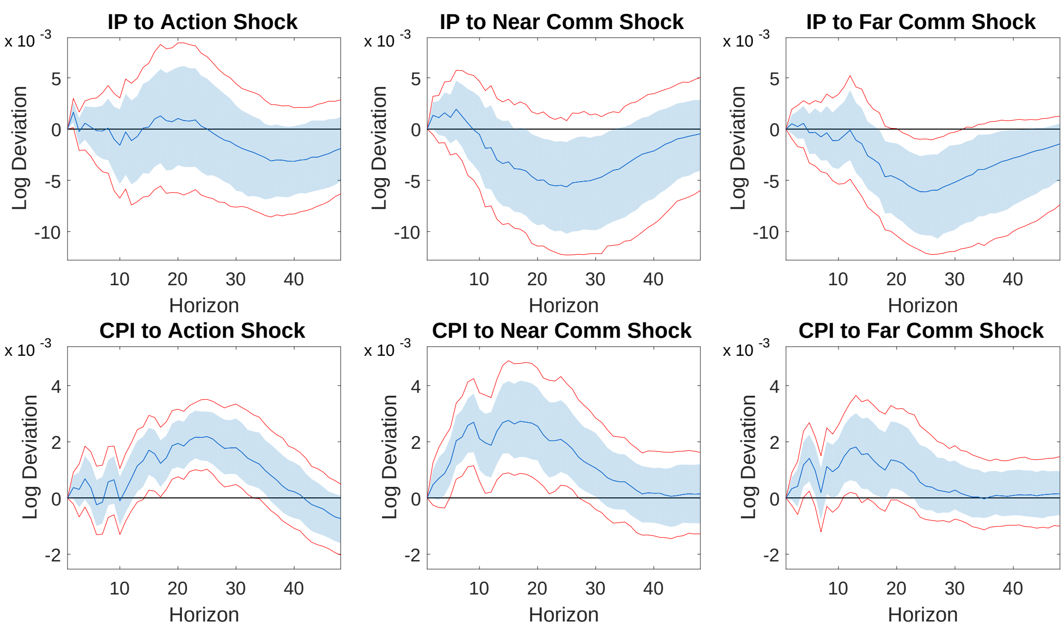


Notes: The graphs depict the impulse responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ in our baseline 5-variable VAR with 12 lags (median blue, 90% confidence band in red), as well as VARs with one, six and 14 lags (median response). The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at the 90% significance level. Responses are shown to a 10 basis point positive shock to the interest rate.

We can see that the responses mostly fall into the 90% confidence bands, except for the specification with one lag at certain horizons. Note that we cannot use more lags (BC use 36), since we would have insufficient degrees of freedom for our 5-variable VAR.

We also estimate separate three-variable VAR systems, loading in one shock at a time. We do this to respond to any concerns regarding the efficiency of our baseline VAR: In our 5-variable system, the shocks are allowed to respond endogenously to each other, when in fact these interaction effects should be limited, given the shocks are orthogonal to each other by construction and externally identified. Figure 8 displays the results, and we can see that our principal findings are robust. The price puzzle does become more pronounced for the action and near communication shocks, however.

Figure 8: Robustness Check – Separate 3-Variable VAR Systems



Notes: Impulse responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to monetary policy shocks, obtained from estimation of three separate 3-variable VAR systems (displayed in consecutive columns). Each of the respective 3-variable VARS contains one of the three cumulated shock series $S^j_{d,t}$, $j \in \{A, NC, FC\}$ – action, near communication and far communication shock respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

Furthermore, since our shocks are identified outside the VAR system, it is not necessary to estimate all interactions between variables as part of a VAR. In fact, our analysis lends itself to the local projection approach of Jordà (2005). Under this approach, we simply run separate forecasting regressions of our macroeconomic variables using the shock as a predictor, while controlling for lags of macroeconomic variables. This approach avoids compounding potential errors, as can happen during the iterative procedure used to compute VAR responses.

Following Ramey (2016), for a given period t, we project future realizations of the vector of macro variables $\mathbf{Y}_{t+q} \equiv [\log(\mathrm{IP}_{t+q}), \log(\mathrm{CPI}_{t+q})]$ onto its lags $(\boldsymbol{Y}_{t-1}, \boldsymbol{Y}_{t-2}, ..., \boldsymbol{Y}_{t-l})$, and (respectively) the lagged value of our externally identified shock series, $\epsilon^{j}_{t-1},\ j \in \{A, NC, FC\}$. Therefore we estimate

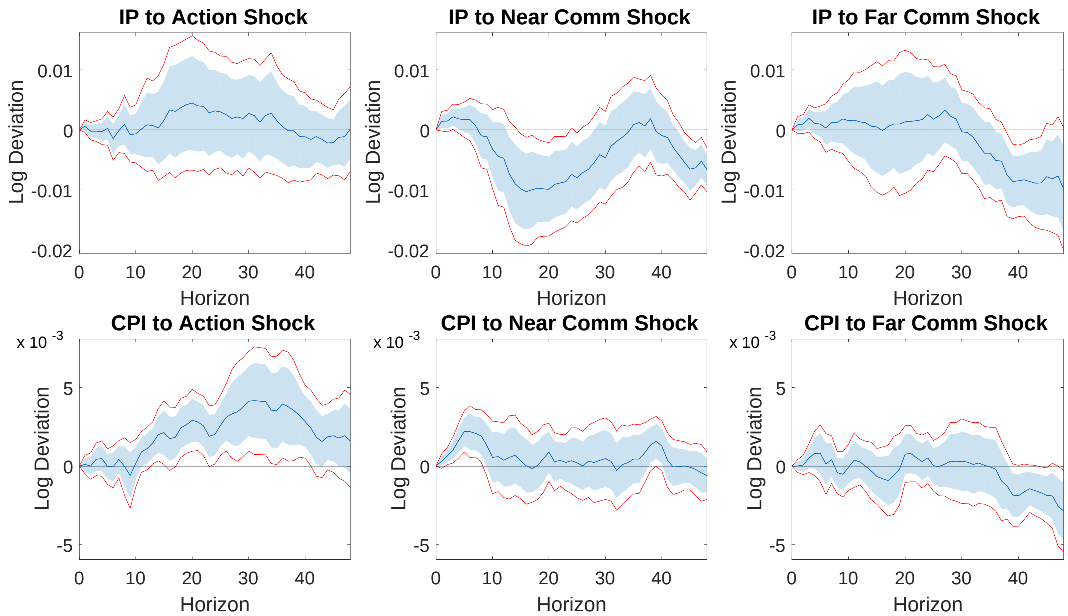
$$\mathbf{Y}_{t+q} = \boldsymbol{D}^{c}_{j} + \sum_{l=1}^{L} \boldsymbol{D}^{q}_{j,l} \mathbf{Y}_{t-l} + \epsilon^{j}_{t-1} + u^{q}_{t+q}, \quad q = 0, 1, 2, ..., Q, \quad j \in \{A, NC, FC\},$$

where $\boldsymbol{D}^{c}_{j}$ is a vector of constants, and the $\boldsymbol{D}^{q}_{j,l}$ are coefficient matrices for given lags l, and horizons q up to Q, for the respective shock j. Here we include two lags of the endogenous variables ($L = 2$), and we are loading the shocks into the estimation without first cumulating them. Further, we mimic the VAR specification insofar as we do impose the recursiveness assumption for our local projections (insofar as the shocks are additionally orthogonalized with respect to contemporaneous and past values of the macro variables, and they do not affect the contemporaneous values of the dependent variable by assumption).

The results are displayed in Figure 9, where we see that IP has an insignificant negative response to a contractionary action shock at longer horizons. We also see evidence for the price puzzle for this shock. The results for the near communication shock are significantly contractionary for IP in the short to medium term (and also at horizons after around 3.5 years). The results for prices are significantly positive at very short horizons. However, the far communication shock qualitatively matches the effects commonly understood to result from contractionary monetary policy, albeit at longer horizons than seen typically: we see a significant fall in industrial production and prices in response to the shock. This delayed impact is interesting, and may reflect the nature of the shock as a communication shock relating to future policy. In this sense the local-projection approach is able to fully resolve the price puzzle for the far communication shock only.

Overall, we believe our analysis is robust to different numbers of lags, and changes in the number of variables included in the VAR. Under the local projection approach, dynamics of the communication shocks change, but sign and significance for IP responses remains largely the same. Further, the local projection approach is able to deliver a significant fall in prices in response to the far communication shock after roughly three years.

Figure 9: Robustness Check – Local Projection Approach



Notes: The graphs depict the impulse responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_\text{t})$ to contractionary action, near communication and far communication shocks under the local projection approach. 90% and 75% confidence intervals were obtained using Newey-West standard errors. Impulse responses scaled to show the effects of a 10 basis point positive shock to the interest rate.

1.4.3 The role of the central bank information set

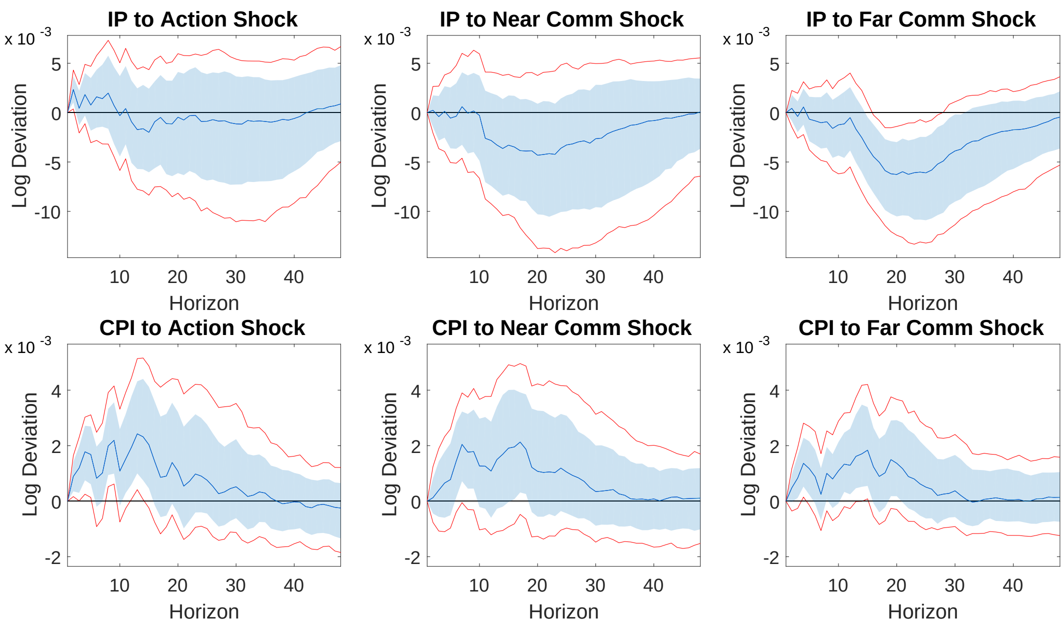
One known issue with the use of high-frequency movements in futures prices as measures of monetary policy surprises is that these movements may simply represent transmission of internal information to markets by the central banker (see Miranda-Agrippino and Ricco, 2017, for a recent detailed analysis). For example, the FOMC may reveal results of its private analyses regarding the state of macroeconomic variables as it announces current and future policy. This would contaminate our measures of monetary policy shocks, understood in the conventional manner as exogenous deviations from a policy rule. If the FOMC had a tendency to reveal new positive forecasts regarding output and inflation at the same time as it increased interest rates, then this would likely bias our estimation of the contractionary effects of policy towards zero, making our results under-estimate the true responses. To correct for this, we follow Romer and Romer (2004) and BC, and orthogonalise our shocks with respect to the internal information of the FOMC.[30] Our proxy for internal information are variables from the Greenbook forecasts, which are released five years after their construction and therefore contain information not necessarily known by markets at the time of central bank announcements.

As can be seen in Figure 10, only the far communication shock retains a significant contractionary impact on industrial production, having been purged of the informational content from the data releases. The near communication shock continues to display a marked negative effect on industrial production at the median, though it is no longer significant. This suggests that the effects of action and near communication shocks are partially driven by information revelation, as much as genuine surprise regarding policy. In the case of the action shock, information revelation seems to explain most of the counter-intuitive expansionary effect on IP. As the purging mostly affects the first two shocks, the public seems to take the information revelation mostly as a description of the current economic situation. In contrast, communication about potential future policy actions seems to contain less hidden information about macroeconomic dynamics: While the trough of the contraction in IP after a far communication shock changes from around 8 percentage points in the baseline VAR and the one with commodity prices, to around 5 percentage points, significance at the 90% confidence level is retained. Thus we find that our key result, of the importance of FOMC communication about future policy, is preserved when we control for contemporaneous information revelation by the FOMC.[31]

[30]Similar orthogonalisations are also used in Gertler and Karadi (2015) and Ramey (2016).

[31]We include the same Greenbook variables as in BC, although like Ramey (2016) we use only the

Figure 10: The Effects of Shocks Orthogonalised with Respect to Fed Internal Information



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three monetary policy shocks. The shocks are orthogonalised with respect to Greenbook forecasts: S_t^j, $j \in \{A, NC, FC\}$ – action, near communication and far communication shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

1.5 Covering the zero-lower bound episode

As discussed previously, following the start of the ZLB period during the financial crisis of 2008, our decomposition of federal funds futures movements into action and communication shocks is no longer possible as these futures prices cease to move. However, longer maturity interest-rate futures contracts which remained

Greenbook forecasts, while BC employ the difference between Blue Chip and Greenbook indicators. The variables are: (1) contemporaneous unemployment, (2) contemporaneous output growth and its lag and first two leads; (3) the GDP deflator and its lag and first two leads; (3) the difference between the output growth forecasts and their previous values; (4) the difference between the GDP deflator forecasts and their previous values.

liquid during this time, namely Eurodollar futures, can help us to analyse communication shocks during the ZLB period.[32]

Because the contracts are defined over quarters and not months, it is no longer possible to extract expectations regarding particular meetings for these contracts. Neither are we able to identify an "action shock" in this case, since the contemporaneous Eurodollar future embeds expectations regarding both the most recent meeting and all future meetings within one quarter. Furthermore, the underlying for the contracts is the 3-month rate on dollar-denominated assets held abroad, as opposed to the overnight federal funds rate, which means the contracts are less tightly linked to the policy decisions of the FOMC.

However, these contracts trade in highly liquid markets, and we still have variation in the Eurodollar contracts, including the shorter-horizon ED4 contract, during the ZLB period. This means that although trading in federal fund rate futures virtually ceased after 2009, markets were still prepared to speculate on changes in 3-month interest rates one year into the future. Further, the pricing of these contracts does move systematically on meeting days of the FOMC, implying that market participants were updating their expectations for future shorter-term interest rates in reaction to central bank communication.

We propose a similar linear decomposition of the Eurodollar contracts to that used in our previous analysis. In principle, one could decompose variation across the pricing of many Eurodollar contracts; we choose to use the ED4, ED8 and ED12 contracts (which represent contracts with horizon of one year, two years, and three years out, respectively). This selection enables us to capture surprises regarding market expectations in the medium and longer-term, in response to communication by policy-makers at the Federal Reserve, without using more contracts than necessary.[33] Thus, we assume the following representation of jumps in our Eu-

[32]Three month Eurodollar futures take as their underlying the 3-month dollar-denominated LIBOR rate. Unlike the federal funds futures contracts, these contracts are defined relative to the interest rate prevailing on the third Wednesday of the expiration month, and are available across quarterly horizons, for the next 10 years.

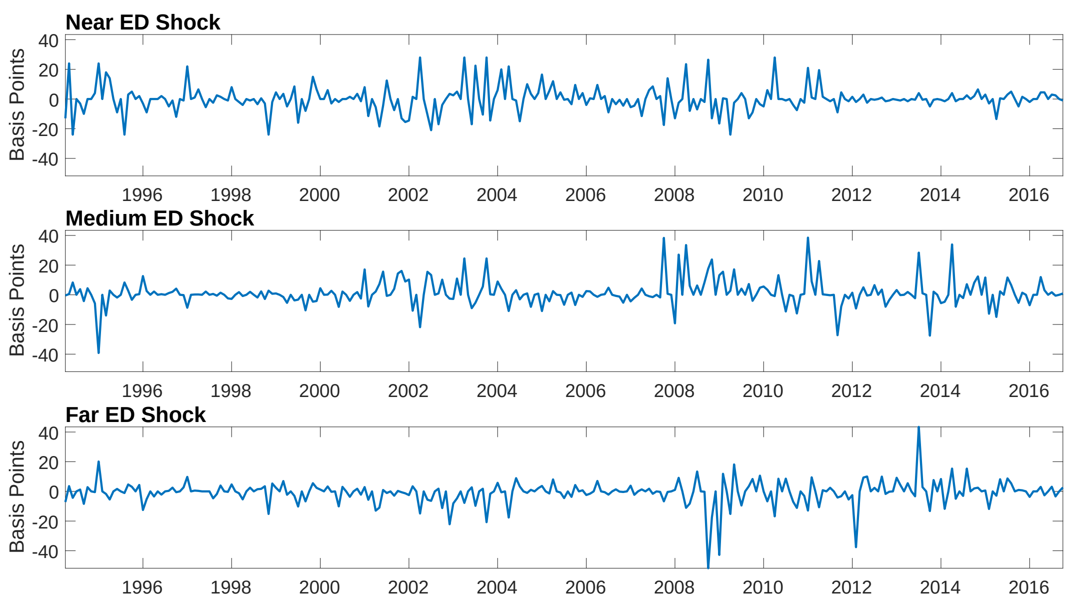
[33]We check robustness to alternative selections below.

rodollar contracts on meeting day d in month t:

$$\begin{bmatrix} \Delta ED^{(4)}_{d,t} \\ \Delta ED^{(8)}_{d,t} \\ \Delta ED^{(12)}_{d,t} \end{bmatrix} = \begin{bmatrix} k_{11} & 0 & 0 \\ k_{21} & k_{22} & 0 \\ k_{31} & k_{32} & k_{33} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon^{NED}_{d,t} \\ \varepsilon^{MED}_{d,t} \\ \varepsilon^{FED}_{d,t} \end{bmatrix} = \mathbf{K} \cdot \mathbf{E}_{d,t}. \tag{5}$$

Here $\Delta ED^{(h)}_{d,t}$ is the daily difference of the Eurodollar contract futures rates at horizon h on the FOMC meeting day indexed by day d and month t. We call these shocks “near ED shock”, “medium ED shock”, and “far ED shock”. It is important to note that the “near ED shock” is quite different to the “action shock” discussed previously. Given that the near ED shock represents the combined effects of all FOMC communication regarding interest rates during the next year, it cumulates the effects of action, near communication, and far communication shocks.

Figure 11: Eurodollar Shock Series

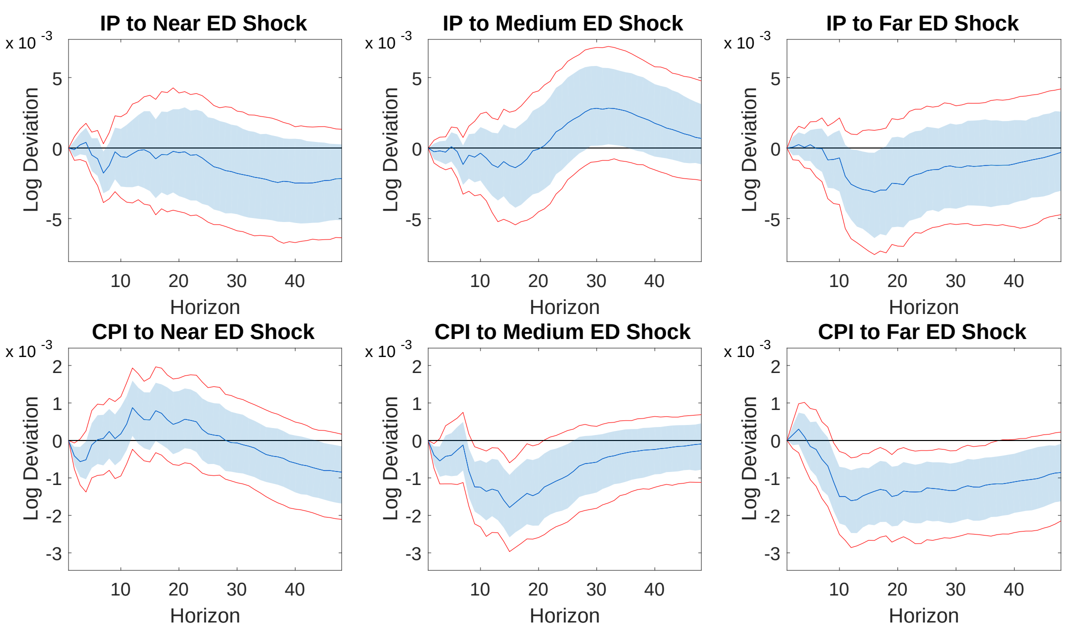


Notes: The figure displays the three Eurodollar shocks S^j_t, $j \in \{NED, MED, FED\}$ – dubbed “Near ED”, “Medium ED”, and “Far ED” shock, respectively.

The shock series are displayed in Figure 11, for our sample period covering

March 1994 until September 2016.[34] A striking feature is the marked shift in volatility from the near ED shock to the longer-term ED shocks during the ZLB period: This suggests that before the Great Recession, markets were less likely to receive important surprise information about monetary policy more than one year into the future during FOMC meetings. However, with the onset of unconventional monetary policy, surprise information about the potential course of central bank decisions two or three years into the future became increasingly important. We can also see a period of larger volatility of the medium ED shock following the dot com bust, which is less clearly a feature of the far ED series. This suggests an increased importance of medium-term information during this period as well.

Figure 12: Responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to Eurodollar Shocks



Notes: Impulse responses from our five-variable VAR, including $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ and three cumulated shock series S_t^j, $j \in \{NED, MED, FED\}$ – near ED, medium ED and far ED shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

[34] We again winsorise the expectation revisions at 1% prior to the extraction of the shocks to deal with outliers.

We follow the baseline SVAR specification used in the above analysis, entering our three cumulated shock series at the end of a vector including industrial production and CPI, with 12 lags. The impulse response functions are displayed in Figure 12. The near ED shock results in a contractionary yet insignificant effect on industrial production. However, the shock has a significant contractionary effect on prices in the very short-term, before a partially significant expansionary effect 12 months out, and a longer-term partially significant contractionary effect 48 months out. In this sense, the results for the near ED shock cohere with our previous results; we would expect the near ED shock to be comprised of a mixture of action shocks and near and far communication shocks, and indeed they have contractionary effects on industrial production, while showing evidence of the price puzzle.

The medium ED shock shows a short-run contractionary effect on industrial production, which is insignificant, but leads to a partially significant expansionary effect later on. The far ED shock has a clearer contractionary effect on industrial production, which is also partially significant. In general, the result that responses of industrial production are smaller and less significant than in our previous analysis may reflect the fact that Eurodollar movements are likely a noisier measure of monetary policy stance than federal funds futures. We also see a swift and persistent fall in the price level after less than a year for both medium and far ED shock. Further, the medium and far ED shocks show significant contractions to CPI, of increasing strength. This would match the predictions of the New Keynesian literature regarding the effects of forward guidance at increasing horizons on inflation (Del Negro et al., 2016; McKay et al., 2016).[35] We reach the conclusion that forward guidance surprises at longer horizons have a stronger and more persistent effect on CPI than on industrial production.[36]

[35]We should be careful in interpreting the results of the ED shock as forward guidance. First, as pointed out in Swanson (2017), LSAP announcements might also drive the dynamics of Eurodollar futures. Second, the far ED shock represents surprise communication that affects expectations three years out, which is longer than U.S. forward guidance extended into the future. However, as the shock is based on market expectations changed during FOMC meetings, it still captures anticipation of the medium-term monetary policy stance by the public.

[36]Our results are robust to choosing different ED futures maturities ([ED4, ED8, ED18] and [ED4, ED8, ED12, ED18]). FEVD analysis underlines the stronger effect on prices relative to industrial

Moreover, historical decompositions of industrial production and CPI (see Figures 44 and 45 in Appendix Section A.3) show that from the announcements of asset purchases and forward guidance in September 2012 onwards, all three ED shocks have an expansionary effect on IP and CPI, speaking for an effect boosting inflation expectations even in the absence of movements in the federal funds rate. Indeed, it is notable that the timing of these later expansionary contributions almost exactly coheres with the timing of the FOMC's explicit forward guidance statements (2012-2015). These decompositions also give a clue about the relatively muted effect of monetary policy on IP here: In the direct aftermath of the financial crisis (2009-11), the communication shocks had a strong stabilising effect on inflation (with the stimulating medium and far ED shocks more than outweighing the contractionary near ED one), while all three are contractionary for IP. This could perhaps be explained in terms of central bank communication contributing to "anchored expectations" (Bernanke, 2010), thereby accounting for the "missing disinflation" during this period. Moreover, the explicit long-term commitments communicated under forward guidance after 2012 have a much more marked effect on CPI than IP. Both episodes partially explain the larger impact on inflation relative to economic activity in response to our ED shocks. Overall, our analysis of Eurodollar futures supports our findings regarding the importance of central bank communication for the macroeconomy, especially at longer horizons.

1.6 Conclusion

In this paper, we have investigated the effect of communication surprises during FOMC meetings on the macroeconomy, and contrasted them with surprises about actual policy decisions. To distinguish surprise action from surprise communication, we use a simple Cholesky decomposition of changes within certain maturity segments of federal funds futures contracts.

For our sample from 1994M3 to 2008M6, we find that communication surprises play a more important role in macroeconomic fluctuations than action shocks. Communication shocks lead to the expected contractionary reaction of industrial

production of communication shocks captured by ED futures. For all these results, see Section A.3 in the Appendix.

production, explain a larger share of variance in macro variables, and can be easily aligned with the recent history of U.S. monetary policy. These findings are robust to various changes in specification. Moreover, while we find that our all shocks display signs of a price puzzle in our VAR systems, we are able to remove this effect for the far communication shock using the local projection approach. Overall, our findings emphasise the crucial importance of central bank communication (in line with the findings of Gürkaynak et al., 2005, for asset prices), and of forward-looking information reception by market participants, even for the period before the explicit adoption of forward guidance as a policy tool by the Federal Reserve. In fact, our analysis suggests that researchers ought to think of "monetary policy shocks", of the type extensively studied in the literature, more in terms of central bank communication rather than unanticipated rate changes.

Our baseline analysis based on federal funds futures is only meaningful before conventional monetary policy hit the zero-lower bound, and these futures markets became illiquid. Therefore we use longer-term communication shocks derived from Eurodollar futures to cover the period until late 2016. We find a shift in the volatility of the shock series to the longer horizons, suggesting a stronger focus on long-term communication by the FOMC. Moreover, there are large effects of central bank communication on inflation, with the size of the effect increasing in the horizon of the shocks, implying that forward guidance has indeed had a strong influence on price stability in the U.S.

Our analysis has shown the importance of central bank communication regarding future actions for the macroeconomy. However, it is likely that Fed policy has become *gradually* more forward-looking over the last twenty years. This would imply an increasing role for our communication shocks–and a decreasing role for our action shocks–within our sample. Indeed, this is partially reflected in the larger contributions of the communication shocks in the later part of our historical decompositions (while the action shock yielded large fluctuations in production only in the pre-2001 part of the sample). Moreover, the Federal Reserve switched to explicit long-term commitments under a policy of forward guidance after the financial crisis. Thus, a time-varying parameter specification, or one with different parameter regimes for the periods before and after explicit forward guidance, may represent a promising area of future research for the high-frequency VAR literature.

2 The Macroeconomic Effects of Bank Capital Requirement Changes: Evidence from a Narrative Approach

(with Sandra Eickmeier and Esteban Prieto)[37]

JEL classifications: G28, G18, C32, E44

Keywords: Financial Regulation, Capital Requirements, Basel Accords, Narrative Approach

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2.1 Introduction

Since the 2008 financial crisis advanced economies around the world have introduced new macroprudential policy measures. Among the most prominent macroprudential policy measures are bank-capital based policy instruments, like capital ratios, countercyclical capital buffers or leverage ratio caps. These policy tools aim at increasing the resilience of the financial sector to external shocks, so that it can maintain its performance under adverse conditions. Policy tools might also be activated to have a dampening effect on credit dynamics during buoyant times. However, experience with capital-based macroprudential policies are limited, especially concerning the transmission mechanism of these policy instruments and their effects on the real economy.

Identifying the macroeconomic effects of a tightening in bank capital regulation is non-trivial. Bank capital is a highly endogenous variable that fluctuates due to a plethora of fundamental shocks. To identify the effects of bank capital regulation one needs to separate movements in bank capital stemming from changes in capital regulation from all other drivers of bank capital. Furthermore, not all movements of the bank capital ratio that are exogenous to current macroeconomic and financial variables need be the result of capital regulation. Bank capital might be affected independently of regulation by variables seldom available to the econometrician, like changes in perceptions of bail-out probabilities or increasing incentives of counterparties to monitor and price default risk. An empirical analysis that lumps together movements in bank capital due to bank-sector specific shocks with those due to regulation might deliver inappropriate policy prescriptions.

We propose a novel strategy to address these pitfalls in identifying the real effects of changes in bank capital regulation. Rather than identifying exogenous changes in the aggregate bank capital ratio using statistical identification methods, we propose a narrative approach in the spirit of Romer and Romer (1989). Specifically, we create a narrative index of tightenings in US capital requirements for 1980M1-2016M8, based on detailed readings of legislative documents. In particular, we identify six events where the US supervisory authorities introduced and tightened capital requirements during that time span. There are two episodes in the early 1980s, when numerical capital requirements where introduced, two in the early 1990s in connection with the first Basel Accord, and two recent ones as a reaction to the Financial Crisis. The stated purpose of the regulations and their often lengthy introduction process both make it unlikely that they were set up as immediate stabilization policies. Thus, we can take them to be exogenous to the state of the financial and business cycle at the date of their introduction.

With the exogenous CRI at hand, we assess the dynamic response of key macroeconomic and financial variables to a tightening in capital requirements. As a benchmark, we use the instrumental-variable local projections approach as in Jordà, Schularick, and Taylor (2015), treating the CRI as an instrument for the changes in bank capital. Our main results concerning the business-cycle effects of a tightening in capital requirements can be summarized as follows:

- The (permanent) tightening in capital requirements leads to a delayed but *permanent* increase in the aggregate bank capital ratio (as prescribed by the supervisory authorities). The sluggish adjustment in the capital ratio, in turn, reflects that regulatory changes of bank capitalization usually come with a phase-in period.

- An unexpected tightening of bank capital requirements has a significantly negative short-run effect on total bank loans. Bank lending reacts to the tightening in capital requirements already within the first three months.

- The tightening in capital requirements leads to a significant reduction in industrial production. Industrial production exhibits a hump-shaped behavior after the tightening in capital regulation, reacting most strongly with a delay of about one year and returning to the baseline value after around three years. Inflation shows a slow but persistent fall after the tightening.

- The federal funds rate drops significantly after around one year following a tightening of bank capital requirements. The reduction in the federal funds rate is likely a response of the federal reserve to the reduction in industrial production.

These findings suggest that banks react to a regulatory capital-requirement tightening in two phases: Initially, banks shrink their balance sheet while the level of capital does not change significantly. The level of bank capital increases only after some time, but then does so permanently. Once capital has been build up, banks increase their balance sheet back to the pre-regulation value. Hence, our results imply that even permanent increases in bank capital have only transitory effects on overall lending and economic activity. The ongoing cost (of holding more capital on the balance sheet permanently) therefore seems not to matter for the long-term path of the real economy.

Our key results are robust to a battery of sensitivity checks. We show that our findings are not driven by specific subsamples, by single events in the CRI or by the benchmark specification of the instrumental-variable local projection regressions. We also obtain qualitatively very similar results when embedding the CRI as an endogenous variable in a structural vector autoregression (SVAR) framework and when using the standard local projection approach of Jordà (2005).

So far, the debate on macroprudential policies has been informed mostly by findings from empirical microeconometric studies and structural models. While both approaches have their merits, we argue there is a gap in the literature investigating the dynamic macroeconomic effects of capital requirements empirically.[38]

Empirical approaches to assess the macroeconomic effects of macroprudential policy are still limited, albeit a surge in contributions studying the effects of changes in bank regulation at disaggregated levels (see, among many others, Aiyar, Calomiris, and Wieladek, 2014, Buch and Goldberg, 2015 and Jiménez, Ongena, Peydró, and Saurina, 2017). Although such microeconometric studies on the transmission of regulatory changes to credit supply provide a high level of econometric credibility, they cannot disentangle the dynamic transmission of capital requirements to the economy, nor account for general-equilibrium effects. Thus, while such microeconometric studies often find large short-run effects of capital requirements on bank lending, they necessarily leave open questions about the transmission to the real economy and whether such changes to credit supply are permanent or transitory. Evaluating the effectiveness of macroprudential poli-

[38] In general, our paper is related to a growing literature studying the macroeconomic effects of shocks originating in the financial market, e.g. Berrospide and Edge (2010), Elliott, Feldberg, and Lehnert (2013), Gilchrist and Zakrajšek (2012) or Walentin (2014).

cies necessarily needs to take into account potential feedback effects between the banking industry and the macroeconomy. Purely microeconometric studies based on bank or even loan-level data are not able to provide estimates of these "overall" effects.

As empirically identifying shocks to capital regulation is difficult, inference on the *macroeconomic* effects of macroprudential bank capital policies to date stems almost exclusively from DSGE models.[39] Although progress has been made in incorporating features of the financial sector into these models to make them suitable for the analysis of macroprudential policy issues, findings often remain highly sensitive to the specific friction included, shock considered or calibration chosen. It is therefore often difficult to draw strong policy conclusions about the effects of macroprudential policies on the real economy. Lindé, Smets, and Wouters (2016) provide a thoughtful discussion about the challenges and shortcomings of current macroeconomic models and an overview of recent advances to address these issues.

There is one other paper investigating dynamic effects of capital requirements on the macroeconomy: Meeks (2016) studies the macroeconomic effects of changes in *microprudential* capital requirements for the UK. For identification purposes, he exploits features of the UK institutional framework in which microprudential supervisors operated. Supervisors did not respond directly to contemporaneous developments in the macroeconomy. From these institutional arrangements, he derives timing restrictions (e.g. zero contemporaneous restrictions) to identify the macro effects of changes in microprudential regulation. Like us, he finds a short-lived contractionary effect on economic activity. Different to us, he finds a strong contractionary effect on mortgage lending and house prices, which indicates some differences between the US and UK.

So our paper is - to the best of our knowledge - the first to assess the dynamic macroeconomic effects of changes in aggregate capital requirements. Our narrative methodology follows an established tradition in analyzing policy changes.[40]

[39]For example, Gerali, Neri, Sessa, and Signoretti (2010), Quint and Rabanal (2014), or Clerc, Derviz, Mendicino, Moyen, Nikolov, Stracca, Suarez, and Vardoulakis (2015).

[40]Narrative approaches have been used to analyze e.g. oil price shocks (Hamilton, 1985, Hoover and Perez, 1994), changes in monetary policy (Romer and Romer, 1989, Romer and Romer, 2004),

The main results from our analysis – that a permanent tightening of capital requirements leads only to a temporary drop in credit supply and economic activity – lend strong support to the assertion of Hanson, Kashyap, and Stein (2011), Admati and Hellwig (2013) and Admati, DeMarzo, Hellwig, and Pfleiderer (2013) that higher capital requirements are not associated with substantial medium to long-run costs for the economy. However, the transition period to a better capitalized banking sector – about two to three years – is costly in terms of output losses.

The structure of the paper is as follows. In Section 2.2 we discuss in detail our CRI. We motivate the specific dates we classify as periods of tightenings in capital regulation based on legal documents and readings of the then contemporaneous literature. In Section 2.3 we present our methodology, the main results about the dynamic effects of a tightening in capital requirement and additional results investigating the transmission of capital-requirement shocks. We show the results from a series of robustness checks in Section 2.4 and conclude in Section 2.5.

2.2 A narrative analysis of changes in aggregate bank capital requirements

In this section, we discuss the key regulatory changes in bank capital requirements in the US over the past 40 years. Based on detailed readings of the contemporary legislative and academic literature, we argue that the motives and intentions for changes in capital regulation were unrelated to short-run business and financial cycle considerations. Rather – the documents suggest – changes in capital regulation are usually slowly drafted and subject to lengthy negotiations between bankers, politicians and regulators. The motives stated for the changes in bank capital regulation are virtually always broad, long-lasting and structural in nature. Furthermore, the regulatory changes are usually drafted such that there is considerable time between the announcement of the final rule, the date at which the rule becomes effective, and the date at which the regulations finally become binding

tax policy (Poterba, 1986, Romer and Romer, 2010), government spending (Ramey and Shapiro, 1998, Ramey, 2011) or government asset purchases (Fieldhouse, Mertens, and Ravn, 2017).

for banks.[41] All these factors make us confident that we can consider the series of capital-requirement changes as predetermined relative to other macro-financial variables. We present the key changes in US bank capital requirements in Table 2, before discussing each of the regulatory changes in turn. The historical evidence we present here draws on academic articles as well as “final rules" published in the *Federal Register*.[42] These final rules often include a detailed purpose and motivation, a background and an overview of the rule. We furthermore consider public comments submitted in response to the proposed rule, and modifications to it.

We aim at two objectives: First, to identify the exact date at which US banks can be expected to have started acting on new regulatory capital requirements. Second, by reviewing the historical documents, we want to understand the regulators' motives and intentions of the changes in capital regulation. We find no evidence that they were driven by current business and financial cycle considerations.

