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Lending Standards, Credit Booms, and Monetary Policy

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This paper investigates the risk channel of monetary policy on the asset side of banks' balance sheets. We use a factor-augmented vector autoregression (FAVAR) model to show that aggregate lending standards of U.S. banks, such as their collateral requirements for firms, are significantly loosened in response to an unexpected decrease in the Federal Funds rate. Motivated by this evidence, we reformulate the costly state verification (CSV) contract to allow for an active financial intermediary, embed the partial equilibrium contract in a New Keynesian DSGE model, and show that – consistent with our empirical findings – an expansionary monetary policy shock implies a temporary increase in bank lending relative to borrower collateral. In the model, this is accompanied by a higher default rate of borrowers.

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Lending Standards, Credit Booms, and Monetary Policy[☆]

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Abstract

This paper investigates the risk channel of monetary policy on the asset side of banks' balance sheets. We use a factor-augmented vector autoregression (FAVAR) model to show that aggregate lending standards of U.S. banks, such as their collateral requirements for firms, are significantly loosened in response to an unexpected decrease in the Federal Funds rate. Motivated by this evidence, we reformulate the costly state verification (CSV) contract to allow for an active financial intermediary, embed the partial equilibrium contract in a New Keynesian DSGE model, and show that – consistent with our empirical findings – an expansionary monetary policy shock implies a temporary increase in bank lending relative to borrower collateral. In the model, this is accompanied by a higher default rate of borrowers.

Keywords: Bank lending standards, Costly state verification, Credit supply, Monetary policy, Risk channel

JEL classification: D53, E44, E52

1. Introduction

One of the narrative explanations of the credit boom preceding the recent financial crisis and the Great Recession is that financial intermediaries took excessive risks because monetary policy rates had been "too

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low for too long" (compare Taylor, 2007). On the one hand, loose monetary policy lowers the wholesale funding costs of banks and other financial intermediaries, incentivizing higher leverage and thus risk on the liability side of their balance sheets. On the other hand, low policy interest rates might also induce banks to lower their lending standards, i.e. to grant more *and* riskier loans. While risk taking on the liability side has received a lot of attention in the recent macroeconomic literature (see, e.g., Angeloni et al., 2013; Gertler and Karadi, 2011; Gertler et al., 2012), much fewer studies have so far addressed the aggregate implications of a risk channel of monetary policy on the asset side. The present paper aims at closing this gap by focusing on the *ex-ante* risk attitude of banks. First, we provide empirical evidence of an asset-side risk channel of monetary policy in the aggregate lending behavior of U.S. banks. Based on this evidence, we develop a dynamic stochastic general equilibrium (DSGE) model, where the financial intermediary decides how much to lend against a given amount of borrower collateral.

Prior research based on microeconomic bank-level data (Jimenez et al., 2014; Bonfim and Soares, 2014) has shown that lower overnight interest rates might induce banks to commit larger loan volumes with fewer collateral requirement to ex-ante riskier firms. For macroeconomic time series, however, the results in the literature are rather ambiguous. For example, Angeloni et al. (2013) use a small-scale vector autoregression (VAR) model and find no statistically significant response of lending standards in the U.S. banking sector to a monetary policy shock, whereas Buch et al. (2014) find evidence in favor of such a channel, albeit only for small U.S. banks, based on a comprehensive panel of banking variables. Focusing on the *ex-post* risk channel of monetary policy, Piffer (2014) finds no increase in the aggregate delinquency rates of U.S. households and firms in response to a monetary expansion.

The use of aggregated data in this context is complicated by the limited availability of adequate measures of banks' ex-ante risk attitude and a comparatively short sample period. On the one hand, econometric models are thus prone to overfitting due to an excessive number of parameters. On the other hand, small-scale VAR models might contain *insufficient information* (compare Forni and Gambetti, 2014) to identify the structural shocks of interest. To address these issues, we follow the factor-augmented vector autoregression (FAVAR) approach proposed by Bernanke et al. (2005), which allows us to parsimoniously extract information from a large set of macroeconomic time series, thereby mitigating both the concern of overfitting and the concern of informational sufficiency. This is crucial, given that "omitted-variable bias" could invalidate the coefficient estimates and thus the impulse responses to a monetary policy shock. In light of the evidence in Barakchian and Crowe (2013), we also account for the possibility that U.S. monetary policy was more forward-looking during our sample period by including 13 variables from the Fed's Greenbook in the observation equation of the FAVAR model.

To capture the credit-risk attitude of banks, we use the quantified qualitative measures from the Federal Reserve's Senior Loan Officer Opinion Survey on Bank Lending Practices (SLOOS), which reflect changes in lending standards of 80 large domestic and 24 U.S. branches and agencies of foreign banks at a quarterly frequency, starting in 1991Q1. In contrast to the prior empirical literature, we consider 19 different measures of lending standards, such as the net percentage of banks *increasing collateral requirements*, *tightening loan covenants*, etc. for various categories of loans, borrowers and banks, in order to capture the comovement in the underlying time series. Based on the one-step Bayesian estimation approach by Gibbs sampling from Bernanke et al. (2005) and Amir Ahmadi and Uhlig (2009), we find that a small number of factors together with the Federal Funds rate as the only observable variable is already sufficient to explain a substantial share of the variation in lending standards, ranging from .48 to .97 in terms of the *adjusted* R^2.

As in Bernanke et al. (2005), we identify monetary policy shocks recursively, with the Federal Funds rate ordered last in the transition equation of the FAVAR model, and find that all 19 measures of lending standards decrease in response to a monetary expansion. The corresponding impulse response functions are both statistically and economically significant, suggesting a nontrivial role for monetary policy in the risk attitude of banks in the U.S. Our findings are qualitatively robust to variations in the FAVAR specification and the inclusion of variables from the Philadelphia Fed's Greenbook data set. Moreover, Bassett et al.'s (2014) measure of the supply component of bank lending standards as well as two alternative measures – Gilchrist and Zakrajšek's (2012) "excess bond premium" and the Chicago Fed's National Financial Conditions credit subindex – also decrease significantly in response to an expansionary monetary policy shock.

Based on the empirical evidence, we reformulate the costly state verification (CSV) contract in Townsend (1979) and Gale and Hellwig (1985) in order to allow for a nontrivial role of financial intermediaries. The CSV contract provides a natural starting point, given that its parties determine both the *quantity* of credit (via the amount lent) and the *quality* of credit (via the borrower's ex-ante implied default risk). In conventional implementations of the contract in DSGE models of the financial accelerator, such as Bernanke et al. (1999) or Christensen and Dib (2008), however, financial intermediaries are passive and do not bear any risk.

We drop this assumption and show that the resulting contract is incentive-compatible, robust to ex-post renegotiations, and resembles a standard debt contract (compare Gale and Hellwig, 1985). Moreover, it implies a unique partial equilibrium solution and the well-known positive relationship between the expected external finance premium (EFP) and the borrower's leverage ratio. In response to an exogenous increase in the expected EFP, e.g. due to a monetary expansion, the bank finds it profitable to lend more against a given amount of borrower collateral. The reason is that it benefits from the increase in borrower leverage through a larger share in total profits, while it can price in the higher default probability of the borrower through the rate of return on the loan.

We then embed our version of the partial equilibrium contract in an otherwise standard New Keynesian DSGE model. In contrast to Bernanke et al. (1999) and most of the existing literature, our model implies an *increase* in bank lending relative to borrower collateral and thus a higher leverage ratio of borrowers in response to an expansionary monetary policy shock. This general equilibrium result is in accordance with our prior empirical finding that, in the U.S., the "net percentage of banks increasing collateral requirements for firms" and similar measures of lending standards decrease significantly in response to an unexpected monetary easing by the Federal Reserve. We further show that the effect increases with the degree of interest-rate smoothing in the monetary policy rule, that is if interest rates are "too low for too long".

The remainder of the paper is organized as follows. Section 2 sketches our econometric approach and presents new empirical evidence of an asset-side risk channel of monetary policy in the U.S. banking sector. Section 3 derives and discusses the partial equilibrium properties of the optimal debt contract. In Section 4, we incorporate this contract into a quantitative New Keynesian DSGE model. Section 5 concludes and gives directions for future research.

2. The Empirical Evidence

The empirical relevance of a risk-taking channel of monetary policy on the asset side has been shown mostly based on microeconomic banking-level data (see, e.g., Jimenez et al., 2014). When macroeconomic time series are used, however, the results are less clear cut. Angeloni et al. (2013) set up a small-scale vector autoregression (VAR) model, including one of the SLOOS measures of bank lending standards among the endogenous variables as a proxy for asset-side risk taking. They find no significant evidence of aggregate risk taking of the U.S. banking sector on the asset side.[1] Using a rich panel of *banking data* containing 140 time series and a FAVAR model, Buch et al. (2014) find evidence in favor of a risk-taking channel on the asset side only for small U.S. banks. Notably, Buch et al. (2014) use a different measure of asset risk – the

[1] In particular, Angeloni et al. (2013) use the net percentage of banks tightening credit standards on C&I loans to large and medium-sized firms.

riskiness of new loans provided in the Survey of Terms of Business Lending of the U.S. Federal Reserve, which restricts their sample period to 1997Q2-2008Q2.

Taking a similar approach, we use the quantified qualitative measures from the Federal Reserve's SLOOS, which are available from 1991Q1 onwards, to capture changes in banks' lending standards. In order to corroborate that the latter are suitable proxies for the risk appetite of banks, Figure 2 plots the fraction of domestic banks reporting that a certain reason was important for loosening their lending standards.[2] Besides the "economic outlook" category, higher risk tolerance was the main determinant of banks' decision to loosen their lending standards prior to the financial crisis of 2007-2008, whereas their capital position and industry-specific problems featured less prominently. The importance of the general economic outlook illustrates that lending standards are an *ex-ante* measure of asset risk. Suppose, for example, that a bank's expectation about future economic activity justify a higher risk tolerance and proves to be true, then ex-ante risk taking does not necessarily result in a riskier loan portfolio in terms of higher borrower default and potential losses to the bank, *ex post*. If the bank's risk tolerance is not in line with the economic outlook or the latter proves to be wrong, however, then ex-ante risk taking translates into ex-post asset risk.

Similar to Buch et al. (2014), we employ a FAVAR model, which allows us to parsimoniously extract information from a large number of macroeconomic time series, thereby reducing the risk of omitted-variable bias, which might contaminate the identification of monetary policy shocks (see also Bernanke et al., 2005). In order to corroborate this argument, consider the following example of a small-scale VAR model of the U.S. economy including four observable variables: real activity (either non-farm employment or real GDP), prices (CPI), banks' risk attitude in lending (the net percentage of domestic banks tightening standards for C&I loans), and a monetary policy instrument (the Federal Funds rate). The VAR model is estimated on quarterly data for 1991Q2-2008Q2 and two lags. As in Angeloni et al. (2013), we detrend the non-stationary variables in logarithms and the stationary variables in levels using the HP-filter (Hodrick and Prescott, 1997) with $\lambda = 1,600$. Monetary policy shocks are identified recursively, ordering the Federal Funds rate last in the VAR. A similar identifying assumption will later be made in the FAVAR analysis.

Figure 3 plots the impulse response functions to a monetary easing of 25 basis points for *two different* specifications of the VAR model. In the upper panel, we include non-farm employment as a proxy for real

[2] A balanced panel of the reasons for easing lending standards of domestic banks can be constructed only after 1997Q1. Since the picture for foreign banks is qualitatively very similar, it is omitted here to conserve space.

economic activity, whereas we include real GDP in the lower panel. Note that all other variables as well as the identifying assumptions are identical across the two specifications. In the upper panel, bank lending standards do not seem to respond significantly, according to the two standard error confidence bands, while the corresponding point estimate suggests a *tightening* of standards with a peak around ten quarters after the expansionary monetary policy shock. In the lower panel, however, where real economic activity is measured by real GDP rather than employment, the impulse response functions suggest a statistically significant *easing* of bank lending standards in response to the same monetary policy shock.

Given the apparent sensitivity of the small-scale VAR results to our selection of variables, we extract so-called factors from a comprehensive set of real economic activity measures including several indicators of production, investment, and employment, thus mitigating the omitted-variable bias illustrated beforehand. In order to detect a possible risk channel of monetary policy, we augment the macroeconomic and financial time series commonly used in the FAVAR literature by 19 different measures of lending standards, such as the net percentage of banks *increasing collateral requirements*, *tightening loan covenants*, etc. for several categories of loans, borrowers. Figure 1 illustrates the substantial comovement between the SLOOS measures of bank lending standards, which should be captured well even by a relatively small number of common factors.

2.1. The Econometric Specification

Suppose that the observation equation relating the $N \times 1$ vector of informational time series, X_t, to the $K \times 1$ vector of unobservable factors, F_t, and the $M \times 1$ vector of observable variables, Y_t, with $K + M << N$, is given by

$$X_t = \Lambda^f F_t + \Lambda^y Y_t + e_t, \tag{1}$$

where Λ^f is an $N \times K$ matrix of factor loadings of the unobservable factors, Λ^y is an $N \times M$ matrix of factor loadings of the observable variables, and e_t is an $N \times 1$ vector of error terms following a multivariate normal distribution with mean zero and covariance matrix, R.