Table 2: Our Capital Requirement Index (CRI)

Date	Change
Dec. 1981	FDIC, Fed and OCC set numerical guidelines for CR
Dec. 1983	International Lending and Supervision Act passed
Apr. 1985	Common CR guidelines by FDCI, Fed and OCC for all banks
Dec. 1990	Basel I effective
Dec. 1991	FDIC Improvement Act passed
Dec. 1992	Prompt Corrective Action effective
Jan. 1997	Market Risk Amendment effective
Apr. 2008	Basel II effective
Dec. 2013	Basel II.5 effective
Dec. 2014	Basel III effective

Note: CR = capital requirement(s); FDIC = Federal Deposit Insurance Corporation; Fed = Federal Reserve System; OCC = Office of the Comptroller of the Currency. There was no aggregate easing of capital requirements during the sample.

[41] The first two points are also mentioned in Fieldhouse et al. (2017) as indicators of structural changes when distinguishing between cyclical and non-cyclical portfolio activity of US housing agencies.

[42] The Federal Register is the daily official journal of the US government, publishing government agency rules, rule proposals and public notices.

Dec. 1981: Regulatory agencies set numerical guidelines. From the 1930s up to the early 1980s, bank supervisors had relied solely on case-by-case decisions when judging banks' capital adequacy. No numerical prescriptions existed about adequate aggregate bank capital ratios.[43] However, a series of banking failures in the 1970s and early 1980s, together with historically low capital ratios, made supervisors rethink the issue. In December 1981, the three supervisory agencies in the US, the Federal Deposit Insurance Corporation (FDIC), the Federal Reserve System (Fed), and the Office of the Comptroller of the Currency (OCC), for the first time announced explicit numerical capital adequacy ratios. The targets varied across the agencies and for different types of banks, but were mostly between five and six percent.[44] The FDIC's motives for introducing numerical bank capital guidelines are stated in the respective statement of policy (Federal Register/Vol. 46, No. 248/Dec. 28, 1981, p. 62693).

> *This policy statement is intended to clearly set forth qualitative criteria to be considered in determining adequacy of bank capital, to inject more objectivity and consistency into the process of determining capital adequacy, to provide nonmember banks with clearly defined goals for use in capital and strategic planning and to address the issue of disparity in capital levels among banks in different size categories by adopting uniform standards regardless of the size of the institution.*

Hence, the 1981 change in capital regulation seems not to have been a response to short-run cyclical developments in the US, but motivated by low frequency considerations. The announcement published in the Federal Reserve Bulletin makes this assertion even more poignantly (Federal Reserve Bulletin/Vol. 68, No.1/Jan. 1982, p. 33):

[43] The regulatory capital prescription for *individual* banks within the scope of "Regulation ABC" are found to have been largely ineffective by Peltzman (1970), Dietrich and James (1983) and Marcus (1983).

[44] For banks supervised by Fed and the OCC "[a] minimum level of primary capital to total assets is established at 5 percent for regional organizations and 6 percent for community organizations. Generally, regional and community banking organizations are expected to operate above the minimum primary capital levels." (Federal Reserve Bulletin/Vol. 68, No.1/Jan. 1982, p. 34) The FDIC instead imposed "a threshold capital-to-assets ratio of 6 percent and a minimum ratio of 5 percent." (FDIC, 2003)

Objectives of the capital adequacy guidelines program are to address the long-term decline in capital ratios, particularly those of the multinational group; introduce greater uniformity, objectivity, and consistency into the supervisory approach for assessing capital adequacy; provide direction for capital and strategic planning to banks and bank holding companies and for the appraisal of this planning by the agencies; and permit some reduction of existing disparities in capital ratios between banking organizations of different size.[45]

The 1981 capital standard changes are generally thought to have had a palpable effect on the financial industry: Keeley (1988) and Wall and Peterson (1987, 1988) find that the capital ratios were largely binding for banks.

Apr. 1985: Harmonization of capital requirements. These changes are the result of the International Lending Supervision Act (ILSA) passed by Congress in 1983 in a reaction to the less developed country debt crisis of 1982. Although the legislative action responded to an immediate banking crisis, the motive for the ILSA was generally long-term, as argued by Smith (1984), pp. 425f.:

When Congress responded to the debt crisis with legislation in 1983, it sought not only to address the immediate liquidity problems of the distressed debtor countries but also to adopt long-range structural reforms for the international financial system. The International Lending Supervision Act of 1983, passed as part of the debt crisis package, imposes new controls on foreign lending that are aimed at preventing a recurrence of the debt buildup.

The ILSA of 1983 specifies that each "appropriate Federal Banking Agency shall cause banking institutions to achieve and maintain adequate capital by establishing minimum levels of capital" (Public Law 98-181 – Nov. 30, 1983, Sec. 908, a 1).

[45]Note that despite the will to "address the long-term decline in capital ratios, particularly those of the multinational group", no minimum capital requirements were imposed for them: "Capital guidelines for the relatively small number of multinational organizations will continue to be formulated and monitored on an individual basis (...)" (Federal Reserve Bulletin/Vol. 68, No.1/Jan. 1982, pp. 33f.)

It was, however, not until March 1985 that the regulatory agencies issued a final ruling with regard to capital adequacy requirements. The new minimum capital standards were set uniformly at 5.5 percent for the ratio of primary capital to assets. In general, the new standards increased capital requirements for larger banks, while they reduced them for smaller banks.[46]

On March 19, the FDIC announced the final ruling and stated the motives for the tighter capital requirement (Federal Register/Vol. 50, No. 53/Mar. 19, 1985, p. 11128):

> *Several factors have, however, emerged over the past few years which are accentuating the potential demands on bank capital. The deregulation of interest rates on bank liabilities together with a weakening of loan portfolios brought about by shocks in the domestic and world economy have caused a decline in bank profitability and increased levels of risk within the system. The competition for financial services has intensified on both an intra-industry and inter-industry basis, placing additional pressures on bank profitability. Further, because of the growing interdependency within the system, problems in one institution can have repercussions on other institutions arguing for stronger capital levels in both individual banks and the system as a whole. Increasing levels of off-balance sheet risks are also a factor in the need for higher capital.*

The excerpt from the final rule shows that the tightening in capital requirements was mostly motivated by structural changes in the financial industry, like deregulation, increased network effects as well as a growing shadow bank sector. The change in capital regulation thus aimed at addressing non-cyclical trends and not short-run financial imbalances. Moreover, the changes envisaged by ILSA in 1983 led to rules floated for comments by regulators in July 1984 (Federal Register/Vol. 49, No. 141/Jul. 20, 1984, p. 29400), which became effective on April 18, 1985 only (Federal Register/Vol. 50, No. 53/Mar. 19, 1985, p. 11128), so there was a consider-

[46]"The minimum primary capital ratio for large banking organizations increased from 5 percent to 5.5 percent of adjusted total assets, while community banks' capital requirements fell from 6 percent to 5.5 percent." (FDIC, 2003)

able lag between design and implementation of the new rules.[47]

The 1985 regulatory changes seem to have had a large effect on bank capital: Baer and McElravey (1993) estimate that the resulting shortfall of bank capital was comparable in magnitude to that which the introduction of risk-weights by Basel I generated.

Dec. 1990: The Basel I Capital Accord. The next major overhaul in bank capital regulation in the US occurred in late 1990 with the implementation of the Basel Accord on Capital Regulation ("Basel I"). With the Basel Accord, capital regulation became based on risk-adjusted asset volumes for the first time. There was a long run-up for Basel I: The three US banking agencies first issued a risk-based capital proposal for public comment on March 27, 1986 (Federal Register/Vol. 51, No. 59/Mar. 27, 1986, p. 10602). However, in reaction to the proposal many commenters asserted that without similar requirements for foreign banks, the envisaged requirements would put US banks at a competitive disadvantage. In light of these concerns, the US banking agencies began working with the Bank of England on the development of a common approach. The OCC published a proposal based upon a joint US/UK risk-based capital agreement in 1987 (Federal Register/Vol. 53, No. 116/Jun. 17, 1987, p. 23045). The scope of the international convergence effort expanded further when the Cooke Committee under the auspices of the Bank of International Settlement in Basel took the US/UK proposal under consideration and addressed the possibility of expanding the agreement to include all of the countries represented on the Committee.[48] The Basel Committee on Banking Regulation then issued the final agreement in bank capital regulation in 1988, and the US published the final rule in January 1989 (Federal Register/Vol. 54, No. 17/Jan. 27, 1989).

The Federal banking agencies state their motives for the change in capital regulation – besides concerns about a competitive disadvantage of US banks – in the final rule (ibid., p. 4168):

[47]Note that e.g. Posner (2014) also cites 1985 (and not 1983) as the date of a "major change" in regulation (p. 4).

[48]The Cooke Committee on capital regulation was composed of members of the G10 countries plus Switzerland and Luxembourg.

> *These final risk-based capital guidelines have a twofold purpose: To make capital requirements more sensitive to differences in risk profiles among banking organizations and to aid in making the definition of bank capital uniform internationally.*

The final regulation was the outcome of a lengthy discussion in an international organization. Furthermore, although the final rule was published in 1989, banks and regulators were supposed to take actions to implement the rules only from 1991 onwards (the effective date of the amendment was December 31, 1990, see Van Roy, 2008). Full implementation had to be guaranteed by December 31, 1992. Hence, we treat the change in capital regulation due to the introduction of the Basel Capital Accord as principally unrelated to the business and financial cycle because of the lengthy negotiations and the pre-announced enforcement and mandatory compliance dates.

Again, there is evidence in the literature that the Basel I regulations affected bank capital significantly. Berger and Udell (1994) find that "capital-deficient banks [i.e. those with risk-based capital below the new standards] represent more than one-fourth of the nation's total banking assets" (p. 588). Jacques and Nigro (1997), using a 3 stage-least squares approach, conclude that "the risk-based capital standards brought about significant increases in capital ratios and decreases in portfolio risk of banks which already met the new risk-based standards" (p. 544). There is some disagreement about the main channels of adjustment, in particular for weakly capitalised US banks: Haubrich and Wachtel (1993) argue that they mainly shifted to less risky assets (government securities instead of mortgages and commercial loans), while Van Roy (2008) finds they mainly increased their capital holdings. However, both papers agree that there were substantial effects on bank capital ratios.

Dec. 1992: The FDIC Improvement Act and Prompt Corrective Action. Almost contemporaneous with Basel I, US Congress passed a law with strict new guidelines for FDIC bank resolutions. This FDIC Improvement Act had as main goals "to require the least-cost resolution of insured depository institutions, to improve supervision and examinations, to provide additional resources to the Bank

Insurance Fund” (Public Law 102-242 – Dec. 19, 1991, preamble). The central prescription was to use “prompt corrective action to resolve the institutions at the least cost to the insurance funds" (ibid., Section 121). For this aim, the FDIC was supposed to classify banks as “well capitalized", “adequately capitalized", “undercapitalized", “significantly undercapitalized" and “critically undercapitalized" (ibid., Section 132). For example, banks with capital ratios of at least 10 percent total risk-based, at least 6 percent Tier-1 risk-based, and at least 5 percent leverage were categorised as well-capitalised (FDIC, 2003). On the other hand, banks with less than two percent of tangible equity to total assets were considered “critically undercapitalized" and to be placed in receivership within 90 days (Federal Register/Vol. 57, No. 189/Sep. 29, 1992, p. 44869). The act specifies that affected regulators should “promulgate final regulations [which] shall become effective not later than 1 year after the date of enactment [Dec. 19, 1991]" (ibid.). Thus, on December 19, 1992, the prompt corrective action provisions by the FDIC became effective (Federal Register/Vol. 57, No. 189/Sep. 29, 1992, p. 44866).

The timing of this regulatory change is less clear-cut than for other dates in our indicator. The fact that Congress had passed very specific rules and a tight implementation deadline in this act seems to have induced banks to increase capital pre-emptively as to avoid the risk of falling under the prompt corrective action scheme. Aggarwal and Jacques (2001) suggest that both adequately capitalised and under-capitalised banks increased their capital ratio as a response to the provision. In particular, the authors show that the majority of weak banks increased their capital holdings substantially between the passing of the FDIC Improvement Act in December 1991 and the prompt corrective action becoming effective in December 1992. To be consistent with the use of effective dates elsewhere, however, we only include the December 1992 date into our index, but show robustness to adding the December 1991 date as well.

Jan. 1997: Market Risk Amendment. There were two legislative changes affecting capital requirements in the years between the introduction of prompt corrective action and the Financial Crisis. First, in January 1997, the Basel I framework was complemented to include measures of market risk. However, as banks were free to develop their own internal models to assess these risks, it is not clear a priori whether this had a tightening or easing effect on overall capital requirements. For example, in a recent study on European banks, Gehrig and Iannino (2017b) find that while the Market Risk Amendment reduced the riskiness of the least risky quartile of banks, it significantly increased it for the upper quartile (mostly larger banks with more developed internal models).

Thus, its effect on capital requirements overall seems not to have been very large – e.g. Posner (2014) does not include this legislation into his enumeration of "the major changes to [capital adequacy] regulations" between 1981 and 2013. We thus choose not to include this date into our baseline specification, but show that results are robust to including this date.

Apr. 2008: Basel II. Second, in April 2008 Basel II became effective after another round of long international negotiations – a first publication on the topic in June 2004, the first proposed rule had been issued in September 2006 (Federal Register/Vol. 72, No. 235/Dec. 7, 2007), and the effective date for the US was in fact more than a year later than in Europe. Basel II was designed around the three pillars of minimum capital requirements, supervisory review and market discipline. The first pillar was thought to set appropriate capital ratios via regulation on credit risk (since Basel I), market risk (since the Market Risk Amendment) and operational risk (new in Basel II). The second pillar aimed to improve supervisory oversight of banks by setting up a framework to deal with systemic and liquidity risk, but also reputational and legal risks. Finally, the third pillar intended to increase market discipline on banks by introducing more unified disclosure requirements for banks. However, Basel II seemed outdated by the time of its introduction, which roughly coincided with the Financial Crisis.

As with the Market Risk Amendment, it is disputed whether the introduction of Basel II had palpable effects on US banks' capital – first because its capital requirement rules were rather pro-cyclical (Repullo and Suarez, 2013), second because its introduction largely coincided with the onset of the Financial Crisis. In a blog post, Gehrig and Iannino (2017a) state:

> *The main drivers of [the evolving capital shortfalls during the 1990s and*

2000s] appear to be the self-regulatory options introduced into the Basel process with the amendment for market risk (1996) and culminating in the introduction of internal models for credit risk in Basel II (2006). Rather than providing incentives for better risk management for the larger and internationally active banks, precisely those sophisticated banks used internal models to carve out even more equity in order to increase return on equity and at the same time reduce resilience.[49]

Moreover, as Basel II is not represented in the index by Cerutti, Correa, Fiorentino, and Segalla (2016), we will not include it either into our baseline CRI. However, we again will show that our findings are robust to including this date.

Jan. 2013: Basel II.5. Even before Basel II had became effective in the US, the Basel Committee met to discuss amendments about capital adequacy and Value at Risk models (Basle Committee on Banking Supervision, 2011). The resulting package of supplements set up in a reaction to the Financial Crisis came to be known as Basel II.5, effective in the US by January 1st, 2013 (Federal Register/Vol. 77, No. 169/Aug. 30, 2012, p. 53060). In a nutshell, it included a move from Value at Risk to Stressed Value at Risk, efforts to include credit margins and default risk in risk weights, new charges for securitized assets on banks balance sheets and a new measure to correlate asset positions on banks' portfolios. Moreover, it intended to correct the treatment of trading and banking bank book capital (see Pepe, 2013).

The regulators stated several goals that they hoped to achieve by the measures (Federal Register/Vol. 77, No. 169/Aug. 30, 2012): The motivation for modeling standards mentions the objective to "provide banks with incentive to model specific risk more robustly" (p. 53072). Similarly, the regulatory changes on debt and security positions aim at increasing "risk sensitivity, transparency, consistency in application, and reduced opportunity for regulatory capital arbitrage" (p. 53074). None of these stated goals implies stabilization policies; instead they all suggest long-term objectives. Different to Basel II, Basel II.5 did have effects on bank capital according to Cerutti et al. (2016). Therefore, we include it into our index.

[49] Note that the dates refer to the implementation dates for European banks instead of the effective dates for US banks.

Jan. 2014: Basel III. Shortly after Basel II.5, the Basel III framework was adopted in the US, representing the latest stage of this reform package to date. Its main content features stronger capital requirements, a minimum capital-to-assets ratio and liquidity requirements. Of most interest for us is the increase in minimum Tier 1 capital (CET1) from 4% over risk-weighted assets under Basel II to 6% under Basel III (from 2015 on). Specifically, this 6% minimum risk-weighted capital ratio is composed of 4.5% of CET1, plus an extra 1.5% of "Additional Tier 1". On top of this, Basel III introduced two more capital buffers: A discretionary countercyclical buffer, which enables national supervisors to require up to additional 2.5% of CET1 capital over risk-weighted assets when financial conditions are good, and a mandatory capital conservation buffer of 2.5% of risk-weighted assets (only from 2019 onwards). With a final rule published in October 2013, it became effective already on January 1, 2014. The motivation for Basel III by the US regulators mentions the avoidance of future banking crises as its main goal, while downplaying the immediate effects on banks (Federal Register/Vol. 78, No. 198/Oct. 11, 2013, p. 62026):

> *The final rule addresses [several weaknesses which became evident during the financial crisis] by helping to ensure a banking and financial system that will be better able to absorb losses and continue to lend in future periods of economic stress. This important benefit in the form of a safer, more resilient, and more stable banking system is expected to substantially outweigh any short-term costs that might result from the final rule. (...)*
>
> *The agencies' analysis also indicates that the overwhelming majority of banking organizations already have sufficient capital to comply with the final rule. In particular, the agencies estimate that over 95 percent of all insured depository institutions would be in compliance with the minimums and buffers established under the final rule if it were fully effective immediately [i.e. October 11, 2013].*

There do not yet exist not many studies on the effects of the Basel III regulatory changes. However, an early OECD study estimated a small negative effect of the

Basel III implementation on growth in its member countries, even though bank capital ratios should rise substantially (Slovik and Cournède, 2011). We follow Cerutti et al. (2016) in including Basel III in our index.

While this section has presented arguments for the choices of our baseline CRI, we find our main results in the next section robust to various other CRI specifications, as detailed in Section 2.4.

2.3 Main results

2.3.1 Dynamic effects of tightening capital requirements

The above section showed that our CRI variable can be considered exogenous to the current state of the economy. With this exogenous CRI at hand we are in a position to explore the dynamic effects of a regulatory bank capital requirement tightening on macroeconomic variables. To do so, we will treat the CRI as an instrument for the regulatory capital requirement shock, and apply an *instrumental-variable local projection* (IVLP) approach (as described in Jordà et al., 2015, see also Ramey, 2016, and Fieldhouse et al., 2017).[50] In our case, the idea is to think of the CRI as some - maybe noisy - measure of the “true" capital requirement shock. Using the IVLP approach, we thus extract exogenous movements in the capital ratio of the banking system, denoted by CR_t, which are due to the changes in the capital regulation as indicated by our dummy indicator. So in the first stage we regress aggregate bank capital CR_{t+h} on our exogenous capital requirement indicator CRI_{t+h}, some deterministic regressors c (a constant and linear trend) and x_t, a collection of control variables which are included both in the first-stage and second-stage regression.[51] So our first-stage regression is given by

$$\mathrm{CR}_t = c + \alpha(L)x_{t-1} + \phi(L) \cdot \mathrm{CRI}_t + u_t. \tag{6}$$

[50]We show robustness to using a SVAR approach below.

[51]Stock and Watson (2017) argue that including such controls will help ensure the exogeneity of the instrument to other variables and leads and lags, plus it will reduce the error variance. The vector of control variables x_t is lagged by one period and consists of (log) industrial production, the (log) PCE deflator, federal funds rate, (log) total lending, as well as term and Baa spread.

From this regression, we generate predicted values $\widehat{\text{CR}_{t+h}}$ of the capital ratio, interpreted as a regulation-induced increase in banks' capital ratio. We then estimate the effect of these changes on various variables of interest, y_t, by regressing them on $\widehat{\text{CR}_{t+h}}$ and the same deterministic regressors c and controls x_t as in the first stage above. The second-stage regression thus takes the form

$$y_{t+h} = c^h + \beta^h(L)x_{t-1} + \gamma^h(L) \cdot \widehat{\text{CR}_t} + u_t. \tag{7}$$

The sequence of parameter estimates $\{\gamma_1^h\}_1^H$ gives the impulse response of y_{t+h} to an exogenous movement in banks' capital ratio due to a tightening in regulatory capital requirements. Hence we are obtaining the impulse-responses horizon-by-horizon.[52] Standard errors are computed using the heteroscedasticity and autocorrelation consistent covariance estimator of Newey and West (1987). FOr our baseline model, we use monthly data from 1980M1 to 2016M8.

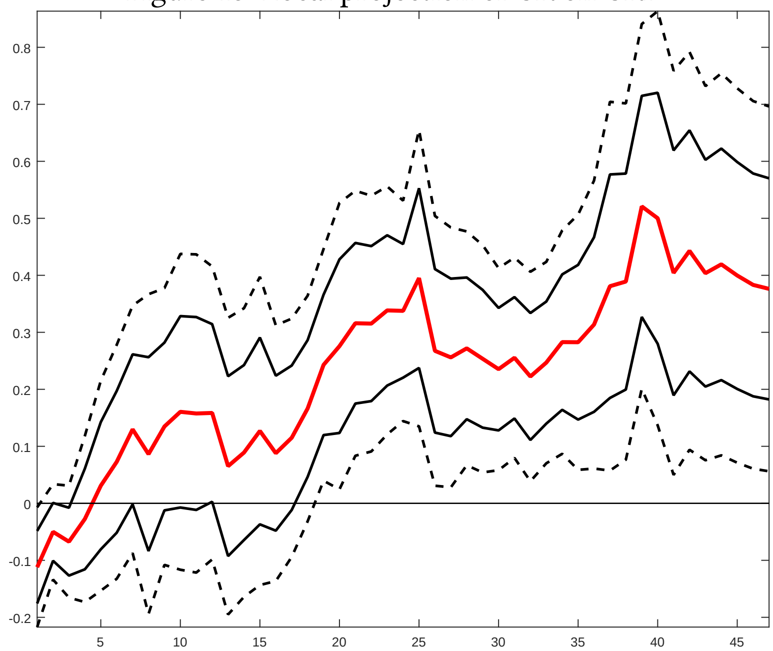
The consistency of the parameter estimates in the instrumental variables setup depends crucially on the validity of the instrument. A valid instrument must satisfy two conditions: instrument relevance and instrument exogeneity. Instrument relevance refers to the condition that our instrument, i.e. the CRI, must be sufficiently highly correlated with the structural shock. We test this statistic by calculating the first stage rk Wald F-statistic suggested in Kleibergen and Paap (2006). We show the first-stage F-statistic below the respective IRF plots. Usually, it is well above the critical value of 16.38 reported in Stock and Yogo (2005).[53] Hence, our instrumental variable usually does not suffer from weak identification and the CRI is indeed a relevant instrument for the bank capital ratio. Concerning the exogeneity of our instrument, we are unfortunately unable to explicitly test for the exogeneity of the instrument. Equation (7) is just-identified, which makes it impossible to apply a test of over-identifying restrictions like the Sargan-Hansen test (see Hansen, 1982).

[52]See Barnichon and Brownlees (2016) for an alternative system-wide approach to generate responses for the case of erratic responses, based on smoothed local projections. As we obtain relatively stable dynamics in the responses, we do not apply this method.

[53]Note that the first-stage F-statistic is the same for our baseline variables here, while it differs for the other variables, which are added one by one to the system.

We start by assessing the effects of a unit shock to the CRI_t dummy to banks' capital ratio CR, i.e. we show the impulse responses from our first-stage local projections regression in eq. (6).

Figure 13: Local projection of CR on CRI

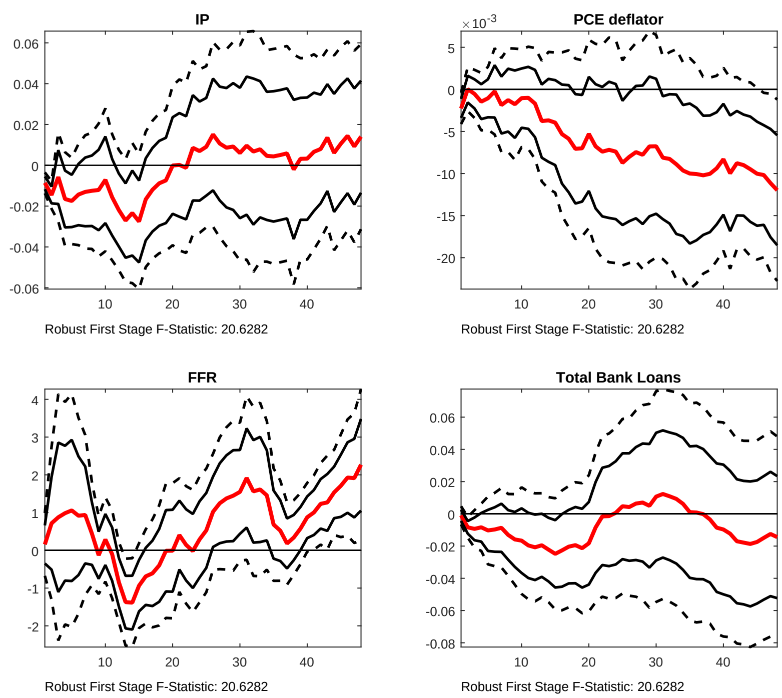


Note: x_t = [log(IP), log(PCE defl.), FFR, log(Total Loans), Term Spread, Baa Spread]'; $\beta^h(L) = \beta_0^h L + \dots \beta_n^h L^n$ and $\gamma^h(L) = \gamma_0^h + \gamma_1^h L + \dots \gamma_m^h L^m$, with $n = m = 2$. Deterministic terms include a constant, trend and squared trend. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

As shown in Figure 13, the bank capital ratio increases permanently following an exogenous tightening in capital requirements. The increase in capitalization is sluggish, with the response of the capital ratio becoming significant only after 18 months. While the permanent increase should be expected as the legal changes coded in the dummy variable specify permanent increases in the capitalization of banks, the sluggish behavior in the capital ratio might reflect the phase-in periods of regulatory bank capitalization changes. The fact that bank capital increases permanently – which is by no way implied by our identification – gives further confidence that our narrative approach does indeed identify exogenous changes in capital requirements. In fact, if our dummy variable simply captured some other sort of temporary recessionary demand shocks, there would be no reason for banks to *permanently* increase their capital ratio. The statistically significant increase comes also at a meaningful size: The long-run increase after a "representative" CRI tightening in our sample is about 40 basis points, showing that our narrative events in fact pick up decisive regulatory events.

Next, we assess the effect of a CRI tightening on our control variables x_t: We thus use future values of the controls as dependent variable in the second-stage regression in eq. (7). We present the results in Figure 14 and top of Figure 15.

Figure 14: Effects of capital requirement shock - baseline variables



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

An unexpected tightening of bank capital requirements leads to a significant reduction in industrial production on impact, followed by a borderline significant slump until a trough is reached after around one year, around 2.5% below the baseline value. The price level also decreases slightly on impact, and then again after around 3.5 years. The decrease is overall economically small though: It hardly surpasses 1 bp.

The federal funds rate drops significantly after around one year following a tightening of bank capital requirements. The reduction in the federal funds rate is likely a response of the Federal Reserve to the reduction in economic activity as witnessed by the drop in industrial production. The strong negative response of the federal funds rate might explain part of the swift recovery in industrial production 18 months after the shock.

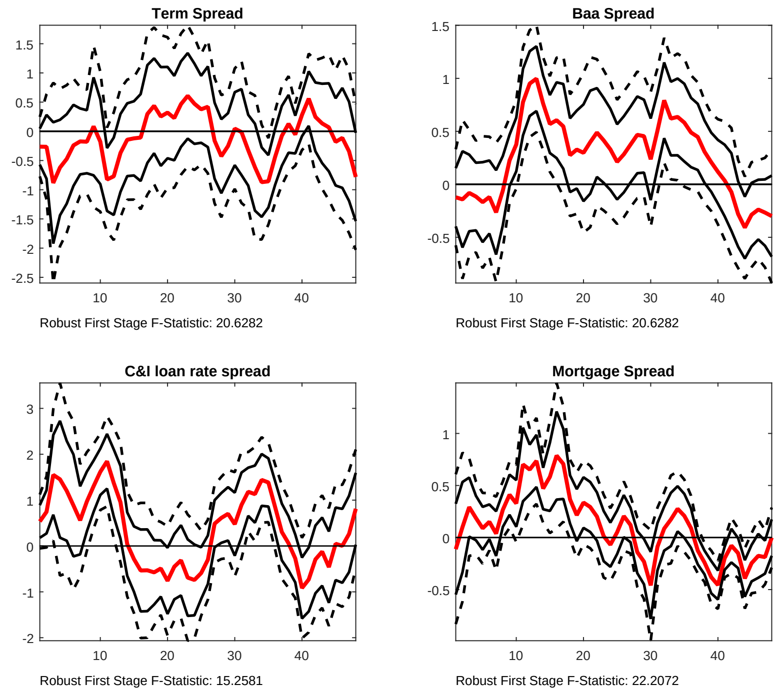
The tightening in capital requirements has a negative short-run effect on total bank loans. Bank lending drops significantly within two months after the capital requirement change and remains below its baseline value until around 18 months later with borderline significance. The timing suggests that after a regulatory capital-requirement tightening, banks in fact contract their balance sheets by reduced lending for about one and a half years, before building up capital and restoring lending to previous levels (or higher). Lending drops by around 3% on maximum.

The term spread (Figure 15) shows a less clear response. It falls by around one percentage point roughly one year after the regulatory change, maybe also due to the policy response in the federal funds rate. After that, there is no unambiguous pattern to observe.

The Baa spread, in contrast, rises significantly less than a year after the CRI tightening, and remains elevated for about two years. This speaks for heightened risk aversion in the financial sector and more difficult borrowing conditions for smaller and younger companies.

To sum up briefly our baseline result, we find that an unexpected increase in capital requirements generates a drop in bank lending, industrial production and prices. With these variables still depressed after around one year, and the Baa spread widening, monetary policy seems to react with easing measures and after around 18 months lending and economic activity are back to their baseline values.

Figure 15: Effects of capital requirement shock - credit and interest rate spreads



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

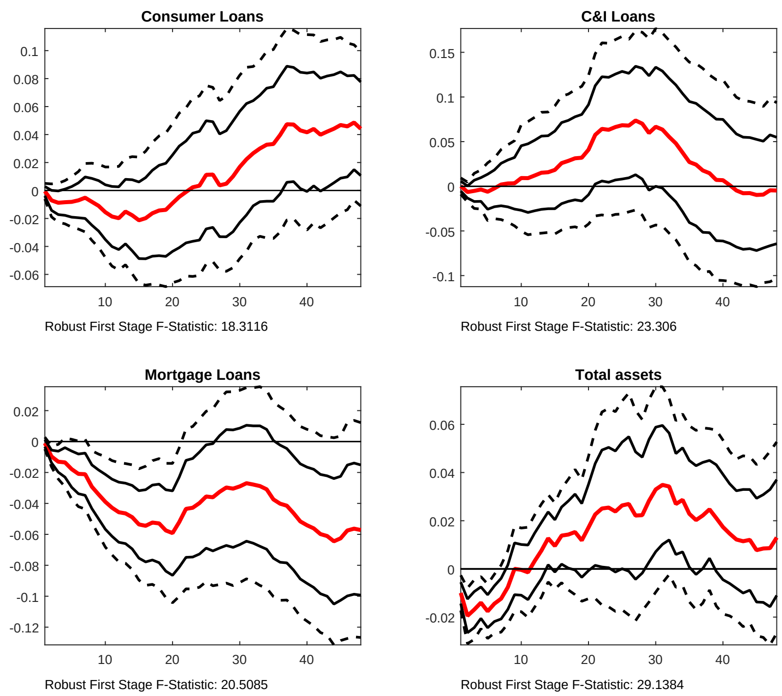
2.3.2 Transmission channels

In the following, we investigate in more detail through which channels capital requirement tightenings are transmitted to the real economy. For each of the plots below, we use the respective variable as dependent variable y_t in our second-stage regression (7). Throughout this section, we include two lags of the endogenous variable into the vector of control variables. The first-stage F-statistics (given below the respective plots) are usually well above the critical threshold of 16.83 in Stock and Yogo (2005).

Loan sub-aggregates

We first disentangle the aggregate of total bank loans into its main components. Specifically, we analyze the responses of consumer loans, commercial and industrial (C&I) loans and real estate loans to the CRI shock. The responses of the loan sub-aggregates might help understand which type of borrower is affected most in terms of a reduction in credit supply: entrepreneurs, consumers or mortgages holders.

Figure 16: Effects of capital requirement shock - Loan subaggregates



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

We present the results for the loan sub-aggregates in Figure 16. The impulse responses show that banks mainly reduce mortgage loans, while consumer loans and C&I loans are not changed significantly. Mortagage loans – which comprise residential and non-residential real-estate lending – drop strongly after the increase in capital requirement and keep falling for 18 months after the shock. They reach a trough with residential loans being 6% below their baseline value and their level remains rather depressed. Consumer loans fall insignificantly and seem to experience a faster recovery. C&I loans increase, if anything, after a CRI tightening. These findings can be contrasted with those in den Haan, Sumner, and Yamashiro (2007). The authors find an increase of C&I loans after monetary policy contractions, while real-estate and consumer loans fall. However, for non-monetary shocks, they find an initial increase in real-estate and consumer loans, while C&I loans fall strongly. In fact, it seems that an exogenous increase in regulatory capital requirements thus affects bank lending much like a (contractionary) monetary policy shock.

The results from this exercise help to better understand the drop in industrial production after the increase in capital requirements. The strong reduction in mortgage loans suggests that the tightening in capital requirements affects industrial production mostly by a fall in construction. As mortgage loans comprise both residential and non-residential mortgages, the question whether household or firms are more affected cannot yet be answered. We will explore this below.

The reaction of total bank assets gives further evidence about how a regulatory capital tightening affects bank lending: Total assets fall significantly on impact, by about 2% after two months, and remain significantly depressed for about 8 months.[54] After that, they quickly revert to their pre-regulation value and increase, if anything, over the next four years. This is further evidence for a relativley quick contractionary adjustment dynamic of capital requirement changes.

Credit spreads

In the two bottom plots of Figure 15 we show the responses of the C&I loan rate spread and the mortgage rate spread. We see that while C&I loan volumes seems to increase after a CRI tightening, also the spread increases, by up to 2 percentage points after around one year. This might reflect a worsening of companies'

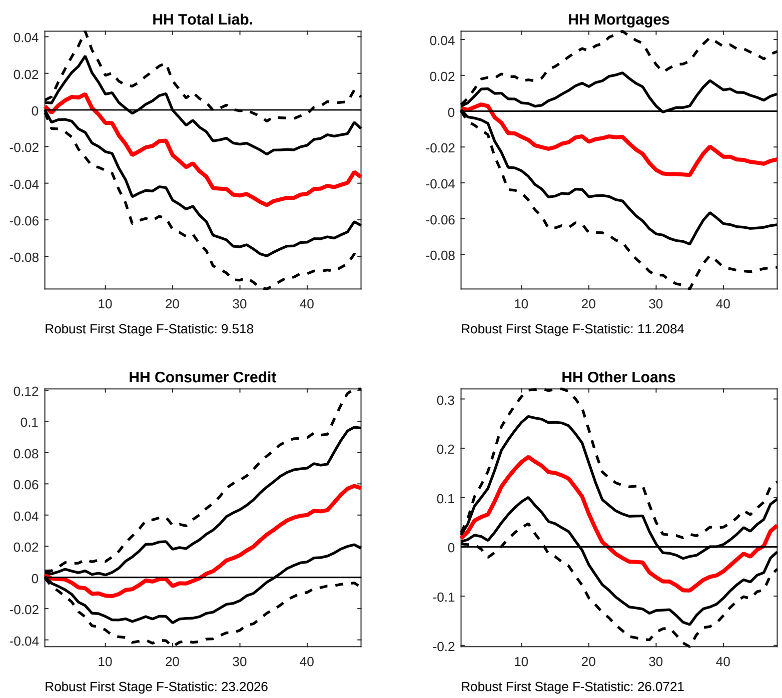
[54] This is in line with Laderman (1994), who found that bank holding companies tended to meet the 1990 risk-based capital requirements of Basel I by reducing their asset growth rather than stock issuance, at least on impact.

credit quality during the downturn in economic activity, or an increase in credit demand by entrepreneurs. On the other hand, the mortgage spread increases significantly only after about 9 months and remains elevated for about one year. Together with the fall in mortgages volumes, this indicates heightened risk aversion towards mortgages borrowers and a shortening of credit supply in this segment.

Households

To analyze whether it is rather households or companies that suffer from lower mortgage issuance after a regulatory capital tightening, we look at data from the Federal Reserve on the financial accounts of both households and corporate non-financial companies.

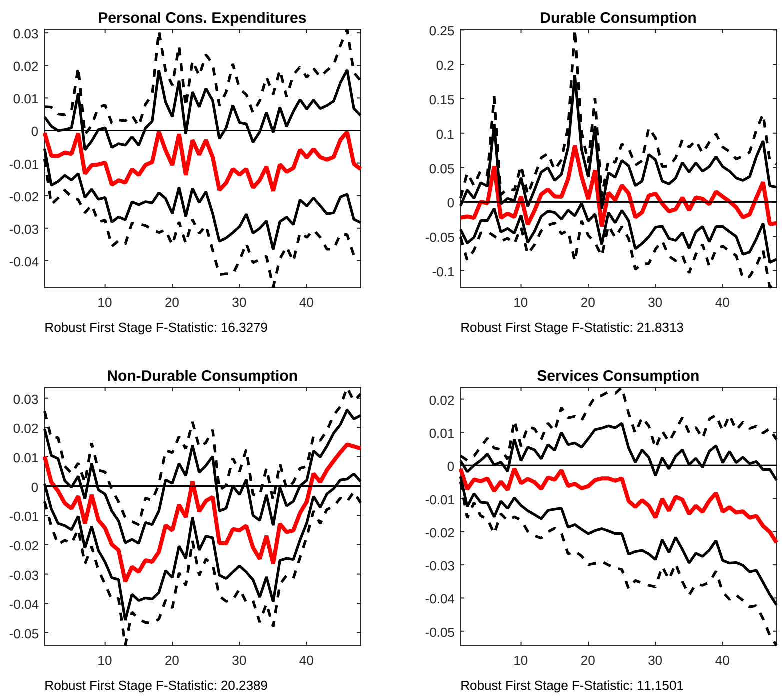
Figure 17: Effects of capital requirement shock - Household liabilities



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Turning to households first, Figure 17 shows some key liability positions of the aggregated household sector. Total liabilities are not affected strongly on impact, but have fallen signficantly by about three years after the CRI tightening. This deleveraging of households seems reflected by a fall in mortgages and other loans, rather than by consumer credit. While this would be in line with the dynamics in bank lending above, reactions are not significant enough here to come to a definitive conclusion.

Figure 18: Effects of capital requirement shock - Household consumption



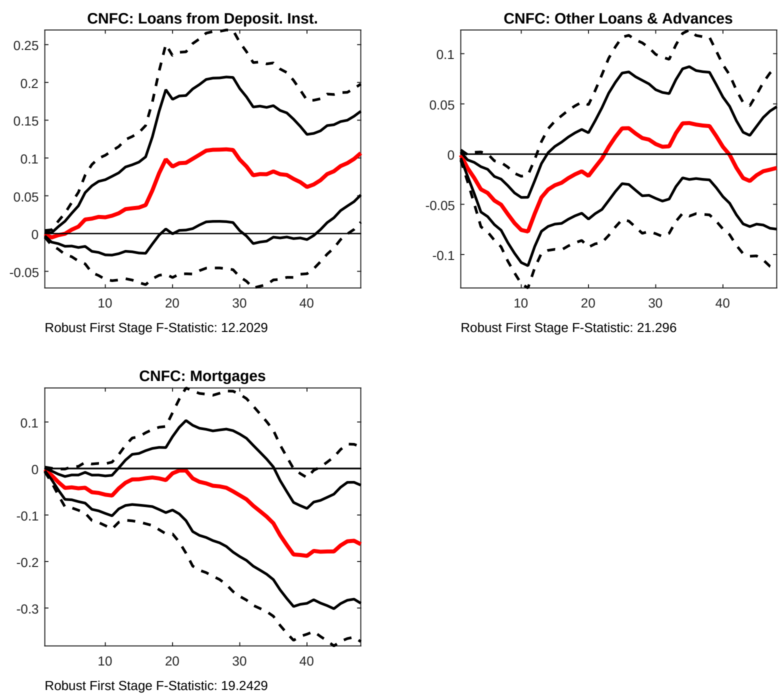
Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Figure 18 looks at the dynamics of some key household consumption aggregates. While personal consumption expenditures and consumption of services depict some fall, especially on impact (though only borderline significant), only non-durable consumption decreases significantly, by around 3% after one year. Surprisingly, durable consumption, which would include housing, does not fall strongly. Altogether, the evidence here speaks rather against a strong fall in household mortgages and residential construction as a driver of the real-economic dynamics after a CRI tightening.

Nonfinancial companies

Next, we turn to nonfinancial companies (NFCs), in particular corporations.

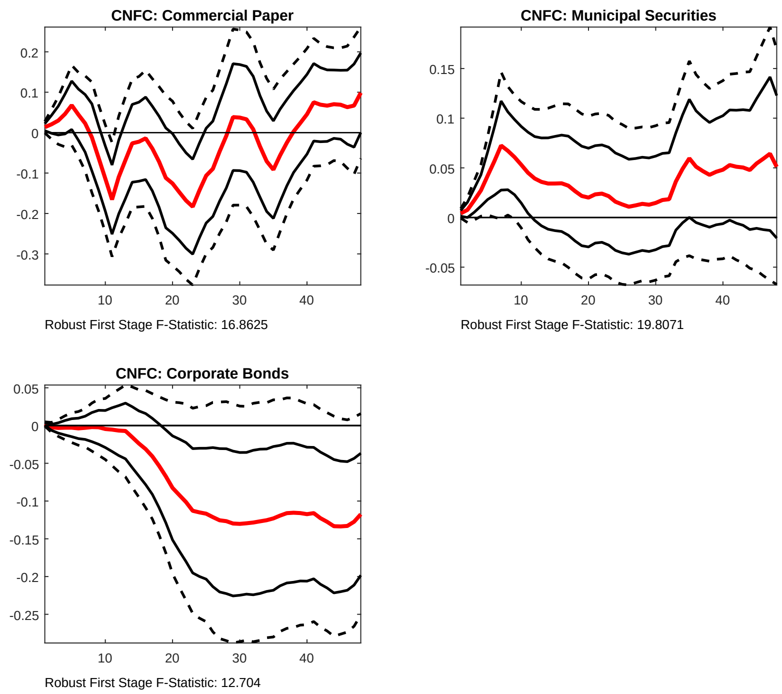
Figure 19: Effects of capital requirement shock - Corp. NFC loans



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Figure 19 shows the dynamics of several corporate NFCs' loan types. While loans from depository institutions seem rather to increase, other loans and advances fall significantly, reaching a trough after one year. Moreover, mortgages to corporate NFCs fall immediately, and up to about 7% after one year (with borderline significance). Thus, companies seem much more affected than households by banks cutting back their mortgage issuance.

Figure 20: Effects of capital requirement shock - Corp. NFC debt securities



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

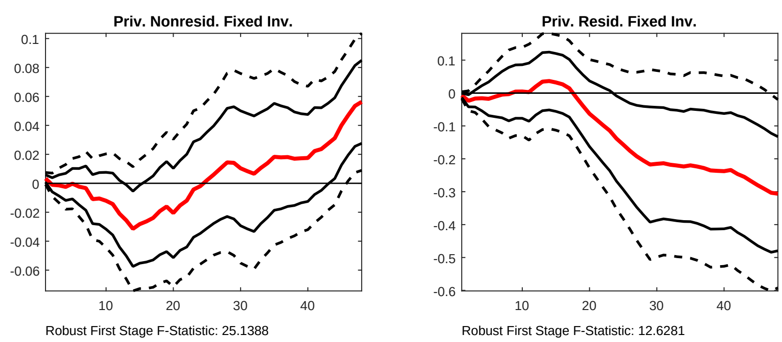
How do firms react to this decrease in credit availability? Figure 20 shows the dynamics in several securities that firms can use as an alternative to bank credit. However, both commercial paper and corporate bonds in general seem to decrease, if anything, after a CRI tightening. In contrast, municipal securities, which can only be issued by local governments, states or related agencies and are often used for infrastructure financing, show a significant increase on impact. So while public institutions might step in to some degree, there is no evidence that (corporate) companies balance the fall in bank mortgage. This suggests they are the more likely candidate for a reduction in construction which could partially explain the fall in industrial production above.

The fact that commercial mortgages fall more strongly on impact than do household mortgages is consistent with Hancock and Wilcox (1997), who find that real-estate lending to firms is much more strongly affected by negative bank-capital shocks than mortgages to single families. They suggest that this larger elasticity of commercial mortgages might arise from this market being less liquid than the one for residential mortgages.

Fixed investment

Looking at the responses of investment further confirms our hypothesis that it is a fall in company rather than household mortgages that explains a fall in real activity. Figure 21 shows the (interpolated) private residential and non-residential fixed investment. While the former falls with borderline significance, reaching a trough after one year, the latter shows no decrease on impact. However, residential investment shows a fall more than three years out after the CRI tightening, which is partially reflected in the second (borderline significant) drop in bank mortgages (Figure 16).

Figure 21: Effects of capital requirement shock - Investment

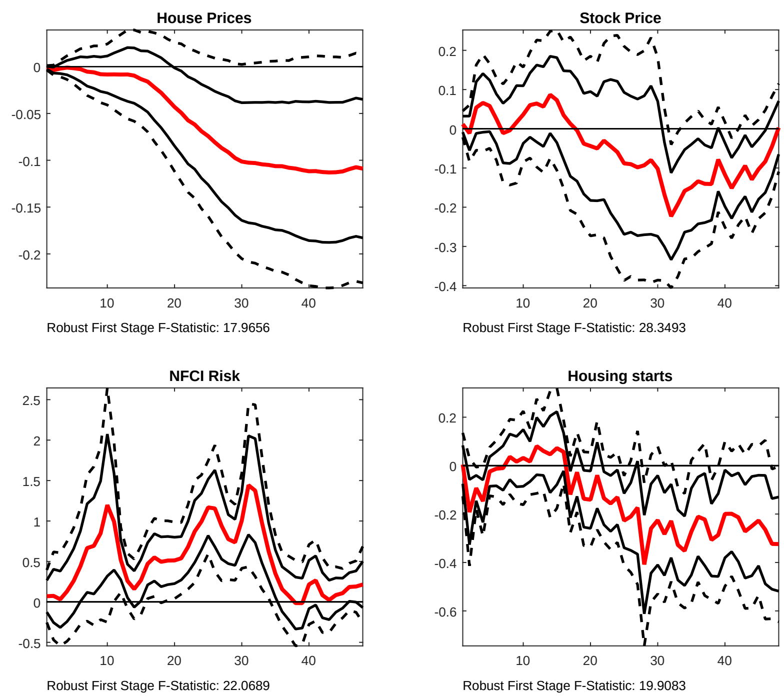


Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Asset prices

Figure 22 depicts two asset prices with great importance for the macroeconomy. First, we see that house prices do in fact not react strongly to a CRI tightening on impact, but start falling after around 18 months and remain below their baseline value after that. This is in line with the dynamics of housing starts, which follow a similar (though more volatile) trajectory. Again, this underscores the second drop in mortgages, which seems to derive from households and residential mortgages rather than firms. Stock prices, the second important asset depicted here, remain mostly unaffected first, but show a significant downturn after around 2.5 years.

Figure 22: Effects of capital requirement shock - Asset prices

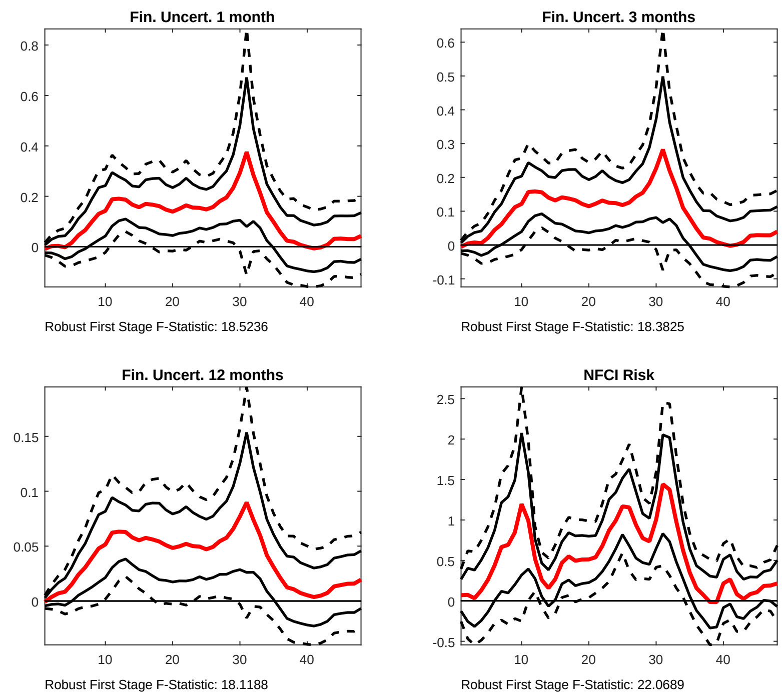


Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Financial uncertainty

To investigate further how regulatory capital requirement changes affect the financial sector, we show their impact on the financial uncertainty indicators as developed in Jurado, Ludvigson, and Ng (2015).

Figure 23: Effects of capital requirement shock - Financial uncertainty



Note: Effect of a unit increase in the capital requirement dummy variable based on IV local projection regressions. The red solid lines show the point estimate. The black solid (dashed) lines show the 1 standard deviation (1.65 standard deviation) confidence intervals, based on heteroskedasticity and autocorrelation consistent standard errors.

Figure 23 plots the reaction of the uncertainty indicators with a horizon of one, three and twelve months, as well as the risk as measured by the NFCI risk index. Although the latter is constructed very differently, dynamics are surprisingly similar: Uncertainty does react on impact, but increases when the economic activity falls after around one year and remain elevated up to a second peak in uncertainty and risk after around 32 months (although the confidence bands for the uncertainty measures are too wide for conclusive evidence). Thus, increases in regulatory capital, for all the stabilizing effect they might have on the financial sector, seem not to have decreased financial uncertainty for the recent US history.

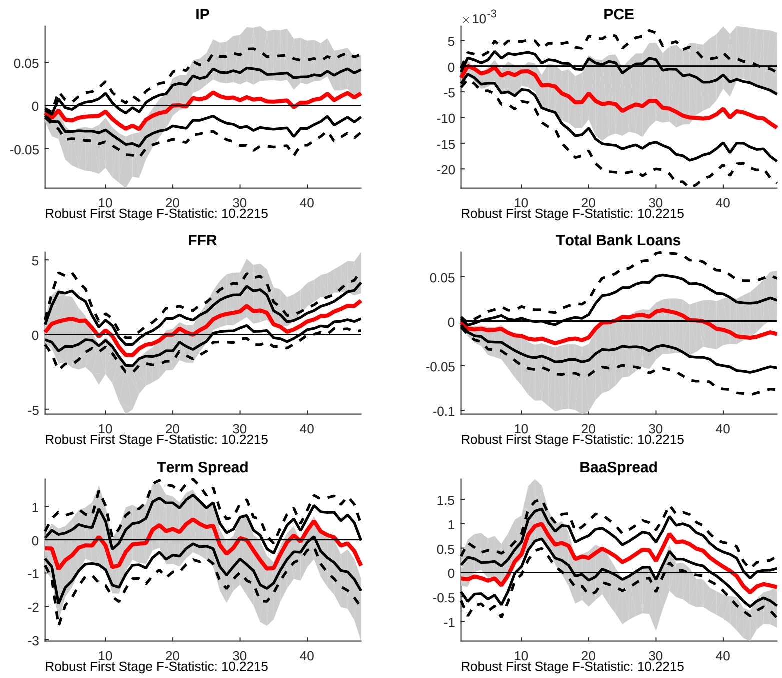
2.4 Robustness

Our main findings indicate that an exogenous tightening in capital requirements reduces bank lending temporarily, which leads to a short-lived drop in economic activity. In this section we perform a battery of robustness checks to our model setup to ensure that these key findings are not only driven by specific modelling choices.

Excluding the crisis period

One potential concern with our sample period is the combination of capital requirement changes before and after the Great Recession: After 2008, the economic environment was characterized by deleveraging, monetary policy facing the zero-lower bound and operating with unconventional monetary policies and the implementation of explicitly "macroprudential" policies for the first time. A valid concern therefore is that our simple baseline model might not appropriately capture the specific post-crisis feature of the economy. In order to test whether including the post financial crisis period is important for our results, we re-estimate the model over the sample 1980M1 to 2006M12.

Figure 24: Robustness 1: Excluding 2008-2016



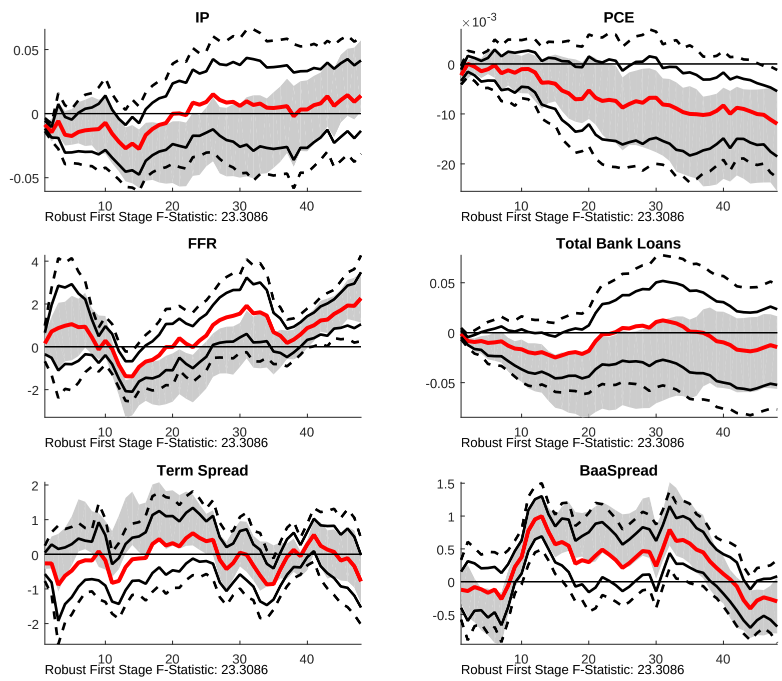
Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model (baseline control variables together with two lags of the new dependent variable). The lines show the impulse responses and confidence intervals from the baseline.

We show the results from this exercise in Figure 24. The grey line and shades are the point estimates and 95% confidence bands of the IV local projections based on the sample without the post-crisis period. We plot them together with the baseline results (the red and the black lines) for better comparability. The impulse responses based on the shorter sample excluding the post-crisis period are very similar in shape and magnitude to the baseline results. In fact, for industrial production, inflation and the federal funds rate, the point estimate is almost always within the confidence intervals of the baseline model. The capital requirement shock generates a slightly stronger drop in total bank lending if we exclude the post-crisis period. However, the shape is still very similar and the main qualitative message continues to hold. Altogether, our results are not particularly sensitive to excluding the post-crisis period.

Including ILSA and FDICIA

We have chosen not to include the dates when Congress passed legislation that finally led to changes in capital requirements. However, it would be conceivable that banks reacted already to this legislation by raising their capital holdings or curtailing lending. In particular the FDICIA with the clear announcement of the prompt corrective action measures to be adopted by regulators might have had this effect, as stressed e.g. by Aggarwal and Jacques (2001).

Figure 25: Robustness 2: Including ILSA and FDICIA



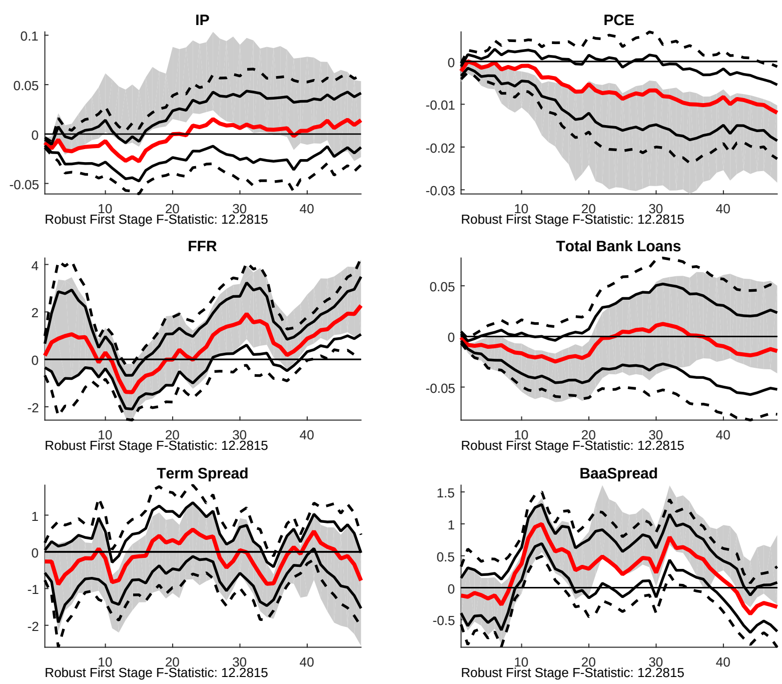
Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model. The control variables in the alternative model consist of the baseline control variables together with two lags of the (new) dependent variable. The lines show the impulse responses and confidence intervals from the baseline.

We therefore check our results for robustness to including the dates when both ILSA and FDICIA were passed (Dec. 1983 and Dec. 1992, respectively) into our CRI index. The results, shown in Figure 25, show that our results are robust to including these dates; if anything, the reactions become longer-lasting and more significant.

Including Market Risk Amendment and Basel II

Moreover, we left the dates of the adoption of the Market Risk Amendment (MRA) and Basel II out of our baseline CRI. Although the literature is somewhat undecided as to whether these dates represent actual capital requirement tightenings for the majority of US banks, it could be that including these dates matters. After all, these were the largest changes in bank capital regulation between the early 1990s and the Great Recession, and in particular Basel II dominated the headlines of financial regulation before the crisis.

Figure 26: Robustness 3: Add Market Risk

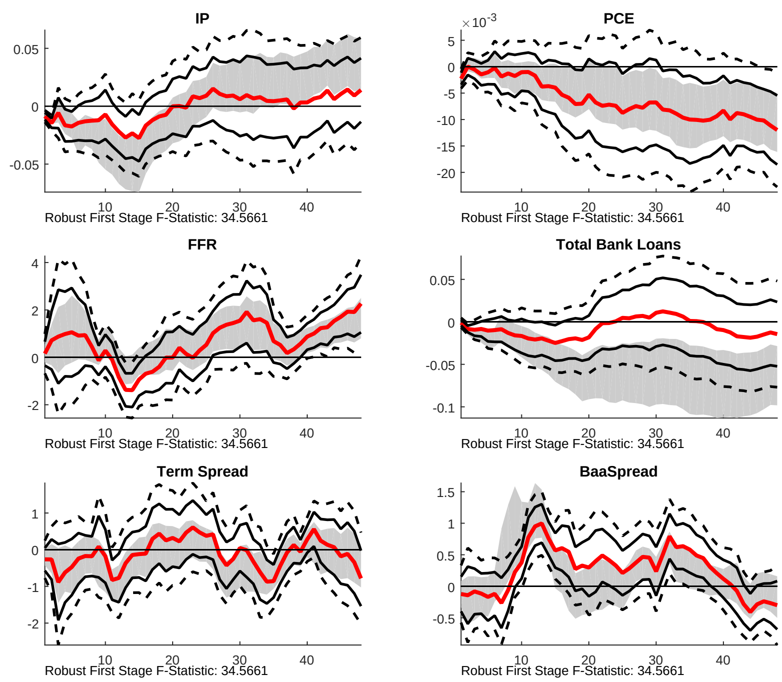


Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model. The control variables in the alternative model consist of the baseline control variables together with two lags of the (new) dependent variable. The lines show the impulse responses and confidence intervals from the baseline.

Figures 26 and 27 show the results when including the effective dates of MRA

(Jan. 1997) and Basel II (Apr. 2008) to our CRI indicator. We include all of these figures because for the case of including Market Risk Amendment, we actually do get a positive effect on industrial production. However, all other variables show reactions consistent with our baseline results (even more drastic for the case of lending and inflation, for example). Furthermore, the first-stage F-statistic is only above 12 in this case, so quite a bit below the critical value of 16.83. Looking at the case where Basel II is added, we see both stronger negative effects and a high first-stage F-statistic above 30.

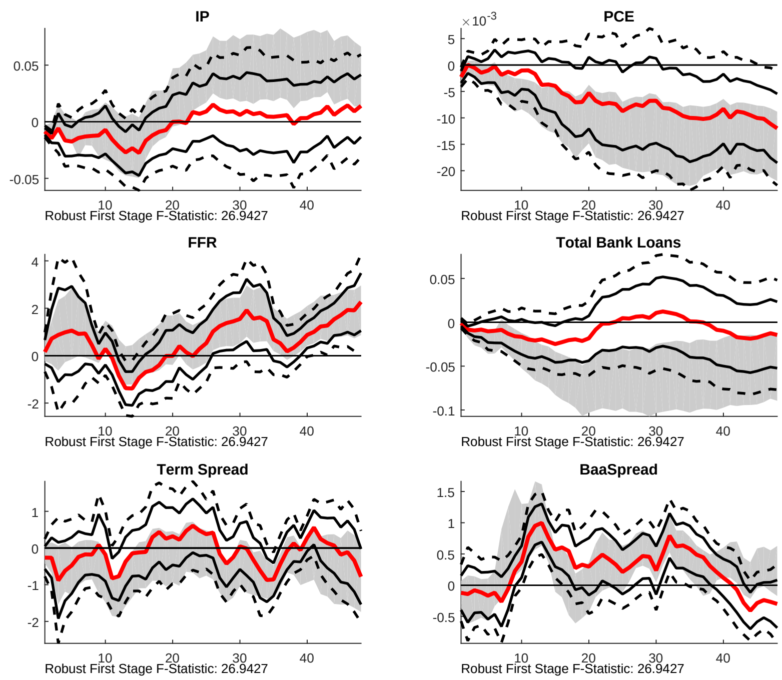
Figure 27: Robustness 4: Add Basel II



Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model. The control variables in the alternative model consist of the baseline control variables together with two lags of the (new) dependent variable. The lines show the impulse responses and confidence intervals from the baseline.

As we believe that the MRA and Basel II are comparable in that they both combined features that might have led to capital tightenings for some (smaller) banks, but for easings for others (larger banks with risk modelling divisions), we also add both effective dates to our CRI in Figure 28. In this case, lending and inflation decrease drastically, while industrial production first declines with borderline significance before increasing. These results have a sufficient first-stage F-statistic, so we conclude that our main findings are robust to both MRA and Basel II.

Figure 28: Robustness 5: Add Market Risk and Basel II



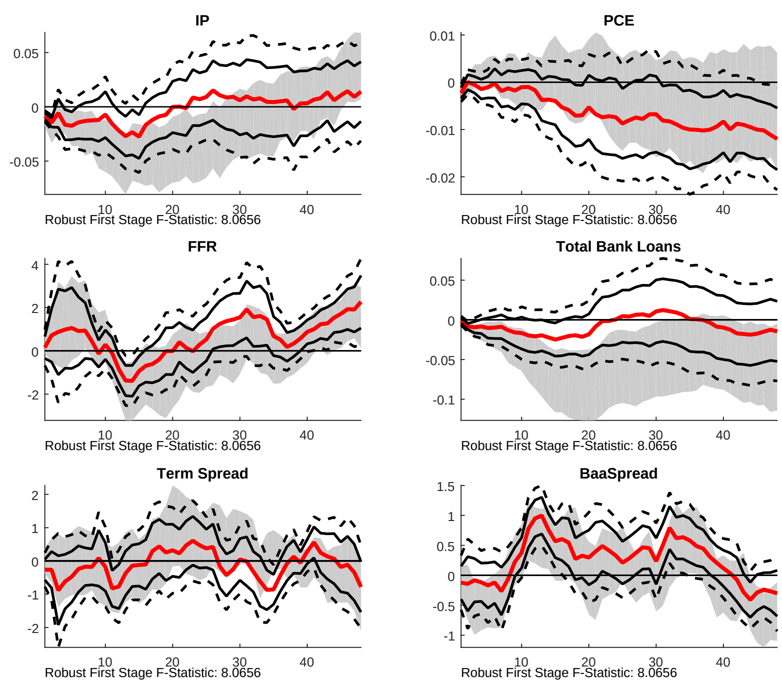
Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model. The control variables in the alternative model consist of the baseline control variables together with two lags of the (new) dependent variable. The lines show the impulse responses and confidence intervals from the baseline.

Using final rules instead of effective dates

Another concern is about the potential announcement effects of regulatory capital requirement changes. While we have argued above that banks might wait until new capital requirements become effective and use the phase-in periods to adjust their capital ratios, it is also possible that they start acting as soon as the rules become available in their final form, i.e. with the publication of the final rules of the respective regulation.

To test for this possibility, we re-run the analysis using the publication dates of the final rules instead of the dates when the regulation became effective (see Table 11 in the Appendix). As Figure 29 shows, we find in fact very similar effects when using these dates. However, the F-statistic of the first stage regression on bank capital is far below the critical value of 16.83, casting doubt on the reliability of the results. While we cannot rule out that (some) banks start acting upon the publication of final rules, we take our main results to be also robust to this specification.

Figure 29: Robustness 6: Only Final Rules

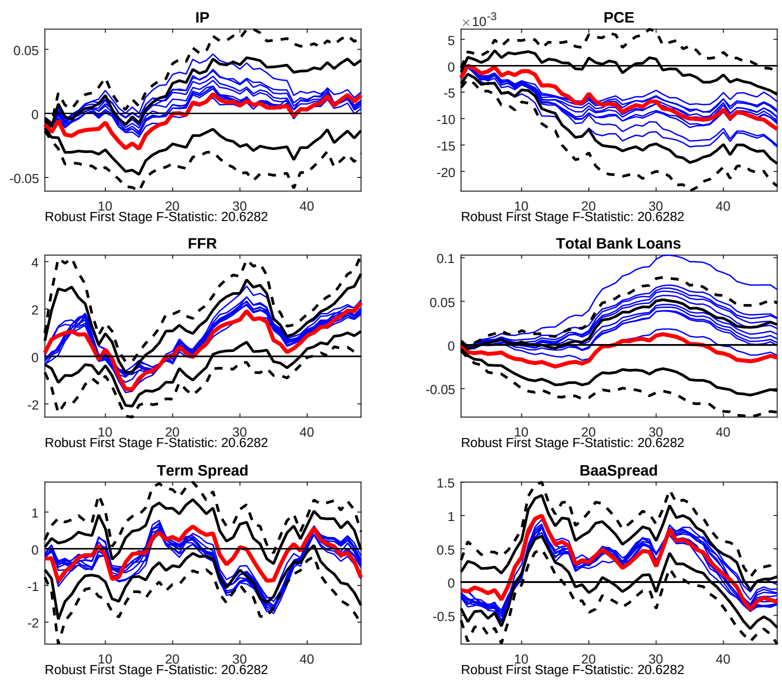


Note: Grey shaded area show the 1 standard deviation confidence interval from the alternative model. The control variables in the alternative model consist of the baseline control variables together with two lags of the (new) dependent variable. The lines show the impulse responses and confidence intervals from the baseline.

Variation in the lag structure in the local projections

Setting the lag length in an IV local projection regression is a delicate task. It is in principle possible to use information criteria to set the lag length, which might then differ for each single horizon. This approach would, however, lead to highly erratic impulse response estimates. As a benchmark case we estimate models including 2 lags of the control variables and 2 lags of the CRI itself. Here we show that our main findings do not change when varying the lag length for either the dummy indicator or the control variables between 2 and 12 lags.

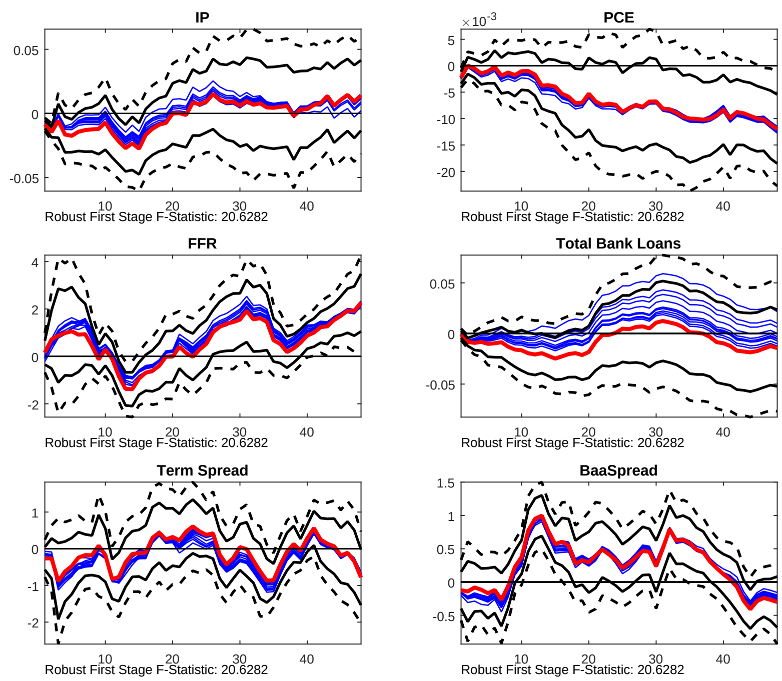
Figure 30: Robustness 7: Varying lag length of controls



Note: Blue dashed lines are the point estimates of model in which we increase the lags of the control variables from 2 lags to 12 lags. The lines show the impulse responses and confidence intervals from the baseline.

Figure 30 contains the results from models in which we keep the lag length of the control variables at 2, but vary the lags of the dummy indicator between 2 and 12 lags. Similarly, Figure 31 shows results from models keeping the lag length of the dummy indicator at 2, but varying the lags of the control variables between 2 and 12 lags.[55] In both cases, results are very close to our baseline specification. Altogether, our results seem not driven by the specific lag structure in the local projections.

Figure 31: Robustness 8: Varying lag length of shock



Note: Blue dashed lines are the point estimates of model in which we increase the lags of the CRI from 2 lags to 12 lags. The lines show the impulse responses and confidence intervals from the baseline.

Using a SVAR approach

Finally, we also want to compare the robustness of our results to employing a structural vector autoregression (SVAR) instead of our instrumental-variable local projections approach. As argued e.g. by Barnichon and Brownlees (2016), the SVAR is more efficient, but is generally less robust to model misspecification. So while we choose to stick with the more robust approach in the baseline, it will nevertheless

[55] For our monthly data, a maximum lag length of 12 seems to be a reasonable choice.

be interesting to see whether results remain similar when we relax the assumption that the CRI is fully exogenous to the state of the business and financial cycle. Instead, here we allow other key macroeconomic and financial variables to affect the CRI variable by modelling it jointly with other variables in a VAR. For this let Y_t be a (7×1) vector containing the (cumulated) CRI and the six variables in our set of controls above.[56] We assume that the dynamics of Y_t are governed by the following vector-autoregressive process:

$$Y_t = c_1 + c_2 \cdot t + \sum_{l=1}^{L} A_l Y_{t-l} + u_t,$$

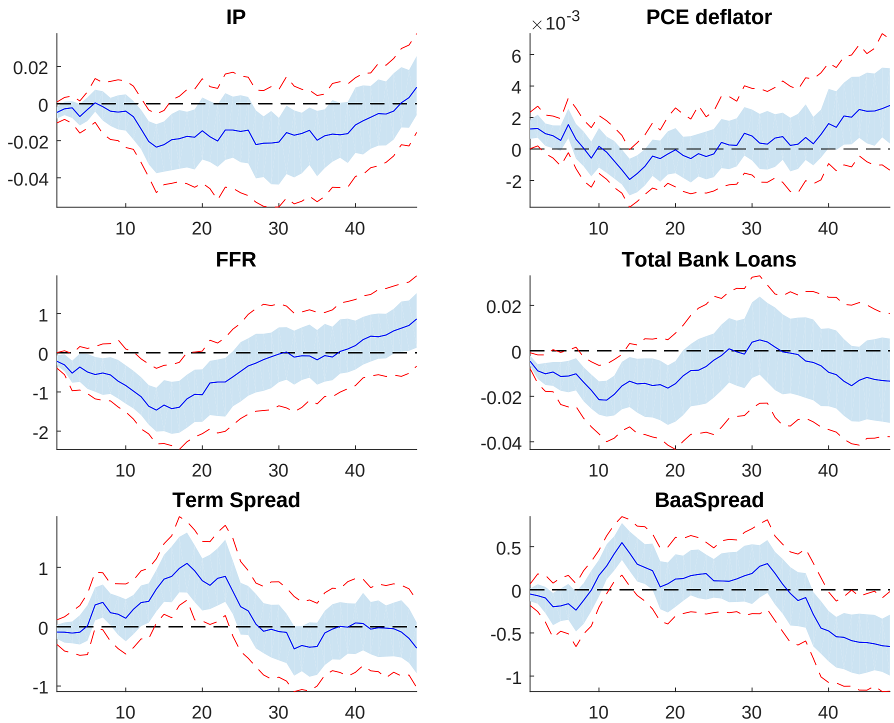
where c_1 is a constant, $c_2 \cdot t$ a linear trend, A_l a (7×7) coefficient matrix and $l = 1 \dots L$ are lags, with L being 36 for our monthly data.[57] The reduced form residuals u_t are Gaussian with mean zero and positive definite covariance matrices $\Sigma_u = E(u_t u_t')$.

The reduced form residuals are related to the structural shocks ϵ_t according to $u_t = A_0 \epsilon_t$, with $E(\epsilon_t \epsilon_t') = I_n$. The impact effects are captured in the orthogonal invertible Gaussian (7×7) matrix A_0 that satisfies $\Sigma_u = A_0 A_0'$. We identify the capital requirement tightening shock using zero contemporaneous restrictions on the matrix A_0. Specifically, we impose the timing restrictions that all other variables in the system can react contemporaneously to the shock. That is, we apply a Cholesky decomposition to Σ_u with the CRI ordered first in Y_t.

[56]For reference, these variables are (log) industrial production, (log) PCE deflator, the federal funds rate, (log) total lending, as well as term spread and Baa spread.

[57]The lag length is larger than in the local projections approach. As the VAR impulse responses are more sensitive to misspecification due to their iterative construction, we want to ensure whiteness of the VAR residuals. We have also experimented with other lags for the SVAR and find our results there robust to a version with 24 and 12 lags: While inference becomes less clear-cut for fewer lags, qualitative results are very similar.