Suppose further that the joint dynamics of the unobserved factors in F_t and the observable variables in Y_t can be captured by the transition equation

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-1} \\ Y_{t-1} \end{bmatrix} + \nu_t, \tag{2}$$

where $\Phi(L)$ is a lag polynomial of order d and ν_t is a $(K+M)\times 1$ vector of error terms following a multivariate normal distribution with mean zero and covariance matrix, Q. The error terms in e_t and v_t are assumed to be contemporaneously uncorrelated.

Estimation of the FAVAR model in (1) and (2) requires transforming the data to induce stationarity of the variables.[3] Our baseline sample contains quarterly observations for 1991Q1-2008Q2. The start of this sample period is determined by the availability of the SLOOS measures of bank lending standards, while we exclude the period after 2008, because, after the bankruptcy of Lehman Brothers, U.S. monetary policy was effectively operating through the balance sheet of the Federal Reserve rather than through the Federal Funds rate. The predominance of unconventional policy measures would require a different strategy for identifying monetary policy shocks during this period, as in Peersman (2011).

Following Bernanke et al. (2005), we identify monetary policy shocks recursively, ordering the Federal Funds rate last in equation (2). In our case, this implies that the unobserved factors do not respond to monetary policy innovations within the same *quarter*, while the idiosyncratic components of the informational time series in X_t are free to respond on impact.[4] One could argue that senior loan officers take into account the current monetary stance when deciding on their lending standards. However, the SLOOS is conducted by the Federal Reserve, so that results are available *before* the quarterly meetings of the Federal Open Market Committee (FOMC), in line with our identification scheme.

Building on Bernanke et al. (2005) and Amir Ahmadi and Uhlig (2009), we estimate the FAVAR model in (1) and (2) by a one-step Bayesian approach.[5] Due to the fundamental indeterminacy of factor models, the unobserved factors can only be estimated up to a rotation. For this reason, we must impose a set of standard restrictions on the observation equation in order to identify the factors uniquely. Following Bernanke et al. (2005), we eliminate rotations of the form $F_t^* = AF_t + BY_t$. Solving this expression for F_t and plugging the result into the observation equation in (1) yields

$$X_t = \Lambda^f A^{-1} F_t^* + (\Lambda^y + \Lambda^f A^{-1} B) Y_t. \tag{3}$$

[3]The transformation of each variable is detailed in Appendix A.1. Note that the measures of bank lending standards enter the FAVAR model in (standardized) levels, i.e. without first-differencing or detrending, given that they are stationary by construction.

[4]Bernanke et al. (2005) apply the same recursive ordering to a FAVAR model in *monthly* data.

[5]As a robustness check, we also estimate the model using a two-step approach based on principal components analysis (see, e.g., Bernanke et al., 2005). However, the latter method seems to be more prone to overfitting, given our relatively short sample, especially with many lags. For a lag order of one quarter, the results based on the two-step approach are very similar to those based on the one-step Bayesian estimation approach.

Hence, the unique identification of factors requires that $A^{-1}F_t^* = F_t$ and $\Lambda^f A^{-1}B = \mathbf{0}$. Bernanke et al. (2005) suggest imposing sufficient (overidentifying) restrictions by setting $A = \boldsymbol{I}$ and $B = \mathbf{0}$. Moreover, the one-step estimation approach requires that the first K variables in the vector X_t belong to the set of *slow-moving* variables (compare Table A.1).

We apply multi-move Gibbs sampling in order to jointly sample from the unobserved factors and the model parameters. Appendix A.2 provides details on the prior distributions, the Gibbs sampler, and how we monitor the convergence of the latter. In the baseline model, we set the lag order of the transition equation to two quarters and consider the Federal Funds rate as the only observable variable in (2), i.e. $M = 1$.[6]

To determine the appropriate number of unobservable factors in our FAVAR specification, we consult a number of selection criteria, monitor the joint explanatory power of F_t and Y_t for bank lending standards, and check the robustness of our results by adding more factors than suggested by the above criteria. The tests of Onatski (2009) and Alessi et al. (2010) point to three and five factors, respectively. Given that our main interest is in explaining the fluctuations in lending standards, we report the adjusted R^2 for each of the 19 SLOOS measures for one, three, five, and seven unobservable factors in Table 1. It turns out that the first factor exhibits a high correlation with most measures of bank lending standards, with the adjusted R^2 ranging from .48 to .97. Adding further factors improves the tight fit only marginally. Nevertheless, we also tried specifications with a larger number of factors and found that our results are not affected substantially, even when including seven factors.[7] Based on these results, we refer to the specification with three unobservable factors as the baseline FAVAR model in what follows.

2.2. *Results from the Structural FAVAR Model*

2.2.1. *Historical Variance Decomposition*

We are primarily interested in the response of the 19 measures of bank lending standards to expansionary monetary policy shocks, on average over the sample period. In order to assess the plausibility of our FAVAR specification and the resulting monetary shock series, we consider the historical variance decomposition (HVD) of the standardized changes in lending standards. Figure 4 plots the cumulative contributions of monetary policy shocks to fluctuations in the Federal Funds rate and lending standards for a single candidate

[6]Results for lag orders one and three are very similar. Adding CPI as an observable variable ($M = 2$) does not affect our results.

[7]Our results are also consistent with the so-called "scree plot", which plots the eigenvalues of X_t in descending order against the number of principal components. In our case, the scree plot displays a steep negative slope and a kink around the fifth principal component, supporting the results based on the selection criteria and the robustness checks.

draw from the Gibbs sampler, after discarding a sufficiently long burn-in phase.[8]

Over the second half of the sample, we find that unexpected monetary policy shocks contribute to the reduction in the Federal Funds rate after the dot-com bubble and, to a lesser extent, to the gradual change in the monetary policy stance during the boom preceding the Great Recession.[9] Moreover, the FAVAR model attributes a sizeable share of the initial tightening and subsequent loosening of bank lending standards between 1998 and 2005 to monetary shocks. Note that this HVD pattern is shared by all 19 measures. In line with conventional wisdom, the abrupt tightening of lending standards in 2008 is *not* associated with unexpected monetary policy shocks.

2.2.2. Impulse Response Functions

Figure 5 plots the impulse responses of the Federal Funds rate and our 19 measures of bank lending standards to an expansionary monetary policy shock, i.e. an unexpected 25bps decrease in the Federal Funds rate, based on the baseline FAVAR model with $K = 3$ unobservable factors. All impulse response functions are in terms of standard deviations, while one period on the x-axis corresponds to one quarter. The dashed and dotted lines around the median responses indicate the pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles, respectively, containing 68 and 90% of the probability mass.[10]

We find that *all* measures of lending standards decrease in response to an expansionary monetary policy shock. The response of lending standards is gradual, peaking after eight to nine quarters before returning to steady state. The effect is both statistically and economically significant. Given that the average standard deviation of bank lending standards equals 21 net percentage points, a 100bps decrease in the Federal Funds rate on an annual basis corresponds to a maximum effect on lending standards of 16-20 net percentage points, on average.

Figure C.1 illustrates that this finding is robust to using a FAVAR specification with only one unobserved factor, while Figures C.2 and C.3 illustrate the robustness for 5 and 7 factors, respectively. Moreover, we challenge our findings by examining two shorter sample periods, starting in 1994Q1 and 1997Q1, in order to eliminate potentially distorting effects of the Savings and Loan crisis and the ensuing U.S. recession of

[8]The reason for plotting the HVD based on a single model is that *pointwise median* contributions based on all draws imply jumping between different candidates and are thus not interpretable in a sensible way. Nevertheless, the latter results are qualitatively and quantitatively very similar to those in Figure 4, which can therefore be considered as representative.

[9]It is well-known that HVD contributions go through a transition phase that can be protracted if the time series in question are serially correlated. Here, the transition phase lasts until roughly 1998 and our discussion therefore focuses on the results thereafter.

[10]All impulse response functions are based on a chain of an effective length of 140,000 iterations with a burn-in phase of 100,000 iterations.

the early 1990s on our results. It turns out that the results based on these subsamples are quantitatively very similar to our baseline results.

2.2.3. Robustness Checks

In contrast to Bassett et al. (2014), we are not interested in an *exogenous* change in the supply of bank credit. In particular, we do not control for banks' "risk tolerance" in our preferred specification, given that this largely coincides with the monetary policy channel we are interested in. To address concerns that our result might be driven by loan demand rather than loan supply, we replace the "raw" lending standards in X_t by the alternative measure proposed by Bassett et al. (2014), which adjusts changes in lending standards for macroeconomic and bank-specific factors that might simultaneously affect the demand for bank credit. Panel (a) of Figure 6 illustrates that, despite a slightly smaller decrease, this alternative indicator responds to an exogenous monetary expansion in exactly the same way.[11]

While the focus of our paper is on lending standards and collateral requirements, in particular, qualitative surveys like the SLOOS can be criticized for being more prone to subjectiveness or intentional misreporting. As a consequence, we also investigate the impulse responses of two market-based measures of the financial sector's risk attitude: the "excess bond premium" proposed by Gilchrist and Zakrajšek (2012) – a component of the "GZ spread" that captures cyclical changes in the relationship between objective default risk and credit spreads – and the credit subindex of the Chicago Fed's National Financial Conditions Index (NFCI) – a composite measure of credit conditions. We find that both the excess bond premium and the NFCI credit component decrease significantly in response to an exogenous monetary expansion, indicating an increase in "the effective risk-bearing capacity of the financial sector" (compare Gilchrist and Zakrajšek, 2012) and thus an expansion in the supply of credit.

Barakchian and Crowe (2013) provide empirical evidence that U.S. monetary policy post 1988 became more forward-looking, implying that a credible identification of exogenous monetary shocks must account for policy makers' expectations about future economic activity and price dynamics during our sample period, in particular. While our benchmark specification of X_t already contains forward-looking variables, such as the S&P 500 or business and consumer survey data, one could argue that the Board of Governors uses

[11]Recall that, in our original FAVAR model, the first factor primarily captures the common comovement in lending standards. While replacing the latter in X_t might therefore affect the impulse response functions even qualitatively, this does *not* seem to be the case. Moreover, Bassett et al. (2014) show that an exogenous disruption in the supply of bank credit leads to a significant *easing* of monetary policy. In this light, the positive conditional comovement that we find between lending standards and the effective Federal Funds rate is unlikely to be contaminated by reverse causality from bank behavior to monetary policy.

additional information when forming its monetary policy decisions. For this reason, we include 13 additional quarterly time series from the Philadelphia Fed's Greenbook data set, expressed in terms of one-year-ahead expectations of average growth rates, directly in the vector X_t and find that the impulse responses of lending standards to an expansionary monetary policy shock are quantitatively very similar to those presented above and statistically significant at the 10% level for 1, 3, and 5 factors. For 7 factors, our estimates become less precise, while the easing of lending standards remains significant according to the error bands containing 68% of the probability mass.[12]

As a final robustness check, we dispose of the FAVAR structure altogether in favor of the formal approach to controlling for endogenous and anticipatory movements in U.S. monetary policy proposed by Romer and Romer (2004). For this purpose, we regress the effective Federal Funds rate and each of the SLOOS lending standards on $P = 4$ own lags as well as the contemporaneous and $Q = 12$ lagged observations of the exogenous shock series in Barakchian and Crowe (2013). Figure 7 plots the impulse response functions to a one-standard-deviation innovation in the quarterly aggregate of this monthly series. Even using an entirely different methodology, we find that all 19 measures of lending standards decrease in response to a monetary easing. In most cases, the reduction is statistically significant at an approximate 5% level and of similar or larger magnitude when compared with the impulse response functions in Figure 5.

To sum up, we provide robust empirical evidence for the existence of an ex-ante risk-taking channel of monetary policy on the asset side of banks' balance sheet. In contrast to Buch et al. (2014), for example, this channel seems to be present and statistically significant also for large domestic and foreign banks in the U.S. banking industry.

3. The Optimal Debt Contract in Partial Equilibrium

In the remainder of this paper, we develop a theoretical model that is capable of replicating the response of banks to a monetary easing identified in the previous empirical analysis. In particular, we want to show that it can be optimal for a bank to increase the amount of lending per unit of borrower collateral in response to an expansionary monetary policy shock, even though this raises the default probability of a given borrower and the default rate across borrowers. In other words, the bank lowers its lending standards.

[12] The projections from the Fed's Greenbook are released to the public with a lag of five years and are currently available up to 2008Q4. For more details, see Table A.2 in Appendix A.1. All results are available from the authors upon request.

For this purpose, we draw on a CSV problem of the type analyzed by Townsend (1979) and Gale and Hellwig (1985), and first incorporated into a New Keynesian DSGE model by Bernanke et al. (1999). The CSV contract accounts for both dimensions of a credit expansion: (i) the quantity of credit, i.e. the amount lent, and (ii) the quality of credit, i.e. the expected default threshold of the borrower that a bank is willing to tolerate. It thus provides a micro-foundation for banks' optimal decision on lending standards during a credit expansion. In contrast to Bernanke et al. (1999) and most recent contributions, however, we reformulate the optimal debt contract from the lender's perspective. Recall that, in the former, there is no active role for the so-called "financial intermediary", which merely diversifies away the idiosyncratic productivity risks of entrepreneurs and institutionalizes the participation constraint of a risk-averse depositor, along which the firm moves when making its optimal capital and borrowing decision.