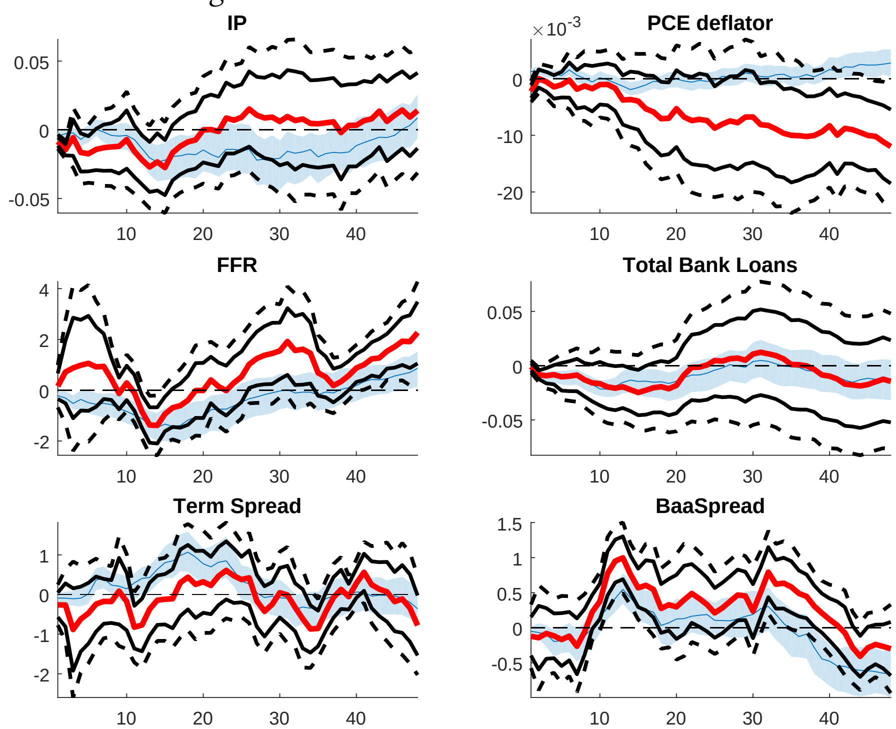
Figure 32: Robustness 9: Using an SVAR



Note: Reactions to a unitary shock to the CRI index (a tightening of capital requirements). Blue line gives the median, red dashed lines and blue shaded area give the 90% and 68% confidence bands, respectively. SVAR specifications as in text.

Figure 32 shows the impulse responses to a unitary innovation in the CRI (i.e. a regulatory capital-requirement tightening of standard size of 1) in the SVAR. We plot the median responses together with the 90% and 68% confidence bands (red dashed line and blue shade, respectively). The quantitative effects are comparable to our baseline specification, with total lending and industrial production declining by around 2%, the federal funds rate reacting by 100 basis points and significant reactions to term and Baa spread. However, under the SVAR the reaction of the inflation (the PCE deflator) is much smaller and less significant, and while the term spread reacts more strongly (increasing by around 100 instead of 50 basis points at the maximum), the reaction of the Baa spread is smaller (50 instead of 100 basis points). Still, overall the dynamics of the responses are quite similar, with the SVAR generally producing smoother reactions. Moreover, the statistical significance of our results improves: Total bank lending now is reduced at the 90% significance level on impact and mostly remains significant until more than 12 months after the capital tightening. Also the hike in the term spread now is significant at the 90% significance level. Figure 33 clarifies the similarity of responses by plotting the 68% confidence bands of the SVAR impulse responses together with the 68% and 90% bands for our baseline model. Except for inflation and the later policy rate, dynamics overlap to a large degree. Overall, we hold our findings to be robust to using a SVAR specification.

Figure 33: Robustness 10: SVAR vs. IVLP



Note: Reactions to a unitary shock to the CRI index (a tightening of capital requirements). Blue line gives the median, red dashed lines and blue shaded area give the 90% and 68% confidence bands, respectively. SVAR specifications as in text. Grey shaded area show the 68% confidence interval from the SVAR model, specified as described in the text. The lines show the impulse responses and confidence intervals from the baseline (instrumental-variable local projections, IVLP) model.

2.5 Conclusion

In this paper, we aim to fill a gap in the literature on the potential effects of macro-prudential capital requirement policies. So far, inference is drawn mainly from either microeconometric empirical studies neglecting dynamic and general-equilibrium effects, or from structural models depending heavily on the frictions and shocks included as well as the calibration used. We suggest a novel narrative indicator of aggregate regulatory capital requirement changes for the US from 1980M1 to 2016M8. The indicator includes six episodes of exogenous capital tightenings.

Using instrument-variable local projections of changes in this capital requirement indicator on various macro-financial variables, we conclude that aggregate capital tightenings lead to rather short-lived credit crunches and contractions in economic activity. In particular, banks reduce their credit supply for around 18 months, before permanently rising their capital levels and restoring lending. Industrial production falls by around 3 percentage points after 12 months before recovering, helped by monetary policy easing.

The lessons for macroprudential capital requirement policies seem clear: While there is a transitory cost associated with the introduction of higher capital levels, it seems not very high historically. However, it should be noted that our analysis cannot capture potential non-linearities associated with ever-higher levels of capital requirements. On the other hand, it could well be that better communication of macroprudential policies would reduce the transitory balance-sheet shrinking of banks once this tool is firmly established. With a Basel IV framework already being drafted, research on this topic is likely to continue for some time into the future.

3 Spoilt for Choice on QE? Which Assets to Purchase to Combat Disinflation

(single-authored)[58]

Keywords: Quantitative Easing, Business Cycles, Unconventional Monetary Policy
JEL classification: E32, E43, E58

[58]I thank Fabio Canova, Juan Dolado, Peter Karadi, Dominik Thaler and seminar participants at the European University Institute and Bundesbank for valuable comments and discussions.

3.1 Introduction

Motivation. On December 8, 2016, the ECB announced that its asset purchase programmes (APPs) would be extended to at least December 2017. By then, the APPs on the balance sheet of the European System of Central Banks (ESCB) will amount to more than €2.4trn, a stock worth around 22.4% of the euro area's 2016 annual nominal GDP. Purchases of public debt represent the lion share of the APPs (see Table 3 and Figure 50 in the Appendix), but the ESCB has additionally purchased covered bonds and asset-backed securities, and since June 2016 also corporate-sector bonds directly. The ECB homepage on APPs defines them as "includ[ing] all purchase programmes under which private sector securities and public sector securities are purchased to address the risks of a too prolonged period of low inflation"[59]. However, few studies have aimed to gauge the effect of these massive purchases on GDP and inflation for the euro area (EA). No structural model has yet aimed to distinguish between the asset classes that the ESCB is currently buying.

Table 3: Overview of the Asset Purchase Programmes by ESCB

Name	Assets targeted	Introduced on	€ mn (Jun. 2017)
[Round 1]			
Securities Markets Programme	public and private debt securities	10 May 2010	99,628
Covered bond PP 1	covered bonds	2 Jul. 2009	9,478
Covered bond PP 2	covered bonds	3 Nov. 2011	5,987
[Round 2]			
Public sector PP	government bonds	9 Mar. 2015	1,609,327
Covered bond PP 3	covered bonds	20 Oct. 2014	222,630
Asset-backed securities PP	securitised loans	21 Nov. 2014	24,135
Corporate sector PP	corp. sector bonds	8 Jun. 2016	96,620
Σ			1,952,712

Source: https://www.ecb.europa.eu/mopo/implement/omt/html/index.en.html

This paper aims to fill this gap by investigating differences in the purchases of

[59] see https://www.ecb.europa.eu/mopo/implement/omt/html/index.en.html

various asset classes, showing the main transmission mechanisms, and addressing the question as to which APP appears most effective in fighting disinflationary pressures. To do so, I build a DSGE model with a role for purchases of three assets (see also the beginning of Section 2 for a non-technical summary of the model). The three assets and the associated model frictions are:

1. Government bonds (as in the public-sector purchasing programme [PP] or PSPP), are held by banks and households. This gives purchases of government bonds a role through a bank balance-sheet channel (higher prices of bonds improve banks' balance sheets and allow them to lend out more, see e.g. Gertler and Karadi, 2013), and through a preferred-habitat channel (higher bond prices reduce the yield of bonds and thus of household savings, encouraging households to save less, see e.g. Ellison and Tischbirek, 2014, or Chen, Cúrdia, and Ferrero, 2012). There is a countervailing effect, as the purchases reduce a source of good collateral for banks (see next point), but this effect turns out to be quantitatively less important here.

2. Financial assets (as in the asset-backed security and third covered-bond PP or ABSPP and CBPP3), securitised by highly leveraged, specialised financial institutions which only deal with other banks. Their pooling of corporate loans or bonds gives the securitised assets a higher collateral value than the underlying loans or bonds themselves. Thus purchases of these securitised assets will improve bank balance sheets, but will also reduce the collateral available to banks, diminishing their lending capacity.

3. Private-sector loans or bonds (as in the corporate sector PP or CSPP), i.e. individual firms' borrowing from a bank in order to buy capital. The modelling of these bonds follows Gertler and Karadi (2011). Direct purchases of corporate bonds will increase their value and thus improve bank balance sheets. This allows banks to increase their leverage and lending, leading in turn to an investment-driven boom in the economy. Therefore, purchases of private-sector bonds represent the effects of a "pure" bank-balance sheet channel, against which the other purchases above can be measured.

To the best of my knowledge, my DSGE model is the first to capture these three distinct asset classes that are currently bought under the APPs. The model is then used to investigate which of the APPs has the best potential to stabilise inflation after a disinflationary shock in an environment characterised by a zero-lower bound, i.e. when conventional monetary policy is no longer applicable.

The results suggest that government bonds (as in the PSPP) are the most suitable asset class to stabilise inflation in such a situation. The reason is the relative strength of the preferred-habitat channel in stimulating households' consumption. Purchases of loans (CSPP) are more effective that those of financial assets (ABSPP, CBPP), as in my model the latter assets have a considerable collateral value for commercial banks. Thus, while purchases of securitised assets will increase their value, the reduction in volumes will be detrimental to commercial banks' leverage.

Related literature. There are many empirical papers investigating the effect of the US and UK quantitative easing (QE) programmes after the crisis, and some for the EA case. For the US, the main programmes were the Large-Scale Asset Purchases (LSAPs) by the Federal Reserve from November 2008 to March 2010.[60] The Bank of England's Asset Purchase Facility were in operation from March 2009 to February 2010.[61] Papers like Lenza, Pill, and Reichlin (2010), Christensen and Rudebusch (2012), Baumeister and Benati (2013), and Weale and Wieladek (2016) compare evidence from both US and UK. For the EA, Giannone, Lenza, Pill, and Reichlin (2012) investigate the first round of asset purchases and Altavilla, Carboni, and Motto (2015) the second, larger round of APPs. See also Den Haan (2016) for a survey.

The consensus of the empirical literature on the asset-purchasing programmes is threefold: First, they did have an impact on GDP and inflation, and have cushioned the effect of the Great Recession in the countries that enacted measures. Second, however, this effect seems small and strongest in times of acute financial

[60]See e.g. in Krishnamurthy and Vissing-Jorgensen (2011; 2013), Gagnon, Raskin, Remache, and Sack (2011), Hamilton and Wu (2012), or Chung, Laforte, Reifschneider, and Williams (2012).

[61]See for example Meaning and Zhu (2011), Joyce, Lasaosa, Stevens, and Tong (2011), Joyce and Tong (2012), Kapetanios, Mumtaz, Stevens, and Theodoridis (2012), and McLaren, Banerjee, and Latto (2014).

distress. Third, purchases potentially affects the macro-economy through several channels:[62]

- A **signalling channel**, i.e. the idea that APPs send a signal about an extended period of dovish monetary policy. This channel is somewhat hard to distinguish from forward guidance and usually not modelled explicitly; however, one of its predictions should be that the shorter yield spectrum is affected more strongly than the longer one as the central bank finds it easier to commit to the near than the distant path of its policy.[63]

- The **local supply** or **scarcity channel** proposes that as assets are not perfect substitutes for one another (in particular in times of financial distress and market malfunctioning), a decline in the supply of certain asset classes will bid up their price and reduce their yield.

- In contrast to the local supply channel, the **portfolio rebalance channel** (Tobin, 1961 and 1969) suggests that financial markets will disseminate lower yields from the assets targeted under QE to other asset classes as well.[64] According to the related **duration channel**, effects should be strongest for longer maturities because their yields are more sensitive to changes in the short-term rate.

- Finally, the **credit premium** or **bank balance-sheet channel** suggests that by easing the balance-sheet constraint of leveraged market participants,

[62]This follows Altavilla et al. (2015), however, I stress the close relation of portfolio rebalance and duration channel. See also Bauer and Rudebusch (2014) on the signalling channel and D'Amico and King (2013) on the local scarcity channel.

[63]I will not investigate this channel below, although it could be included as a time-varying risk premium on the return on capital (which gets reduced by purchases) in a potential estimation of the model. See footnote 72 on page 99.

[64]When announcing the PSPP on January 22, 2015, ECB President Draghi referred to this channel when saying that the APP would "substitute bonds with cash, and therefore banks, at that point, will have more incentive to lend to the private sector, households and companies" (ECB press conference, January 22, 2015, https://www.ecb.europa.eu/press/pressconf/2015/html/is150122.en.html). However, ECB Board member Benoît Cœuré has hinted also at a scarcity, duration and signalling channel as potential transmissions for PSPP (in an interview on March 10, 2015 https://www.ecb.europa.eu/press/key/date/2015/html/sp150310_1.en.html).

QE will compress credit premia required by these leveraged arbitrageurs and thereby facilitate the functioning of financial markets (see e.g. Draghi, 2016a,b). Besides this direct effect, the credit spread reductions ease investment and stimulate aggregate demand, giving rise to a feedback loop or **general equilibrium effect** as the probability of default declines and further reduces risk premia.

In my model, purchases of all three assets will affect the economy through the bank-balance sheet channel (purchases increase the prices of assets, which restores banks' balance sheets and allows them to lend out more, which increases investment and thus output). An opposite effect derives from the reduction of good collateral in the case of purchases of government debt and securitised assets. Enabling the commercial bank in the model to equate asset returns (or not) allows me to gauge the importance of a local-supply channel (versus a portfolio-rebalancing channel). I do not find that the difference has large effects on the model dynamics. Moreover, by the fact that households also hold government debt I can allow for a preferred-habitat effect on households' savings decision, which turns out to be very important for the relatively large effect of public-debt purchases on inflation.

The paper is structured as follows: Section 3.2 outlines the model and Section 3.3 its calibration. Section 3.4 presents some initial results, while Section 3.5 examines the effectiveness of asset purchases in alleviating disinflationary pressures under a zero-lower bound environment. Section 3.6 concludes.

3.2 The model

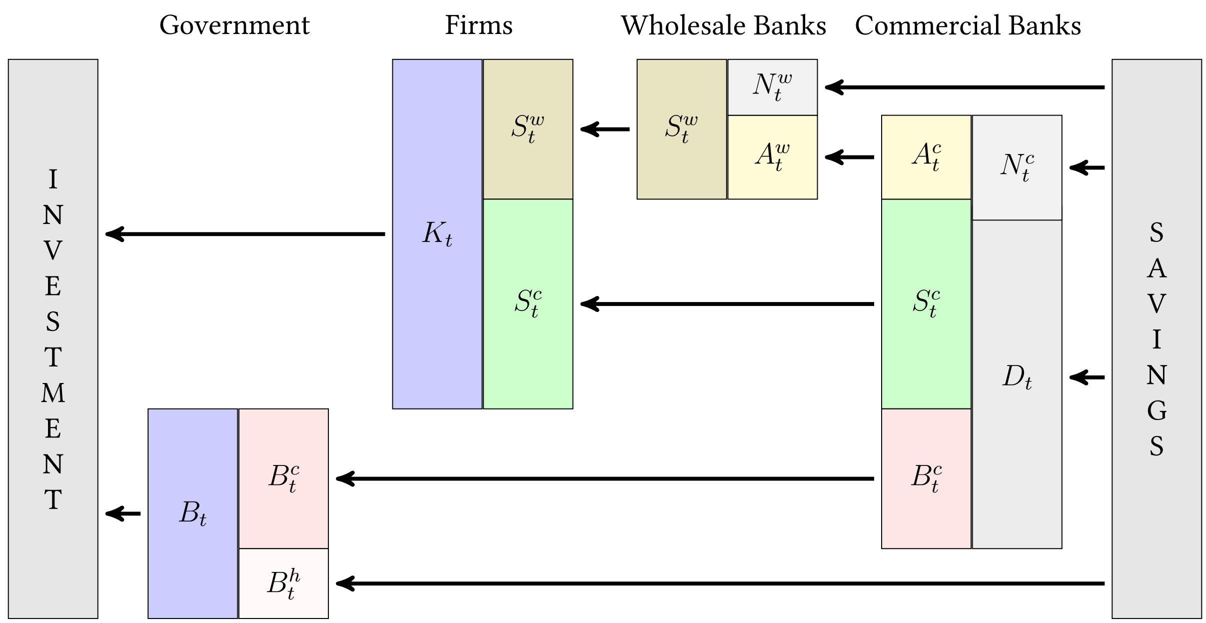
This section presents the setup of my model. I try to keep it as small as possible, but include what is needed to distinguish the three asset classes meaningfully. The behaviour of households and firms is standard. A competitive capital-producer subject to adjustment costs creates a price for capital. To allow for the analysis of nominal variables like inflation, I include a retail sector with some market power. On the other hand, my model does not include labour market frictions and has a closed-economy setting, which reflects a choice for parsimony.[65]

In order to break the irrelevance result for central-bank asset purchases by Wallace (1981), I introduce two frictions: First a moral-hazard friction à la Gertler and Karadi (2011), implying that bankers can divert funds, which will lead to an endogenous bank balance-sheet constraint.[66] The main bank in the model, the "commercial bank", will hold three assets on its balance sheet: firm bonds or loans, securitised financial assets created by specialised "wholesale banks", and government debt. The wholesale bank introduces heterogeneity into bank lending to firms: It operates under higher leverage, can adjust its balance sheets more quickly and the securitised assets it creates are better collateral for commercial banks than firm loans. While the government bonds are also better collateral, they have another peculiarity: Households use them to save besides bank deposits, and bonds and deposits are assumed to be imperfect substitutes to households, even though both deliver a safe return. This allows purchases of government bonds to have a stimulatory effect on the economy both by a bank-lending or credit-premium channel (as they improve commercial banks balance sheet situation) and by a preferred-habitat channel: As households have preferences as to always save via public debt to some degree, reduced yields on government bonds by central-bank purchases will induce them to save less and spend more instead.

[65]One would expect both frictions to increase the effectiveness of asset purchases (whose inflationary effect would lighten labour market rigidity and reduce the real exchange rate), so my results can maybe be seen as a lower bound of the stimulatory effect of APPs. Also note that publications like De Santis (2016) and Bundesbank (2016) mention the exchange-rate channel of the APPs, but to my knowledge no structural model investigates it.

[66]Cúrdia and Woodford (2011) and Gertler and Kiyotaki (2010) are other early contributions including a role for asset purchases in DSGE models.

Figure 34: Balance sheet for firms, commercial and wholesale banks and government



Note: D deposits; S loans; A assets; N net worth; B gov. bonds; K capital; see text for details [graph not to scale of calibration].

The financial frictions that give a role to the different asset classes in the model are shortly discussed upfront in a non-technical manner. Figure 34 shows the transmission of household savings (in the form of deposits D_t) into investments (in the form of capital K_t or government bonds B_t) via the balance sheets of the financial-sector agents (to be read from right to left). As the net worth of both commercial and wholesale banks, N_t^c and N_t^w, is finally consumed by households, it also represents savings in a larger sense. Commercial banks finance loans to firms S_t^c, and holdings of bonds B_t^c and financial assets A_t^c, by their net worth N_t^c and deposits D_t. A costly-enforcement problem due to the possibility that bankers divert funds leads to endogenously determined constraints on their balance sheets and a financial accelerator through changes in their balance sheet composition. Note that there are no defaults of these loans in the model,[67] and that there will be

[67] See Kuehl (2016) for a contribution that does model firm loans with default.

no difference between firm loans or bonds for simplicity. In fact, I will call S_t^c both "loans" and "(corporate) bonds" interchangeably below. Moreover, financial assets A_t^w are created by wholesale banks from securitised loans or bonds S_t^w, and held by commercial banks as A_t^c. Firm capital K_t must consist of either direct loans S_t^c or securitised borrowing, S_t^w. K_t and government debt B_t are the only types of final investment.

In the following, the model is outlined in detail. Derivations of first-order conditions, as well as an overview of all model equations in levels and log-linearised form can be found in Appendices C.1, C.2 and D.

3.2.1 Households

Households save via both bank deposits and domestic bonds.[68] Their savings preferences are represented by a CES composite index over deposits D_t and bond holdings B_{ht}:

$$\text{Sav}_t = \left[\kappa_s^{\frac{1}{\epsilon_s}} D_t^{\frac{\epsilon_s - 1}{\epsilon_s}} + (1 - \kappa_s)^{\frac{1}{\epsilon_s}} (B_t^h)^{\frac{\epsilon_s - 1}{\epsilon_s}} \right]^{\frac{\epsilon_s}{\epsilon_s - 1}},$$

where κ_s is the steady-state share of bonds in savings Sav_t, and ϵ_s the elasticity of substitution between the two assets. The aggregate return on savings is given by the identity

$$R_{ht}\text{Sav}_t = R_t D_t + R_{bt} B_t^h,$$

where R_{ht}, R_t and R_{bt} are the (safe) gross real return on household savings, deposits and government bonds.[69] Note that these savings preferences induce households always to hold some part of their savings in domestic bonds. Thus, purchases of bonds by the central bank, which drive up their price and lower their yield R_{bt}, will induce households to save less. This effect will be bigger, the smaller κ_s, and

[68] The latter is justified by the fact that life insurance schemes and pension funds savings, which constitute a large part of household savings, are largely based on government bond holdings in the EA (see the calibration below).

[69] I will denote gross interest rates/returns by capital letters and net interest ones by small letters throughout.

the more inelastic households' bond demand, i.e. the smaller ϵ_s.

Households solve the problem[70]

$$\max_{C_t, L_t, \text{Sav}_t} \sum_{t=0}^{\infty} \beta^t x_{dt} \left(\frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \chi x_{lt} \frac{L_t^{1+\varphi}}{1+\varphi} \right) \tag{8}$$

$$\text{s.t. } C_t + \text{Sav}_t + T_t = w_t L_t + R_{ht-1}\text{Sav}_{t-1} + \Pi_t. \tag{9}$$

The household receives utility from consumption C_t, subject to external habits at degree h, and disutility from supplying hours or labour L_t. β is its discount factor, σ its inter-temporal elasticity of substitution of consumption, φ the inverse Frisch elasticity and χ is a disutility parameter that helps pin down the steady state of L_t. Utility in every period is subject to an exogenous AR(1) shock to inter-temporal preferences, x_{dt} (reducing patience and spurring consumption at the expense of savings and investment), and to intra-temporal preferences, x_{lt} (a "labour supply shock" shifting the consumption/leisure trade-off towards leisure).[71]

The budget constraint for households (in real terms) further specifies their behaviour: Besides consuming and saving, households receive lump-sum transfers T_t from the government and central bank. Households finance their expenditures by (real) wage income $w_t L_t$, the returns from savings, $R_{ht-1}\text{Sav}_t$, and the combined profits of retailers, capital producers, and banks, Π_t.

3.2.2 Productive firms

Competitive firms combine existing capital K_{t-1} and labour L_t to create output Y_{pt} according to a Cobb-Douglas production function with capital share α and subject to a stochastic AR(1) variation in total factor productivity x_{pt}:

$$Y_{pt} = x_{pt} K_{t-1}^{\alpha} L_t^{1-\alpha} \tag{10}$$

[70] All first-order conditions and resulting model equations are derived in Appendix C.1.
[71] All shock processes are outlined in Subsection 3.2.10.

They rent capital K_{t-1} at the (net) real return of productive capital r_{pkt} and sell their output Y_t to the retailer at price P_{pt}, solving the profit maximisation problem

$$\max_{K_{t-1},L_t} P_{pt}Y_{pt} - r_{pkt}K_{t-1} - w_t L_t \text{ s.t. (10)}$$

A firm buys its capital stock from the capital producer and finances the purchase via bank loans S_t from banks commercial and wholesale banks (loans are idiosyncratic from the firm's perspective). As returns on capital are perfectly observable for the commercial bank, the firm can pledge all its returns on capital to the banks. While its outlays for the productive capital stock in period $t-1$ will be $Q_{st-1}K_{t-1}$ (where Q_{st} is the price of capital), its returns in t are $[(1-\delta)Q_{st} + r_{pkt}]K_{t-1}$. This defines the gross return on capital as[72]

$$R_{st} = \frac{(1-\delta)Q_{st} + r_{pkt}}{Q_{st-1}}. \tag{11}$$

3.2.3 Capital producers

Capital producers are owned by households, thus discounting at ϱ_t. At the end of period t, they obtain non-depreciated old capital $(1-\delta)K_{t-1}$ from the firms, mend it with the consumption good and sell the new capital K_t back to the firms. They undergo a cost of unity for this mending, implying investments of size I_t, subject to an investment-specific technology shock x_{it} as in Justiniano, Primiceri,

[72] In a potential estimation, one could include a risk-premium term η_t here to capture announcement or signalling effects that might affect investment over and above the bare fundamentals. Eq. (11) would become

$$R_{st} = \frac{(1-\delta)Q_{st} + r_{pkt}/\eta_t}{Q_{st-1}},$$

where the risk premium could be affected by asset purchases as

$$\log(\eta_t) = -\psi_s S_t^g - \psi_b B_t^g - \psi_a A_t^g.$$

So for $\psi_i > 0$, $i \in \{s, b, a\}$, asset purchases will lower the risk premium, giving asset purchases an additional expansionary effect via a not further specified "market sentiment" or "signalling" channel. This possibility is, however, not pursued in the following.

and Tambalotti (2011):

$$K_t = x_{it} I_t + (1-\delta) K_{t-1} \tag{12}$$

New capital trades at price Q_{st} as there are quadratic adjustment costs when changing the level of investment I_t from its level in the previous period, so the capital producers solve

$$\max_{I_t} \; E_t \left\{ \sum_{t=0}^{\infty} \beta^t \frac{\varrho_t}{\varrho_0} \left[Q_{st} - 1 - \frac{\chi_I}{2} x_{it} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \right\}.$$

3.2.4 Retailer

The retailer is owned by the households, so it shares their discounting settings. It buys output from the productive firm at price P_{pt} and transforms it into a retail good without incurring any cost. Due to monopolistic competition, a retailer z has some pricing power when setting its price $P_t(z)$ according to the demand $Y_t(z)$. Specifically, I assume the demand function

$$Y_t(z) = (P_t(z)/P_t)^{-\epsilon_p} \, Y_t,$$

where Y_t is total demand and ϵ_p the price elasticity of substitution between goods. Nominal price-setting frictions arise from retailers being able to adjust their price only with probability $(1-\gamma)$, while indexing it to lagged inflation at degree κ_p if no resetting is possible. The retailer thus resets its price optimally at P_t^* solving

$$\max_{P_t^*} \; E_0 \left\{ \sum_{i=0}^{\infty} \gamma^i \beta^i \frac{\varrho_{t+i}}{\varrho_0} \left[\frac{P_t^*}{P_{t+i}} \prod_{j=1}^{i} (1+\pi_{t+j-1})^{\kappa_p} - P_{pt+i} \right] \left(\frac{P_{t+i}(z)}{P_{t+i}} \right)^{-\epsilon_p} Y_t \right\}. \tag{13}$$

3.2.5 Commercial banks

Some household members become commercial bankers every period. As bankers, they cannot consume, but will maximise their bank's net worth. With some exogenous probability, bankers retire back to being households and consume their whole net worth.[73] Commercial banks manage households' deposits and guarantee a safe return R_t on them. Bank j operates by combining its net worth (or equity) $N_t^c(j)$ with deposits $D_t(j)$ borrowed at gross rate R_t, in order to finance loans to firms and the holding of bonds and financial assets. Since there is no friction between firms and commercial banks, the value of its loans $S_t^c(j)$ corresponds to the value of capital, Q_{st}. Moreover, bank j holds bonds $B_t^c(j)$ at price Q_{bt} and buys financial assets $A_t^c(j)$ from the wholesale bank (see below) at price Q_{at}. The balance sheet identity for any commercial bank equates its balance-sheet assets (loans, bonds and financial assets) to its liabilities (deposits and net worth):

$$Q_{st}S_t^c(j) + Q_{bt}B_t^c(j) + Q_{at}A_t^c(j) = D_t(j) + N_t^c(j) \tag{14}$$

The commercial bank cannot raise new equity to increase its net worth, so $N_t^c(j)$ only grows through retained earnings. As there is no friction between firms and commercial banks, the later earn the stochastic (gross) return on capital R_{st+1} on loans $S_t^c(j)$. Moreover, they earn a return R_{bt+1} from bonds $B_t^c(j)$ and R_{at+1} from financial assets $A_t^c(j)$. The law of motion of an existing commercial bank j's net worth is given by

$$N_{t+1}^c(j) = R_{st+1}Q_{st}S_t^c(j) + R_{bt+1}Q_{bt}B_t^c(j) + R_{at+1}Q_{at}A_t^c(j) - R_tD_t(j) \tag{15}$$

In the following, I will neglect the qualifier j and directly use the fact that all commercial banks are symmetric in equilibrium and can be treated as one aggregate commercial bank. The return on government bonds and assets is given by

$$R_{bt} = \frac{r_b + Q_{bt}}{Q_{bt-1}} \tag{16}$$

$$R_{at} = \frac{r_a + Q_{at}}{Q_{at-1}}. \tag{17}$$

[73]This assumption rules out that banks' net worth grows large enough to fully finance their operations.

Define the commercial-bank leverage of bank loans over net worth as

$$\phi_t^c = \frac{Q_{st} S_t^c}{N_t^c} \tag{18}$$

Now we come to the frictions that give a role to financial intermediation in the first place. The central assumption is a moral-hazard problem as in Gertler and Karadi (2011): Commercial bankers can choose to transfer ("divert") the deposits they receive back to their households. Depositors will then force the banker into bankruptcy and recover some of the assets, but a share λ_c of the diverted deposits cannot be recovered due to costly enforcement. This will lead to an endogenous bank leverage, as banks will only receive deposits up to an incentive-compatibility constraint, eq. (20) below. The second important assumption adds a role for B_t^c and A_t^c: I assume that depositors consider both bonds and financial assets as better collateral against fund diversion than loans. That assumption can be justified by the more liquid nature of assets like bonds or securitised loans as compared to firm loans, whose valuation may be possible only for the commercial banks which have a close client relationship with the firms.[74] This implies that banks have an additional value of holding these assets instead of loans on their balance sheet: As B_t^c and A_t^c are harder to divert, they can be pledged to depositors to a higher degree, allowing banks to operate under higher leverage and thus increasing their profits.

Technically, I assume that bonds B_t^c and financial assets A_t^c have an additional collateral value Δ_b and Δ_a, respectively. The agency problem in combination with the higher collateral value of assets leads to the incentive compatibility constraint (20) below: The continuation value of the bank has to be at least as large as the share λ_c of loans and financial assets that can be diverted, where it is harder for bankers to divert bonds and assets by a factor Δ_b and Δ_a, respectively.

Bankers operating the commercial bank have the sole objective of maximising

[74]See Gertler and Karadi (2013). Meeks, Nelson, and Alessandri (2014, p. 14) state further arguments why this assumption seems justified for the case of asset-backed securities. Here, this higher collateral value can be motivated by the fact that government debt B_t^c is generally less prone to default than corporate debt, and by interpreting A_t^c as a pool of firm loans whose return is more easily observed by the public.

the discounted net worth of the bank.[75] A commercial bank's value function thus is

$$\mathcal{V}_t^c = \max_{S_t^c, B_t^c, A_t^c} E_t \left\{ \sum_{t=0}^{\infty} (1-\theta_c)\theta_c^t \beta^t \frac{\varrho_{t+1}}{\varrho_t} N_{t+1}^c \right\} \tag{19}$$

$$\text{s.t. } N_{t+1}^c = R_{st+1} Q_{st} S_t^c + R_{bt+1} Q_{bt} B_t^c + R_{at+1} Q_{at} A_t^c - R_t D_t \tag{15}$$

$$\mathcal{V}_t^c \geq \lambda_c \left[Q_{st} S_t^c + \Delta_b Q_{bt} B_t^c + \Delta_a Q_{at} A_t^c \right] \tag{20}$$

This means a commercial bank maximises the net worth of its members which go back to households every period (a share $1-\theta_c$), subject to the evolution of net worth (15) and the incentive-compatibility constraint that its continuation (or "going-concern") value $\mathcal{V}_t^c$ is at least as large as the value of assets that can be diverted, eq. (20). We can employ a guess-and-verify approach to show that the going-concern value $\mathcal{V}_t^c$ can be re-written as a function that is linear in $Q_{st}S_t^c$, $Q_{bt}B_t^c$, $Q_{at}A_t^c$ and N_t^c:

$$\mathcal{V}_t^c = \mu_{st} Q_{st} S_t^c + \mu_{bt} Q_{bt} B_t^c + \mu_{at} Q_{at} A_t^c + \nu_t N_t^c,$$

where μ_{st}, μ_{bt}, μ_{at} and ν_t are the discounted expected values of expanding the existing commercial banks' loans (μ_{st}), bonds (μ_{bt}), financial assets (μ_{at}) and net worth (ν_t) by a marginal unit, respectively, holding the other items constant (see Appendix C.1 for a detailed derivation). This allows us to rewrite the incentive compatibility constraint as

$$\phi_t^c \leq \frac{\nu_t}{\left(1 + \Delta_b \frac{Q_{bt} B_t^c}{Q_{st} S_t^c} + \Delta_a \frac{Q_{at} A_t^c}{Q_{st} S_t^c}\right)(\lambda_c - \mu_{st})}$$

Intuitively, the equation specifies that *ceteris paribus* the endogenous commercial bank leverage will be higher when the marginal value of net worth, ν_t is high. It will be lower when the fraction of assets that can be diverted, λ_c, is high, but this effect will be attenuated when banks have incentives to remain in business due to

[75] In fact, this setup is equivalent to banks maximising dividend payments for the case that these are only feasible with an exogenous probability θ_c every period.

a high marginal value of loans, μ_{st}. The reason why the marginal values of bonds and assets, μ_{bt} and μ_{at}, do not show up in this equation is that in equilibrium firms will always choose to hold bonds and assets as to keep μ_{bt} and μ_{at} as a constant fraction of Δ_b and Δ_a of μ_{st}, respectively. This is due to the following arbitrage conditions:

$$\mu_{bt} = \Delta_b \mu_{st}$$
$$\mu_{at} = \Delta_a \mu_{st}$$

So the bank will hold assets such that the net value of the assets on its balance sheet will co-move at a ratio that is determined by the degree of asset pledgeability. This optimal adjustment of balance-sheet assets will equate returns between asset groups perfectly in the absence of further frictions, as suggested by the portfolio-rebalancing channel. However, there is empirical evidence for the existence of a local-scarcity channel (under which asset returns are not fully equated): Altavilla et al. (2015) show that the announcements of APPs by the ESCB affect the spreads of various asset classes differently (see the calibration in Section 3.3 below). Therefore, I introduce a wedge into the arbitrage conditions above by assuming a diversion premium in the collateral value of an asset that decreases in the amount of it purchased: Δ_j will be higher (i.e. it will be relatively harder to divert asset j), the more of it is purchased.[76] I introduce this premium as

$$\Delta_{bt} = \Delta_b \exp\{\eta_b B_t^g - \eta_{sb} S_t^g\} \tag{21}$$

$$\Delta_{at} = \Delta_a \exp\{\eta_a A_t^g - \eta_{sa} S_t^g\} \tag{22}$$

Thus, when the central buys government bonds B_t^g or a securitised asset A_t^g, it will also increase this asset's collateral value (i.e. of B_t^c or A_t^c) relative to loans S_t^c,

[76]This assumption of a diversion premium is a simple way to introduce differences in yields resulting from purchases. A microeconomic underpinning could be that government purchases will raise public attention to the assets bought, making them harder to divert. Alternatively, the market perception of the safety of the assets might be raised, allowing firms to intermediate more deposits for each unit of the asset held on its balance sheet. The result in any case is a divergence of spreads, with the spread decreasing more for the asset that is being purchased. This prohibits a perfect rebalancing of bank portfolios and gives rise to the local-scarcity effect of purchases.

which increases the spread of the asset and makes it more worthwhile to hold on the commercial bank's balance sheet. Similarly, when the central bank purchases loans S_t^g, the relative collateral value of B_t^c and A_t^c will diminish.

Finally, note that the aggregate law of motion of commercial bank net worth deviates slightly from the net worth of *existing* commercial banks, equation (15): Only a fraction θ_c of bankers continues from one period to the other, carrying over the last period's net worth grown according to (15). The existing net worth is subject to a valuation shock x_{nt}, representing a disturbance to the financial sector itself as after 2007. Moreover, there are transfers from households to new entrants into the commercial banking business. Like Gertler and Karadi (2011), I assume that these transfers equal a constant fraction ω_c of existing banks' loans and financial assets:[77]

$$\begin{aligned} N_t^c = \theta_c\big[&(R_{st} - R_{t-1})Q_{st-1}S_{t-1}^c + (R_{bt} - R_{t-1})Q_{bt-1}B_{t-1}^c \\ &+ (R_{at} - R_{t-1})Q_{at-1}A_{t-1}^c + R_{t-1}N_{t-1}^c\big]/x_{nt} \\ &+ \omega_c(Q_{st}S_{t-1}^c + Q_{bt}B_{t-1}^c + Q_{at}A_{t-1}^c) \end{aligned} \tag{23}$$

3.2.6 Wholesale banks

While commercial banks are a stand-in for the more "standard" savings banks in Europe, wholesale banks are an umbrella concept capturing specialised services within the financial sector. In particular, wholesale banks are supposed to capture any financial intermediation creating assets "held for trading" or held-to-maturity outside of the originating institution.[78] Their existence allows for some heterogeneity within the banking sector: Wholesale banks do not deal with households

[77]Note that in Meeks et al. (2014), transfers occur at last period's market price for loans, Q_{jt-1}, instead.