Instead, we assume that a risk-neutral lender – "the bank" – decides how much to lend against a given amount of borrower collateral and thus the expected default threshold. As a result, the bank determines the entrepreneur's total capital expenditure. Note that introducing an active financial intermediary is a prerequisite for analyzing the effect of monetary policy on bank lending standards. In our model, the latter are endogenously determined through the bank's constrained profit-maximization problem.

We further assume that market power in the credit market is in the hands of the bank, which makes a "take-it-or-leave-it" loan offer to borrowers, similar to that in Valencia (2014). In order for a firm to accept this offer, it must be at least as well off as without the loan. While this represents one of many conceivable profit-sharing agreements, it can be motivated by the prevalence of relationship lending between banks and small or medium-sized enterprises. For example, Petersen and Rajan (1995) use a simple dynamic setting to show that the value of lending relationships decreases in the degree of competition in credit markets. The reason is that a monopolist lender can postpone interest payments in order to extract future rents from the borrowing firm, effectively "subsidizing the firm when young or distressed and extracting rents later" (Petersen and Rajan, 1995, p.408). A similar argument applies for the monopolist bank in our model, which can fully diversify the idiosyncratic productivity risks by lending to the entire cross section of firms.

The details of the optimal loan contract in partial equilibrium with and without aggregate risk will be specified in the following. Assuming that each entrepreneur borrows from at most one bank, the latter can enter a contract with one entrepreneur independently of its relations with others, and we can consider a representative bank-entrepreneur pairing (compare Gale and Hellwig, 1985).

3.1. The Contracting Problem

Suppose that, at time t, entrepreneur i purchases capital $Q_t K_t^i$ for use at $t+1$, where K_t^i is the quantity of capital purchased and Q_t is the price of one unit of capital in period t. The gross return per unit of capital expenditure to entrepreneur i, $\omega_{t+1}^i R_{t+1}^k$, depends on the ex-post aggregate return on capital, R_{t+1}^k, and an idiosyncratic component, ω_{t+1}^i. Following Bernanke et al. (1999), we assume that the random variable $\omega_{t+1}^i \in [0,\infty)$ is i.i.d. across entrepreneurs i and across time t, with a continuous and differentiable cumulative distribution function (c.d.f.) $F(\omega)$ and an expected value of unity.

Entrepreneur i finances capital purchases at the end of period t using accumulated net worth, N_t^i, as well as the borrowed amount B_t^i, so that

$$Q_t K_t^i = N_t^i + B_t^i. \tag{4}$$

Abstracting from alternative investment opportunities of entrepreneurs, the maximum equity participation (MEP) condition in Gale and Hellwig (1985) is trivially satisfied.[13] As in Valencia (2014), entrepreneur i borrows the amount B_t^i from a monopolistic bank, that is endowed with end-of-period-t net worth or bank capital N_t^b and raises deposits D_t from households. Defining *aggregate* lending to borrowers as $B_t \equiv \int_0^1 B_t^i di$, the bank's aggregate balance sheet identity in period t is given by

$$B_t \equiv N_t^b + D_t. \tag{5}$$

Following Bernanke et al. (1999), we motivate the need for borrower collateral by the presence of a state-verification cost paid by the lender in order to observe entrepreneur i's realization of ω_{t+1}^i, which is private information. We assume that this cost corresponds to a fixed proportion $\mu \in (0,1]$ of the entrepreneur's total return on capital in period $t+1$, $\omega_{t+1}^i R_{t+1}^k Q_t K_t^i$, so that initially uninformed agents may become informed by paying a fee which depends on the invested amount and the state (compare Townsend, 1979).

Both the borrower and the lender are assumed to be *risk-neutral* and to care about expected returns only, whereas depositors are *risk-averse*. Accordingly, the bank promises to pay the risk-free gross rate of return R_t^n on deposits in each aggregate state of the world, as characterized by the realization of R_{t+1}^k.

Denote the gross non-default rate of return on the period-t loan to entrepreneur i by Z_t^i. Given R_{t+1}^k,

[13] Proposition 2 in Gale and Hellwig (1985) states that any optimal contract is weakly dominated by a contract with MEP, where the firm puts all of its own liquid assets – here N_t^i – on the table.

$Q_t K_t^i$, and N_t^i, the financial contract specifies a relationship between Z_t^i and an ex-post cutoff value

$$\bar{\omega}_{t+1}^i \equiv \frac{Z_t^i B_t^i}{R_{t+1}^k Q_t K_t^i}, \tag{6}$$

such that the borrower pays the lender the fixed amount $\bar{\omega}_{t+1}^i R_{t+1}^k Q_t K_t^i$ and keeps the residual $\left(\omega_{t+1}^i - \bar{\omega}_{t+1}^i\right) \cdot R_{t+1}^k Q_t K_t^i$ if $\omega_{t+1}^i \geq \bar{\omega}_{t+1}^i$. If $\omega_{t+1}^i < \bar{\omega}_{t+1}^i$, the lender monitors the borrower, incurs the CSV cost, and extracts the remainder $(1-\mu)\,\omega_{t+1}^i R_{t+1}^k Q_t K_t^i$, while the entrepreneur defaults and receives nothing.

In contrast to Bernanke et al. (1999), we assume that the bank determines the amount of lending to entrepreneur i, B_t^i, for a given amount of borrower collateral, N_t^i. Yet, the entrepreneur will only accept the bank's loan offer if the corresponding expected return is at least as large as in "financial autarky", that is without the bank loan:

$$E_t \left\{ \int_{\bar{\omega}_{t+1}^i}^{\infty} \left(\omega - \bar{\omega}_{t+1}^i\right) R_{t+1}^k Q_t K_t^i dF(\omega) \right\} \geq E_t \left\{ \int_0^{\infty} \omega R_{t+1}^k N_t^i dF(\omega) \right\} = E_t R_{t+1}^k N_t^i, \tag{7}$$

where the last equality uses the assumption that $\int_0^{\infty} \omega dF(\omega) = E(\omega) = 1$. Hence, the bank must promise the borrower an expected return no smaller than the expected return from investing just his or her own net worth, N_t^i, which implies that investment opportunities are continuous and do *not* have a minimum size.

The bank's expected gross return on a loan to entrepreneur i can be written as

$$E_t \left\{ \bar{\omega}_{t+1}^i \left[1 - F\left(\bar{\omega}_{t+1}^i\right)\right] + (1-\mu) \int_0^{\bar{\omega}_{t+1}^i} \omega dF(\omega) \right\} R_{t+1}^k Q_t K_t^i.$$

Given that the bank pays the risk-free rate of return, R_t^n, on deposits, while we assume that no costs accrue on its own net worth, N_t^b, the bank's aggregate funding costs equal

$$R_t^n D_t = R_t^n \left(B_t - N_t^b\right) = R_t^n \left(Q_t K_t - N_t - N_t^b\right).$$

Suppose that the bank assigns $N_t^{b,i}$ of its total net worth, N_t^b, to the loan to entrepreneur i.[14] Then the bank's

[14] We only consider cases where aggregate shocks are small enough, so that the bank never defaults. As a consequence, the assignment of bank capital to a particular loan i is without loss of generality and mainly for notational consistency.

constrained profit maximization problem for the ith loan is given by

$$\begin{aligned} \max_{K_t^i, \bar{\omega}_{t+1}^i} \quad & E_t \left\{ \bar{\omega}_{t+1}^i \left[1 - F\left(\bar{\omega}_{t+1}^i\right) \right] + (1-\mu) \int_0^{\bar{\omega}_{t+1}^i} \omega dF(\omega) \right\} R_{t+1}^k Q_t K_t^i - R_t^n \left(Q_t K_t^i - N_t^i - N_t^{b,i} \right), \quad (8) \\ \text{s. t.} \quad & E_t \left\{ \int_{\bar{\omega}_{t+1}^i}^{\infty} \left(\omega - \bar{\omega}_{t+1}^i \right) R_{t+1}^k Q_t K_t^i dF(\omega) \right\} \geq E_t R_{t+1}^k N_t^i. \end{aligned}$$

3.2. The Contract without Aggregate Risk

As a starting point, consider the case when the aggregate return on capital, R_{t+1}^k, is known in advance and there is no aggregate risk. As a consequence, the only risk immanent in the loan contract between the bank and entrepreneur i arises from the idiosyncratic productivity realization, ω_{t+1}^i.

Given that the non-default repayment on the loan to entrepreneur i, $Z_t^i B_t^i$, is constant across all unobserved ω-states and the CSV cost is a fixed proportion μ of the entrepreneur's total return, the financial contract is *incentive-compatible* according to Proposition 1 in Gale and Hellwig (1985). The contract without aggregate risk further resembles a *standard debt contract* (SDC), since (i) it involves a fixed repayment to the lender as long as the borrower is solvent, (ii) the borrower's inability to repay is a necessary and sufficient condition for bankruptcy, and (iii) if the borrower defaults, the bank recovers as much as it can.[15] Hence, the optimal contract between the bank and each entrepreneur is a SDC with MEP, as in Bernanke et al. (1999). Moreover, the optimal contract is robust to ex-post renegotiations, if μ represents a *pure verification cost* rather than a bankruptcy cost. In the latter case, it would be optimal ex post to renegotiate the terms of the loan in order to avoid default, whereas, in the former case, incentive compatibility requires monitoring the borrower whenever he or she cannot repay.[16]

In period t, entrepreneur i approaches the bank for a loan and brings his or her net worth to the counter. Given N_t^i, the bank decides on the amount of the loan and thus on the total amount of the capital expenditure, $Q_t K_t^i = N_t^i + B_t^i$. For notational convenience, define the expected share of total profits accruing to the lender in period t as

$$\Gamma\left(\bar{\omega}_t^i\right) \equiv \bar{\omega}^i \left[1 - F\left(\bar{\omega}_t^i\right) \right] + \int_0^{\bar{\omega}_t^i} \omega dF(\omega),$$

[15] Proposition 3 in Gale and Hellwig (1985) states that any contract is weakly dominated by a SDC with the above three features.

[16] The central assumption is that the bank incurs the CSV cost in order to verify the entrepreneur's idiosyncratic realization of ω *before* agreeing to renegotiate, because the borrower cannot truthfully report default without the risk of being monitored (compare Covas and Den Haan, 2012).

where $0 < \Gamma\left(\bar{\omega}_t^i\right) < 1$ by definition, define the expected CSV costs of the lender as

$$\mu G\left(\bar{\omega}_t^i\right) \equiv \mu \int_0^{\bar{\omega}_t^i} \omega dF(\omega),$$

and note that

$$\Gamma'\left(\bar{\omega}_t^i\right) = 1 - F\left(\bar{\omega}_t^i\right) > 0, \qquad \Gamma''\left(\bar{\omega}_t^i\right) = -f\left(\bar{\omega}_t^i\right) < 0, \qquad \mu G'\left(\bar{\omega}_t^i\right) \equiv \mu\bar{\omega}_t^i f\left(\bar{\omega}_t^i\right) > 0.$$

We can then write the expected share of total profits net of monitoring costs going to the lender and the expected share of total profits going to the borrower as $\Gamma\left(\bar{\omega}_t^i\right) - \mu G\left(\bar{\omega}_t^i\right)$ and $1 - \Gamma\left(\bar{\omega}_t^i\right)$, respectively.

Using the above notation and further defining the ex-ante expected *external finance premium* (EFP), $s_t \equiv R_{t+1}^k / R_t^n$, the entrepreneur's capital/net worth ratio, $k_t^i \equiv Q_t K_t^i / N_t^i$, and $n_t^i \equiv N_t^{b,i} / N_t^i$, the bank's constrained profit maximization problem in (8) can equivalently be written as

$$\max_{k_t^i, \bar{\omega}_{t+1}^i} \quad \left[\Gamma(\bar{\omega}_{t+1}^i) - \mu G(\bar{\omega}_{t+1}^i)\right] s_t k_t^i - (k_t^i - 1 - n_t^i) \quad \text{s. t.} \quad \left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right] s_t k_t^i = s_t,$$

where we have dropped the expectations operator, since R_{t+1}^k and thus s_t are assumed to be known in advance. The corresponding first-order conditions with respect to k_t^i, $\bar{\omega}_{t+1}^i$, and the Lagrange multiplier λ_t^i are

$$\begin{aligned}
k_t^i: &\quad \left[\Gamma(\bar{\omega}_{t+1}^i) - \mu G(\bar{\omega}_{t+1}^i)\right] s_t - 1 + \lambda_t^i \left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right] s_t = 0, \\
\bar{\omega}_{t+1}^i: &\quad \left[\Gamma'(\bar{\omega}_{t+1}^i) - \mu G'(\bar{\omega}_{t+1}^i)\right] s_t k_t^i - \lambda_t^i \Gamma'(\bar{\omega}_{t+1}^i) s_t k_t^i = 0, \\
\lambda_t^i: &\quad \left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right] s_t k_t^i - s_t = 0.
\end{aligned}$$

Appendix B.1 shows that the optimal contract implies a positive relationship, $k_t^i = \psi(s_t)$ with $\psi'(s_t) > 0$, between the EFP and the optimal capital/net worth ratio. Note that the same qualitative result emerges from the optimal contract without aggregate risk in Bernanke et al. (1999), where the entrepreneur rather than the bank determines the amount of lending against collateral. An exogenous increase in the expected EFP, e.g. due to a reduction in the risk-free interest rate, R_t^n, induces the bank to lend more against a given amount of borrower net worth and thus collateral.