[78]The modelling of this type of securitising bank goes back to Meeks et al. (2014). For example, one could imagine wholesale banks as traders originating and distributing specialised corporate bonds (valued by banks due to their superior collateral value, e.g. due to their higher liquidity). Alternatively, we could picture them as shadow banks creating securitised assets from commercial banks' loans, an interpretation taken e.g. in Meeks et al. (2014). In this case, the higher collateral value derives from the fact that under securitisation, several loans are bundled, so that a potential lemons problem becomes attenuated. Yet another interpretation could be as equity-financed hedge funds or funds of funds whose shares are held by commercial banks.

directly, have a higher leverage than commercial banks and survive with a lower probability ($\theta_w < \theta_c$), which makes their net worth react faster to shocks. Also, they generate the third type of assets: Be they covered bonds or securitised loans, these assets are more liquid than loans and therefore a better collateral.

Analogous to above, some household members become wholesale bankers every period. Like commercial bankers, wholesale bankers have the sole objective of maximising final net worth, but they operate with a different technology: They are experts in creating liquid financial assets based on corporate debt, and selling them to the commercial banks. Wholesale banks' balance sheet assets S_t^w (newly acquired bonds, non-securitised loans, direct investments via hedged funding) priced at Q_{st}, are equal to their liabilities, financial assets A_t^w originated and distributed to the commercial banks at price Q_{at}, and the wholesale bank net worth N_t^w (I aggregate over individual banks at once):

$$Q_{st} S_t^w = Q_{at} A_t^w + N_t^w \tag{24}$$

Wholesale bank leverage is defined as balance-sheet assets over net worth

$$\phi_t^w \equiv \frac{Q_{st} S_t^w}{N_t^w}. \tag{25}$$

The wholesale bank's value function is

$$\mathcal{V}_t^w = \max_{S_t^w} E_t \left\{ \sum_{t=0}^{\infty} (1-\theta_w) \theta_w^t \beta^t \frac{\varrho_{t+1}}{\varrho_t} N_{t+1}^w \right\} \tag{26}$$

$$\text{s.t. } N_{t+1}^w = (R_{st+1} - R_{at}) Q_{st} S_t^w + R_t N_t^w$$

$$\mathcal{V}_t^w \geq \lambda_w Q_{st} S_t^c$$

This means that analogous to commercial banks, wholesale banks maximise the consumption by retiring bankers (at retirement rate $1-\theta_w$), subject to a law of motion of (individual) net worth $N_t^w(j)$ and an incentive-compatibility constraint prescribing that the value of the bank operations $\mathcal{V}_t^w$ be larger than the bank loans that can be diverted. As above, we can use a guess-and-verify approach to show that $\mathcal{V}_t^w$ can be re-written as a linear function of $Q_{st} S_t^w$, $Q_{at} A_t^w$ and N_t^w (again see Appendix C.1). Moreover, wholesale banks are also subject to an endogenous balance sheet constraint: Their bankers can divert funds like commercial bankers. However, I assume that the fraction of diverted funds that cannot be recovered, λ_w, is lower than for commercial banks, leading to a less costly enforcement problem and a higher leverage for wholesale banks. This assumption can be justified both intuitively (wholesale bankers operate in more formalised markets, e.g. the bond market) and empirically: The leverage ratios of commercial banks are lower than those for more specialised financial intermediaries.[79] As above, an incentive compatibility constraint ensures that leverage is contained such that the continuation value of wholesale banks surmounts the gains from diversion:

$$\phi_t^w = \frac{\nu_t^w}{\lambda_w - \mu_t^w}, \tag{27}$$

where ν_t^w and η_t^w are the discounted expected value of expanding the existing wholesale bank balance-sheet assets $Q_{st}S_t^w$ and net worth N_t^w by a marginal unit, respectively, while holding the respective other constant (see Appendix C.1).

Net worth can only be increased by retaining earnings from the share of non-retiring wholesale bankers, θ_w. Moreover, entering bankers obtain a constant share ω_w of total intermediated funds in the wholesale banking sector $Q_{st}S_{t-1}^w$, so that the law of motion for aggregate wholesale-bank net worth is given as

$$N_t^w = \theta_w[(R_{st} - R_{at})\phi_{t-1}^w + R_{at}]N_{t-1}^w + \omega_w Q_{st}S_{t-1}^w. \tag{28}$$

[79]For example, the ratio of total assets/liabilities to capital and reserves between 2010 and 2016 is 13.72 for Credit Institutions, but 59.81 for Financial Vehicles (Source: ECB Statistical Warehouse Database). The corresponding model assumption is that wholesale bankers' ability to divert assets, i.e. the relative share that can be diverted λ_w, is lower than that for commercial banks. One possible motivation is that as wholesale banks deal with other bankers and not households, their counterparties will be harder to steal from. The assumption that their net worth reacts faster to shocks is due to the fact that shadow banks and hedge funds in reality largely rely on other banks and investors for the funding of their net worth. This funding can be withdrawn at short notice, leading to more unstable funding than that of commercial banks' capital (see Doyle, Hermans, Molitor, and Weistroffer, 2016).

3.2.7 Monetary policy

The central bank has two roles in the model: Under conventional monetary policy, it sets the nominal return on short-term bonds,

$$R_{pt} = R_t \cdot \pi_{t+1}$$

according to a Taylor rule with the objective of stabilising inflation around a target (or steady-state) inflation level of π. I assume that the policy reaction is persistent at degree ρ_R, and that a shock x_{rt} captures surprise actions by conventional monetary policy:

$$R_{pt} = R_{pt-1}^{\rho_R} \left[R_p \cdot \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \right]^{1-\rho_R} x_{rt} \tag{29}$$

Moreover, the central bank has several options for unconventional monetary policy: It can buy government debt B_t^g, acquire financial assets A_t^g or directly intermediate loans S_t^g. These purchases can be modelled in two ways: First, as an exogenous AR(1) shocks, like x_{st} in the case of loan purchases. Second, purchases can be undertaken as a reaction function to a fall in inflation, to proxy the motivation behind ESCB's current APPs. This gives purchases as

$$S_t^g = -\Psi_{\pi s}(\pi_t - \pi) + K \cdot x_{st} \tag{30}$$

$$B_t^g = -\Psi_{\pi b}(\pi_t - \pi) + B \cdot x_{bt} \tag{31}$$

$$A_t^g = -\Psi_{\pi a}(\pi_t - \pi) + A^w \cdot x_{at}. \tag{32}$$

Note that I will shut off the reactions functions ($\Psi_{\pi j} = 0$) if not otherwise stated.

The central bank refinances these purchases by increasing reserves for the banks. Reserves get the same return as deposits and cannot be diverted, so that they enlarge banks' balance sheet without affecting leverage.[80] The asset-purchases generate seigniorage, which is redistributed to households in the form of lump-sum transfers. There is a potential efficiency cost $\tau_p > 0$ for the central bank to

[80] See Gertler and Karadi (2013), pp. 22f., for why this would be equivalent to assuming the central bank finances purchases by issuing some short-term debt directly to households.

hold any of the assets, reflecting potentially less efficient intermediation by central bankers than banks (see the goods market clearing condition below). Finally, the (quarterly) APPs affect the size of the central bank balance sheet $CBBS_t$ relative to steady state annual GDP as

$$BS_t \equiv \frac{CBBS_t}{4 \cdot Y} = \frac{Q_{st}S_t^g + Q_{bt}B_t^g + Q_{at}A_t^g}{4 \cdot Y}. \tag{33}$$

3.2.8 Welfare

As bankers only can consume their net worth once returned to the households, overall welfare is given by a value function for households' per-period utility, (8). Households derive utility from consumption and leisure as specified above, and discount future welfare by the discount factor β:

$$\mathcal{W}_t = x_{dt} \left(\frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \chi \frac{L_t^{1+\varphi}}{1+\varphi} \right) + \beta \mathcal{W}_{t+1}. \tag{34}$$

3.2.9 Market clearing

Productive firms' total capital stock will equal the lending to them via loans S_t^c, bonds or securitised loans S_t^w and direct government intermediation S_t^g:

$$K_t = S_t^c + S_t^w + S_t^g \tag{35}$$

The supply for long-term assets is fixed at B. Markets for bonds and financial assets clear:

$$B = B_t^c + B_t^h + B_t^g \tag{36}$$

$$A_t^w = A_t^c + A_t^g \tag{37}$$

Finally, goods markets clear: Output is used on private and (exogenous) government consumption, investment, adjustment costs for capital producer, and the central bank cost of intermediating bank balance sheet items:

$$Y_t = C_t + I_t \left[1 + \frac{\chi_I}{2} x_{it} \left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] + G_t + \tau_p \left(S_t^g + A_t^g + B_t^g\right) \tag{38}$$

3.2.10 Shocks

The shocks to inter-temporal preferences ("preference shock") and intra-temporal preferences (labour-supply shock), total factor productivity, investment technology, commercial banks' net worth, monetary policy, government consumption, and the three types of asset purchases ($j \in \{s, b, a\}$) follow AR(1) processes:[81]

$$\log(x_{jt}) = \rho_j \log(x_{jt-1}) + \sigma_j \varepsilon_{jt} \qquad \forall j \in \{d, l, p, i, n, r, g, s, b, a\} \tag{39}$$

3.3 Calibration

Non-financial sectors. I calibrate the model to quarterly EA data for the ZLB episode (2009Q1 to 2015Q4); all calibrated parameters are summarised in Table 4. Some "standard" DSGE model parameters – elasticity of consumption σ, habit parameter h, inverse Frisch elasticity φ, Calvo parameter γ – are taken from the posteriors of Smets and Wouters (2003). Although their paper does not include financial frictions, its core model is very similar to mine, the data are comparable and the values are in line with other models estimated for the EA like Christoffel, Coenen, and Warne (2008). However, due to the lack of additional financial frictions, I set the (quarterly) investment adjustment costs χ_I to 3, a value lower than their suggest 6.77, but larger than the 1.728 in Gertler and Karadi (2011). The capital share α is set to the value of 0.4 and the Frisch elasticity to 0.276. The degree of retailer price indexation κ_p is set to zero. As deposit rates during 2009-14 were far below the value of 4% p.a. implied by the standard discount factor of $\beta = 0.99$, I choose them to take a lower 2%, yielding $\beta = 0.995$. The depreciation rate is set to $\delta = 0.025$. The government share G/Y is calibrated to 0.196 in line with data from the area-wide model, see Appendix D.2. Moreover, I assume a zero net inflation steady state, so $\pi = 1$. The degree of interest-rate smoothing ρ_R is set to

[81] Note that not all shocks are used in the following analysis.

0.9 and the Taylor rule weight on inflation is 1.5 (while for the analysis conducted at the ZLB below, $\phi_\pi = 0$). The elasticity of substitution between retailer inputs, ϵ_p, is 4.167, implying a steady-state price markup of around 30 percent.

Financial sector. I set the survival probability of commercial bankers to $\theta_c = 0.9$, while for wholesale banks I specify $\theta_w = 0.75$. This means net worth accumulation for wholesale banks is less persistent than for commercial banks and swings in asset prices affect the former more strongly, as observed during the financial crisis. The values are both between the 0.972 chosen in Gertler and Karadi (2011) and the considerably lower estimates for the US in Canova, Ferroni, and Matthes (2016). The efficiency cost of the central bank holding assets on its balance sheet, τ_p, is set to zero. In fact, an efficiency cost larger than zero will mechanically increase output in the fashion of an aggregate demand shock (like government spending in my model), which I hold to be undesirable.[82] The loan spread is calibrated as the difference between loans and deposit rates between 2009 and 2016 (see Appendix D.2), so we have $[R_s^{\text{emp}} - R^{\text{emp}}]/4 = 0.0056$ for the empirical series. Similarly, $R_b - R$ is calibrated as the difference between a synthetic 10-year EA government bond yield and deposit rates as $[R_b^{\text{emp}} - R^{\text{emp}}]/4 = 0.0038$. As returns on securities are harder to come by, I set their return to a suggestive intermediate value: $R_a = (R_s - R_b)/2$, implying that securitised debt has a collateral value between that of corporate loans and government bonds. The pledgeability of bonds and financial assets relative to loans, Δ_b and Δ_a, implicitly define the bond and asset spread, $R_b - R$ and $R_a - R$ (see below). Moreover, I set the spread between the composite household returns, R_h, and the returns on deposits, R, to half the spread between bond yields and deposits, to a (quarterly) 0.0019. The motivation is that EA households hold similar amounts of their savings in deposits and life insurance and deposits (see the calibration of ϵ_s below).

Shocks. The persistence of the asset purchase shocks is set to 0.9755, as the quarterly autocorrelation of the sum of SMP and PSPP is 0.9758 and that of CBPP1-

[82] My simulations suggest that this channel actually drives the output reaction to asset purchases in Gertler and Karadi (2013) to a non-negligible degree.

3 and ABSPP is 0.9751. The persistence of all other shocks is set to a suggestive 0.7. The standard deviation of shocks is set to 0.1 if shocks are not targeted to certain macroeconomic effects (see below).

Table 4: Calibration choices

real economy			financial sector		
capital share	α	0.4	CB survival probability	θ_c	0.9
discount factor	β	0.995	WB survival probability	θ_w	0.75
depreciation rate	δ	0.025	CeB cost of holding APPs	τ_p	0
intertemp. elast. of subst.	σ	1.35	SS loan spread	$R_s - R$	0.0056
Frisch elasticity	φ	0.276	rel. spread bonds	Δ_b	0.6892
investment AC	χ_I	3	rel. spread assets	Δ_a	0.8446
habit parameter	h	0.829	SS CB loan leverage	ϕ^c	4.52
elast. of subst. goods	ϵ_p	4.167	SS WB leverage	ϕ^w	10
Calvo parameter	γ	0.908	SS bonds/loans	Ξ_b	0.3837
Taylor rule weight π_t	κ_π	1.5	SS assets/loans	Ξ_a	0.3720
interest-rate smoothing	ρ_R	0.9	APP reaction parameters	$\Psi_{\pi\{s,b,a\}}$	0
SS HH return spread	$R_h - R$	0.0019			
SS inflation rate	π	1	shocks		
SS labour supply	L	1/3	persistence APP shocks	$\rho_j, j = s,b,a$	0.9755
SS gvt. spending / GDP	G/Y	0.196	persistence other shocks	$\rho_j, j \neq s,b,a$	0.7
degree price indexation	κ_p	0	standard deviation	σ_j	0.1

Note: SS = steady state, HH = household, CB = commercial bank, WB = wholesale bank, gvt. = government, CeB = central bank, elast. of subst. = elasticity of substitution, AC = adjustment costs.

Finally, I calibrate the values of certain parameters to define the steady-state values of certain variables (for details, see Appendix D.1):

- The disutility parameter of supplying labour, χ, is set as to ensure $L = 1/3$, a widely used value for the steady-state labour supply or hours.
- The steady-state amount of bonds held by households, $\bar{B}_h$, is set such that the steady-state shares of total bonds, $\overline{B^h/B}$, equals 0.7741 as in the data (see Appendix D.2). This subsumes all bond holdings of agents other than deposit-taking corporations.

- The capital stock K is pinned down in steady state by the choice for the loan spread $R_s - R$. Δ_b and Δ_a are set to target $R_b - R = 0.0039$ and $R_a - R = 0.0048$, see Appendix D.2.

- The shares of bank funds that can be diverted by bankers, λ_c and λ_w, are implied by the (targeted) steady-state leverages of wholesale banks and of commercial banks with respect to loans, set to $\phi^c = 4.52$ and $\phi^w = 10$. The former value is calibrated to the commercial bank leverage ratio (App. D.2); for the latter, I put the same value as Meeks et al. (2014) – see their footnote 24 on the wide array of leverage ratios potentially to consider here. As stated above, wholesale banks capture a variety of different banks. For shadow banks, and especially investment funds, nominal leverage ratios (simple asset-to-equity ratios) are usually lower than for commercial banks, and especially for investment funds (Malatesta, Masciantonio, and Zaghini, 2016). However, a key characteristics of these banks is that their equity can be withdrawn at short notice, making de-facto funding more unstable (Doyle et al., 2016). On the other hand, classic financial vehicles in the securitising business often have staggering leverage ratios: For example, while the ratio of total assets/liabilities to capital and reserves between 2010 and 2016 is 13.72 for Credit Institutions, it is 59.81 for Financial Vehicles (Source: ECB Statistical Warehouse Database). These high leverage ratios are also in line with Bakk-Simon, Borgioli, Giron, Hempell, Maddaloni, Recine, and Rosati (2012). In conclusion, I set a higher leverage ratio for the wholesale bank as a portmanteau of all these banks, but check the sensitivity of my results to ϕ^w below.

- Household transfers to entering banks, ω_c and ω_w, are set as to meet the values for steady-state bonds and financial assets over total loans, Ξ_b and Ξ_a. These are calibrated to 0.3837 and 0.3720 using balance sheet data from the SDW database, see Appendix D.2.

- The share of deposits in overall household savings, κ_s, is obtained as 0.5196 from the calibration, implying $D/B^h = 1.0817$. This comes surprisingly close to the ratio of household holdings of currency and deposits over household holdings of life insurance and pensions for the EA, which is 1.0216. The elasticity between household deposit and government bond holdings, ϵ_s, also implied by steady-state relationships, is 0.0335 (see Appendix D.1).

- I calibrate the risk-premium parameters η_b and η_a as follows: Altavilla et al. (2015) show that around the APP event dates, spreads of Euro Area 5-year maturity bonds decreased by 35 basis points (bps) relative to German bunds (taken to represent the risk-free rate).[83] At the same time, spreads for bonds by BBB-rated financial corporations fell by 27 bps and those of BBB-rated non-financial corporations by 22 bps (all these are from the controlled event study in Table 5, p. 38).[84] The announcements considered in this paper are mostly about the Public Sector PP. So let us take the average effect of B_t^g on public and non-public debt to be 35 and 27 bps, respectively. Now this gives us a (rough) measure of the effect of B_t^g on $R_{bt} - R_t$, the public-debt spread in my model, over $R_{st} - R_t$ (or $R_{at} - R_t$). I extrapolate to other asset classes and set η_j, $j \in \{b, a, sb, sa\}$ such that the impact effect of the asset bought on its own spread is always $35/27 = 1.30$ as large as for other assets.[85]

Note that my calibration implies the following values for the share of bank assets that can be diverted: $\lambda_c = 0.2551$ and $\lambda_w = 0.1292$. Moreover, it implies proportional transfers to entering bankers of $\omega_c = 0.0007$ and $\omega_w = 0.0116$. While λ_c and ω_w are in line with recent parameter estimates by Canova et al. (2016), λ_w and ω_c both lie somewhat below the estimates there. The difference is mostly due to the very low interest rates and spreads that prevail under my calibration.

I examine the sensitivity of my simulations to some key parameters below.

[83] See the 2-day change of their controlled event study in Table 5, p. 38.

[84] Gagnon et al. (2011) report similar magnitudes for the US LSAP announcements, which were, however, undertaken during times of more acute financial distress.

[85] So for example, $R_{bt} - R_t$ will react to B_t^g 1.30 times as much as the average of $R_{at} - R_t$ or $R_{st} - R_t$.

3.4 Results

This section presents results from several simulations of my model. First, the reactions to some shocks widely used in the literature are shown in order to convince the reader that my financial sector does not distort the standard model dynamics. Second, I give some intuition about the dynamics resulting from asset purchases after a disinflationary shock, with a look at the transmission channels and sensitivity of results to some key parameters.

3.4.1 Results for some standard shocks

Here I show some impulse responses for shocks common in the DSGE literature: A shock to total factor productivity, x_{pt}, as the quintessential supply shock, to (wasteful) government spending; x_{gt}, as a demand shock; to the Taylor rule policy rate (monetary policy shock x_{rt}); and to commercial banks' net worth, as a stand-in for shocks to the financial sector (x_{nt}).[86] All shocks are chosen to have a contractionary effect on output, leading to a trough of 1 percentage point below the steady-state value.

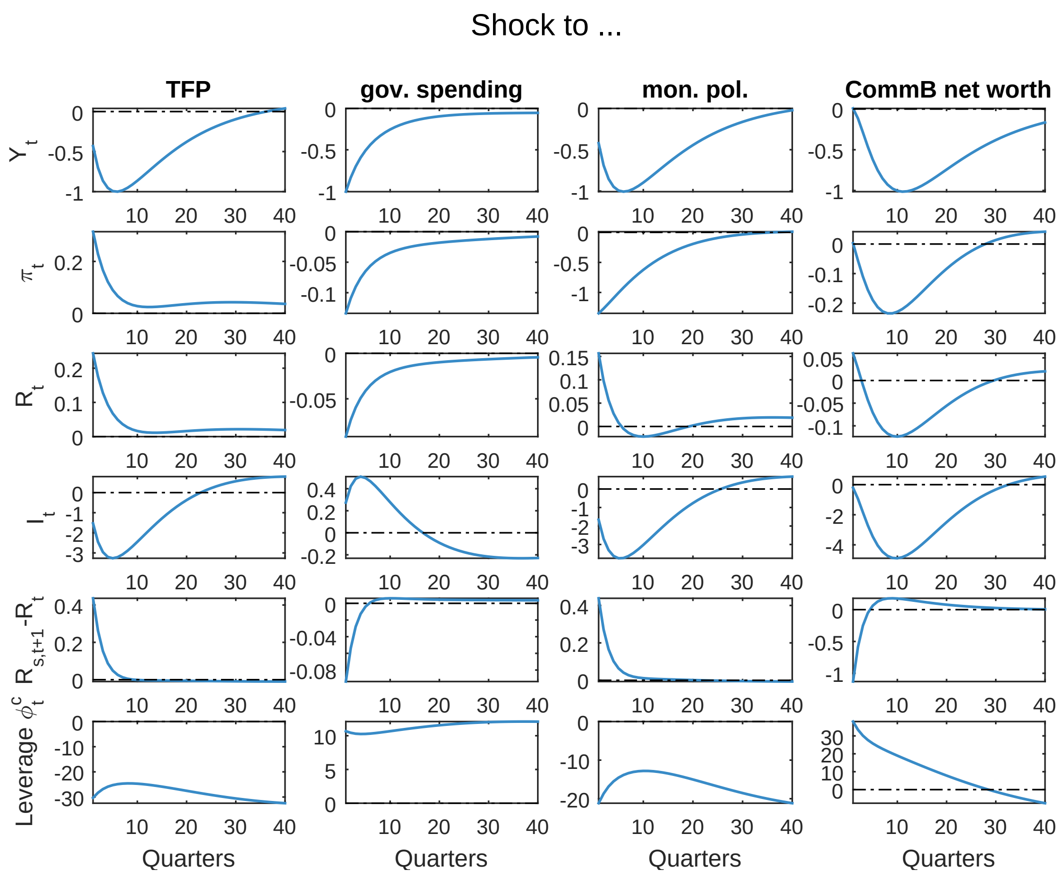
We see that a *TFP shock* will decrease output and investment, while raising prices as marginal costs increase. As the marginal productivity of capital falls, returns on lending are depressed and commercial bank leverage ϕ_t^c remains below its steady-state value for an extended period. A negative *government spending shock* will depress overall demand, but simultaneously crowd out household consumption. The resulting increase in savings leads to a rise in investment under my calibration, amplified by an increase in the value of loans and thus banks' net worth, leading to an extension of leverage and a fall in spreads. A *monetary policy shock* will decrease aggregate demand by increasing savings. This reduces the scope for investment and depresses bank profits, net worth, and leverage, with the lending spread increasing strongly. Finally, a negative shock to commercial banks' net worth N_t^c will force banks to reduce lending in order to de-leverage, thus leading to depressed investment, output and prices.

This illustrates that in spite of the quite complex financial sector in my setup,

[86]The non-financial shocks are those used also in Gust, Herbst, López-Salido, and Smith (2017).

the model still generates traceable dynamics to standard shocks.[87]

Figure 35: Responses to several common DSGE shocks



Notes: Impulse responses (percentage deviations from steady state) to unexpected innovations in TFP technology x_{pt}, (wasteful) government spending x_{gt}, monetary policy x_{rt}, and the net worth of commercial banks (a financial shock) x_{nt}, each following an AR(1) process with persistence parameter $\rho_j = 0.7$. All shocks are defined to be contractionary and lead to a trough of GDP 1% below its steady state.

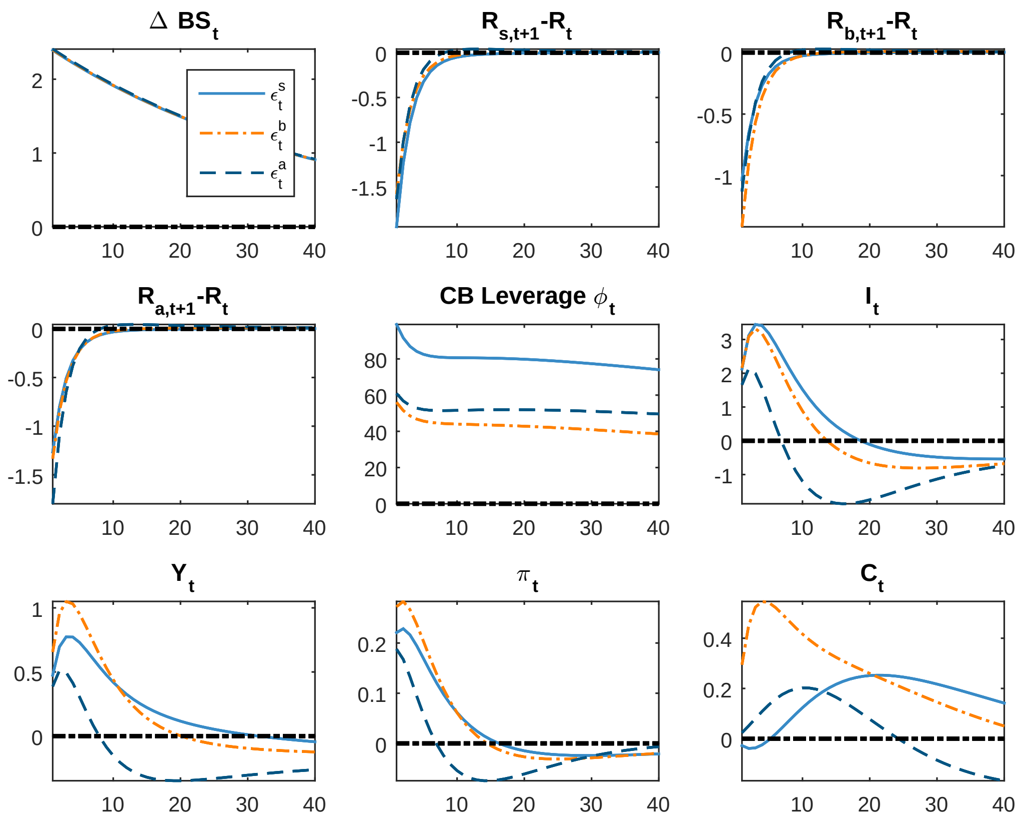
[87] Moreover, Subsection D.3.1 in the Appendix shows that my model is able to replicate the impulse responses from the Gertler and Karadi (2013) model under their (US) calibration (and with the wholesale bank as well as preferred-habitat and local-scarcity channel, which are not included in their model, switched off). This can be seen as another check for internal consistency of the model.

3.4.2 Responses to asset purchases

Figure 36 gives the responses to central bank purchases of bonds B_t^g, financial assets A_t^g and corporate-sector debt S_t^g under my calibration. These correspond to ESCB purchases under 1. the public sector PP, 2. the asset-backed securities PP and covered bond PP and 3. the corporate sector PP. The shocks are calibrated to be of the same size on the central bank balance sheet, reaching a maximum of 2.42% of (annual) steady-state GDP, roughly equivalent of the (quarterly) €240bn relative to the annual EA nominal GDP.[88] The autoregressive coefficient of the exogenous shock to the respective asset purchases is set to 0.9755 to reflect the strong autocorrelation of the APPs (up to now). Note that in this experiment, conventional monetary policy is not yet switched off and will counteract the asset purchases.

[88] The average EA annual nominal GDP for 2009Q1:2016Q3 was €9,936.8bn according to Eurostat.

Figure 36: Responses to unexpected purchases of different asset classes



Notes: Impulse responses to unexpected purchases of loans (ε_t^s), bonds (ε_t^b), and assets (ε_t^a), each following an AR(1) process with persistence 0.9755.

The bank-balance sheet channel. In the following, I will first look at the reactions to purchases of corporate loans, S_t^g. These are solely driven by the bank-balance sheet channel, which (to a varying degree) is common to all asset purchase shocks here. I will then look at the additional transmission channels specific to other asset purchases. We see that in fact all shocks increase the central-bank balance sheet by 2.42% on impact (first plot). The purchases increase the prices of the targeted assets and thus reduce their yields, which is also visible in a spread reduction. There are strong co-movements in asset prices, or, in terms of Altavilla et al. (2015), there is considerable portfolio rebalancing as the commercial bank adjusts all of its asset holdings. However, spreads are most strongly reduced for the respective assets being purchased, in line with the local-scarcity channel.[89]

We see that the leverage of commercial banks is generally increased by the rise in asset prices. The resulting increase in lending translates into higher investment on impact, with a hump-shape due to capital adjustment costs. After some time, however, investment falls below its steady-state value as the effect of purchases recedes and the capital stock slowly moves back to its steady state. The investment boom greatly determines the dynamics of output and inflation, pulling them up and later down with it. Consumption generally acts as a "buffer", in that it will increase when the capital stock is large but investment is already receding.

As a side note, it should be mentioned that in my model, a rise in asset prices after central-bank QE will always stimulate investment as banks will mechanically increase lending when their balance-sheets allow them to. However, as documented in Altavilla, Canova, and Ciccarelli (2016), this mechanical increase in lending might not be empirically valid. Banks could instead choose to invest in other assets like housing or foreign investment, which are not modelled here. Instead, the focus is on the relative importance of the bank-balance sheet lending channel for my two types of banks, and compared relative to the preferred-habitat of government bond purchases.[90]

The role of the wholesale bank and collateral value. Comparing the purchases of S_t^g and A_t^g, we see that purchases of the securitised financial asset have smaller and less persistent expansionary effects, which furthermore turn negative relatively quickly (after 6 instead of 15 quarters).

In general, there are several reasons why the transmission mechanism differs.

[89] The reduction is around 150 basis points (bps) on average, which is larger than the empirical estimates of Altavilla et al. (2015), who, however, focus only on impact effects (within one or two days).

[90] An estimation could test the degree of pass-through of APP measures to lending by having an exogenous disturbance term between aggregate lending to firms, and the amount of productive capital K_t, as in

$$K_t = S_t^c + S_t^w + S_t^g - x_{PTt}$$

If the estimation picks up large values for x_{PTt}, this would be evidence for a weak pass-through rate of bank balance sheets restoration by APPs to lending and investment in the real economy.

First, the increase in Q_{at} by the asset purchases will not only increase commercial banks' balance sheets, but also reduce wholesale bank leverage, as their liabilities rise. This effect is relatively subdued as wholesale banks have a relatively high steady-state leverage (so their net worth is reduced relatively less), but it will reduce lending to firms in the form of S_t^w. Moreover, the effects on the interest-rate spread are less persistent because the leverage effect on wholesale banks recedes more quickly (their survival probability θ_w is relatively low, meaning that there is a faster adjustment in net worth through transfers from the households instead of retained earnings). On the other hand, the effect of the increase in collateral value Δ_{at} by the purchases, introduced via the (assumed) local-scarcity channel, is quantitatively not very important for the results, as the next subsection shows. Finally and importantly, securitised assets A_t^c are a source of good collateral for commercial banks, which they value because it is hard to divert and thus allows them to lever up. Reducing the amount of A_t^c available to commercial banks will allow them to lever up less than for purchases of corporate bonds S_t^g. Although purchases will increase the price Q_{at} of the asset (with positive repercussions for banks' balance sheets), their quantity available to banks is reduced (decreasing banks' leverage opportunities). This negative effect has first been mentioned in Meeks et al. (2014).

Overall, my model thus suggests that purchases of securitised financial assets as in the asset-backed securities PP and the covered bond PPs are less effective than direct purchases of corporate debt as in the corporate sector PP.[91]

The preferred-habitat channel. Of the three assets purchased by the central bank, I allow only government debt to be held by households. As households' reaction to changes in relative interest rates is not fully elastic (they have a "preferred habitat" for saving via public debt), purchases B_t^g will deprive households of some of their savings vehicles. In fact, while (real) deposit rates R_t increase together with

[91]The fact that purchases A_t^g are less effective could of course be due to my calibration. Even with a higher leverage for wholesale banks, the high collateral value of assets for commercial banks is due to my calibration of Δ_a. While I calibrate this value using interest-rate spreads, an estimation could give insights into which value is suggested by the model likelihood. Note that conveniently for an estimation, the empirical equivalents of A_t^g, ABSPP and CBPP1-3, reach back to the very start of the APPs in 2011.

the policy rate R_{pt} as inflation rises, in the case of government bond purchases the return on bonds will fall, reducing the overall return on household savings R_{ht} and inducing households to consume more. In fact, for purchases of B_t^g, consumption shows no initial crowding-out, different to purchases of A_t^g and S_t^g. Instead, consumption increases strongly by a maximum of 55bps over its steady-state value, pulling output and inflation up more than under the other types of purchases. The effect on consumption is also slightly more persistent than that on leverage (due to relatively strong habits), smoothing out the response of output and inflation relative to investment for purchases of B_t^g. The local-scarcity channel introduced via the risk premium on the collateral value Δ_b of public debt also increases the effectiveness of B_t^g, however to a relatively small degree, as the next subsection shows. Finally, the purchases of government debt will also make a good source of collateral scarcer for commercial banks as discussed above (and even more so than for financial assets, as $\Delta_b > \Delta_a$). That this negative effect is more than outweighed by the preferred-habitat channel highlights its quantitative importance for the results.

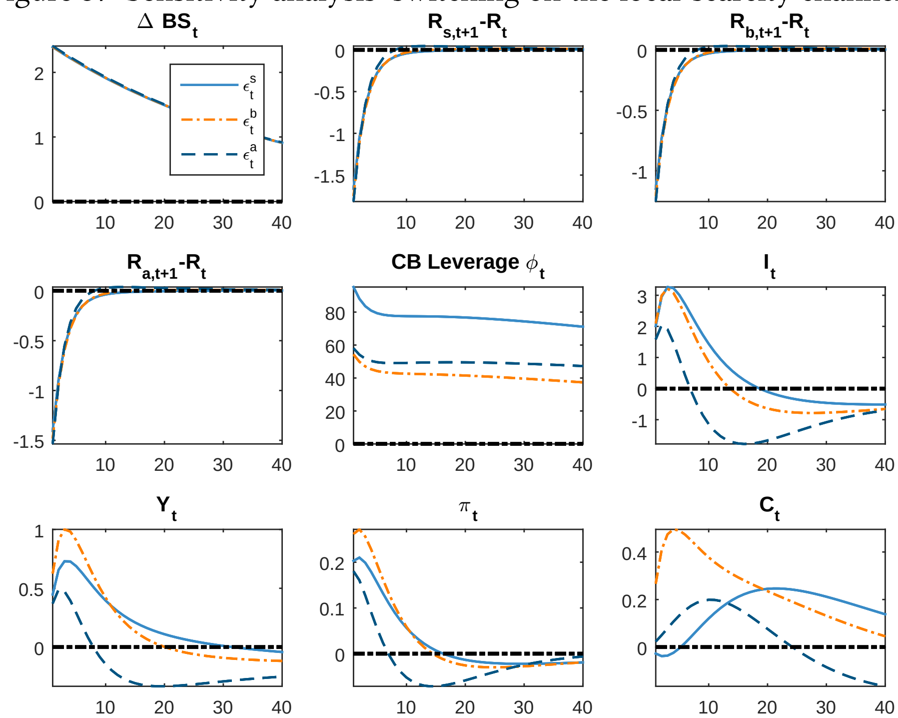
Quantitative effects. The maximum increase in output (for the case of public-debt purchases B_t^g) is 1.05%, which lies roughly between the estimates from empirical papers (like the 3% reported in Baumeister and Benati, 2013, or the 1.5% for UK in Kapetanios et al., 2012) and the 0.13% from the DSGE estimated for the US in Chen et al. (2012) – in the case without a ZLB. The maximum increase in inflation is 27 bps (0.27%), well above the value in Chen et al. (2012), who obtain an impact of 3bps in the case of the ZLB environment, but of only 1.8bps in the case without a ZLB. However, it is still far below the estimates from the empirical literature: Kapetanios et al. (2012) report an effect of around 1.25% for the UK, and Baumeister and Benati (2013) of 1% for the US. There are several reasons why the effect on inflation here is substantially larger than in the estimated model in Chen et al. (2012): First, my model includes a bank-balance sheet channel besides the preferred-habitat channel in their model. Second, in their study the authors obtain very low parameter estimates for the degree of segmentation and the elasticity of the risk premium to household debt, both of which mainly govern the effectiveness of public-debt purchases.

3.4.3 Sensitivity analysis

Here, I check whether my results are robust to shutting down the premium on assets' collateral value (i.e. disabling the local-scarcity channel), and to varying some central parameters.

Sensitivity to the local-scarcity channel. Figure 37 shows the results from repeating the analysis above with the local-scarcity channel shut off, i.e. $\eta_b = \eta_a = \eta_{sb} = \eta_{sa} = 0$. Thus, purchases of one asset no longer reduce the spreads of this asset more than others, as banks optimally equate them. In other words, there is no longer any impediment to perfect portfolio-rebalancing of the commercial banks balance sheet. Note, however, that the response of the financial-asset spread $R_{at} - R_t$ keeps its more short-lived dynamics as the effect of purchases diminishes faster. The reason is that wholesale banks' survival rate is smaller, so that they can more quickly restore their balance sheets.