The mechanism driving this partial equilibrium result is illustrated in Figure 8, where we suppress time subscripts and index superscripts for notational convenience. Note that the lender's iso-profit curves (IPCs) and the borrower's participation constraint (PC) can be plotted in $(k, \bar{\omega})$-space and that the constrained profit maximum of the bank is determined by the tangential point between the (lowest) IPC and the PC.[17] The corresponding expressions for the lender's IPC and the borrower's PC are

$$k_{IPC} = \frac{\pi^b - 1 - n}{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1}, \tag{9}$$

$$k_{PC} \geq \frac{1}{1 - \Gamma(\bar{\omega})}, \tag{10}$$

where π^b denotes an arbitrary level of bank profits.

From (10), the PC is not affected by the EFP, s. In the absence of aggregate risk, the borrower's expected share of total profits, $1 - \Gamma(\bar{\omega})$, must be no smaller than his or her "skin in the game", $1/k \equiv N/QK$. For any given value of $\bar{\omega}$ and thus an expected share of total profits, the borrower's PC determines a minimum value of k and thus of the lender's "skin in the game", below which the entrepreneur would not accept the offered loan contract.

The IPC in (9) accounts for expected monitoring and funding costs. The bank maximizes expected profits by choosing the tangential point between the borrower's PC and its lowest IPC in $(k, \bar{\omega})$-space. As a result, the bank minimizes its "skin in the game" for a given expected share of total profits, $\Gamma(\bar{\omega})$.

The first panel of Figure 8 illustrates the tangential point between the borrower's PC and the lender's IPC for the calibration in Bernanke et al. (1999). Note that, for $QK = N$, the borrower is fully self-financed, will never default ($\bar{\omega} = 0$), and retains all the profits ($1 - \Gamma(0) = 1$).

Now consider the effects of a monetary expansion when R^k is known in advance, i.e. a decrease in R^n and thus an increase in $s \equiv R^k/R^n$. While the borrower's PC remains unaffected, the lender's IPCs are tilted upwards, as shown in the second panel. Although the borrower would accept any point above its PC on the new IPC, this is no longer optimal from the lender's perspective. Instead, the bank can move to a lower IPC, which implies a higher profit share, as indicated in the third panel. In doing so, however, it must satisfy the borrower's PC, as in the new optimal contract $(k^*_{new}, \omega^*_{new})$, where both the bank's expected profit share, $\Gamma(\bar{\omega})$, and its "skin in the game", k, have increased.

The previous discussion illustrates an important feature of the optimal debt contract in partial equilibrium. For a profit-maximizing bank, it is optimal to respond to an increase in the EFP, e.g. due to a monetary

[17] Appendix B.1 proves that the optimal contract yields a *unique interior* solution.

expansion, by lending more to entrepreneurs against a given amount of collateral, thus increasing the default threshold. This theoretical result squares nicely with our empirical finding that banks in the U.S. lower their standards for C&I loans to firms in response to an unexpected decrease in the Federal Funds rate.

3.3. The Contract with Aggregate Risk

In the dynamic model, the aggregate return on capital is *ex ante* uncertain. As a consequence, the default threshold characterizing a loan contract between the bank and entrepreneur i, $\bar{\omega}^i_{t+1}$, generally depends on the ex-post realization of R^k_{t+1}. Bernanke et al. (1999) circumvent this complication by simplifying the risk-sharing agreement between the borrower and the lender. Given the risk aversion of depositors, they assume that the lender's participation constraint must be satisfied *ex post* and that the entrepreneur bears any aggregate risk. Similarly, we assume that the borrower's PC must be satisfied ex post and that the bank absorbs any aggregate risk. This assumption is only viable, if the bank's capital buffer, N^b_t, is sufficient to shield depositors from any fluctuations in R^k_{t+1}, so that the bank never defaults.[18]

In order to understand the implications of our assumption, recall the PC in equation (10). Given that the borrower's capital expenditure, $Q_t K^i_t$, and net worth, N^i_t, are predetermined in period $t+1$, the ex-post share of total profits, $1 - \Gamma\left(\bar{\omega}^i_{t+1}\right)$, and the corresponding default threshold, $\bar{\omega}^i_{t+1}$, can *not* be made contingent on the aggregate state of the economy. From the definition of the cutoff in (6), however, this implies that the non-default rate of return, Z^i_t, must be state-contingent in order to absorb unexpected changes in R^k_{t+1}.

In contrast to Bernanke et al. (1999), where both $\bar{\omega}^i_{t+1}$ and Z^i_t are state-contingent and *countercyclical* (e.g., a higher than expected realization of R^k_{t+1} lowers the default threshold and thus the non-default rate of return required by the lender), here $\bar{\omega}^i_{t+1}$ is predetermined and *acyclical*, while Z^i_t is *procyclical*. Hence, a higher than expected realization of R^k_{t+1} raises Z^i_t, whereas the borrower's and the lender's expected profit shares continue to be determined by their "skin in the game", i.e. by the relative shares of N^i_t and B^i_t in $Q_t K^i_t$. Note that neither of the ex-post versions seems fully consistent with the common perception that the non-default rate of return on bank credit is predetermined and thus acyclical. Yet, the procyclicality of Z^i_t in our contract can be interpreted as the bank having a stake in the firm in terms of either equity or a long-term lending relationship. In this case, it is in the bank's interest that borrowers default only due to idiosyncratic risk, which can be diversified away, rather than due to aggregate risk.

[18] In other words, we assume that the fluctuations in the bank's return on lending net of monitoring costs, $\int_0^1 \left[\Gamma\left(\bar{\omega}^i_{t+1}\right) - \mu G\left(\bar{\omega}^i_{t+1}\right)\right] R^k_{t+1} Q_t K^i_t di$, are small enough to be absorbed without the bank defaulting.

While a formal proof of the optimality of this risk-sharing agreement is beyond the scope of the current paper, our assumption is based on a simple heuristical argument. Suppose that Z_t^i was predetermined and thus acyclical in period $t+1$. Given that B_t^i and $Q_t K_t^i$ are also predetermined in $t+1$, the definition of the default threshold in (6) implies that $\bar{\omega}_{t+1}^i$ is a strictly convex, decreasing function in $R_{t+1}^k \ \forall Z_t^i, R_{t+1}^k > 0$.[19] As a result, an unexpected decrease in R_{t+1}^k raises $\bar{\omega}_{t+1}^i$ by more than an equivalent unexpected increase in R_{t+1}^k lowers $\bar{\omega}_{t+1}^i$, i.e., symmetric fluctuations in R_{t+1}^k imply *asymmetric* fluctuations in the default threshold and thus in the default rate of entrepreneurs, even if the idiosyncratic productivity shocks were uniformly distributed. This asymmetry is amplified if ω_{t+1}^i follows a log-normal distribution with $\bar{\omega}_{t+1}^i$ in the left tail of the distribution, as we assume below. Since default imposes a resource cost on the economy in this model, any (unexpected) cyclicality of $\bar{\omega}_{t+1}^i$ over the business cycle is undesirable. Our risk-sharing agreement, where the bank bears the aggregate risk and hence $\bar{\omega}_{t+1}^i$ is acyclical on impact, eliminates the share of the monitoring cost that is due to the asymmetric fluctuations in entrepreneur default.

The ex-post version of our financial contract is *incentive-compatible* and resembles a *standard debt contract*, if and only if R_{t+1}^k is observed by both parties without incurring a cost (compare Gale and Hellwig, 1985).[20] Otherwise, the non-default rate of return on the loan, Z_t^i, can *not* be made contingent on the state of the economy, whereas entrepreneurs generally have no incentive to misreport a true observed state. As in the case without aggregate risk, the optimal debt contract is robust to ex-post renegotiations, if μ represents a pure verification cost.

Appendix B.2 shows that the optimal debt contract between the bank and entrepreneur i implies a positive relation between the expected EFP, $s_t \equiv E_t \left\{ R_{t+1}^k \right\} / R_t^n$, and the optimal capital/net worth ratio, $Q_t K_t^i / N_t^i$:

$$Q_t K_t^i = \psi(s_t) N_t^i, \qquad \psi'(s_t) > 0. \tag{11}$$

In what follows, we embed the partial equilibrium loan contract into an otherwise standard New Keynesian DSGE model.

[19]Recall that Z_t^i and R_{t+1}^k are the *gross* non-default rates of return on a loan to entrepreneur i and per unit of capital, respectively.

[20]One could argue that, holding a perfectly diversified loan portfolio, the bank can deduce the ex-post realization of R_{t+1}^k, unless entrepreneurs misreport their returns in an unobserved state in a systematic way across i. However, we already know that entrepreneurs have no incentive to lie, if Z_t^i is independent of ω_{t+1}^i. Note that a similar argument must implicitly hold in Bernanke et al. (1999) for optimality.

4. The General Equilibrium Model

The general equilibrium model incorporates seven types of economic agents: A representative household, a representative capital goods producer, a representative intermediate goods producer, a continuum of monopolistically competitive retailers, a continuum of entrepreneurs, a monopolistic bank, and a monetary authority.

4.1. The Model Environment

The representative household supplies labor to intermediate goods producers, consumes, and saves in terms of risk-free bank deposits. The representative capital goods producer buys the non-depreciated capital stock from entrepreneurs, takes an investment decision subject to adjustment costs and sells the new capital stock to entrepreneurs within the same period without incurring any capital gains or losses. The representative intermediate goods producer hires labor from households and rents capital from entrepreneurs in competitive factor markets and sells intermediate output to retailers in a competitive wholesale market. Retailers diversify the homogeneous intermediate good without incurring any costs and are thus able to set the price on final output above their marginal cost, i.e. the price of the intermediate good.[21] Monetary policy follows a standard Taylor (1993) rule. Since the optimization problems of these agents are standard in the literature, we defer their detailed discussion until later, focusing instead on the dynamic behavior of competitive entrepreneurs and the monopolistic bank in general equilibrium.

4.1.1. Entrepreneurs

At the end of period t, entrepreneurs use their accumulated net worth, N_t, to purchase productive capital, K_t, from capital goods producers at a price Q_t in terms of the numeraire. To finance the difference between net worth and total capital expenditures, $Q_t K_t$, entrepreneurs must borrow an amount $B_t = Q_t K_t - N_t$ in real terms from banks, where variables without an index superscript denote economy-wide aggregates.

The aggregate real rate of return per unit of capital in period t depends on the real rental rate of capital, r_t^k, and the capital gain in real terms of the non-depreciated capital stock, $(1-\delta)K_{t-1}$, between $t-1$ and t:

$$R_t^k = \frac{r_t^k + (1-\delta)Q_t}{Q_{t-1}}. \tag{12}$$

[21] Retailers are introduced in order to allow for nominal price rigidities without unnecessarily complicating the production and investment decisions of firms (compare Bernanke et al., 1999).

We assume a continuum of risk-neutral entrepreneurs, indexed $i \in [0,1]$, which are hit by an idiosyncratic disturbance ω_t^i in period t, so that the ex-post rate of return of entrepreneur i per unit of capital equals $\omega_t^i R_t^k$. Following Bernanke et al. (1999), we assume that ω_t^i is i.i.d. across time t and across entrepreneurs i, with a continuous and differentiable cumulative distribution function $F(\omega)$ over a non-negative support, and $E\left\{\omega_t^i\right\} = 1 \ \forall t$.[22]

In contrast to Bernanke et al. (1999) and variations thereof, we assume that entrepreneurs can also operate in *financial autarky*, purchasing $Q_t K_t = N_t$ in period t. In order for an entrepreneur to accept a loan offer, the terms of the loan, i.e. the amount B_t and the nominal non-default rate of return Z_t, must be such that the entrepreneur expects to be no worse off than in financial autarky. Assuming constant returns to scale (CRS), the distribution of net worth, N_t^i, across entrepreneurs is irrelevant. For this reason, the aggregate version of the participation constraint in equation (7) can be written as

$$E_t\left\{\int_{\bar{\omega}_{t+1}}^{\infty} \omega R_{t+1}^k Q_t K_t - \frac{Z_t}{\pi_{t+1}} dF(\omega)\right\} \geq E_t\left\{R_{t+1}^k\right\} N_t, \tag{13}$$

where the expectation is over R_{t+1}^k, and $\bar{\omega}_{t+1}$ denotes the *expected* default threshold in period $t+1$, which is defined by $E_t\left\{\bar{\omega}_{t+1} R_{t+1}^k\right\} Q_t K_t \equiv E_t\left\{Z_t/\pi_{t+1}\right\} B_t$.