Figure 37: Sensitivity analysis: switching off the local-scarcity channel



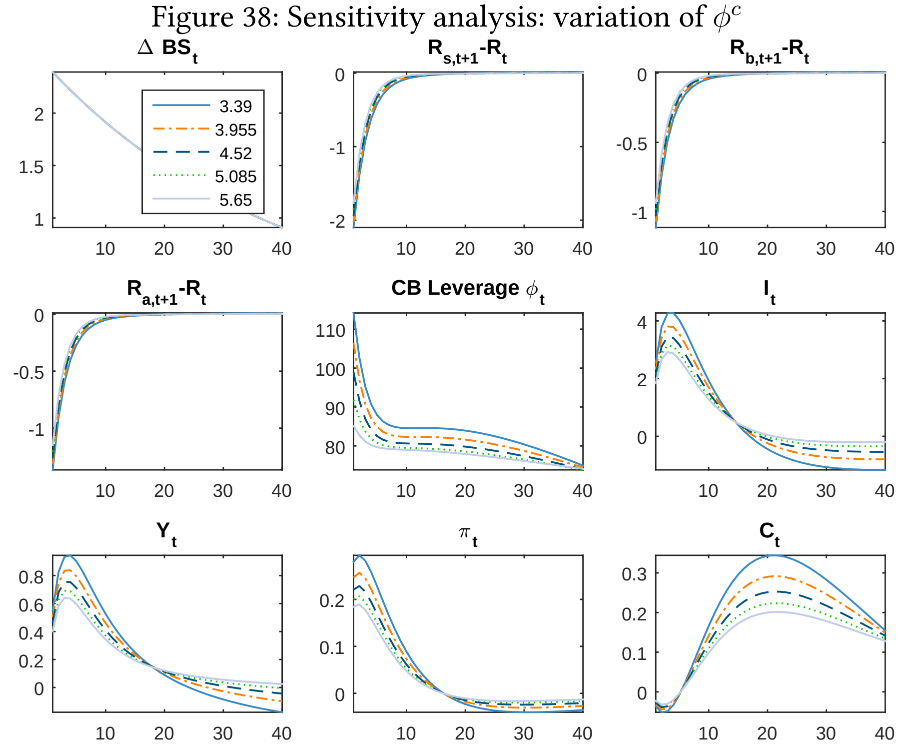
Note: Impulse responses to unexpected purchases of loans (x_{st}), bonds (x_{bt}), and assets (x_{at}), each following an AR(1) process with persistence 0.9755. The local scarcity channel is shut off, i.e. $\eta_b = \eta_a = \eta_{sb} = \eta_{sa} = 0$ (spreads do not react to purchases differently).

We see that switching off the local-scarcity demand does not affect results much. The effect on government-bond purchases on investment (through the bank-balance sheet channel) is somewhat diminished, but it still appears the most powerful type of purchases to revive economic activity and inflation. Instead of a maximum increase in output and inflation by 1.05% and 28bps, we now obtain maximum effects of 1.02% and 27bps. The main transmission is thus rather driven by the other dynamics (in particular, the preferred-habitat channel of household consumption). This is reassuring, as the calibration of the local-scarcity channel had to be rather ad-hoc. However, an estimation of the model could give more definitive answers on how purchases of different assets affect the returns on other asset classes, and thus help to quantify the local-scarcity channel versus the portfolio-rebalancing channel.

Sensitivity to central parameters. This subsection presents some sensitivity analysis to judge which parameters are most crucial for the model dynamics. There are graphs for additional parameters in Appendix D.3.2.

First, I look at the steady-state commercial bank leverage ratio ϕ^c. This value is calibrated to the total loans over total capital in the EA, but it could be argued that total loans underestimate the lending to private firms (which would also be possibly e.g. via corporate bonds), and an even higher leverage could be suggested. On the other hand, e.g. Gertler and Karadi (2011) use a slightly lower leverage ratio of 4 in their calibration for the US. To examine the importance of variations in the parameter ϕ^c, I show impulse responses of a shock to loan-purchases x_{st} for variations of ϕ^c from 75% to 125% of the calibrated value of 4.53 in Figure 38.

Figure 38: Sensitivity analysis: variation of ϕ^c

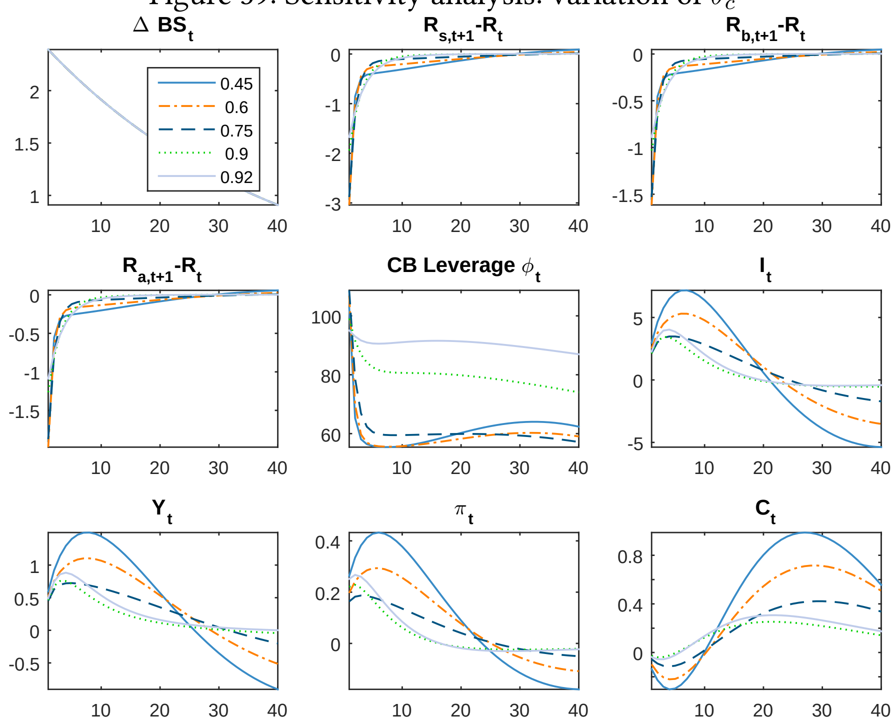


Note: Impulse responses to an AR(1) loan-purchase shock x_{st} with persistence 0.9755.

We see that results are not much affected: While a smaller steady-state leverage leads to larger effects of purchases (as they will buy a larger share of assets and thus reduce the spread more effectively), the range of maximum output effects reaches from 99 bps to 67 bps or 124% and 84% of the baseline 80 bps, i.e. less than the relative variation in leverage.

Moreover, I show the impulse responses to an S_t^g shock for varying values of the commercial bankers' survival probability θ_c. Remember that I set this parameter to a relatively high value of 0.9, as in e.g. Gertler and Karadi (2011), while Altavilla et al. (2016) estimate a much lower value for this parameter using US data (between 0.46 and 0.8 depending on the specification).

Figure 39: Sensitivity analysis: variation of θ_c



Note: Impulse responses to an AR(1) loan-purchase shock x_{st} with persistence 0.9755.

The survival rate parameter affects model dynamics to some degree. The smaller the survival probability, the larger and more hump-shaped is the effect on investment and output. We also see a significant undershooting of real activity after around 28 quarters when θ_c is smaller than 0.75 (in fact, dynamics appear to become slightly oscillatory). This is a caveat that much smaller values for θ_c will actually change dynamics, however, they are likely only to increase the expansionary (impact) effect of asset purchases.

3.5 Purchases in a zero-lower bound environment

This subsection presents an investigation of how the central bank can use asset purchases to stabilise inflation and reduce business-cycle fluctuations after a disinflationary shock. In particular, I use a piecewise linear solution method to obtain simulations at the ZLB, after a series of negative preference shocks.

3.5.1 Which purchases most forcefully revive inflation?

At this point I introduce a systematic reaction of the central bank to deviations of inflation: The central bank will buy assets whenever inflation is below its steady-state value. For convenience I reproduce the asset-purchase equations from above:

$$S_t^g = -\Psi_{\pi s}(\pi_t - \pi) + K \cdot x_{st} \tag{30}$$
$$B_t^g = -\Psi_{\pi b}(\pi_t - \pi) + B \cdot x_{bt} \tag{31}$$
$$A_t^g = -\Psi_{\pi a}(\pi_t - \pi) + A^w \cdot x_{at} \tag{32}$$

Below, I will distinguish the effects of a disinflationary (preference) shock to the economy with the reaction function parameters $\Psi_{\pi j}$, $j \in \{s, b, a\}$, being successively switched on. There are no exogenous purchases here, so $x_{jt} = 0$.

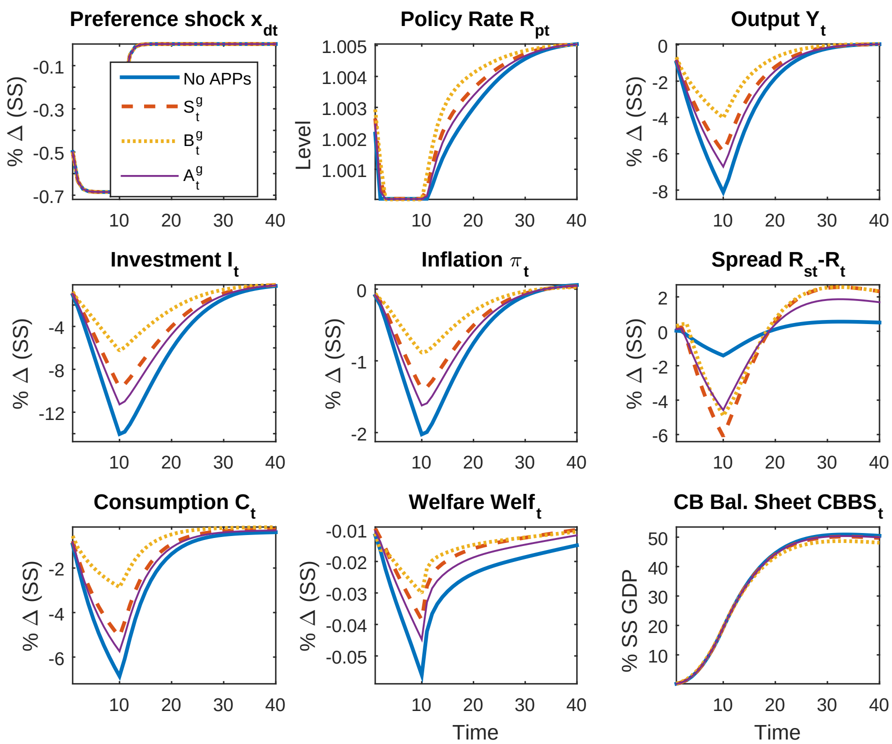
A piecewise linear solution. I use the toolbox provided by Guerrieri and Iacoviello (2015b) to simulate my model under an occasionally binding ZLB constraint. The piecewise linear solution method employed takes the (log-linearised) first-order approximation to the model dynamics in two different regimes: A "normal" one in which the nominal policy rate is non-constrained $R_t E_t\{\pi_{t+1}\} = R_{pt} > 1$, and follows the Taylor Rule as in eq. (29). This means that in the normal regime the nominal rate in the economy can freely deviate from its steady state as long as $\hat{R}_t + \hat{\pi}_{t+1} = \hat{R}_{pt} > -r = -(1/\beta - 1)$. Second, a "constrained" regime in which the policy rate is at the ZLB, $R_{pt} = 1$ and $\hat{R}_{pt} = 0$, which implies $\hat{R}_t = -\hat{\pi}_{t+1}$.

The piecewise linear solution correctly accounts for moving from one regime to the other, including agents' expectations. Moreover, it will select the appropriate amount of periods that the economy remains in the constrained regime. This comes at the cost of only allowing for simulations at first-order approximations to the model dynamics, so that I cannot apply a full-fledged welfare analysis here.

A disinflationary shock under the ZLB. To show the effect of asset purchases in my model, I follow Guerrieri and Iacoviello (2015b) in using a series of negative preference shocks which drive the policy rate to the ZLB.[92] The ZLB then increases the effect of the shock considerably, leading to a drop in output and inflation by 8% and 2% (close to deflation) at the maximum. My model requires this relatively drastic series of shocks to reach the ZLB for a significant amount of time. While other shocks could be used here, the preference shock is often employed in the literature as a shortcut to activate the ZLB and create a disinflationary environment.

[92]The shocks are a series of 10 negative preference shocks with a relatively small autocorrelation of 0.27.

Figure 40: Disinflation at the ZLB and asset purchases



Note: Impulse responses to a series of unexpected contractionary preference shocks that drive the economy to the zero-lower bound (ZLB) of nominal rates. The graphs plot the responses in the case of no asset-purchases (blue cont. line), and in the case where the central bank reacts to inflation by purchasing either loans ($\Psi_{\pi S} > 0$; orange dashed line), government bonds ($\Psi_{\pi B} > 0$; yellow dotted line), or financial assets ($\Psi_{\pi A} > 0$; violet thin line). The reaction parameters $\psi_{\pi j}$ are calibrated such that the central bank's balance sheet reaches 22.95% of GDP after 11 quarters (roughly in line with the ESCB APP purchases).

To investigate the effectiveness of different asset purchases to stabilise the economy after such a disinflationary shock, I calibrate the asset-purchase reaction function parameter $\Psi_{\pi j}$ in a way that the central-bank balance sheet (CBBS) reaches 22.95% of GDP after 11 quarters.[93] Note that differently to above, I show the *cumulated* amount of asset purchases as a share of GDP here in order to illustrate

[93] As of July 2017, the second round of APPs will accumulate to a total of €2,280bn (€60bn per month from 2015M3:2016M3 and 2017M4:2017M12, and €80bn per month from 2016M4:2017M3), which is 22.95% of the average annual EA GDP in 2009Q1:2016Q3 of €9,936bn.

the overall impact on the central-bank balance sheet.

The asset purchases are able to stabilise output, investment and inflation considerably. However, this is possible only via a very large reduction in interest rate spreads: $R_{at} - R_t$, $R_{bt} - R_t$ and $R_{st} - R_t$ fall by 4.58, 4.91 and 6.11 percentage points at their trough.[94] Note also that investment is relatively less stabilised under the ZLB than in the results above: The ratio of maximum effects of B_t^g on Y_t and I_t was about 3, while here this relative effectiveness of stabilisation is closer to 2.5. One reason for this is that the interest-rate spreads are already compressed by the preference shock, making the bank balance-sheet channel of asset purchases less effective.

Moreover, for any of the three reaction functions, the ZLB will be hit one period later than without purchases (3 instead of 2 periods after onset of shocks), and leave it one period earlier (10 instead of 11 quarters after the onset).

Purchases of government bonds appear most suitable to stabilise inflation in this environment. They prevent a drop in output of 4.09% of its steady state value and of 1.14% in inflation. The reason for their relatively large effectiveness again is the preferred-habitat channel: Through the preference shock households have particularly large incentives to save, and purchases of B_t^g will considerably reduce one of the assets by which households can increase savings. This strongly alleviates the effect on consumption and thereby also stabilises output and inflation. On the other hand, welfare will not be affected as drastically as consumption, because the labour supply recedes together with consumption.

Thus, altogether the relative sizes of the different ESCB APPs, with their strong focus on public debt (see Table 3) seem justified. Note, however, that the reaction function also implies a subsequent increase of purchased assets on the central bank's balance sheet of up to 48.7% of GDP (for the case of $\Psi_{\pi b} > 0$), which is more than the ESCB currently proposes to buy.[95]

[94]These are tremendous decreases, especially given that as R_t is stuck at zero and steady-state spreads are very low, they also represent almost equally large *absolute* negative values of the reference rates. While the yields of several assets have entered negative territory during the recent ZLB episode, the absolute size of these rates remain far from the ones implied here.

[95]On the other hand, this analysis abstracts from sovereign debt. Given that the APPs were introduced in the aftermath of the European Sovereign Debt crisis, there were probably additional stabilising effects of public-debt purchases.

3.5.2 Welfare

Obtaining a measure of the effect of APPs on welfare is difficult in this context. The piecewise-linear solution approach does not allow me to simulate the model at a second-order approximation of its decision rules, making it impossible to estimate the overall effect of inflation stabilisation on welfare in a ZLB environment. However, to get an idea about the welfare consequences of APPs, I show the effect on welfare for the case of the particular shock depicted above. As is standard in the literature, welfare is given by the consumer value function in eq. (8) above. Focusing on one shock, I can neglect the effect of uncertainty about other shocks. This yields a simplified measure of the welfare gains of the stabilisation policies shown in the above subsection.

In particular, I calculate the difference of the welfare losses in the case of no stabilisation ($\Delta\mathcal{W}_t^0$) and in the case of the stabilisation of inflation by purchases of S_t^g, B_t^g, or A_t^g ($\Delta\mathcal{W}_t^j,\ j \in \{s, b, a\}$), for an horizon of 40 periods. I follow Debortoli, Kim, Lindé, and Nunes (2015) in computing the consumption-equivalent variation (CEV) units as

$$\text{CEV}_t^j = 100 \cdot \left(\frac{\Delta\mathcal{W}_t^j - \Delta\mathcal{W}_t^0}{C\left(\frac{\partial U}{\partial C}|_{SS}\right)} \right),$$

where $C\left(\frac{\partial U}{\partial C}|_{SS}\right)$ gives the steady-state increase in welfare for a one-percent increase in steady-state consumption. Then I add up the CEV units across an horizon of 10 years (40 quarters).

Table 5: Welfare improvement after disinflation at the ZLB for different APPs

	$\varphi_s > 0$	$\varphi_b > 0$	$\varphi_a > 0$
$\sum_h^{40} \frac{\text{CEV}_h^j}{\text{hor}}$	2.25 bps	8.52 bps	1.65 bps

Note: Average per-period difference in welfare $\mathcal{W}_t$ in consumption equivalents over the 10-year (40-quarter) horizon of the IRFs depicted in Fig. 40.

As we can see from Table 5, welfare is improved considerably under purchases of government bonds, and slightly less so under purchases of other assets.

The average increase over the 40-period horizon depicted in Figure 40 is 8.52 bps (0.0852%) of steady-state consumption. This means that agents would be indifferent between having the purchases in place or an increase of their consumption by 8.52 bps. Some caveats should also be mentioned: First, while this value seems relatively small, it should be kept in mind that I cannot account for the reduction in uncertainty nor steady-state gains from it (see e.g. Mendicino, Nikolov, Suarez, and Supera, 2016, for the context of macroprudential policies). Second, note that the overall welfare increase relative to no purchases is not as strong as the difference in consumption, because labour-supply falls more strongly without purchases, which in my model increases welfare (there is no disutility from unemployment). If employment was more stable (e.g. by introducing wage rigidity), welfare gains could increase. In this light, the absolute welfare gains can maybe seen as a lower bound.

Importantly, however, government bonds have a much stronger effect on welfare than purchases of other assets. The reason lies in the stronger increase of consumption, which improves household welfare despite the heightened demand for hours needed to produce it. Thus, also from a (simplistic) welfare point of view, purchases of government bonds seem preferable among the choices of APPs.

3.6 Conclusion

The asset purchase programmes (APPs) represent the main tool at the ESCB's disposal in its fight against current disinflationary pressures in the euro area. Despite their importance and massive size, the programmes have as yet been little analysed in structural models. This paper distinguishes three different asset classes in a DSGE with a financial accelerator, allowing me to quantitatively assess and compare the public sector purchase programme (PP), the ABSPP and covered bond PP, and the corporate sector PP in their effectiveness in stabilising inflation.

My analysis suggests that (unexpected) purchases of government bonds have a larger expansionary effect on GDP and inflation than those of securitised financial assets or corporate bonds. Moreover, after a disinflationary shock, government bonds purchases are particularly effective in stabilising inflation and increase welfare more than those of other assets. In general, while a bank-balance sheet channel is operative for all these purchases, whether I impose local scarcity or allow full portfolio rebalancing makes not much difference in my model. On the other hand, a relatively important preferred-habitat channel of household savings, which is activated for government bonds but not the other assets, makes purchases of public debt particularly powerful. Purchases of securitised financial assets crowd out good collateral for commercial banks and thus are less effective than the outright purchases of corporate bonds.

This paper can only be a first step in evaluating the relative effectiveness of the European APPs in a structural context. One could think about including more frictions to better capture some particularities of the euro area and the ESCB APPs: Labour market frictions as in Smets and Wouters (2003), or an open-economy setting to capture the strong devaluation and thus competitiveness effects of the APPs. A potentially even more interesting step in the opposite direction would be an estimation of a simplified model under a zero-lower bound environment. For this, one could follow the approach by Guerrieri and Iacoviello (2015a), who obtain a measure of model likelihood from the piecewise linear solution instead of the Kalman filter.[96]

It is likely that research into the effectiveness of QE measures will continue for some time, as asset purchases could become more frequently used in the future by central banks: Tellingly, in her 2016 Jackson Hole speech Janet Yellen stated that she "(...) expect[s] that forward guidance and asset purchases will remain important components of the Fed's policy toolkit." (Yellen, 2016). In an environment characterised by secular stagnation and historically low interest rates, episodes at the zero-lower bound and the use of such unconventional policies both become more likely.

[96]Some first attempts into this direction suggest that the model dynamics might be too rich for an estimation. I am considering an estimation with a simplified model containing only a preferred-habitat and bank-lending channel (and no wholesale banks) for the future.

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A Appendix to "Monetary Policy Communication Shocks and the Macroeconomy"

A.1 Studies of correlations between shock series

In order to better understand how our shock series relate to other high-frequency monetary shock series available in the literature, this section examines correlations between different measures.

We first examine the relation between our shock series and that of BC. From Table 6 we note that all our shocks are positively correlated with the shock of BC, i.e. the first principal component across maturities of contract. In fact, the action shock is the most strongly correlated with the BC shock. This is somewhat surprising, since when we examine the impulse-response functions, we find that the communication shocks yield responses closest to those of the BC shock. We can also see that the far communication shock is slightly more strongly correlated with the BC shock relative to the near communication shock.

With respect to the second principal component extracted by BC from the futures jumps, we can see that only the action shock is positively correlated with the second factor. The far communication shock is more negatively correlated than the near communication shock. Therefore it is not true that our communication shock series merely reflect information captured by the second factor of BC. This is heartening, since we know from BC that the second factor explains only a small fraction of the variance. We can conclude that our structural decomposition offers different kinds of information relative to the two factors of BC (although they restrict their analysis to the first factor).

Table 6: Correlation Between Our Shocks and BC Shocks

	BC Shock	BC 2nd Factor
Action	0.62***	0.43***
Near Comm	0.39***	-0.37***
Far Comm	0.44***	-0.64***

Notes: Correlations computed on a sample of 119 observations.

When we examine the relation between our shocks and those of GSS (2005) we find largely expected results, as displayed in Table 7. Our action shock is strongly and significantly correlated with the GSS target shock. Our near and far communication shocks show an almost identical correlation with the GSS path factor, although it is smaller, at 0.43. Therefore our shocks should be understood to be closely related, but not reducible, to those of GSS.

Table 7: Correlation Between Our Shocks and GSS Shocks

	GSS Target Factor	GSS Path Factor
Action	0.84***	-0.12
Near Comm	0.09	0.43***
Far Comm	-0.04	0.43***

Notes: Correlations computed on a sample of 81 observations.

We moreover find that the action shock is significantly correlated with the Romer and Romer (2004) shock, but the communication shocks are not. When we examine a longer period, using the series computed by Wieland and Yang (2016), we find that the near communication shock correlation coefficient rises to a level comparable with the action shock, and is statistically significant.

Table 8: Correlation Between Our Shocks and Romer and Romer (2004) Shocks

	RR Shock Original Sample	RR Shock Updated
Action	0.49**	0.22**
Near Comm	0.04	0.21**
Far Comm	-0.17	-0.13

Notes: Correlations computed over 23 observations for the original sample, and over 114 observations for the updated sample. The updated sample was made available in the data appendix of Wieland and Yang (2016).

Finally, all our shocks are positively correlated to that of Nakamura and Steinsson (2016). The fact that the correlation structure looks much like those of our shocks with that of the BC shock, with the greatest correlation for the action shock, is unsurprising since the Nakamura and Steinsson (2016) shock is also the first principal component, although the bundle of futures jumps includes longer horizon Eurodollar contracts also.

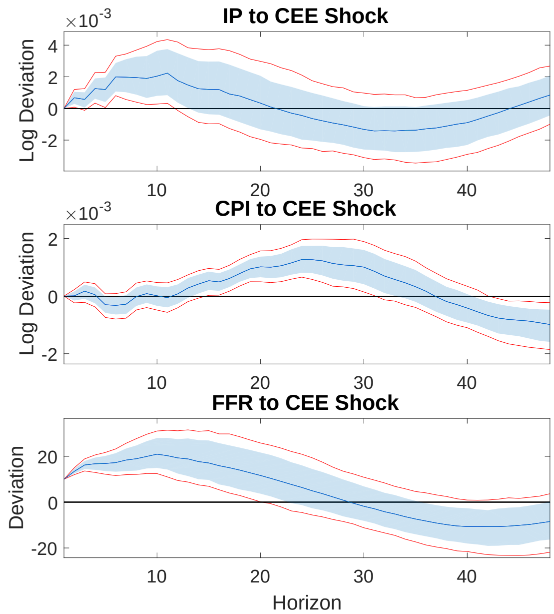
Table 9: Correlation Between Our Shocks and the Nakamura and Steinsson (2016) Shock

	Nakamura and Steinsson (2016) Shock
Action	0.64***
Near Comm	0.51***
Far Comm	0.42***

Notes: Correlations computed over 23 observations for the original sample, and over 114 observations for the updated sample.

A.2 Responses to recursively identified shocks

Figure 41: IRFs from Christiano et al. (1996) Shocks



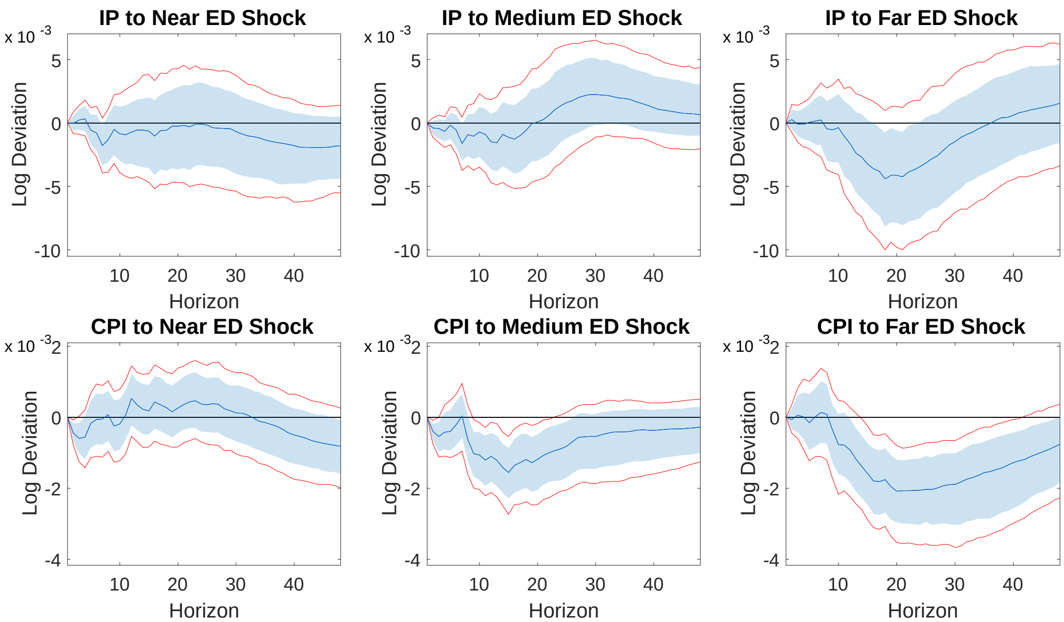
Notes: Responses of $\log(\text{IP}_t)$, $\log(\text{CPI}_t)$, and the Federal Funds Rate to a 10 basis point contractionary shock, identified via the lower triangular restriction of Christiano et al. (1996). The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels.

A.3 Further results using Eurodollars

A.3.1 Robustness checks for the Eurodollar specification

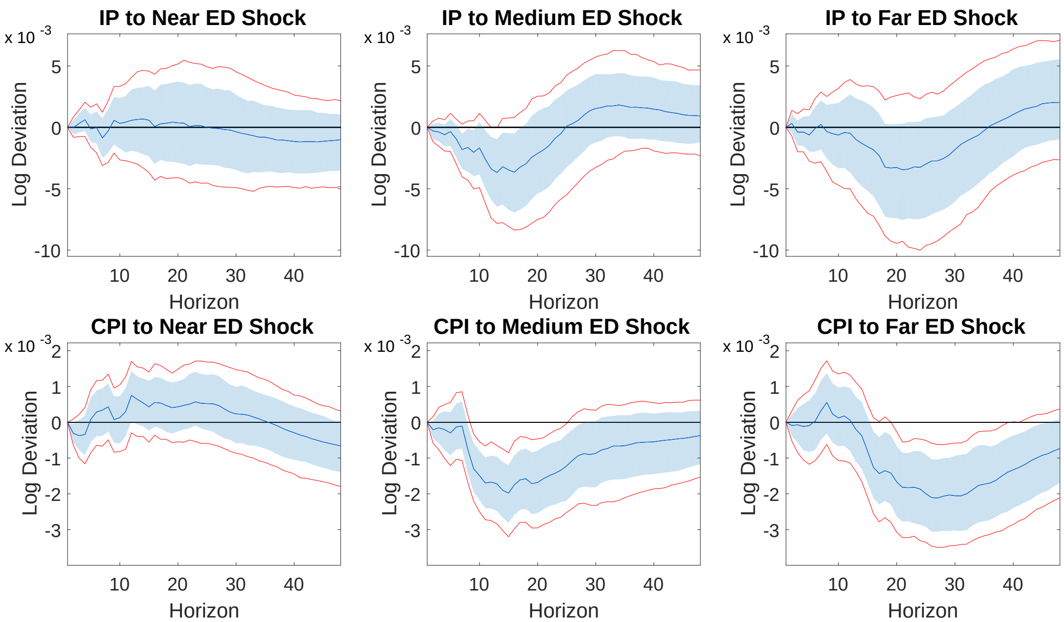
We assess the robustness of our results to different selections of Eurodollar contracts, namely $[ED4, ED8, ED18]$ and $[ED4, ED12, ED18]$. We display the IRFs in Figures 42 and 43. Results are qualitatively unaffected by our choices.

Figure 42: Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ to Eurodollar Shocks (Using Contracts 4, 8, and 18)



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series $S_t^j, j \in \{NED,\ MED,\ FED\}$ – near ED, medium ED and far ED shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

Figure 43: Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ to Eurodollar Shocks (Using Contracts 4, 12, and 18)



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series $S_t^j, j \in \{NED, MED, FED\}$ – near ED, medium ED and far ED shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the interest rate.

A.3.2 Forecast error variance decomposition

We also examine forecast-error variance decompositions of the contribution of our Eurodollar-derived shocks to movements in macro variables, which are displayed for the 12, 18, 24 and 36 month horizons in Table 10. We chart economically significant differences between the contributions of shocks according to their horizon, with the further forward Eurodollar shocks typically having a larger contribution. In general, movements in the medium-term ED communication shock have a particularly strong forecasting power relative to the other two communication shocks.

Table 10: Forecast Error Variance Decomposition at Business Cycle Frequency

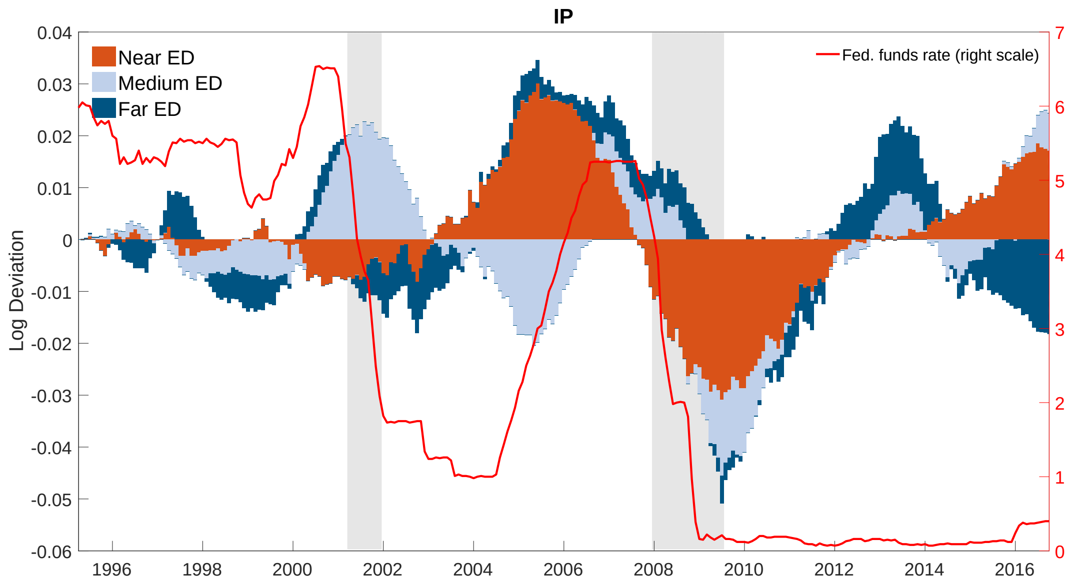
	Horizon (months)	S_t^{NED}	S_t^{MED}	S_t^{FED}
IP_t	12	7.83	87.05	5.12
	18	6.11	79.83	14.06
	24	6.32	65.03	28.65
	36	6.33	54.72	38.95
CPI_t	12	9.51	87.49	3.00
	18	7.14	78.84	14.02
	24	6.13	64.30	29.57
	36	5.02	44.75	50.23

Notes: Relative contribution of our shocks to a forecast-error variance decomposition of IP and CPI at the 12, 18, 24 and 36 month horizons from our baseline 5-variable VAR. The identified three shocks are $S_{d,t}^{j}$, $j \in \{A, NC, FC\}$– action, near communication and far communication shock respectively. As we are only interested in the relative importance of our shocks, we present the contribution of the three shocks as a percentage of their combined contribution.

A.3.3 Historical decompositions for the Eurodollar specification

Here we discuss in detail the results of historical decompositions of our ED futures analysis for both industrial production and prices. What is perhaps most interesting for us is the decomposition of industrial production during and after the Great Recession, shown in Figure 44.

Figure 44: Historical Decomposition of $\log(\text{IP}_t)$ Under Eurodollar Specification



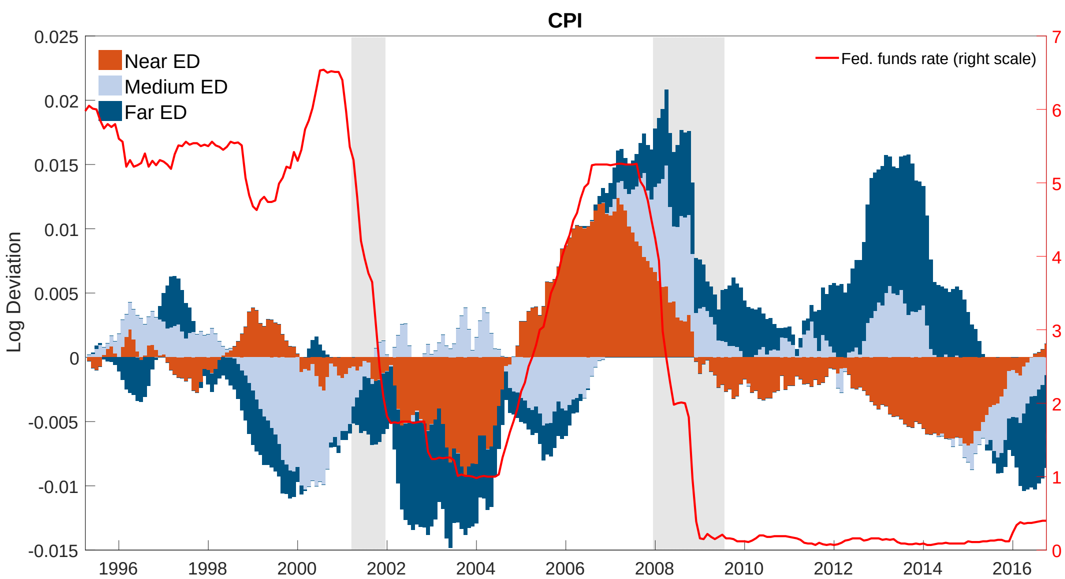
Notes: Historical decomposition of $\log(\text{IP}_t)$ in our 5-variable VAR, including the variables $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series S_t^j, $j \in \{NED, MED, FED\}$ – near ED, medium ED and far ED shock respectively. The bar plots are stacked, so their height above the zero-axis represents the cumulative historical contribution of our monetary shocks to industrial production above its unconditional mean. Similarly for their height below the zero-axis. We also display the federal funds rate (using the right-hand scale) for reference. NBER recession periods are shown as grey areas.

Surprisingly, the model suggests that from the onset of the crisis in early 2008 to around 2010, communication at all three horizons (1, 2 and 3 years) had a recessionary impact. This would likely reflect information about the Fed's negative outlook for the economy superseding its communication that these conditions were "likely to warrant exceptionally low levels of the federal funds rate for some time".[97] However, almost exactly from the onset of the asset purchases made in September 2012 onwards, all three ED shocks have an expansionary effect on IP, speaking for an inflation-expectations boosting effect even in the absence of movements in the federal funds rate, which remained close to zero until late 2015. And just in line with the mentioning of a possible exit of the ZLB in late 2015, the far ED

[97] See https://www.federalreserve.gov/faqs/what-is-forward-guidance-how-is-it-used-in-the-federal-reserve-monetary-policy.htm.

shock shows a contractionary effect on IP again. We therefore conclude that the ED shocks seem well-suited to track the recent history of Fed announcements on market expectations and thus the real economy, just as our federal funds futures shocks do for the pre-2008 period. The historical decomposition of CPI, shown in Figure 45, shows a strong positive contribution of the further forward ED shocks to inflation during the ZLB period. This suggests that despite generally weaker effects on output in the aftermath of the financial crisis, FOMC communication was supportive of inflation and inflation expectations.