Using the definition of $\bar{\omega}_{t+1}$ to substitute out $E_t\left\{Z_t/\pi_{t+1}\right\}$ and expressing the aggregate profit share of entrepreneurs in period t as $1 - \Gamma(\bar{\omega}_t)$, equation (13) can equivalently be written as

$$E_t\left\{\left[1 - \Gamma(\bar{\omega}_{t+1})\right] R_{t+1}^k\right\} Q_t K_t \geq E_t\left\{R_{t+1}^k\right\} N_t. \tag{14}$$

Note that the ex-post realized value of $\Gamma(\bar{\omega}_{t+1})$ generally depends on the realization of R_{t+1}^k through $\bar{\omega}_{t+1}$. Similar to Bernanke et al. (1999), we assume that this constraint must be satisfied *ex post*. Implicit in this is the assumption that R_{t+1}^k is observed by both parties without incurring a cost, and that the non-default repayment, Z_t, can thus be made contingent on the aggregate state of the economy.

In order to avoid that entrepreneurial net worth grows without bound, we assume that an exogenous fraction $(1 - \gamma^e)$ of the entrepreneurs' share of total realized profits is consumed in each period.[23] Accordingly,

[22] We further assume that the corresponding *hazard rate* $h(\omega) \equiv f(\omega) / [1 - F(\omega)]$ satisfies $\partial \omega h(\omega)/\partial \omega > 0$.

[23] In the literature, it is common to assume that an exogenous fraction of entrepreneurs "dies" each period and consumes its net worth upon exit. The dynamic implications of either assumption are identical.

entrepreneurial net worth at the end of period t evolves according to

$$N_t = \gamma^e [1 - \Gamma(\bar{\omega}_t)] R_t^k Q_{t-1} K_{t-1}. \tag{15}$$

To sum up, the entrepreneurs' equilibrium conditions comprise the real rate of return per unit of capital in (12), the ex-post participation constraint in (14), the evolution of entrepreneurial net worth in (15), and the real amount borrowed, $B_t = Q_t K_t - N_t$. Moreover, the definition of the expected default threshold, $E_t \bar{\omega}_{t+1}$, determines the expected non-default repayment per unit borrowed by the entrepreneurs, $E_t \{Z_t / \pi_{t+1}\}$.

4.1.2. Banks

For tractability, we assume a single *monopolistic* financial intermediary, which collects deposits from households and provides loans to entrepreneurs. In period t, this bank is endowed with net worth or bank capital N_t^b. Abstracting from bank reserves or other types of bank assets, the balance sheet identity in real terms is given by equation (5). The CSV problem in Townsend (1979) implies that, if entrepreneur i defaults due to $\omega_t^i R_t^k Q_{t-1} K_{t-1}^i < Z_{t-1}^i B_{t-1}^i$, the bank incurs a proportional cost $\mu \omega_t^i R_t^k Q_{t-1} K_{t-1}^i$ and recovers the remaining return on capital, $(1 - \mu) \omega_t^i R_t^k Q_{t-1} K_{t-1}^i$.

In period t, the risk-neutral bank observes entrepreneurs' net worth, N_t^i, and makes a take-it-or-leave-it offer to each entrepreneur i. As a consequence, it holds a perfectly diversified loan portfolio between period t and period $t+1$. Although the bank can thus diversify away any idiosyncratic risk arising from the possible default of entrepreneur i, it is subject to aggregate risk through fluctuations in the ex-post rate of return on capital, R_{t+1}^k, and the aggregate default threshold, $\bar{\omega}_{t+1}$. In order to be able to pay the risk-free nominal rate of return R_t^n on deposits *in each state of the world*, the bank must have sufficient net worth to protect depositors from unexpected fluctuations in R_{t+1}^k.

Now consider the bank's problem of making a take-it-or-leave-it offer to entrepreneur i with net worth N_t^i in period t. The contract offered by the bank specifies the real amount of the loan, B_t^i, and the nominal gross rate of return in case of repayment, Z_t^i. Given that N_t^i is predetermined at the end of period t, the bank's choice of B_t^i also determines the entrepreneur's total capital expenditure, $Q_t K_t^i = B_t^i + N_t^i$. Moreover, given $Q_t K_t^i$ and N_t^i, the bank's choice of Z_t^i implies an expected default threshold $E_t \bar{\omega}_{t+1}$ through $E_t \left\{ \bar{\omega}_{t+1} R_{t+1}^k \right\} Q_t K_t \equiv E_t \{Z_t / \pi_{t+1}\} B_t$. Hence, we can equivalently rewrite the bank's constrained profit-maximization problem for a loan to entrepreneur i as

$$\max_{K_t^i, \bar{\omega}_{t+1}^i} \quad E_t \left\{ \left[\Gamma\left(\bar{\omega}_{t+1}^i\right) - \mu G\left(\bar{\omega}_{t+1}^i\right) \right] R_{t+1}^k Q_t K_t^i - \frac{R_t^n}{\pi_{t+1}} \left(Q_t K_t^i - N_t^i - N_t^{b,i} \right) \right\}, \tag{16}$$

where $\Gamma\left(\bar{\omega}_t^i\right) \equiv \int_0^{\bar{\omega}_t^i} \omega dF(\omega) + \bar{\omega}_t^i \left[1 - F\left(\bar{\omega}_t^i\right)\right]$, $\mu G\left(\bar{\omega}_t^i\right) \equiv \mu \int_0^{\bar{\omega}_t^i} \omega dF(\omega)$, and $N_t^{b,i}$ denotes the share of total bank net worth assigned to the loan to entrepreneur i, subject to the participation constraint in (7).

The corresponding first-order conditions with respect to $\left\{K_t^i, E_t \bar{\omega}_{t+1}^i, \lambda_t^{b,i}\right\}$, where $\lambda_t^{b,i}$ denotes the ex-post value of the Lagrange multiplier on the participation constraint, are

$$K_t^i : \quad E_t \left\{ \left[\Gamma(\bar{\omega}_{t+1}^i) - \mu G(\bar{\omega}_{t+1}^i) + \lambda_t^{b,i} \left(1 - \Gamma(\bar{\omega}_{t+1}^i)\right) \right] R_{t+1}^k \right\} = E_t \left\{ \frac{R_t^n}{\pi_{t+1}} \right\}, \tag{17}$$

$$E_t \bar{\omega}_{t+1}^i : \quad E_t \left\{ \left[\Gamma'(\bar{\omega}_{t+1}^i) - \mu G'(\bar{\omega}_{t+1}^i) \right] R_{t+1}^k \right\} = E_t \left\{ \lambda_t^{b,i} \Gamma'(\bar{\omega}_{t+1}^i) R_{t+1}^k \right\}, \tag{18}$$

$$\lambda_t^{b,i} : \quad \left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right] R_{t+1}^k Q_t K_t^i = R_{t+1}^k N_t^i. \tag{19}$$

Following Bernanke et al. (1999), we show in Appendix B.2 that the optimal debt contract between entrepreneur i and the bank implies a positive relationship between the expected EFP, $s_t \equiv E_t \left\{ R_{t+1}^k \pi_{t+1} / R_t^n \right\}$, and the optimal capital/net worth ratio, $k_t^i \equiv Q_t K_t^i / N_t^i$.

Here, instead, we go beyond this "reduced-form" result and utilize the entire information incorporated in the above first-order conditions. Note that equation (17) equates the expected marginal return of an additional unit of capital to the bank and the entrepreneur to the expected marginal cost of an additional unit of bank deposits in real terms and, assuming that the participation constraint is satisfied ex post, implies a positive relationship between $E_t \left\{ R_{t+1}^k \pi_{t+1} \right\} / R_t^n$ and $E_t \left\{ \bar{\omega}_{t+1}^i \right\}$. Moreover, equation (19) equates the entrepreneur's expected payoff *with* and *without* the bank loan and implies a positive relation between $E_t \left\{ \bar{\omega}_{t+1}^i \right\}$ and $Q_t K_t^i / N_t^i$.[24] Together, these two equations determine the positive ex-ante relationship between the expected EFP in period $t+1$ and the leverage ratio chosen by the bank in period t, while the first-order condition with respect to $E_t \left\{ \bar{\omega}_{t+1}^i \right\}$ pins down the ex-post value of the Lagrange multiplier, $\lambda_t^{b,i}$.

[24] This becomes evident, when we use the ex-post assumption that R_{t+1}^k and $\bar{\omega}_{t+1}$ are uncorrelated and rewrite (19) as

$$\left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right] \geq \frac{N_t^i}{Q_t K_t^i} \equiv \frac{1}{k_t^i},$$

i.e., entrepreneur i's expected return on capital with the loan relative to financial autarky must be no smaller than the entrepreneur's "skin in the game". Since $\left[1 - \Gamma(\bar{\omega}_{t+1}^i)\right]$ is strictly decreasing in $E_t \left\{ \bar{\omega}_{t+1}^i \right\}$, the participation constraint implies a positive relationship between $E_t \left\{ \bar{\omega}_{t+1}^i \right\}$ and k_t^i.

Given N_t^i, $Q_t K_t^i$, and $E_t \left\{R_{t+1}^k\right\}$, the definition of the expected default threshold, $E_t \left\{\bar{\omega}_{t+1}^i\right\}$, implies an expected non-default real rate of return on the loan to entrepreneur i, $E_t \left\{Z_t^i / \pi_{t+1}\right\}$, while the same equation evaluated ex post determines the actual non-default repayment conditional on N_t^i, $Q_t K_t^i$, $E_t \left\{\bar{\omega}_{t+1}^i\right\}$, and the realization of R_{t+1}^k.

By the law of large numbers, $\Gamma\left(\bar{\omega}_t^i\right) - \mu G\left(\bar{\omega}_t^i\right)$ denotes the bank's *expected* share of total period-t profits (net of monitoring costs) from a loan to entrepreneur i as well as the bank's *realized* profit share from its diversified loan portfolio of all entrepreneurs. Accordingly, we can rewrite the bank's aggregate expected profits in period $t+1$ as

$$E_t V_{t+1}^b = E_t \left\{ \left[\Gamma\left(\bar{\omega}_{t+1}\right) - \mu G\left(\bar{\omega}_{t+1}\right)\right] R_{t+1}^k Q_t K_t - \frac{R_t^n}{\pi_{t+1}} \left(Q_t K_t - N_t - N_t^b\right) \right\}, \tag{20}$$

where the expectation is over possible realizations of R_{t+1}^k and π_{t+1}, while V_{t+1}^b is free of any idiosyncratic risk. The entrepreneurs' participation constraint in (14) implies that $\bar{\omega}_{t+1}$ and thus $\left[\Gamma\left(\bar{\omega}_{t+1}\right) - \mu G\left(\bar{\omega}_{t+1}\right)\right]$ are predetermined in period $t+1$. In order to keep the problem tractable, we assume that aggregate risk is small relative to the bank's net worth, N_t^b, so that bank default never occurs in equilibrium.

In order to avoid that its net worth grows without bound, we assume that an exogenous fraction $(1 - \gamma^b)$ of the bank's share of total realized profits is consumed each period.[25] Accordingly, bank net worth at the end of period t evolves according to

$$N_t^b = \gamma^b V_t^b. \tag{21}$$

4.1.3. Households

The representative household is risk-averse and derives utility from a Dixit-Stiglitz aggregate of imperfectly substitutable consumption goods,

$$C_t = \left[\int_0^1 C_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{22}$$

Households have an infinite planning horizon and discount their future expected utility with the subjective discount factor $\beta < 1$. They can transfer wealth intertemporally by saving in terms of bank deposits, which

[25] Alternatively, one could think of this "consumption" as a distribution of dividends to share holders or bonus payments to bank managers, which are instantaneously consumed.

pay risk-free nominal interest R_t^n between t and $t+1$.[26] The household's constrained optimization problem can be summarized as

$$\max_{C_t,H_t,D_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{H_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right\},$$

$$\text{s. t.} \quad C_t + D_t \leq W_t H_t + \frac{R_{t-1}^n}{\pi_t} D_{t-1},$$

where D_t are nominal deposits, W_t denotes the real wage, $\pi_t = P_t/P_{t-1}$ is the gross inflation rate, and $P_t \equiv \left[\int_0^1 P_t(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}}$ is the corresponding aggregate price index.

The first-order conditions with respect to $\{C_t, H_t, D_t\}$, where λ_t denotes the Lagrange multiplier of the budget constraint, are

$$
\begin{aligned}
C_t: &\quad C_t^{-\sigma} = \lambda_t, \\
H_t: &\quad \chi H_t^{\frac{1}{\eta}} = \lambda_t W_t, \\
D_t: &\quad \lambda_t = \beta E_t \left\{ \lambda_{t+1} \frac{R_t^n}{\pi_{t+1}} \right\}.
\end{aligned}
$$

4.1.4. Capital Goods Producers

After production in period t has taken place, capital producers purchase the non-depreciated capital stock from entrepreneurs, invest in a Dixit-Stiglitz aggregate of imperfectly substitutable investment goods, $I_t \equiv \left[\int_0^1 I_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$, and sell the new stock of capital to entrepreneurs at the relative price Q_t. We assume that turning final output into productive capital, i.e. gross investment, is costly due to possible disruptions of the production process, replacement of installed capital, or learning. The capital accumulation equation can then be written as

$$K_t = (1-\delta)K_{t-1} + \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{23}$$

where $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\phi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$, $S(1) = S'(1) = 0$, and $S''(1) = \phi$ (compare, e.g., Christiano et al., 2005).