Figure 45: Historical Decomposition of $\log(\text{CPI}_t)$ Under Eurodollar Specification



Notes: Historical decomposition of $\log(\text{CPI}_t)$ in our 5-variable VAR, including the variables $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three cumulated shock series S_t^j, $j \in \{NED, MED, FED\}$ – near ED, medium ED and far ED shock respectively. The bar plots are stacked, so their height above the zero-axis represents the cumulative historical contribution of our monetary shocks to industrial production above its unconditional mean. Similarly for their height below the zero-axis. We also display the federal funds rate (using the right-hand scale) for reference. NBER recession periods are shown as grey areas.

A.4 References

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B Appendix to "The Macroeconomic Effects of Bank Capital Requirement Changes: Evidence from a Narrative Approach "

Table 11: CR changes overview

CR change	rules for comment	final rules published	effective date	compliance date
num. guidelines	–	–	Dec. 17, 1981 (FR46/62693)	Dec. 17, 1981 (FR46/62694)
ILSA	Jul. 20, 1984 (FR49/29400)	Apr. 18, 1985 (FR50/11128)	Apr. 18, 1985 (FR50/11128)	Apr. 17, 1986 (FR50/11139)
Basel I	Mar. 27, 1986 (FR51/10602)	Jan. 18, 1989 (FR54/4186)	Dec. 31, 1990 (FR54/4186)	Dec. 31, 1992 (FR54/4193)
FDICIA/PCA	Jul. 1, 1992 (FR57/29226)	Sep. 29, 1992 (FR57/44866)	Dec. 19, 1992 (FR57/44866)	Dec. 19, 1992 (FR57/44866)
Mkt Risk Amend.	Jul. 25, 1995 (FR61/47358)	Sep. 6, 1996 (FR61/47358)	Jan. 1, 1997 (FR61/47358)	Jan. 1, 1998 (FR61/47358)
Basel II	Sep. 6, 2006 (FR71/55830)	Dec. 7, 2007 (FR72/69288)	Apr. 1, 2008 (FR72/69288)	Oct. 1, 2008 (FR72/69406)[98]
Basel II.5	Jan. 11, 2011 (FR77/53061)	Aug. 30, 2012 (FR77/53060)	Jan. 1, 2013 (FR77/53060)	Jan. 1, 2013 (FR77/53060)
Basel III	Aug. 30, 2012 (FR78/62020)	Oct. 11, 2013 (FR78/62018)	Jan. 1, 2014 (FR78/62018)	Jan. 1, 2014 (FR78/62018)[99]

Notes: Sources in parenthesis: FR refers to Federal Register issues as detailed below; after the slash the page number.
FDICIA refers to FDIC Improvement Act (PubLaw_1991Dec19_FDICIA)
FR46 refers to Federal Register/Vol. 46, No. 248/Monday, December 28, 1981
FR49 refers to Federal Register/Vol. 49. No. 141/Friday, July 20, 1984
FR50 refers to Federal Register/Vol. 50, No. 53/Tuesday, March 19, 1985
FR51 refers to Federal Register/Vol. 51, No. 59/Thursday, March 27, 1986
FR54 refers to Federal Register/Vol. 54, No. 17/Friday, January 27, 1989
FR57/29226 refers to Federal Register/Vol. 57, No. 127/Wednesday, July 1, 1992
FR57/44866 refers to Federal Register/Vol. 57, No. 189/Tuesday, September 29, 1992
FR61 refers to Federal Register/Vol. 61, No. 174/Friday, September 6, 1996
FR71 refers to Federal Register/Vol. 71, No. 185/Monday, September 25, 2006
FR72 refers to Federal Register/Vol. 72, No. 235/Friday, December 7, 2007
FR77 refers to Federal Register/Vol. 77, No. 169/Thursday, August 30, 2012
FR78 refers to Federal Register/Vol. 78, No. 198/Friday, October 11, 2013
For final rules for comment on Basel I, consider also Jul. 1986 (BIS) BIS refers to Basle Committee on Banking Supervision (1989)

C Appendix to "Spoilt for Choice on QE? Which Assets to Purchase When Combatting Disinflation"

C.1 Detailed derivation of model equations

This appendix derives all model equations in detail, from (40) to (85). They are also listed in Appendix C.2 below.

Households. The households' problem (9) subject to the budget constraint yields the first-order conditions with respect to C_t, Sav_t, and L_t:

$$\varrho_t = x_{dt}(C_t - hC_{t-1})^{-\sigma} - x_{dt+1}\beta h(C_{t+1} - hC_t)^{-\sigma} \tag{40}$$

$$\varrho_t = \beta\varrho_{t+1}R_t \tag{41}$$

$$\chi L_t^{\varphi} x_{lt} = (1-\alpha)\varrho_t P_{pt} Y_t / L_t \tag{42}$$

[Excursion: The household's savings schedule.] Assume agents' savings Sav_t are given by a CES composite index

$$\text{Sav}_t = \left[\kappa_s^{\frac{1}{\epsilon_s}} D_t^{\frac{\epsilon_s - 1}{\epsilon_s}} + (1-\kappa_s)^{\frac{1}{\epsilon_s}} (B_t^h)^{\frac{\epsilon_s-1}{\epsilon_s}}\right]^{\frac{\epsilon_s}{\epsilon_s - 1}},$$

where D_t and B_t^h denote savings via deposits and domestic bonds, respectively, and κ_s is the equilibrium share of savings via deposits. Agents maximise their savings Sav_t given the nominal identity for savings returns:

$$R_{ht}\text{Sav}_t = R_t D_t + R_{bt} B_t^h \tag{Sav.}$$

The solution to their problem

$$\max_{D_t, B_t^h} \text{Sav}_t = \left[\kappa_s^{\frac{1}{\epsilon_s}} D_t^{\frac{\epsilon_s - 1}{\epsilon_s}} + (1-\kappa_s)^{\frac{1}{\epsilon_s}} (B_t^h)^{\frac{\epsilon_s-1}{\epsilon_s}}\right]^{\frac{\epsilon_s}{\epsilon_s - 1}} \text{ s.t. } \text{Sav}_t = \frac{R_t}{R_{ht}} D_t + \frac{R_{bt}}{R_{ht}} B_t^h$$

gives the two first-order conditions necessary for an optimum

$$D_t = \kappa_s \left(\frac{R_t}{R_{ht}}\right)^{-\epsilon_s} \text{Sav}_t$$
$$B_t^h = (1-\kappa_s)\left(\frac{R_{bt}}{R_{ht}}\right)^{-\epsilon_s} \text{Sav}_t.$$

Combining these, we obtain

$$D_t = \frac{\kappa_s}{1-\kappa_s}\left(\frac{R_t}{R_{bt}}\right)^{-\epsilon_s} B_t^h. \tag{43}$$

Inserting these back into the savings constraint (Sav.) above, we get the composite return index R_{ht}:

$$\begin{aligned} R_{ht}\text{Sav}_t &= R_t D_t + R_{bt} B_t^h \\ &= R_t \cdot \kappa_s \left(\frac{R_t}{R_{ht}}\right)^{-\epsilon_s} \text{Sav}_t + R_{bt} \cdot (1-\kappa_s)\left(\frac{R_{bt}}{R_{ht}}\right)^{-\epsilon_s} \text{Sav}_t \\ &= \left[\kappa_s R_t^{1-\epsilon_s} + (1-\kappa_s) R_{bt}^{1-\epsilon_s}\right] R_{ht}^{\epsilon_s}\text{Sav}_t \\ R_{ht} &= \left[\kappa_s R_t^{1-\epsilon_s} + (1-\kappa_s) R_{bt}^{1-\epsilon_s}\right]^{\frac{1}{1-\epsilon_s}} \end{aligned} \tag{44}$$

[End of excursion]

Productive firms. Solving the problem of productive firms, subject to their production function

$$Y_t = x_{pt} K_{t-1}^{\alpha} L_t^{1-\alpha}, \tag{45}$$

defines the return on productive capital r_{pkt} and wages w_t as

$$\begin{aligned} r_{pkt} &= \alpha P_{pt} Y_t / K_{t-1} \\ w_t &= (1-\alpha) P_{pt} Y_t / L_t. \end{aligned} \tag{46}$$

The overall return on capital, (11), is reproduced here:

$$R_{st} = \frac{\alpha P_{pt} Y_t / K_{t-1} + (1-\delta) Q_{st}}{Q_{st-1}} \tag{47}$$

Capital producer. The law of motion of capital is reproduced as

$$K_t = x_{it} \cdot I_t + (1-\delta) K_{t-1}. \tag{48}$$

The first-order condition of the capital producer defines the price of capital as

$$\begin{aligned} Q_{st} = 1 &+ \frac{\chi_I}{2} x_{it} (I_t / I_{t-1} - 1)^2 + \chi_I x_{it} (I_t / I_{t-1} - 1) I_t / I_{t-1} \\ &- E_t \left\{ \frac{\beta \varrho_{t+1}}{\varrho_t} \chi_I x_{it+1} (I_{t+1}/I_t - 1)(I_{t+1}/I_t)^2 \right\}. \end{aligned} \tag{49}$$

Retailer. The output of productive firms, Y_{pt}, equals the product of the final consumption good, Y_t, and a price dispersion term $\mathcal{D}_t$:

$$Y_{pt} = \mathcal{D}_t Y_t, \tag{50}$$

where price dispersion[100] is defined as

$$\mathcal{D}_t = \gamma \mathcal{D}_{t-1} \pi_{t-1}^{-\kappa \epsilon_p} \pi_t^{\epsilon_p} + (1-\gamma) \left(\frac{1 - \gamma \pi_{t-1}^{\kappa(1-\gamma)} \pi_t^{\gamma - 1}}{1-\gamma} \right)^{-\epsilon_p (1-\gamma)} \tag{A.disp}$$

The first-order condition from the retailer problem (13) above is

[100]In the model log-linearised around a zero-inflation steady state, price dispersion will actually not matter since $\hat{\mathcal{D}}_t = 0$. Therefore, I will not include this equation into the model equation summary below.

$$E_0 \left\{ \sum_{i=0}^{\infty} \gamma^i \beta^i \frac{\varrho_{t+i}}{\varrho_0} \left[\frac{P_t^*}{P_{t+i}} \prod_{j=1}^{i} (1+\pi_{t+j-1})^{\gamma} - \frac{\epsilon_p}{\epsilon_p - 1} P_{pt+i} \right] \left(\frac{P_{t+i}(z)}{P_{t+i}} \right)^{-\epsilon_p} Y_t \right\}. \tag{FOC-P}$$

Closely following derivations in Schmitt-Grohe and Uribe (2004), pp. 11-12, for the symmetric equilibrium, we obtain the recursive optimality conditions:

$$F_t = P_{pt} Y_t + \beta\gamma \frac{\varrho_{t+1}}{\varrho_t} \pi_{t+1}^{\epsilon_p} \pi_t^{-\epsilon_p \kappa} F_{t+1} \tag{51}$$

$$H_t = Y_t + \beta\gamma \frac{\varrho_{t+1}}{\varrho_t} \pi_{t+1}^{\epsilon_p - 1} \pi_t^{\kappa(1-\epsilon_p)} H_{t+1} \tag{52}$$

$$\pi_t^* = \frac{\epsilon_p}{\epsilon_p - 1} \frac{F_t \pi_t}{H_t}, \tag{53}$$

where π_t^* is defined as $\pi_t^* \equiv P_t^*/P_t$. Moreover, we obtain an expression for the aggregate price index:

$$P_t = \left[\gamma \left(\pi_{t-1}^{\kappa} P_{t-1}^{1-\epsilon_p} \right)^{1-\epsilon_p} + (1-\gamma) \left(P_t^* \right)^{1-\epsilon_p} \right]^{\frac{1}{1-\epsilon_p}}$$

or

$$\pi_t^{1-\epsilon_p} = \gamma \pi_{t-1}^{\kappa(1-\epsilon_p)} + (1-\gamma)(\pi_t^*)^{1-\epsilon_p} \tag{54}$$

Commercial banks. As hinted at in Section 3.2.5 above, we can show that a commercial bank's value function is linear in its holdings of loans $Q_{st} S_t^c$, bonds $Q_{bt} B_t^c$, assets $Q_{at} A_t^c$, and net worth N_t^c. We can take this linearity as given (following the analogy to the case without financial assets A_t^c in Gertler and Karadi, 2011), or derive it using a guess-and-verify approach as below.

[Excursion: The guess-and-verify approach to show linearity of $\mathcal{V}_t^c$] The bank solves the problem

$$\mathcal{V}_t^c = \max_{S_t^c, B_t^c, A_t^c} E_t \left\{ \sum_{t=0}^{\infty} (1-\theta_c)\theta_c^t \beta^t \frac{\varrho_{t+1}}{\varrho_t} N_{t+1}^c \right\} \tag{19}$$

$$\text{s.t. } N_{t+1}^c = (R_{kt+1} - R_t) Q_{st} S_t^c + (R_{bt+1} - R_t) Q_{bt} B_t^c + (R_{at+1} - R_t) Q_{at} A_t^c + R_t N_t^c \tag{15}$$

$$\mathcal{V}_t^c \geq \lambda_c \left[Q_{st} S_t^c + \Delta_{bt} Q_{bt} B_t^c + \Delta_{at} Q_{at} A_t^c \right] \tag{20}$$

Guess that the value function V_t is linear in $Q_{st}S_t^c$, $Q_{bt}B_t^c$, $Q_{at}A_t^c$ and N_t^c:

$$V_t = \mu_{st} Q_{st} S_t^c + \mu_{bt} Q_{bt} B_t^c + \mu_{at} Q_{at} A_t^c + \nu_t N_t^c, \tag{aux.1}$$

which will be verified below. Denoting the multiplier on constraint (20) by ξ_t, the Lagrangian to the above problem is given by

$$\begin{aligned}
\mathcal{L} &= \mathcal{V}_t^c + \xi_t \left[\mathcal{V}_t^c - \lambda_c (Q_{st} S_t^c + \Delta_{bt} Q_{bt} B_t^c + \Delta_{at} Q_{at} A_t^c) \right] \\
&= (1+\xi_t)\mathcal{V}_t^c - \xi_t \lambda_c (Q_{st} S_t^c + \Delta_{bt} Q_{bt} B_t^c + \Delta_{at} Q_{at} A_t^c) \\
&= (1+\xi_t)(\mu_{st} Q_{st} S_t^c + \mu_{bt} Q_{bt} B_t^c + \mu_{at} Q_{at} A_t^c + \nu_t N_t^c) - \xi_t \lambda_c (Q_{st} S_t^c + \Delta_{bt} Q_{bt} B_t^c + \Delta_{at} Q_{at} A_t^c)
\end{aligned}$$

The consolidated first order conditions w.r.t. S_t^c, B_t^c and A_t^c are

$$\mu_{st} = \frac{\lambda_c \xi_t}{1+\xi_t}$$
$$\mu_{bt} = \frac{\lambda_c \Delta_{bt} \xi_t}{1+\xi_t}$$
$$\mu_{at} = \frac{\lambda_c \Delta_{at} \xi_t}{1+\xi_t}$$

From this follow two arbitrage conditions between the value of a marginal unit of loans on the one hand, and bonds or assets on the other:

$$\mu_{bt} = \Delta_{bt} \cdot \mu_{st} \tag{55}$$

$$\mu_{at} = \Delta_{at} \cdot \mu_{st} \tag{56}$$

Moreover, as long as $\xi_t > 0$, we have that

$$\mu_{st} Q_{st} S_t^c + \mu_{bt} Q_{bt} B_t^c + \mu_{at} Q_{at} A_t^c + \nu_t N_t^c = \lambda_c (Q_{st} S_t^c + \Delta_{bt} Q_{bt} B_t^c + \Delta_{at} Q_{at} A_t^c)$$

or

$$Q_{st} S_t^c = \frac{\nu_t}{\lambda_c - \mu_{st}} N_t^c - \frac{\lambda_c \Delta_{bt} - \mu_{bt}}{\lambda_c - \mu_{st}} Q_{bt} B_t^c - \frac{\lambda_c \Delta_{at} - \mu_{at}}{\lambda_c - \mu_{st}} Q_{at} A_t^c.$$

Plugging this into (aux.1) and solving, we get

$$\begin{aligned} \mathcal{V}_t^c &= \frac{\lambda_c (\Delta_{bt} \mu_{st} - \mu_{bt})}{\lambda_c - \mu_{st}} Q_{bt} B_t^c + \frac{\lambda_c (\Delta_{at} \mu_{st} - \mu_{at})}{\lambda_c - \mu_{st}} Q_{at} A_t^c + \frac{\lambda_c \nu_t}{\lambda_c - \mu_{st}} N_t^c \\ &\overset{(55), (56)}{=} \frac{\lambda_c \nu_t}{\lambda_c - \mu_{st}} N_t^c. \end{aligned}$$

Like Gertler and Karadi (2011) in their equation (16), I define the expected shadow value of a unit of net worth as

$$\Omega_t = 1 - \theta_c + \theta_c \frac{d\mathcal{V}_t^c}{dN_t^c} = 1 - \theta_c + \theta_c \frac{\lambda_c \nu_t}{\lambda_c - \mu_{st}} \tag{aux.2}$$

With our guess for the form of $\mathcal{V}_t^c$, (aux.1) from above, we have

$$\begin{aligned} \mathcal{V}_t^c &= \mu_{st} Q_{st} S_t^c + \mu_{bt} Q_{bt} B_t^c + \mu_{at} Q_{at} A_t^c + \nu_t N_t^c \\ &= \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1} N_{t+1}^c \\ &= \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1} \left[(R_{st+1} - R_t) Q_{st} S_t^c + (R_{bt+1} - R_t) Q_{bt} B_t^c + (R_{at+1} - R_t) Q_{at} A_t^c + R_t N_t^c \right] \end{aligned}$$

Equating coefficients, we get the following expressions for the commercial bank's discounted expected value of expanding loans S_t^c, bonds B_t^c, assets A_t^c, and net worth N_t^c:

$$\mu_{st} = \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1}(R_{st+1} - R_t) \tag{57}$$

$$\mu_{bt} = \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1}(R_{bt+1} - R_t) \tag{58}$$

$$\mu_{at} = \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1}(R_{at+1} - R_t) \tag{59}$$

$$\nu_t = \beta \frac{\varrho_{t+1}}{\varrho_t} \Omega_{t+1} R_t \tag{60}$$

The linear coefficients μ_{st}, μ_{bt}, μ_{at}, and ν_t are described in turn. μ_{st} is the discounted expected value of expanding the existing commercial banks' loans[101] by a marginal unit, holding both assets and net worth constant (i.e., financing the new loans by issuing more deposits at rate R_t). Intuitively, μ_{st} is given by the additional return of a marginal loan unit in case the banker retires or continues her business. If she retires (with probability $1-\theta_c$), the value-added of the loan unit is the spread of loan return over the cost of refinancing at the savings bank (remember that net worth is kept constant). If the bank continues (with probability θ_c), its loan sum will grow in line with net worth growth and be evaluated at tomorrow's marginal value μ_{st+1}. μ_{bt} and μ_{at} are the corresponding value of marginally expanding the the commercial bank's bonds and assets, respectively. Finally, ν_t is the corresponding value of expanding net worth (note that internal refinancing saves the bank the deposit cost R_t).

[End of excursion]

Moreover, define the ratio of bonds and assets held relative to loans as

$$\Xi_{bt} = \frac{Q_{bt} B_t^c}{Q_{st} S_t^c} \tag{61}$$

$$\Xi_{at} = \frac{Q_{at} A_t^c}{Q_{st} S_t^c}. \tag{62}$$

[101] So the transfers to entering bankers outlined below do not enter.

Combining (20) with (aux.1) and using some previous results, we get

$$\begin{aligned}\nu_t N_t^c &= (\lambda_c - \mu_{st})Q_{st}S_t^c + (\Delta_{bt}\lambda_c - \mu_{bt})Q_{bt}B_t^c + (\Delta_{at}\lambda_c - \mu_{at})Q_{at}A_t^c \\ &\overset{(55),\,(56)}{=} (\lambda_c - \mu_{st})(Q_{st}S_t^c + \Delta_{bt}Q_{bt}B_t^c + \Delta_{at}Q_{at}A_t^c) \\ &\overset{(61),\,(62)}{=} (\lambda_c - \mu_{st})Q_{st}S_t^c(1 + \Delta_{bt}\Xi_{bt} + \Delta_{at}\Xi_{at}),\end{aligned}$$

Combine this with the definition of loan leverage above,

$$\phi_t^c = \frac{Q_{st}S_t^c}{N_t^c}, \tag{63}$$

to get a reformulation of the incentive compatibility constraint (aux.1):

$$\phi_t^c = \frac{\nu_t}{(\lambda_c - \mu_{st})(1 + \Delta_{bt}\Xi_{bt} + \Delta_{at}\Xi_{at})} \tag{64}$$

Using this equation, we can reformulate (aux.2) as

$$\begin{aligned}\Omega_t &= 1 - \theta_c + \theta_c \frac{d\mathcal{V}_t^c}{dN_t^c} = 1 - \theta_c + \theta_c \frac{\lambda_c \nu_t}{\lambda_c - \mu_{st}} \\ &\overset{(64)}{=} 1 - \theta_c + \theta_c \nu_t \left(1 + \frac{\mu_{st}}{\lambda_c - \mu_{st}}\right).\end{aligned} \tag{65}$$

The law of motion for net worth, (23), can be re-written as

$$\begin{aligned}N_t^c = {}& \theta_c N_{t-1}^c \left[R_{t-1} + \phi_{t-1}^c(R_{st} - R_{t-1})(1 + \Delta_{bt}\Xi_{bt-1} + \Delta_{at}\Xi_{at-1})\right]/x_{nt} \\ & + \omega_c(Q_{st}S_{t-1}^c + Q_{bt}B_{t-1}^c + Q_{at}A_{t-1}^c)\end{aligned} \tag{66}$$

Finally, I just replicate equations (16) and (17), as well as equations (21) and (22) from above:

$$R_{bt} = \frac{r_b - Q_{bt}}{Q_{bt-1}} \tag{67}$$

$$R_{at} = \frac{r_a - Q_{at}}{Q_{at-1}} \tag{68}$$

$$\Delta_{bt} = \Delta_b \exp\{\eta_b B_t^g - \eta_{sb} S_t^g\} \tag{69}$$

$$\Delta_{at} = \Delta_a \exp\{\eta_a A_t^g - \eta_{sa} S_t^g\} \tag{70}$$

Wholesale banks. As stated in Section 3.2.6, we can write the value function of wholesale banks, $\mathcal{V}_t^w$, as a linear function of their intermediated funds $Q_{st} S_t^w$ and net worth N_t^w. Again one can derive this using the guess-and-verify approach below.

[Excursion: The guess-and-verify approach to show linearity of $\mathcal{V}_t^w$] The Bellman equation for wholesale banks is

$$\mathcal{V}_t^w = \max_{S_t^w, A_t^w} E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w) N_{t+1}^w + \theta_w \mathcal{V}_{t+1}^w \right] \right\}.$$

Guess that $\mathcal{V}_t^w$ is linear in the coefficients μ_{wt} and ν_{wt}:

$$\mathcal{V}_t^w = \mu_{wt} Q_{st} S_t^w + \nu_{wt} N_t^w$$

Directly plugging the guess into the value function yields

$$\begin{aligned} \mu_{wt} Q_{st} S_{wt} + \nu_{wt} N_t^w = E_t \Bigg\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \Bigg[& (1-\theta_w) \left((R_{st+1} - R_{at+1}) Q_{st} S_t^w + R_{at} N_t^w \right) \\ & + \theta_w \left(\frac{Q_{st+1} S_{t+1}^w}{Q_{st} S_t^w} Q_{st} S_t^w \mu_{wt+1} + \frac{N_{t+1}^w}{N_t^w} N_t^w \nu_{wt+1} \right) \Bigg] \Bigg\}. \end{aligned}$$

Matching coefficients, we get

$$\mu_{wt} = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w)(R_{st+1} - R_{at+1}) + \theta_w \frac{Q_{st+1} S^w_{t+1}}{Q_{st} S^w_t} \mu_{wt+1} \right] \right\}$$
$$= E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w)(R_{st+1} - R_{at+1}) + \theta_w \frac{\phi^w_{t+1}}{\phi^w_t} \left((R_{st+1} - R_{at+1})\phi^w_t + R_{at+1} \right) \mu_{wt+1} \right] \right\} \tag{71}$$

$$\nu_{wt} = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w) R_{at+1} + \theta_w \frac{N^w_{t+1}}{N^w_t} \nu_{wt+1} \right] \right\}$$
$$= E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w) R_{at+1} + \theta_w \left((R_{st+1} - R_{at+1})\phi^w_t + R_{at+1} \right) \nu_{wt+1} \right] \right\}. \tag{72}$$

The linear coefficients μ_{wt} and ν_{wt} represent the discounted expected value of expanding the existing wholesale bank balance-sheet assets $Q_{st} S^w_t$ and net worth N^w_t by a marginal unit, respectively, while holding the respective other constant. The interpretation is similar to the one for commercial banks above (note that for wholesale banks holding one extra unit of net worth saves R_{at+1}, as deposits at rate R_t are not available to them).

[End of excursion]

Equations (25), (27), (28), and (24) are just replicated from above:

$$\phi^w_t = \frac{Q_{st} S^w_t}{N^w_t} \tag{73}$$

$$\phi^w_t = \frac{\nu_{wt}}{\lambda_w - \mu_{wt}} \tag{74}$$

$$N^w_t = \theta_w [(R_{st} - R_{at})\phi^w_{t-1} + R_{at}] N^w_{t-1} + \omega_w Q_{st} S^w_{t-1} \tag{75}$$

$$A^w_t = (Q_{st} S^w_t - N^w_t)/Q_{at} \tag{76}$$

Monetary policy. The monetary policy reaction functions under unconventional policies are merely replicated from above [(29) to (33)] for convenience:

$$R_t\pi_{t+1} = (R_{t-1}\pi_t)^{\rho_R}\left[R\pi \cdot \left(\frac{\pi_t}{\pi}\right)^{\kappa_\pi}\right]^{1-\rho_R} x_{rt} \tag{77}$$

$$S_t^g = \Psi_{Rs}\left[R_{st+1} - R_t - (R_s - R)\right] - \Psi_{\pi s}(\pi_t - \pi) + K \cdot x_{st} \tag{78}$$

$$B_t^g = \Psi_{Rb}\left[R_{st+1} - R_t - (R_s - R)\right] - \Psi_{\pi b}(\pi_t - \pi) + B \cdot x_{bt} \tag{79}$$

$$A_t^g = \Psi_{Ra}\left[R_{st+1} - R_t - (R_s - R)\right] - \Psi_{\pi a}(\pi_t - \pi) + A^w \cdot x_{at}. \tag{80}$$

Market clearing. Again, I just replicate the market clearing conditions [(35) to (38)] for convenience:

$$Y_t = C_t + G_t + I_t\left[1 + \frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] + \tau_p(S_t^g + A_t^g + B_t^g) \tag{81}$$

$$K_t = S_t^c + S_t^w + S_t^g \tag{82}$$

$$B = B_t^c + B_t^h + B_t^g \tag{83}$$

$$A_t^w = A_t^c + A_t^g \tag{84}$$

Shocks. As detailed in equation (39):

$$\log(x_{jt}) = \rho_j \log(x_{jt-1}) + \sigma_j \varepsilon_{jt} \qquad \forall j \in \{d, l, p, i, n, r, g, s, b, a\} \tag{85}$$

Additional variables. Here, I derive some additional variables that are used in plotting results. The central bank balance sheet is given by (33):

$$BS_t = \left(Q_{st}S_t^g + Q_{bt}B_t^g + Q_{at}A_t^g\right)/(4 \cdot Y) \tag{86}$$

The nominal policy rate is given by

$$R_{pt} = R_t\pi_{t+1}. \tag{87}$$

The spreads of loan, bond and asset rates over deposit rates are simply defined as

$$pr_{st} = R_{st+1}/R_t \tag{88}$$

$$pr_{bt} = R_{bt+1}/R_t \tag{89}$$

$$pr_{at} = R_{at+1}/R_t \tag{90}$$

Welfare in each period is given by household utility (remember that bankers cannot consume nor work before retiring), see eq. (8):

$$\mathcal{W}_t = x_{dt} \left(\frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \chi \frac{L_t^{1+\varphi}}{1+\varphi} \right) + \beta \mathcal{W}_{t+1} \tag{91}$$

The overall amount of deposits is given by

$$D_t = Q_{st} S_t^c + Q_{bt} B_t^c + Q_{at} A_t^c - N_t^c. \tag{92}$$

C.2 Model equations

Households.

$$\varrho_t = x_{dt}(C_t - hC_{t-1})^{-\sigma} \tag{40}$$

$$\varrho_t = \beta \varrho_{t+1} R_t \tag{41}$$

$$\chi L_t^{\varphi} x_{lt} = (1-\alpha) \varrho_t P_{pt} Y_t / L_t \tag{42}$$

$$D_t = \frac{\kappa_s}{1-\kappa_s} \left(\frac{R_t}{R_{bt}} \right)^{-\epsilon_s} B_t^h \tag{43}$$

$$R_{ht}^{1-\epsilon_s} = \kappa_s R_t^{1-\epsilon_s} + (1-\kappa_s) R_{bt}^{1-\epsilon_s} \tag{44}$$

Goods and capital production.

$$Y_{pt} = x_{pt} K_{t-1}^{\alpha} L_t^{1-\alpha} \tag{45}$$

$$r_{pkt} = \alpha P_{pt} Y_t / K_{t-1} \tag{46}$$

$$R_{st} = \frac{r_{pkt} + (1-\delta) Q_{st}}{Q_{st-1}} \tag{47}$$

$$K_t = x_{it} I_t + (1-\delta) K_{t-1} \tag{48}$$

$$\begin{aligned} Q_{st} = {} & 1 + \frac{\chi_I}{2} x_{it} (I_t / I_{t-1} - 1)^2 + \chi_I x_{it} (I_t / I_{t-1} - 1) I_t / I_{t-1} \\ & - E_t \left\{ \frac{\beta \varrho_{t+1}}{\varrho_t} \chi_I x_{it+1} (I_{t+1} / I_t - 1)(I_{t+1} / I_t)^2 \right\} \end{aligned} \tag{49}$$

Retailer.

$$Y_{pt} = \mathcal{D}_t Y_t \tag{50}$$

$$F_t = P_{pt} Y_t + \beta \gamma \frac{\varrho_{t+1}}{\varrho_t} \pi_{t+1}^{\epsilon_p} \pi_t^{-\epsilon_p \kappa_p} F_{t+1} \tag{51}$$

$$H_t = Y_t + \beta \gamma \frac{\varrho_{t+1}}{\varrho_t} \pi_{t+1}^{\epsilon_p - 1} \pi_t^{\kappa_p (1-\epsilon_p)} H_{t+1} \tag{52}$$

$$\pi_t^* = \frac{\epsilon_p}{\epsilon_p - 1} \frac{F_t \pi_t}{H_t} \tag{53}$$

$$\pi_t^{1-\epsilon_p} = \gamma \pi_{t-1}^{\kappa_p (1-\epsilon_p)} + (1-\gamma)(\pi_t^*)^{1-\epsilon_p} \tag{54}$$

Commercial banks.

$$\mu_{bt} = \Delta_{bt}\mu_{st} \tag{55}$$

$$\mu_{at} = \Delta_{at}\mu_{st} \tag{56}$$

$$\mu_{st} = \beta\frac{\varrho_{t+1}}{\varrho_t}\Omega_{t+1}(R_{st+1} - R_t) \tag{57}$$

$$\mu_{bt} = \beta\frac{\varrho_{t+1}}{\varrho_t}\Omega_{t+1}(R_{bt+1} - R_t) \tag{58}$$

$$\mu_{at} = \beta\frac{\varrho_{t+1}}{\varrho_t}\Omega_{t+1}(R_{at+1} - R_t) \tag{59}$$

$$\nu_t = \beta\frac{\varrho_{t+1}}{\varrho_t}\Omega_{t+1}R_t \tag{60}$$

$$\Xi_{bt} = \frac{Q_{bt}B_t^c}{Q_{st}S_t^c} \tag{61}$$

$$\Xi_{at} = \frac{Q_{at}A_t^c}{Q_{st}S_t^c} \tag{62}$$

$$\phi_t^c = \frac{Q_{st}S_t^c}{N_t^c} \tag{63}$$

$$\phi_t^c = \frac{\nu_t}{(1 + \Delta_{bt}\Xi_{bt} + \Delta_{at}\Xi_{at})(\lambda_c - \mu_{st})} \tag{64}$$

$$\Omega_t = 1 - \theta_c + \theta_c\nu_t\left(1 + \frac{\mu_{st}}{\lambda_c - \mu_{st}}\right) \tag{65}$$

$$\begin{aligned} N_t^c = {} & \theta_c N_{t-1}^c\left[R_{t-1} + \phi_{t-1}^c(R_{kt} - R_{t-1})(1 + \Delta_b\Xi_{bt-1} + \Delta_a\Xi_{at-1})\right]/x_{nt} \\ & + \omega_c\left(Q_{st}S_{t-1}^c + Q_{bt}B_{t-1}^c + Q_{at}A_{t-1}^c\right) \end{aligned} \tag{66}$$

$$R_{bt} = \frac{r_b + Q_{bt}}{Q_{bt-1}} \tag{67}$$

$$R_{at} = \frac{r_a + Q_{at}}{Q_{at-1}} \tag{68}$$

$$\Delta_{bt} = \Delta_b\exp\{\eta_b B_t^g - \eta_{sb}S_t^g\} \tag{69}$$

$$\Delta_{at} = \Delta_a\exp\{\eta_a A_t^g - \eta_{sa}S_t^g\} \tag{70}$$

Wholesale banks.

$$\mu_t^w = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w)(R_{st+1} - R_{at}) + \theta_w \frac{\phi_{t+1}^w}{\phi_t^w} \left((R_{st+1} - R_{at})\phi_t^w + R_{at} \right) \mu_{t+1}^w \right] \right\} \tag{71}$$

$$\nu_t^w = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[(1-\theta_w) R_{at} + \theta_w \left((R_{st+1} - R_{at})\phi_t^w + R_{at} \right) \nu_{t+1}^w \right] \right\} \tag{72}$$

$$\phi_t^w = \frac{Q_{st} S_t^w}{N_t^w} \tag{73}$$

$$\phi_t^w = \frac{\nu_t^w}{\lambda_w - \mu_t^w} \tag{74}$$

$$N_t^w = \theta_w [(R_{st} - R_{at-1})\phi_{t-1}^w + R_{at-1}] N_{t-1}^w + \omega_w Q_{st} S_{t-1}^w \tag{75}$$

$$A_t^w = (Q_{st} S_t^w - N_t^w)/Q_{at} \tag{76}$$

Monetary policy.

$$R_t \pi_{t+1} = (R_{t-1}\pi_t)^{\rho_R} \left[R\pi \cdot \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \right]^{1-\rho_R} x_{rt} \tag{77}$$

$$S_t^g = -\Psi_{\pi s}(\pi_t - \pi) + K \cdot x_{st} \tag{78}$$

$$B_t^g = -\Psi_{\pi b}(\pi_t - \pi) + B \cdot x_{bt} \tag{79}$$

$$A_t^g = -\Psi_{\pi a}(\pi_t - \pi) + A^w \cdot x_{at}. \tag{80}$$

Market clearing.

$$Y_t = C_t + G_t + I_t + \frac{\chi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t + \tau_p (S_t^g + A_t^g + B_t^g) \tag{81}$$

$$K_t = S_t^c + S_t^w + S_t^h \tag{82}$$

$$B = B_t^c + B_t^h \tag{83}$$

$$A_t^w = A_t^c + A_t^g \tag{84}$$

Shock processes.

$$\log(x_{j,t}) = \rho_j \log(x_{j,t-1}) + \sigma_j \varepsilon_t^j, \ \forall j = \left\{ d, l, p, i, n, r, g, s, b, a \right\} \tag{85}$$

Additional variables.

$$BS_t = (Q_{st}S_t^g + Q_{bt}B_t^g + Q_{at}A_t^g)/(12 \cdot Y) \tag{86}$$

$$R_{nt} = R_t \pi_{t+1} \tag{87}$$

$$pr_{st} = R_{st+1}/R_t \tag{88}$$

$$pr_{bt} = R_{bt+1}/R_t \tag{89}$$

$$pr_{at} = R_{at+1}/R_t \tag{90}$$

$$\mathcal{W}_t = x_{dt}\left(\frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \chi\frac{L_t^{1+\varphi}}{1+\varphi}\right) + \beta\mathcal{W}_{t+1} \tag{91}$$

$$D_t = Q_{st}S_t^c + Q_{bt}B_t^c + Q_{at}A_t^c - N_t^c \tag{92}$$

D Log-linearised equations

I will use the fact that in steady state, $\pi = Q_s = Q_b = Q_a$ throughout.