The problem of the representative capital goods producer, subject to the capital accumulation equation in (23), is

$$\max_{I_t} \quad \sum_{t=0}^{\infty} \beta^t \left\{ Q_t [K_t - (1-\delta)K_{t-1}] - I_t \right\}.$$

[26] Note that deposits are risk-free despite the fact that the bank bears the aggregate risk, as long as the bank carries sufficient net worth to shield its depositors from fluctuations in the aggregate return on capital.

The corresponding FOC with respect to investment is given by

$$Q_t \left[1 - \frac{\phi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \phi \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta \phi E_t \left[Q_{t+1} \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right] = 1. \tag{24}$$

4.1.5. Intermediate Goods Producers

Intermediate goods producers rent the productive capital stock from entrepreneurs and hire labor from households, paying a competitive rental rate of capital and a competitive wage rate, respectively. To convert capital and labor into intermediate or wholesale goods, they use the following Cobb-Douglas production function:

$$Y_t = K_{t-1}^{\alpha} H_t^{1-\alpha},$$

where a shock to total factor productivity (TFP) has been omitted for notational convenience.

Suppose that the price of the homogeneous wholesale good in terms of the numeraire is $1/X_t$, so that the gross flexible-price markup of retail goods over the wholesale good is X_t. The static optimization problem of the intermediate goods producer can then be summarized as

$$\max_{K_{t-1}, H_t} \quad \frac{1}{X_t} K_{t-1}^{\alpha} H_t^{1-\alpha} - r_t^k K_{t-1} - W_t H_t,$$

which yields the following FOCs:

$$\begin{aligned} K_{t-1}: \qquad X_t r_t^k &= \alpha \frac{Y_t}{K_{t-1}}, \\ H_t: \qquad X_t W_t &= (1-\alpha) \frac{Y_t}{H_t}. \end{aligned}$$

4.1.6. Retailers

Monopolistically competitive retailers purchase homogeneous intermediate output, diversify at no cost, and resell to households and capital goods producer for consumption and investment purposes, respectively. We assume staggered price setting à la Calvo (1983), where θ denotes the exogenous probability of *not* being able to readjust the price.

A retailer allowed to reset its price in period t chooses the optimal price, P_t^*, in order to maximize the present value of current and expected future profits, subject to the demand function for the respective product variety in period $t + s$, $s = 0, ..., \infty$, $Y_{t+s}(j) = (P_{t,s}/P_{t+s})^{-\epsilon} Y_{t+s}$, where $P_{t,s}$ is the price of a retailer that was last allowed to be set in period t.[27] Hence, the profit maximization problem of a retailer in period t is

$$\max_{P_t^*} \quad E_t \left\{ \sum_{s=0}^{\infty} \theta^s \Lambda_{t,t+s} \Pi_{t,s} \right\},$$

where $\Lambda_{t,t+s} \equiv \beta^s E_t \left[U'(C_{t+s})/U'(C_t) \cdot P_t/P_{t+s} \right]$ denotes the stochastic discount factor and

$$\Pi_{t,s} \equiv (P_t^* - MC_{t,s}) \left[\frac{P_t^*}{P_{t+s}} \right]^{-\epsilon} Y_{t+s},$$

where $MC_{t,s}$ is the retailer's nominal marginal cost in period $t + s$. The corresponding optimality condition is given by

$$E_t \sum_{s=0}^{\infty} \theta^s \Lambda_{t,t+s} Y_{t+s} P_{t+s}^{\epsilon} \left[P_t^* - \frac{\epsilon}{\epsilon - 1} MC_{t,s} \right] = 0.$$

In order to arrive at the New Keynesian Phillips curve, we combine the above FOC with the definition of the aggregate price index,

$$P_t = \left\{ \theta P_{t-1}^{1-\epsilon} + (1-\theta) \left(P_t^* \right)^{1-\epsilon} \right\}^{1/(1-\epsilon)}.$$

4.1.7. Monetary Policy and Market Clearing

We assume that the central bank sets the *nominal* interest rate, R_t^n, according to the following standard Taylor rule:

$$\frac{R_t^n}{R_{ss}^n} = \left(\frac{R_{t-1}^n}{R_{ss}^n} \right)^{\rho} \left[\left(\frac{\pi_t}{\pi_{ss}} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_{ss}} \right)^{\phi_y} \right]^{1-\rho} e^{\nu_t}. \tag{25}$$

Hence, the central bank reacts to deviations of inflation and output from their respective steady-state values and might smooth interest rates over time with a weight ρ. Unsystematic deviations from the Taylor rule in (25) are captured by a mean-zero i.i.d. random variable, ν_t.

The model is closed by the economy-wide resource constraint,

$$Y_t = C_t + C_t^e + C_t^b + I_t + \mu G(\bar{\omega}_t) R_t^k Q_{t-1} K_{t-1}, \tag{26}$$

where C_t^e and C_t^b denote the real consumption of entrepreneurial and bank net worth, respectively, while $\mu G(\bar{\omega}_t) R_t^k Q_{t-1} K_{t-1}$ denotes aggregate monitoring costs in period t.

[27] The isoelastic demand schedule for the product of retailer j can be derived from the definitions of aggregate demand $Y_t = \left[\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}$ and the aggregate price index $P_t = \left[\int_0^1 P_t(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}$.

4.2. Calibration and Steady State

The New Keynesian DSGE model described in the previous subsection is parsimoniously parameterized and standard in many dimensions. For this reason, we follow the related literature in calibrating most of the parameter values. We assume a coefficient of constant relative risk aversion, σ, equal to 2 and a Frisch elasticity of labor supply, η, equal to 3. The relative weight of labor in the utility function, χ, is determined by a target value of $1/3$ for steady-state H. The representative household discounts future utility with a subjective discount factor, β, of 0.995, which implies a steady-state real interest rate of 2% per annum. Following Basu (1996) and Chari et al. (2000), we assume an elasticity of substitution between different consumption and investment varieties, ϵ, equal to 10.

The productive capital stock depreciates with a quarterly rate of $\delta = 2.5\%$. Given the absence of habit formation in consumption, we calibrate the investment adjustment cost parameter, ϕ, to a moderate value of 0.1.[28] The role of investment adjustment costs for the dynamics in the model will be discussed further below. As in Bernanke et al. (1999), the elasticity of output with respect to the previous period capital stock, α, is set to 0.35, and the Calvo probability that a retailer can adjust its price in any given period, θ, is assumed to be 0.75 – a value in the middle of the range of estimates in Christiano et al. (2005).

We assume a substantial amount of interest rate inertia in monetary policy by setting ρ to 0.95, while the central bank's responsiveness to contemporaneous deviations of inflation and output from their steady state, ϕ_π and ϕ_y, equals 1.5 and 0.5, respectively. The only exogenous disturbance in the model – the shock to the Taylor rule, ν_t – follows a mean-zero i.i.d. process with an unconditional standard deviation, σ_ν, of 0.25.

The remaining parameters relate to the optimal debt contract between the bank and the continuum of entrepreneurs. In order to avoid that either the bank or an entrepreneur grows indefinitely, we assume that 5% and 1.5% of their net worth is consumed each quarter, implying an average survival rate of 5 and 16 years, respectively.[29] The relative monitoring cost in case of default, μ, is set to 20%, a value at the lower end of the range reported in Carlstrom and Fuerst (1997) and in the middle of the range of estimates reported in Levin et al. (2004).

[28]Christiano et al. (2005) evaluate the role of real and nominal rigidities for parameter estimates in a similar model. Using the same formulation of investment adjustment costs and excluding habit formation in consumption, they obtain a point estimate of the adjustment cost parameter equal to 0.91 with a standard deviation of 0.18. However, their specification also includes nominal wage rigidity and money in the utility function.

[29]Note that, in addition to this exogenous consumption, an endogenous fraction of entrepreneurs defaults in each period due to an insufficient idiosyncratic realization of ω^i. Total exit of firms is thus given by the sum of the *exogenous* consumption and the *endogenous* default rate.

Moreover, we assume that idiosyncratic productivity draws are log-normally distributed with unit mean and a variance of 0.18 and that the default threshold, $\bar{\omega}$, is 0.35 in the steady state. Together, these parameter values imply an annual default rate of entrepreneurs close to 4.75%, an annual non-default interest rate on bank loans of 4.8%, and a leverage ratio of entrepreneurs equal to 1.537, which corresponds to the median value of leverage ratios for U.S. non-financial firms in Levin et al. (2004). Their sample of quoted firms ranges from 1997Q1 to 2003Q3. Table 2 summarizes the benchmark calibration of parameter values.

The benchmark calibration implies an annual capital-output ratio of 1.945, a consumption share of households, entrepreneurs, and bankers of 0.696, 0.078, and 0.025, respectively, and an investment share in output of 0.195 in the steady state. The share of net worth and loans in total capital purchases amounts to 0.651 and 0.350, respectively, and implies an equivalent distribution of gross profits between entrepreneurs and the bank. Monitoring costs amount to less than 0.6% of steady-state output. Bank loans are funded through deposits and bank capital with relative shares of 0.824 and 0.176. The implied leverage ratio of entrepreneurs of 1.537 was explicitly targeted in the calibration.

We assume that there is no trend inflation in the steady state. Accordingly, all interest rates can be interpreted in real terms and price dispersion does not affect the results. From the benchmark calibration, we obtain an annualized risk-free rate of return on deposits of 2%, an annualized aggregate rate of return on capital of 6.2%, a non-default rate of return on bank loans of 6.8%, and an annualized EFP of 4.2%.

The steady-state default rate of entrepreneurs increases with the default threshold, $\bar{\omega}$, and the exogenous variance of idiosyncratic productivity realizations, σ_{ω}^2. For our preferred calibration, the annualized default rate equals 4.7%. Note that this default accounts for only part of the overall turnover of entrepreneurs in the steady state. Each period, 1.5% of entrepreneurial and 5% of bank net worth are consumed exogenously. The steady-state values of selected variables and ratios are summarized in Table 3.

4.3. Dynamic Simulation Results

Figure 9 plots selected impulse responses to an expansionary monetary policy shock, i.e. an exogenous reduction in the unsystematic component of the Taylor rule by 25 basis points on a quarterly basis, for our benchmark calibration. All impulse response functions, except for bank interest rates and the EFP, are expressed in terms of *relative* deviations from the respective variable's steady-state value.

In response to the monetary expansion, the policy rate, R_t^n, decreases on impact, albeit not by the full amount of the shock, since the interest rate rule implies a contemporaneous reaction to inflation and output, which are both above their steady-state values. The reduction in the policy rate is passed through to the non-default rate of return on loans, Z_t, which also decreases on impact and follows virtually the same pattern.

Assuming that the entrepreneurs' participation constraint must be satisfied ex post, their share in gross profits, $1 - \Gamma(\bar{\omega}_t)$, is predetermined in the period of the shock. Accordingly, neither the default threshold, $\bar{\omega}_t$, nor the default rate, $F(\bar{\omega}_t)$, of entrepreneurs responds on impact. Nonzero investment adjustment costs imply an unexpected increase in the price of capital, Q_t, and thus in the gross real rate of return on capital, R_t^k, as well as the ex-post realized EFP.[30] The fact that profits are split according to the predetermined leverage ratio, $Q_{t-1}K_{t-1}/N_{t-1}$, implies that both entrepreneurs and the bank benefit from the monetary expansion. As a result, bank net worth, N_t^b, and entrepreneurial net worth, N_t, increase on impact and remain above their steady-state values for more than 20 quarters.

From $t + 1$ onwards, the price of capital starts to decline, implying capital losses for the entrepreneurs, which are correctly anticipated by all economic agents under rational expectations (RE) in the absence of further shocks. Nevertheless, the expected EFP for period $t + 1$ is above its steady-state value by about 0.2 basis points, which induces the bank to grant more loans both in absolute terms and *relative to entrepreneurs' net worth*. As a consequence, the leverage ratio of entrepreneurs increases from the end of period t onwards and peaks after 4 quarters at 7.4 basis points above its steady-state value of 1.537.

This increase in borrower leverage allows the bank to demand a larger share of gross expected profits realized in period $t+1$. The distribution of profits, however, hinges on the non-default rate of return on bank loans, Z_t, and the implied expected default threshold, $E_t\bar{\omega}_{t+1}$. Together with the latter, the default rate of entrepreneurs, $F(\bar{\omega}_{t+1})$, rises above its steady-state value. The maximum effect is attained after 5 quarters, when the default threshold is about 0.049 or 0.14% above its steady-state value of 0.35, and the default rate of entrepreneurs is 1 basis point or 0.86% above its steady-state value of 1.18%.