Households.

$$\hat{\varrho}_t = (1-\beta h)^{-1}\left[\hat{x}_{dt} - \beta h\hat{x}_{dt+1} - \frac{\sigma}{1-h}\left(\hat{C}_t - h\hat{C}_{t-1} - \beta h(\hat{C}_{t+1} - h\hat{C}_t)\right)\right] \tag{40*}$$

$$\hat{R}_t = \hat{\varrho}_t - \hat{\varrho}_{t+1} \tag{41*}$$

$$\varphi\hat{L}_t = \hat{\varrho}_t + \hat{P}_{pt} + \hat{Y}_t - \hat{L}_t - \hat{x}_{lt} \tag{42*}$$

$$\hat{D}_t = \epsilon_s(\hat{R}_{bt} - \hat{R}_t) + \hat{B}_t^h \tag{43*}$$

$$R_h\hat{R}_{ht} = \kappa_s R\hat{R}_t + (1-\kappa_s)R_b\hat{R}_{bt} \tag{44*}$$

Good and capital production.

$$\hat{Y}_{pt} = \hat{x}_{pt} + (1-\alpha)\hat{L}_t + \alpha\left(\hat{\xi}_t + \hat{K}_{t-1}\right) \tag{45}^*$$

$$\hat{r}_{pkt} = \hat{P}_{pt} + \hat{Y}_t - \hat{\xi}_t - \hat{K}_{t-1} \tag{46}^*$$

$$\hat{R}_{st} = \hat{\xi}_t - \hat{Q}_{st-1} + R_s^{-1}\left(r_{pk}\hat{r}_{pkt} + (1-\delta)\hat{Q}_{st}\right) \tag{47}^*$$

$$\hat{K}_t = (I/K)\hat{I}_t + (1-\delta)\left(\hat{\xi}_t + \hat{K}_{t-1}\right) \tag{48}^*$$

$$\hat{Q}_{st} = \chi_I\left(\hat{I}_t - \hat{I}_{t-1}\right) - \beta\chi_I\left(\hat{I}_{t+1} - \hat{I}_t\right) \tag{49}^*$$

Retailer.

$$\hat{Y}_{pt} = \hat{\mathcal{D}}_t + \hat{Y}_t \tag{50}^*$$

$$\hat{F}_t = (1-\beta\gamma)(\hat{Y}_t + \hat{P}_{p,t}) + \beta\gamma\left[\hat{\varrho}_{t+1} - \hat{\varrho}_t + \epsilon_p(\hat{\pi}_{t+1} - \kappa\hat{\pi}_t) + \hat{F}_{t+1}\right] \tag{51}^*$$

$$\hat{H}_t = (1-\beta\gamma)\hat{Y}_t + \beta\gamma\left[\hat{\varrho}_{t+1} - \hat{\varrho}_t + (\epsilon_p - 1)(\hat{\pi}_{t+1} - \kappa\hat{\pi}_t) + \hat{H}_{t+1}\right] \tag{52}^*$$

$$\hat{\pi}_t^* = \hat{F}_t + \hat{\pi}_t - \hat{H}_t + \frac{1}{\epsilon_p - 1}\hat{\epsilon}_{pt} \tag{53}^*$$

$$\hat{\pi}_t = \gamma\kappa\hat{\pi}_{t-1} + (1-\gamma)\hat{\pi_t^*} \tag{54}^*$$

Commercial banks.

$$\hat{\mu}_{bt} = \hat{\Delta}_{bt} + \hat{\mu}_{st} \tag{55}^*$$

$$\hat{\mu}_{at} = \hat{\Delta}_{at} + \hat{\mu}_{st} \tag{56}^*$$

$$\hat{\mu}_{st} = \hat{\varrho}_{t+1} - \hat{\varrho}_t + \hat{\Omega}_{t+1} + \frac{R_s\hat{R}_{st+1} - R\hat{R}_t}{(R_s - R)} \tag{57}^*$$

$$\hat{\mu}_{bt} = \hat{\varrho}_{t+1} - \hat{\varrho}_t + \hat{\Omega}_{t+1} + \frac{R_b\hat{R}_{bt+1} - R\hat{R}_t}{(R_b - R)} \tag{58}^*$$

$$\hat{\mu}_{at} = \hat{\varrho}_{t+1} - \hat{\varrho}_t + \hat{\Omega}_{t+1} + \frac{R_a\hat{R}_{at+1} - R\hat{R}_t}{R_a - R} \tag{59}^*$$

$$\hat{\nu}_t = \hat{\varrho}_{t+1} - \hat{\varrho}_t + \hat{\Omega}_{t+1} + R_t \tag{60}^*$$

$$\hat{\Xi}_{bt} = \hat{Q}_{bt} + \hat{B}^c_t - \hat{S}^c_t - \hat{Q}_{st} \tag{61}^*$$

$$\hat{\Xi}_{at} = \hat{Q}_{at} + \hat{A}^c_t - \hat{S}^c_t - \hat{Q}_{st} \tag{62}^*$$

$$\hat{\phi}^c_t = \hat{\nu}_t + \hat{\psi}_t + \frac{\mu_s}{\lambda_c - \mu_s}\hat{\mu}_{st} - \frac{1}{1 + \Delta_b\Xi_b + \Delta_a\Xi_a}(\Delta_b\Xi_b\hat{\Xi}_{bt} + \Delta\Xi_a\hat{\Xi}_{at}) \tag{63}^*$$

$$\hat{\phi}^c_t = \hat{S}^c_t + \hat{Q}_{st} - \hat{N}^c_t \tag{64}^*$$

$$\hat{\Omega}_t = \theta_c \left(1 + \frac{\mu_s}{\lambda_c - \mu_s}\right) \hat{\nu}_{t+1} + \theta_c \frac{\lambda_c \mu_s}{(\lambda_c - \mu_s)^2} \hat{\mu}_{st+1} \tag{65*}$$

$$\begin{aligned}\hat{N^c_t} &= \theta_c \left[R + \phi^c(R_s - R)(1 + \Delta_b \Xi_b + \Delta_a \Xi_a)\right] \left(\hat{N^c_{t-1}} - \hat{x}_{nt}\right) \\ &\quad + \theta_c \left[1 - \phi^c(1 + \Delta_b \Xi_b + \Delta_a \Xi_a)\right] R \hat{R}_{t-1} \\ &\quad + \theta_c \phi^c (R_s - R)(\Delta_b \Xi_b \hat{\Xi}_{bt-1} + \Delta_a \Xi_a \hat{\Xi}_{at-1}) \\ &\quad + \theta_c \left[\phi^c(R_s - R)(1 + \Delta_b \Xi_b + \Delta_a \Xi_a)\right] \left[\hat{\phi^c_{t-1}} + \frac{R_s}{R_s - R} \hat{R}_{st} - \hat{\psi}_{t-1}\right] \\ &\quad + \omega_c / N^c \left[S^c(\hat{Q}_{st} + \hat{S}^c_{t-1}) + B^c(\hat{Q}_{bt} + \hat{B}^c_{t-1}) + A^c(\hat{Q}_{at} + \hat{A}^c_{t-1})\right]\end{aligned} \tag{66*}$$

$$\hat{R}_{bt} = \frac{Q_b}{r_b + Q_b} \hat{Q}_{bt} - \hat{Q}_{bt-1} \tag{67*}$$

$$\hat{R}_{at} = \frac{Q_a}{r_a + Q_a} \hat{Q}_{at} - \hat{Q}_{at-1} \tag{68*}$$

$$\hat{\Delta}_{bt} = \eta_b \hat{B}^g_t - \eta_{sb} \hat{S}^g_t \tag{69*}$$

$$\hat{\Delta}_{at} = \eta_a \hat{A}^g_t - \eta_{sa} \hat{S}^g_t \tag{70*}$$

Wholesale banks.

$$\begin{aligned}\hat{\mu^w_t} &= \hat{\varrho}_{t+1} - \hat{\varrho}_t + \frac{\theta_w(1 - \phi^w)\nu^w - 1 + \theta_w}{\mu^w} R_a \hat{R}_{at+1} + \frac{1 - \theta_w + \theta_w \phi^w \mu^w}{\mu^w} R_s \hat{R}_{st+1} \\ &\quad + \theta_w \left[(R_s - R_a)\phi^w + R_a\right] \left(\hat{\mu^w_{t+1}} + \hat{\phi^w_{t+1}} - \hat{\phi^w_t}\right)\end{aligned} \tag{71*}$$

$$\begin{aligned}\hat{\nu^w_t} &= \hat{\varrho}_{t+1} - \hat{\varrho}_t + \frac{\left[1 - \theta_w + \theta_w \nu^w (1 - \phi^w)\right]}{\nu^w} R_a \hat{R}_{at+1} \\ &\quad + \theta_w \phi^w R_s \hat{R}_{st+1} + \theta_w \left[(R_s - R_a)\phi^w + R_a\right] \hat{\nu^w_{t+1}}\end{aligned} \tag{72*}$$

$$\hat{\phi^w_t} = \hat{Q}_{st} + \hat{S^w_t} - \hat{N^w_t} \tag{73*}$$

$$\hat{\phi^w_t} = \hat{\nu^w_t} - \frac{\mu^w}{\lambda_w - \mu^w} \hat{\mu^w_t} \tag{74*}$$

$$\begin{aligned}\hat{N^w_t} &= \theta_w [(R_s - R_a)\phi^w + R_a] \hat{N^w_{t-1}} + \theta_w R_s \hat{R}_{st} + \theta_w (1 - \phi^w) R_a \hat{R}_{at-1} \\ &\quad + \theta_w (R_s - R_a) \phi^w \hat{\phi^w_{t-1}} + \omega_w \frac{S^w}{N_w} (\hat{Q}_{st} + \hat{S^w_{t-1}})\end{aligned} \tag{75*}$$

$$N^w \hat{N^w_t} = S^w(\hat{Q}_{st} + \hat{S^w_t}) - A^w(\hat{Q}_{at} + \hat{A^w_t}) \tag{76*}$$

Central Bank.

$$\hat{R}_t + \hat{\pi}_{t+1} = \rho_R(\hat{R}_{t-1} + \hat{\pi}_t) + (1-\rho_R)\kappa_\pi \hat{\pi}_t + \hat{x}_{rt} \tag{77*}$$

$$\hat{S}^g_t = -\Psi_{\pi s}\hat{\pi}_t + \hat{x}_{st} \tag{78*}$$

$$\hat{B}^g_t = -\Psi_{\pi b}\hat{\pi}_t + \hat{x}_{bt} \tag{79*}$$

$$\hat{A}^g_t = -\Psi_{\pi a}\hat{\pi}_t + \hat{x}_{at} \tag{80*}$$

Market clearing and policy.

$$Y\hat{Y}_t = C\hat{C}_t + I\hat{I}_t + G\hat{G}_t + \tau K\hat{\psi}_t \tag{81*}$$

$$K\hat{K}_t = S^c\hat{S}^c_{t\,t} + S^h\hat{S}^h_t + S^w\hat{S}^w_t + \hat{S}^g_t \tag{82*}$$

$$0 = B^c\hat{B}^c_t + B^h\hat{B}^h_t + \hat{B}^g_t \tag{83*}$$

$$\hat{A}^w_t = \hat{A}^c_t + \hat{A}^g_t \tag{84*}$$

Shocks.

$$\hat{x}_{jt} = \rho_j\hat{x}_{jt-1} + \sigma_j\varepsilon^j_t,\ \forall j = \left\{d, l, p, i, n, r, g, s, b, a\right\} \tag{85*}$$

Additional variables.

$$\widehat{BS}_t = \left(\hat{S}^g_t + \hat{B}^g_t + \hat{A}^g_t\right)/(4\cdot Y) \tag{86*}$$

$$\hat{R}_{nt} = \hat{R}_t + \hat{\pi}_{t+1} \tag{87*}$$

$$\hat{pr}_{st} = \hat{R}_{st+1} - \hat{R}_t \tag{88*}$$

$$\hat{pr}_{bt} = \hat{R}_{bt+1} - \hat{R}_t \tag{89*}$$

$$\hat{pr}_{at} = \hat{R}_{at+1} - \hat{R}_t \tag{90*}$$

$$\widehat{\text{Sav}}_t = \left[R\cdot D\cdot(\hat{R}_t + \hat{D}_t) + R_b\cdot B_h\cdot(\hat{R}_{bt} + \hat{B}_{ht})\right]/(\text{Sav}\cdot R_h)$$

$$\hat{\mathcal{W}}_t = (1-\beta)\hat{x}_{dt} + \frac{1}{\mathcal{W}}\left[(1-h)^{-\sigma}C^{1-\sigma}(\hat{C}_t - h\hat{C}_{t-1}) - \chi L^{1+\varphi}\hat{L}_t\right] + \beta\hat{\mathcal{W}}_{t+1} \tag{91*}$$

$$D\hat{D}_t = S^c(\hat{S}^c_t + \hat{Q}_{st}) + B^c(\hat{B}^c_t + \hat{Q}_{bt}) + A^c(\hat{A}^c_t + \hat{Q}_{at}) - N^c\hat{N}^c_t \tag{92*}$$

$$\hat{w}_t = \hat{P}_{pt} + \hat{Y}_t - \hat{L}_t$$

D.1 Steady states

I fix the steady states of $R_s - R$, $R_b - R$, $R_a - R$, Ξ_b, Ξ_a, ϕ^c, ϕ^w, (K_h/K), (B_h/B), and L. The parameters K, Δ_b, Δ_a, ω_c, ω_w, λ_c, λ_w, $\overline{K}_h$, $\overline{B}_h$, and χ are calibrated to comply with the chosen values.

Moreover, I choose a zero (net) inflation steady state, so $\pi = 1$.

Set χ to get L: from (42), (40), (45)

$\chi = \frac{\lambda w}{L^\varphi} = \frac{[(1-h)C]^{-\sigma}(1-\alpha)P_p Y/L}{L^\varphi} = \frac{\epsilon_p - 1}{\epsilon_p} \frac{[(1-h)(Y-\delta K-G)]^{-\sigma}(1-\alpha)Y}{L^{1+\varphi}}$

Set ω_c to get $R_s - R$

Set Δ_b to get $\overline{R_b - R}$: $\Delta_b = \overline{R_b - R}/\overline{R_s - R}$

Set Δ_a to get $\overline{R_a - R}$: $\Delta_a = \overline{R_a - R}/\overline{R_s - R}$

Set λ_c to get ϕ^c: $\lambda_c = \mu_s + \frac{\nu}{\phi^c(1+\Delta_b \Xi_b + \Delta_a \Xi_a)}$

Set B to get Ξ_b: $\Xi_b = \frac{(1-\overline{B_h/B})B}{\left[1-\overline{S^h/K}-\left(1-\overline{S^h/K}\right)/\left(\frac{1-1/\phi^w}{\Xi_a}+1\right)\right]K}$, from (61), (83) and (82)

Set ω_w to get ϕ^w: $\omega_w = \left(1 - \theta_w \left[(R_s - R_a)\phi_w + R_a\right]\right)/\phi_w$ (75) and (73)

Ξ_a: $\left(1 - \theta_w \left[(R_s - R_a)\phi^w + R_a\right]\right)/\phi^w$, from (75) and (73)

Set λ_w to get ϕ^w: $\lambda_w = \mu_w + \nu_w/\phi^w$, from (74)

$\mathcal{D} = 1$, from (A.disp)

$Q_s = 1$, from (49)

$Q_b = 1$, from (67)

$Q_a = 1$, from (68)

$P_p = (\epsilon_p - 1)/\epsilon_p$, from (FOC-P)

$R = 1/\beta$, from (41)

R_s – targeted (set K accordingly)

R_b – targeted (calibrate Δ_b accordingly)

R_a – targeted (calibrate Δ_a accordingly)

R_h – targeted (calibrate ϵ_s accordingly)

L – targeted (calibrate χ accordingly)

ϕ^c – targeted (calibrate λ_c accordingly)

ϕ^w – targeted (calibrate ω_w accordingly)

Ξ_b – targeted (calibrate ω_c accordingly)

Ξ_a – targeted (calibrate λ_w accordingly)

$B^h = \overline{B^h/B} \cdot B$ – targeted (calibrate α_s accordingly)

$K = (\alpha P_p / [R_s - 1 + \delta])^{1/(1-\alpha)} L$, from (47) and (45)

$B = \Xi_b K \left[1 - \overline{S^h/K} - \left(1 - \overline{S^h/K}\right) / \left(\frac{1-1/\phi^w}{\Xi_a} + 1\right)\right] / (1 - \overline{B^h/B})$, from (61), $\overline{B^h/B}$, (82), $\overline{S^h/K}$, (76), (73), (62)

$S^c = (K - S^h)/[1 + \Xi_a/(1 - 1/\phi^w)]$, from (82), $\overline{K_h/K}$, (76), (73), (62)

$B^c = B - \overline{B}_h$, from (83)

$Y = K^\alpha L^{(1-\alpha)}$, from (45)

$Y_p = Y$, from (50)

$I = \delta K$, from (48)

$C = Y - I - G$, from (81)

$\varrho = (1 - \beta h)[(1 - h)C]^{-\sigma}$, from (40)

$r_{pk} = \alpha P_p Y / K$, from (46)

$F = \frac{P_p Y}{1 - \beta\gamma}$, from (51)

$H = \frac{Y}{1 - \beta\gamma}$, from (52)

$\Omega = \frac{1-\theta_c}{1-\theta_c-\theta_c\beta(R_k-R)(1+\Delta_b\Xi_b+\Delta_a\Xi_a)\phi^c}$, from (65)

$\mu_s = \beta\Omega(R_s - R)$, from (57)

$\mu_b = \beta\Omega(R_b - R)$, from (58)

$\mu_a = \beta\Omega(R_a - R)$, from (59)

$\nu = \Omega$, from (60)

$\lambda_c = \mu_s + \frac{\nu}{\phi^c(1+\Delta_b\Xi_b+\Delta_a\Xi_a)}$, from (64)

$N^c = S^c/\phi^c$, from (63)

$\mu_w = \frac{\beta(1-\theta_w)(R_s-R_a)}{1-\beta\theta_w[(R_s-R_a)\phi_w+R_a]}$, from (71)

$\nu_w = \frac{\beta(1-\theta_w)R_a}{1-\beta\theta_w[(R_s-R_a)\phi_w+R_a]}$, from (72)

$\lambda_w = \mu_w + \nu_w/\phi_w$, from (74)

$A^c = \Xi_a S^c$, from (62)

$A^w = A^c$, from (84)

$S^w = K - K^h - K^c$, from (82)

$N^w = S^w - A^w$, from (76)

$\omega_w = \frac{1-\theta_w[(R_s-R_a)\phi^w+R_a]}{\phi^w}$, from (75) and (73)

$\omega_c = \frac{N(1-\theta_c[R+\phi^c(R_s-R)(1+\Delta_b\Xi_b+\Delta_a\Xi_a)])}{K+B+A^c}$, from (66)

$D = S^c + B^c + A^c - N^c$, from (92)

$\kappa_s = \left[1 + (R/R_b)^{-\epsilon_s} B^h/D\right]^{-1}$, from (43)

ϵ_s is obtained from (44)

Additional variables.
$pr_s = R_s/R$
$pr_b = R_b/R$
$pr_a = R_a/R$
$\mathcal{W} = \left[\frac{[(1-h)C]^{1-\sigma}}{1-\sigma} - \frac{\chi L^{1+\varphi}}{1+\varphi}\right]/(1-\beta)$

D.2 Data used for calibration

All values are calibrated using samples from 2009m1(q1) to 2015m12(q4).

Steady-state leverage of commercial banks. The value of ϕ^c is set to the (TotLoans)/TotCap, where

- TotLoans: BSI.M.U2.N.U.A20.A.1.U2.2000.Z01.E = "*Loans vis-a-vis euro area non-MFI reported by MFI in the euro area (stock)*"
- TotCap: BSI.M.U2.N.A.L60.X.1.Z5.0000.Z01.E = "*Capital and reserves, reported by MFI excluding ESCB (stock)*"

Steady-state share of bonds held by households. I define $\overline{B^h/B}$ as $1-\overline{B^c/B}$, where the latter is the 2009-2015 average of the annual series

- GFS.A.N.I8.W2.S13.S122.C.L.LE.GD.T._Z.XDC_R_B1GQ._T.F.V.N._T = "*Government debt held by other monetary financial institutions (as % of GDP)*"

By this I subsume all other holders of government debt (foreign agents, households, non-deposit issuing financial sector, central bank) into B^h.

Government spending over GDP. G/Y is set as the average of nominal government consumption, GCR$\times$GCD, over nominal GDP, YER$\times$YED, from the area-wide model database (see Fagan, Henry, and Mestre, 2001).

Loan and bond spread. To calibrate the spread of both loan rate and government yields to deposit rate, I use the 2009-15 average of the series R_s^{emp}, R_b^{emp} and R^{emp} (1.03541; 1.02833; 1.01295), which are taken from, respectively,

- MIR.M.U2.B.A2A.F.R.0.2240.EUR.N = "*Credit and other institutions (MFI except MMFs and central banks) reporting sector - Rate on loans other than revolving loans and overdrafts, convenience and extended credit card debt, Up to 1 year initial rate fixation, Up to and including EUR 1 million amount*"

- FM.M.U2.EUR.4F.BB.U2_10Y.YLD = "*Euro area 10-year Government Benchmark bond yield - Yield*"

- MIR.M.U2.B.L23.D.R.A.2250.EUR.N = "*Credit and other institutions (MFI except MMFs and central banks) reporting sector - Rate on deposits redeemable at notice (up to 3 months period of notice)*"

The spreads are then obtained as $(R_j - R) = (R_j^{\text{emp}} - R^{\text{emp}})/4$ for $j = \{b, s\}$, and $\Delta_b = (R_b - R)/(R_s - R)$.

Bonds and financial assets relative to loans. To calibrate the steady state shares Ξ_b and Ξ_a, I use the 2009-2016 average of the following series as stand-ins for $Q_{st}S_t^c$, $Q_{bt}B_t^c$ and $Q_{at}A_t^c$, respectively:

- BSI.M.U2.N.A.A20.A.1.U2.2240.EUR.E = "*Euro area (changing composition), Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Loans, Total maturity, Euro - Euro area (changing composition) counterpart, Non-Financial corporations (S.11) sector, denominated in Euro, data Neither seasonally nor working day adjusted*"

- BSI.M.U2.N.A.A30.A.1.U2.2100.Z01.E = "*Euro area (changing composition), Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Debt securities held, Total maturity, All currencies combined - Euro area (changing composition) counterpart, General Government sector, denominated in Euro, data Neither seasonally nor working day adjusted*"

- BSI.M.U2.N.A.A30.A.1.U2.1000.EUR.E = "*Euro area (changing composition), Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Debt securities held, Total maturity, Euro - Euro area (changing composition) counterpart, Monetary financial institutions (MFIs) sector, denominated in Euro, data Neither seasonally nor working day adjusted*"

Household holdings of deposits and government bonds. The data are only used for comparison, the value of κ_s is implied by steady state relationships.

- QSA.A.N.I8.W0.S1M.S1.N.A.F.F2._Z._Z.XDC_R_POP._T.S.V.CY._T = "*Currency and deposits of households, per capita. Euro area 19 (fixed composition), reporting institutional sector Households and non profit institutions serving households (NPISH)*"
- QSA.A.N.I8.W0.S1M.S1.N.A.F.F6._Z._Z.XDC_R_POP._T.S.V.CY._T = "*Insurance, pension and standardized guarantee schemes of households, per capita. Euro area 19 (fixed composition), reporting institutional sector Households and non profit institutions serving households (NPISH)*"

D.3 Other results

D.3.1 Replication of GK13 results

With my model, I am able to replicate very closely the dynamics after an unexpected shock to loan and bond purchases as described in Gertler and Karadi (2013, "GK13"). Figure 46 shows the responses to several economic variables after unexpected purchases of government bonds, along with a commitment to keep the zero-lower bound binding for another four periods. To introduce the ZLB, I replace equation (77) by

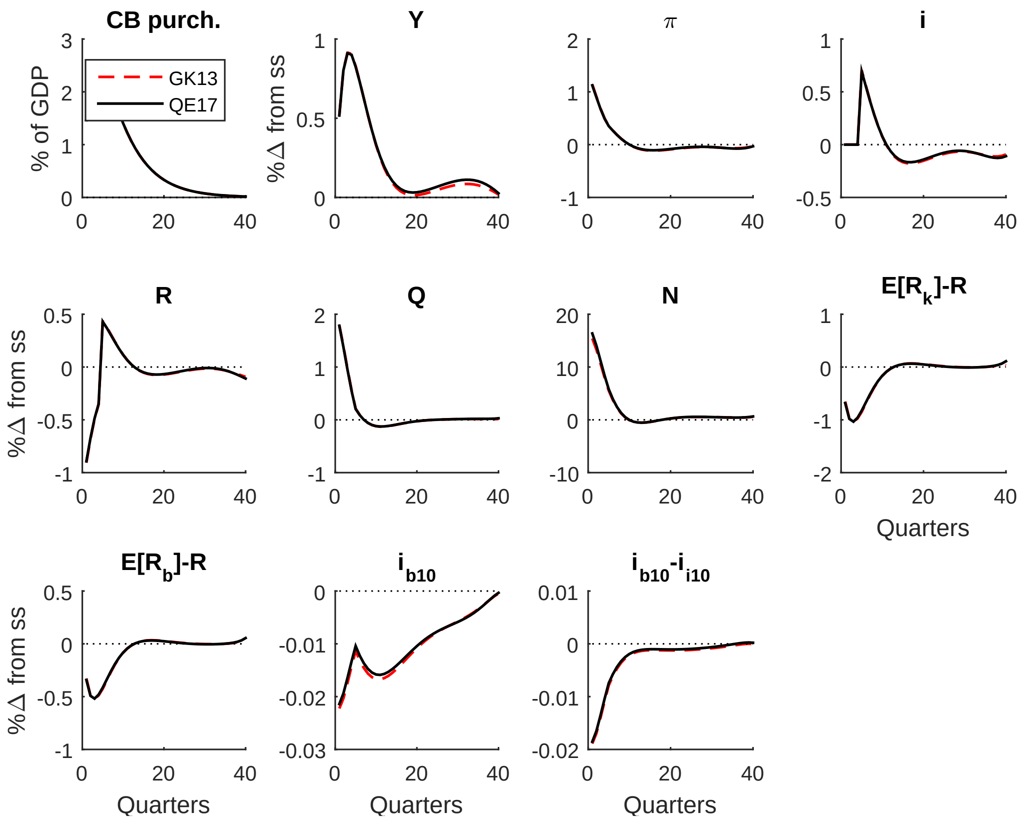
$$R_t\pi_{t+1} = z_t \cdot 0 + (1 - z_t) \cdot (R_{t-1}\pi_t)^{\rho_R} \left[R\pi \cdot \left(\frac{\pi_t}{\pi}\right)^{\kappa_\pi} (P_p/P_{pt})^{\kappa_y} \right]^{1-\rho_R} x_{rt}$$
$$\log(z_t) = \log(z_{t-1}) + \varepsilon_{st} - \varepsilon_{st-4} + \varepsilon_{bt} - \varepsilon_{bt-4} + \varepsilon_{at} - \varepsilon_{at-4},$$

or, log-linearised,

$$\hat{R}_t + \hat{\pi}_{t+1} = (1 - \hat{z}_t) \left[\rho_z(\hat{R}_{t-1} + \hat{\pi}_t) + (1 - \rho_z) \left(\kappa_\pi \hat{\pi}_t - \kappa_y \hat{P}_{pt} + \hat{x}_{rt} \right) \right]$$
$$\hat{z}_t = \hat{z}_{t-1} + \varepsilon_{st} - \varepsilon_{st-4} + \varepsilon_{bt} - \varepsilon_{bt-4} + \varepsilon_{at} - \varepsilon_{at-4}.$$

So a shock to asset purchases will also trigger zero movement in the policy rate for four periods (quarters). The calibration follows GK13 and takes one period to be a quarter, so the ZLB is in effect for one year. The result shows that shutting off the financial assets and changing calibration, my model dynamics are in effect very comparable to GK13.

Figure 46: Comparison to IRFs from Gertler and Karadi (2013)

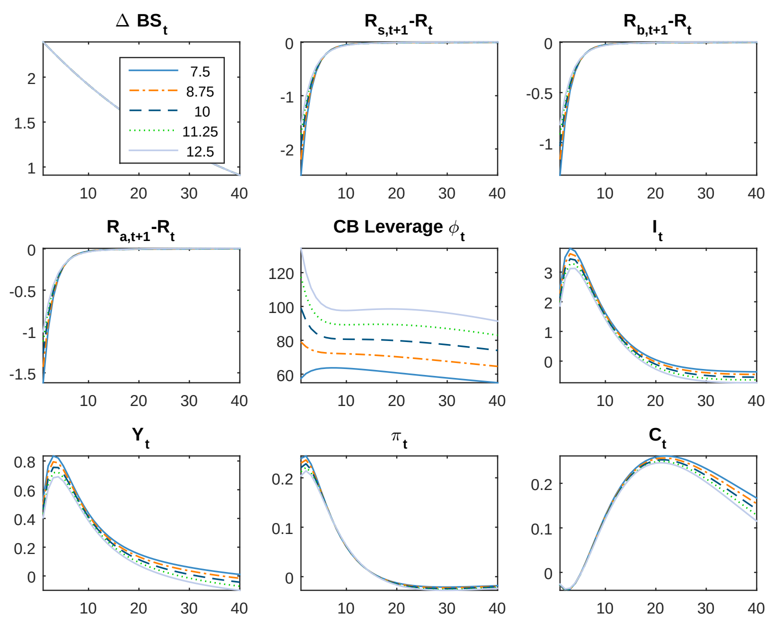


Notes: Impulse responses to unexpected purchases of bonds (ε_t^b) in Gertler and Karadi (2013, "GK13") and my model. Both depict deterministic simulations with a zero-lower bound for 4 periods after the unexpected purchases. Calibration follows GK13. Their model is reproduced using a slightly adjusted version from the Macroeconomic Model Data Base, see Wieland, Cwik, Müller, Schmidt, and Wolters (2012) – I mainly undo the changes from the MMDB to the original code.

D.3.2 More results from sensitivity analysis

Another parameter for which I have no good empirical measure is the aggregate steady-state leverage ratio in the wholesale banking sector, ϕ^w. However, as Figure 47 shows, the dynamics and quantitative results are not very sensitive to changes in that parameter: For a variation between 75 and 125% of the baseline value of 10, the effect on output will be changed by less than 10 basis points up or down, or be within a [87.5%, 112.5%] interval. Still, the expansionary effect of the loan purchases does not turn negative within the 40-periods horizon considered here for the case of a low leverage of 7.5 (implying stronger financial-accelerator effects through the bank-lending channel), while it will undershoot for all larger values of steady-state leverage ϕ^w.

Figure 47: Sensitivity analysis: variation of ϕ^w

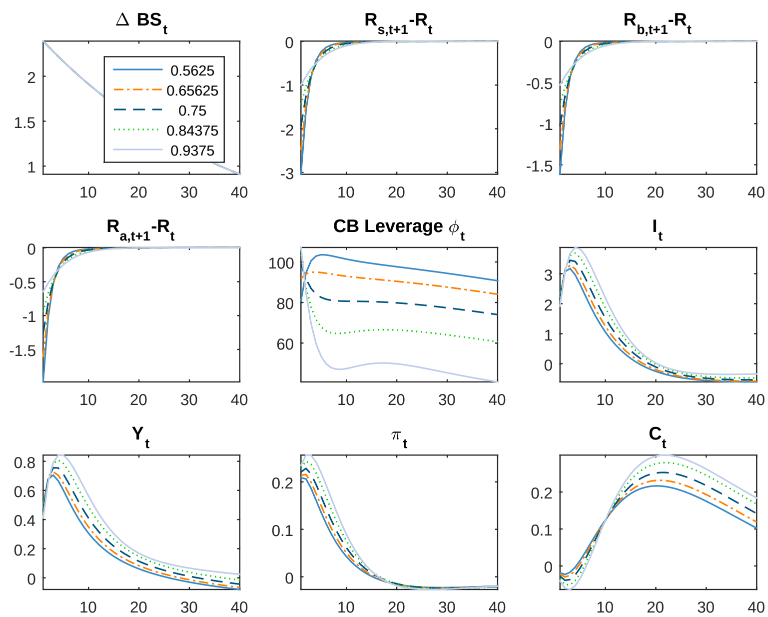


Note: Impulse responses to an AR(1) loan-purchase shock x_{st} with persistence 0.9755.

Similarly, I have checked that variation of the following parameters has no strong impact on model dynamics: variation of of the survival rate of wholesale banker, θ_w, between 0.5 and 0.95 (Figure 48), of the interest-rate spread $R_s - R$

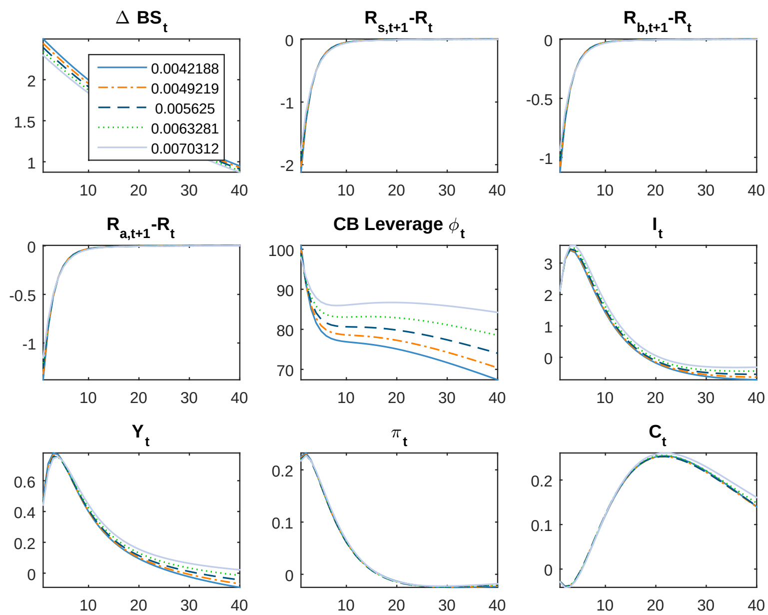
between 0.004 and 0.007 (Figure 49), of the steady-state commercial-bank holdings of government bonds and financial assets over loans, Ξ_b and Ξ_a, between 0.25 and 0.5 (not shown). The results do not seem to be very sensitive to changes in these parameters, even though these are substantial and cover the range of values that the parameter could realistically take.

Figure 48: Sensitivity analysis: variation of θ^w



Note: Impulse responses to an AR(1) loan-purchase shock x_{st} with persistence 0.9755.

Figure 49: Sensitivity analysis: variation of $R_s - R$



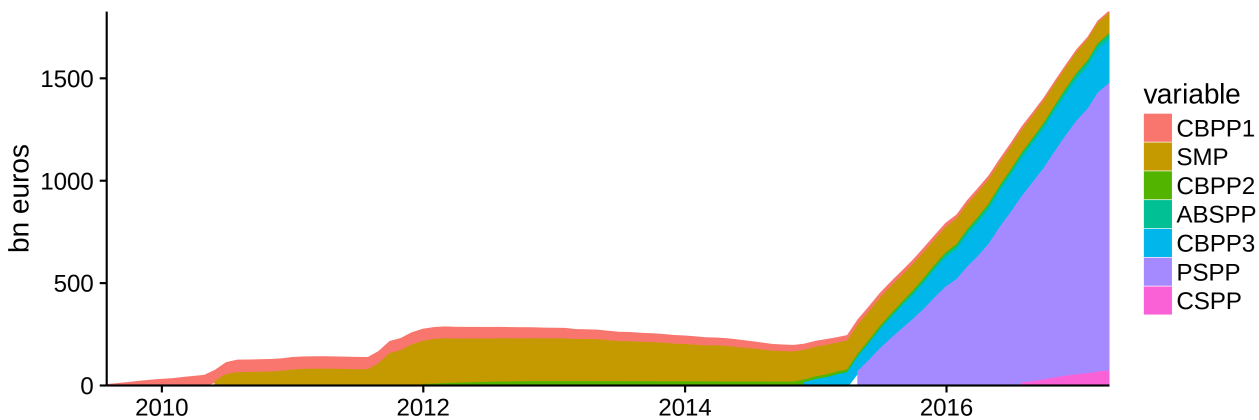
Note: Impulse responses to an AR(1) loan-purchase shock x_{st} with persistence 0.9755.

D.4 ESCB asset purchasing programmes

This subsection presents a short overview of the ESCB's APPs.

All asset purchases are conditional on the inflation outlook (analogous to conventional monetary policy conduct), however, ECB has announced targets of their overall size. While no concrete breakdown of the announced €60bn of monthly purchases was given, ECB has communicated that the purchases of the second round of purchases started in January 22, 2015 ("Extended APP") will be structured similarly to the ones in the first round, i.e. with a stronger weight on public sector debt than financial assets. Direct intermediation by buying corporate sector debt (CSPP) was only introduced in June 2016. Figure 50 gives an overview of the size of APPs since the start of the programme.

Figure 50: APPs on the ESCB balance sheet



Source: ECB's Statistical Data Warehouse. See Appendix D.4 for details on the ESCB APPs.

Round 1 (2009 to 2011)

Covered Bond Purchase Programmes (1 and 2). From 2009-10, ESCB bought €60bn worth of covered bonds over one year. From 2011-12, ESCB announced purchases of up to €40bn worth of covered bonds in the second CBPP (around €16bn were bought). Covered bonds are very safe, as they have preferential rights in case issuer becomes insolvent. Stated goal: to bring inflation closer to 2%.

Securities Markets Programme. From May 2010 to September 2012, ESCB undertook interventions in the public and private debt securities markets "to ensure depth and liquidity in those markets" (€210bn).

Round 2: Extended APP (2014 to today)

Common denomination for CBPP3, ABSPP and PSPP. Initiated to "to address the risks of a too prolonged period of low inflation" (see ECB homepage). Purchases of €80 billion (from March 2015 to March 2016: €60bn). Intended initially to be carried out until the end of March 2017, extended until end of December 2017.

Covered Bond Purchase Programme 3. Since October 20, 2014 (announced September 4), there is a third programme, scheduled for two years.

Asset-Backed Securities Purchase Programme. Since November 21, 2014, ESCB buys asset-backed securities on primary and secondary markets.

Public Sector Purchase Programme. Announced on January 22, 2015, and started in March 9, 2015, ESCB buys €60bn worth of bonds issued by EA central governments, agencies and European institutions, at residual maturities of two to 30 years.

Corporate Sector Purchase Programme. Since June 8, 2016, ESCB buys high-quality bonds of European corporate firms.

[Outright Monetary Transactions]

Announced, never triggered. The potential purchases of securities related to ECB President Draghi's "whatever it takes" speech (September 2012). Any government bonds of countries in European Financial Stability Facility/European Stability Mechanism (EFSF/ESM) programme are eligible, no limits have been specified.