While the effects of an expansionary monetary policy shock on the entrepreneurs' leverage ratio and default rate and on the expected EFP appear quantitatively small in our baseline simulation, they can be magnified substantially by a slight change in the monetary policy rule, for example. Suppose that the monetary authority does not respond to deviations of output from its steady-state value, i.e., $\phi_y = 0$. In this case, the maximum effect on the leverage ratio and the default threshold increases from 7 to 23 basis points

[30]The impulse response function in Figure 9 shows the *ex-ante expected* rather than the *ex-post realized* EFP and does therefore not reflect the unexpected increase in the period of the monetary policy shock.

and from 14 to 43 basis points, respectively.

Importantly, the impulse responses in Figure 9 *qualitatively* replicate our empirical results. In particular, the entrepreneurs' leverage ratio, $Q_t K_t / N_t$, which can be interpreted as the (inverse) model counterpart of the SLOOS lending standards measures 5 and 11, i.e. "domestic banks increasing collateral requirements for large and middle firms" respectively "domestic banks increasing collateral requirements for small firms", follows a hump-shaped response and decreases below its steady-state value after 12 quarters. The slightly earlier peak in the theoretical model is due to the fact that the maximum reduction in the policy rate occurs on impact rather than with a lag, as in the FAVAR model.

4.3.1. Sensitivity Analysis

An important question is whether the above theoretical results are sensitive to our choice of parameter. For this reason, we perform a number of robustness checks within the range of parameter values commonly used in the related literature.

First, our findings are qualitatively robust to habit formation in consumption. More precisely, a nonzero weight on consumption in period $t-1$ raises the peak response of the borrowers' leverage ratio and default rate without affecting their persistence, thus *strengthening* the risk channel of monetary policy in the model.

Second, our results are qualitatively robust to the introduction of nonzero trend inflation. For example, an annualized steady-state inflation rate of 1% lowers the peak response of the borrowers' leverage ratio and default rate without affecting their persistence.[31]

Third, our findings are not sensitive to the particular assumptions about the price setting of retailers. Allowing for indexation of non-adjusting firms' prices to past inflation, for example, slightly lowers both the peak response and the persistence of the entrepreneurs' leverage ratio and default rate, without making a qualitative difference. The same is true when combining price indexation with nonzero trend inflation.

Fourth, our results are qualitatively robust to alternative specifications of the interest rate rule in equation (25), such as a response to past or expected future rather than current inflation (compare Bernanke et al., 1999), a response to past or expected future rather than current output, or a stronger response of monetary policy to inflation deviations from steady state, for example. The latter reduces both the peak response and the persistence of the entrepreneurs' leverage ratio and default rate.[32]

[31] Higher rates require a stronger response of monetary policy to deviations of inflation from trend inflation in order to avoid *indeterminacy* (compare Ascari and Ropele, 2009).

[32] Note that our results are not affected by a response of monetary policy to the so-called "output gap", i.e. the deviation of actual

The single critical parameter seems to be the coefficient of investment adjustment costs, ϕ. Given our reformulation of the CSV contract from the bank's perspective, we require a low value of ϕ in order to overturn the theoretical result in Bernanke et al. (1999) and subsequent contributions that a monetary expansion *reduces* the expected EFP and thus the leverage ratio and default rate of entrepreneurs. While our result is qualitatively robust to the particular specification of adjustment costs in investment or capital, the latter must generally be low relative to empirical estimates in the literature. The reason is that the degree of adjustment costs determines the dynamics of the capital price, Q_t, and thus the gross return on capital, R_t^k. The higher the value of ϕ, the larger will be the initial increase in Q_t and the lower will therefore be $E_t R_{t+1}^k$ as well as the expected EFP from period $t+1$ onwards. From the analysis of the contract in partial equilibrium, we know that the leverage ratio $Q_t K_t / N_t$ is positively related to the expected EFP. Hence, a decrease in the latter due to a large expected devaluation of capital between period t and $t+1$ would lead to a decrease rather than an increase in the entrepreneurs' leverage ratio, in contrast to our empirical finding in Section 2. Finally, with a relative standard deviation about 3.8 times that of output, our model and calibration do *not* seem to imply an excessive volatility of investment. This value is robust to the inclusion of TFP shocks and to HP-filtering of the theoretical moments.

4.3.2. The Role of the Optimal Debt Contract

The sensitivity of our results to the parameter ϕ raises the question, whether the impulse responses of the expected EFP and borrower leverage in Figure 9 can indeed be attributed to our reformulation of the optimal financial contract, or merely to our assumption of low investment adjustment costs. For this reason, we embed the CSV contract of Bernanke et al. (1999) in our general equilibrium model, while maintaining the exact benchmark calibration.

Recall that the original formulation of the contract implies that entrepreneur i determines the optimal amount of the loan, B_t^i, and thus the leverage ratio for a predetermined amount of net worth, N_t^i, while the "financial intermediary" only corresponds to a participation constraint. Assuming perfect diversification across borrowers and the risk-sharing agreement in Bernanke et al. (1999), the passive financial intermediary must break even in each realized aggregate state of the economy. Hence, there is no role for bank capital or consumption, i.e., $N_t^b = C_t^b = 0 \; \forall t$.

from potential output, under flexible prices. Due to the neutrality of money, potential output is identical to steady-state output in the absence of nominal rigidities.

Figure 10 plots selected impulse responses to the same expansionary monetary policy shock for "Our contract" and the "BGG contract." Note that the formulation of the optimal financial contract is the only dimension along which the two models differ and that all impulse response functions are expressed in terms of *percentage* deviations from the corresponding steady-state values.[33] Our key finding is that, for the BGG contract, the entrepreneurs' default threshold, default rate, and leverage ratio as well as the expected EFP all *decrease* on impact before monotonically converging back to steady state. However, a sustained reduction in the leverage ratio of borrowers seems at odds with our empirical evidence that banks *lower* their collateral requirements in response to an expansionary monetary policy shock. In contrast with both our contract and the popular notion of a *bank lending channel* of monetary policy, the BGG contract furthermore implies an initial contraction rather than an expansion of aggregate bank lending.

These crucial differences arise from the assumption in Bernanke et al. (1999) that a competitive financial intermediary merely transforms household deposits, which fall in response to a monetary expansion, into loans to entrepreneurs *one for one*. In contrast, the monopolistic bank in our model retains a share of total profits, accumulates own net worth, and is thus able to expand lending despite an even more pronounced and persistent reduction in deposits. The bank's market power and our assumption about aggregate risk sharing also manifest themselves in a weaker response of the loan rate relative to the BGG contract.

The more pronounced increase in borrower net worth, N_t, as well as the contraction of aggregate bank lending, B_t, imply the well-known decrease in the leverage ratio of entrepreneurs, $Q_t K_t / N_t = (N_t + B_t) / N_t$, in Bernanke et al. (1999), whereas the introduction of a *bank balance sheet channel* in this paper facilitates a reduction in deposits and an expansion of bank lending at the same time. We therefore believe that our formulation of the optimal CSV contract, where the bank determines the amount of credit for a given amount of borrower collateral, is more plausible in the narrative dimension as well as in terms of its qualitative prediction that banks optimally lower their lending standards in response to a monetary expansion.

4.3.3. "Too Low for Too Long"

Inspired by the motivation in Taylor (2007), we conduct an informal test of the "too-low-for-too-long" hypothesis. According to this hypothesis, a prolonged deviation of monetary policy from what is justified by economic conditions might lead to excessive risk taking in the financial sector. Note that, in our model, a transitory deviation from the Taylor rule becomes more persistent, the higher the degree of interest-rate

[33] It is important to note that, apart from $N^b_{ss} = C^b_{ss} = V^b_{ss} = 0$, reformulating the contract has little effect on steady-state values.

inertia. In this subsection, we therefore compare the effects of a typical expansionary monetary policy shock for two different values of the Taylor-rule coefficient on the lagged policy rate, ρ, without modifying the other parameters of the model.

Figure 11 illustrates that higher interest-rate inertia and thus a more persistent reduction in the policy rate, R_t^n, implies an increase in both the peak effect and the persistence of the impulse response functions of the entrepreneurial leverage ratio and default threshold to a monetary easing. Accordingly, the optimal loosening of bank lending standards, measured by the increase in bank lending relative to borrower collateral in our model, and the subsequent increase in the default rate of borrowers becomes more pronounced, when the nominal policy rate is more inertial.

In the current example, an increase in the Taylor-rule coefficient, ρ, from 0.90 to 0.95 almost doubles the maximum response of the leverage ratio from 3.9 to 7.4 basis points above its steady-state value of 1.537 and postpones the turning point in the leverage ratio (from above to below its steady state) by 1 quarter. The effects on the impulse response functions of output, consumption, and investment are qualitatively the same and of a similar order of magnitude.

5. Concluding Remarks

In this paper, we provide robust empirical evidence for the popular notion that expansionary monetary policy induces financial intermediaries to grant loans to ex-ante riskier borrowers. In particular, we include quarterly observations of 19 measures of bank lending standards from the Federal Reserve's Senior Loan Officer Opinion Survey (SLOOS) in a FAVAR model and show that U.S. banks significantly lower their lending standards, such as the collateral requirements for firms, in response to an unexpected reduction in the effective Federal Funds rate. We interpret this results as evidence for a risk channel of monetary policy on the asset side of banks' balance sheets.

Based on the empirical evidence, we reformulate the well-known application of Townsend's (1979) CSV contract in Bernanke et al. (1999) from the perspective of a monopolistic bank that chooses the amount of risky lending against collateral to a continuum of entrepreneurs, subject to an ex-post participation constraint of the borrower. We assume that both the bank and the entrepreneurs are risk-neutral. While the bank can diversify any idiosyncratic default risk of borrowers, it bears all the aggregate risk. We show that, in partial equilibrium, the debt contract has a unique interior solution for the default threshold of entrepreneurs, which implies a positive relationship between the expected EFP and the optimal leverage ratio chosen by the bank.

As a result, an exogenous increase in the expected EFP induces the bank to lend more against a given amount of borrower collateral in order to gain a larger "share of the pie". At the same time, entrepreneurs become more leveraged and thus more likely to default ex post.

We then embed our version of the CSV contract in an otherwise standard New Keynesian DSGE model with sticky prices and a moderate degree of investment adjustment costs. In contrast to the prior literature, an expansionary monetary policy shock leads to a hump-shaped increase in the expected EFP. Accordingly, our model implies an increase in bank lending relative to borrower collateral and thus a higher leverage ratio of entrepreneurs. This general equilibrium result strongly resembles our prior empirical finding that, in the U.S., the share of "domestic banks increasing collateral requirements for firms" and similar lending standards decrease significantly in response to an unexpected monetary easing by the Federal Reserve. We further show that this effect increases with the degree of interest-rate smoothing in the monetary policy rule, in line with the "too low for too long" hypothesis.

While the focus of this paper is on merging new empirical evidence with a theoretical model of the effects of expansionary monetary policy on banks' lending standards, we stop short of analyzing the implications of this channel for the stability of the banking sector as a whole. In our model, the bank is endowed with sufficient equity to avoid bankruptcy in all aggregate states of the world. Models of financial intermediation that allow for outright bank default, such as Valencia (2014) and Malherbe (2014), necessarily simplify along other dimensions. Nevertheless, we believe that our model potentially lends itself to the future analysis of the virtues and vices of monetary policy and macroprudential regulation.

6. References

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Appendix A. Econometric Methodology

A.1. Data

Table A.1: Data and Transformations Used in the Baseline FAVAR Model.

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
1	1	INDPRO	yes	5	Industrial Production Index: Total (2007=100, SA)
2	2	IPBUSEQ	yes	5	Industrial Production: Business Equipment (2007=100, SA)
3	3	IPCONGD	yes	5	Industrial Production: Consumer Goods (2007=100, SA)
4	4	IPDCONGD	yes	5	Industrial Production: Durable Consumer Goods (2007=100, SA)
5	5	IPDMAN	yes	5	Industrial Production: Durable Manufacturing (NAICS) (2007=100, SA)
6	6	IPDMAT	yes	5	Industrial Production: Durable Materials (2007=100, SA)
7	7	IPFINAL	yes	5	Industrial Production: Final Products (Market Group) (2007=100, SA)
8	8	IPMAN	yes	5	Industrial Production: Manufacturing (NAICS) (2007=100, SA)
9	9	IPMAT	yes	5	Industrial Production: Materials (2007=100, SA)
10	10	IPMINE	yes	5	Industrial Production: Mining (2007=100, SA)
11	11	IPNCONGD	yes	5	Industrial Production: Nondurable Consumer Goods (2007=100, SA)
12	12	IPNMAN	yes	5	Industrial Production: Nondurable Manufacturing (NAICS) (2007=100, SA)
13	13	IPNMAT	yes	5	Industrial Production: nondurable Materials (2007=100, SA)
14	14	IPUTIL	yes	5	Industrial Production: Electric and Gas Utilities (2007=100, SA)
15	15	BSCURT02USM160S	yes	1	Business Tendency Surveys for Manufacturing: Rate of Capacity Utilization (% of Capacity), SA
16	16	RPI	yes	5	Real personal income, Billions of 2009 chained USD, SAAR

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
17	17	PIECTR	yes	5	Real personal income excluding current transfer receipts, Billions of 2009 chained USD, SAAR
18	18	GDPC1	yes	5	Real Gross Domestic Product, Billions of 2009 USD chained , SAAR
19	1	CE16OV	yes	5	Civilian Employment (thous., SA)
20	2	DMANEMP	yes	5	All Employees: Durable Goods (thous., SA)
21	3	EMRATIO	yes	4	Employment-Population Ratio (Percent, SA)
22	4	MANEMP	yes	5	All Employees: Manufacturing (thous., SA)
23	5	PAYEMS	yes	5	All Employees: Total Nonfarm (thous., SA)
24	6	SRVPRD	yes	5	All Employees: Service Providing Industries (thous., SA)
25	7	USCONS	yes	5	All Employees: Construction (thous., SA)
26	8	USGOVT	yes	5	All Employees: Government (thous., SA)
27	9	USINFO	yes	5	All Employees: Information Services (thous., SA)
28	10	USMINE	yes	5	All Employees: Mining and Logging (thous., SA)
29	11	USPRIV	yes	5	All Employees: Total Private Industries (thous., SA)
30	12	CES0600000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees (SA)
31	13	CES0800000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Mining and Logging (SA)
32	14	CES1000000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Private Service Providing, (SA)
33	15	CES2000000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Durables (SA)
34	16	CES3100000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Construction (SA)

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
35	17	CES4000000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Information (SA)
36	18	CES5000000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Trade, Transportation, Utilities (SA)
37	19	CES6000000007	yes	1	Average Weekly Hours of Production and Nonsupervisory Employees: Professional and Business Services (SA)
38	1	PCECC96	yes	5	Real Personal consumption expenditure, SAAR, chained 2009 BIL USD
39	1	HOUST	no	4	Housing Starts: Total: New Privately Owned Housing Units Started (thsd. of units) SAAR
40	2	HOUSTMW	no	4	Housing Starts:Midwest: New Privately Owned Housing Units Started (thsd. of units) SAAR
41	3	HOUSTNE	no	4	Housing Starts: Northeast: New Privately Owned Housing Units Started (thsd. of units) SAAR
42	4	HOUSTS	no	4	Housing Starts: South: New Privately Owned Housing Units Started (thsd. of units) SAAR
43	5	HOUSTW	no	4	Housing Starts: West: New Privately Owned Housing Units Started (thsd. of units) SAAR
44	6	PERMIT	no	4	New Private Housing Units Authorized by Building Permits, (thsd. of units) SAAR
45	1	S&P 500	no	5	S&P 500 Stock Price Index, NSA, end of period
46	1	EXCAUS	no	5	Canadian Dollars to One U.S. Dollar, NSA
47	2	EXJPUS	no	5	Japanese Yen to One U.S. Dollar, NSA
48	3	EXSZUS	no	5	Swiss Francs to One U.S. Dollar, NSA

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
49	4	EXUSUK	no	5	U.S. Dollars to One British Pound, NSA
50	1	AAA	no	1	Moody's Seasoned Aaa Corporate Bond Yield, Percent, NSA
51	2	BAA	no	1	Moody's Seasoned Baa Corporate Bond Yield, Percent, NSA
52	3	FEDFUNDS	no	1	Effective FFR, Percent, NSA
53	4	GS1	no	1	1-Year Treasury Constant Maturity Rate, Percent, NSA
54	5	GS10	no	1	10-Year Treasury Constant Maturity Rate, Percent, NSA
55	6	GS3	no	1	3-Year Treasury Constant Maturity Rate, Percent, NSA
56	7	GS3M	no	1	3-Month Treasury Constant Maturity Rate, Percent, NSA
57	8	GS5	no	1	5-Year Treasury Constant Maturity Rate, Percent, NSA
58	9	AAA_FFR	no	1	Spread: AAA-FFR
59	10	BAA_FFR	no	1	Spread: BAA-FFR
60	11	GS1_FFR	no	1	Spread: GS1-FFR
61	12	GS10_FFR	no	1	Spread: GS10-FFR
62	13	GS3_FFR	no	1	Spread: GS3-FFR
63	14	GS3M_FFR	no	1	Spread: GS3M-FFR
64	15	GS5_FFR	no	1	Spread:GS5-FFR
65	1	BOGNONBR	no	5	Non-Borrowed Reserves of Depository Institutions, Mill USD, SA
66	2	AMBSL	no	5	Monetary Base, Bill USD, SA
67	3	M1	no	5	M1, Bill USD, SA
68	4	M2	no	5	M2, Bill USD, SA
69	5	MZM	no	5	MZM, Bill USD, SA
70	6	LOANS	no	5	Total Loans and Leases, Bill USD, SA
71	7	REALLN	no	5	Real estate loans, Bill USD, SA
72	8	BUSLOANS	no	5	C&I loans, Bill USD; SA
73	9	CONSUMER	no	5	Consumer loans, Bill USD, SA
74	1	CPIAUCSL	yes	5	Consumer Price Index for All Urban Consumers: All Items, 1982-84=100, SA
75	2	CPIFABSL	yes	5	Consumer Price Index for All Urban Consumers: Food and Beverages, 1982-84=100, SA

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
76	3	CPILFESL	yes	5	Consumer Price Index for All Urban Consumers: All Items Less Food & Energy, 1982-84=100, SA
77	4	CPIMEDSL	yes	5	Consumer Price Index for All Urban Consumers: Medical Care, 1982-84=100, SA
78	5	DNRGRG3M086SBEA	yes	5	Personal consumption expenditures: Energy goods and services, chain-type index, 2009=100
79	6	DPCXRG3M086SBEA	yes	5	Personal consumption expenditures: Market-based PCE excluding food and energy , chain-type index, 2009=100
80	7	PPICRM	no	5	Producer Price Index: Crude Materials for Furt1er Processing, 1982=100, SA
81	8	PPIFCG	yes	5	Producer Price Index: Finished Consumer Goods, 1982=100, SA
82	9	PPIFGS	yes	5	Producer Price Index: Finished Goods, 1982=100, SA
83	10	PPIIEG	yes	5	Producer Price Index: Intermediate Energy Goods, 1982=100, SA
84	11	PPIITM	yes	5	Producer Price Index: Intermediate Materials: Supplies & Components, 1982=100, SA
85	1	CSCICP02USM661S	no	1	Consumer Opinion Surveys: Confidence Indicators: Composite Indicator, 2005=1.00, SA, end of period
86	1	SUBLPDCILS_N.Q	no	1	Net percentage of domestic banks tightening standards for C&I loans to large and middle-market firms, Percentage
87	2	SUBLPDCILTC_N.Q	no	1	Net percentage of domestic banks increasing the cost of credit lines to large and middle-market firms, Percentage
88	3	SUBLPDCILTL_N.Q	no	1	Net percentage of domestic banks tightening loan covenants for large and middle-market firms, Percentage

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
89	4	SUBLPDCILTM_N.Q	no	1	Net percentage of domestic banks reducing the maximum size of credit lines for large and middle-market firms, Percentage
90	5	SUBLPDCILTQ_N.Q	no	1	Net percentage of domestic banks increasing collateral requirements for large and middle-market firms, Percentage
91	6	SUBLPDCILTS_N.Q	no	1	Net percentage of domestic banks increasing spreads of loan rates over banks' cost of funds to large and middle-market firms, Percentage
92	7	SUBLPDCISS_N.Q	no	1	Net percentage of domestic banks tightening standards for C&I loans to small firms, Percentage
93	8	SUBLPDCISTC_N.Q	no	1	Net percentage of domestic banks increasing the cost of credit lines to small firms, Percentage
94	9	SUBLPDCISTL_N.Q	no	1	Net percentage of domestic banks tightening loan covenants for small firms, Percentage
95	10	SUBLPDCISTM_N.Q	no	1	Net percentage of domestic banks reducing the maximum size credit lines for small firms, Percentage
96	11	SUBLPDCISTQ_N.Q	no	1	Net percentage of domestic banks increasing collateral requirements for small firms, Percentage
97	12	SUBLPDCISTS_N.Q	no	1	Net percentage of domestic banks increasing spreads of loan rates over banks' cost of funds to small firms, Percentage
98	13	SUBLPDRCS_N.Q	no	1	Net percentage of domestic banks tightening standards for commercial real estate loans, Percentage
99	14	SUBLPFCIS_N.Q	no	1	Net percentage of foreign banks tightening standards for approving C&I loans, Percentage
100	15	SUBLPFCITC_N.Q	no	1	Net percentage of foreign banks increasing costs of credit lines, Percentage

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
101	16	SUBLPFCITL_N.Q	no	1	Net percentage of foreign banks tightening loan covenants, Percentage
102	17	SUBLPFCITM_N.Q	no	1	Net percentage of foreign banks reducing the maximum size of credit lines, Percentage
103	18	SUBLPFCITQ_N.Q	no	1	Net percentage of foreign banks increasing collateralization requirements, Percentage
104	19	SUBLPFRCS_N.Q	no	1	Net percentage of foreign banks tightening standards for commercial real estate loans, Percentage
105	1	AHETPI	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Total Private, USD per Hour, SA
106	2	CES0600000008	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Goods producing, USD per hour, SA
107	3	CES0800000008	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Private Service Producing, USD per Hour, SA
108	4	CES1000000008	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Mining and Logging, USD per Hour, SA
109	5	CES2000000008	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Construction, USD per Hour, SA
110	6	CES3000000008	yes	5	Average Hourly Earnings of Production and Nonsupervisory Employees: Manufacturing, USD per Hour, SA
111	1	B015RX1Q020SBEA	no	1	Change in real private inventories: Nonfarm, Billions of 2009 chained USD, SAAR

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
112	2	B018RX1Q020SBEA	no	1	Change in real private inventories: Farm, Billions of 2009 chained USD, SAAR
113	3	NAPMNOI	no	1	ISM Manufacturing: New Orders Index, SA
114	4	INVRES	no	5	Real Gross Private Domestic Residential Investment, Billions of Real Dollars, SA
115	5	INVNONRES	no	5	Real Gross Private Domestic Nonresidential Investment, Billions of Real Dollars, SA
116	1	TFBAIL_MA_NQ	no	1	Charge-off rate on loans; All commerical banks, NSA
117	2	STTFBAILB_MA_NQ	no	1	Charge-off rate on business loans; All commerical banks, NSA
118	3	STTFBAILB_MA_NQ	no	1	Charge-off rate on business loans; All commerical banks, NSA
119	4	STTFBAILCC_MA_NQ	no	1	Charge-off rate on credit card loans; All commerical banks, NSA
120	5	STTFBAILCO_MA_NQ	no	1	Charge-off rate on other consumer loans; All commerical banks, NSA
121	6	STTFBAILF_MA_NQ	no	1	Charge-off rate on loans to finance agricultural production; All commerical banks, NSA
122	7	STTFBAILR_MA_NQ	no	1	Charge-off rate on lease financing receivables; All commerical banks, NSA
123	8	STTFBAILS_MA_NQ	no	1	Charge-off rate on loans secured by real estate; All commerical banks, NSA
124	9	STTFBAILSF_XDO_MA_NQ	no	1	Charge-off rate on farmland loans, booked in domestic offices; All commerical banks, NSA
125	10	STTFBAILSS_XDO_MA_NQ	no	1	Charge-off rate on single family residential mortgages, booked in domestics offices; All commerical banks, NSA
126	11	STTFBAILSX_XDO_MA_NQ	no	1	Charge-off rate on commercial real estate loans (excluding farmland), booked in domestic offfices; All commerical banks, NSA

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Table A.1 – *Continued from previous page*

Overall No.	No. in Block	Series ID[a]	Slow[b]	Transformation[c]	Description
127	12	STTFBAIL_XEOP_MA_NQ	no	1	Delinquency rate on loans; All commerical banks, NSA
128	13	STTFBAILB_XEOP_MA_NQ	no	1	Delinquency rate on business loans; All commerical banks, NSA
129	14	STTFBAILC_XEOP_MA_NQ	no	1	Delinquency rate on consumer loans; All commerical banks, NSA
130	15	STTFBAILCC_XEOP_MA_NQ	no	1	Delinquency rate on credit card loans; All commerical banks, NSA
131	16	STTFBAILCO_XEOP_MA_NQ	no	1	Delinquency rate on other consumer loans; All commerical banks, NSA
132	17	STTFBAILF_XEOP_MA_NQ	no	1	Delinquency rate on loans to finance agricultural production; All commerical banks, NSA
133	18	STTFBAILR_XEOP_MA_NQ	no	1	Delinquency rate on lease financing receivables; All commerical banks, NSA
134	19	STTFBAILS_XEOP_MA_NQ	no	1	Delinquency rate on loans secured by real estate; All commerical banks, NSA
135	20	STTFBAILSF_XEOP_XDO_MA_NQ	no	1	Delinquency rate on farmland loans, booked in domestic offices; All commerical banks, NSA
136	21	STTFBAILSS_XEOP_XDO_MA_NQ	no	1	Delinquency rate on single-family residential mortgages, booked in domestic offices; All commerical banks, NSA
137	22	STTFBAILSX_XEOP_XDO_MA_NQ	no	1	Delinquency rate on commercial real estate loans (excluding farmland), booked in domestic offices; All commerical banks, NSA

[a] Macroeconomic time series are taken from the FRED database, lending standards measures are taken from the Senior Loan Officer Opinion Survey (SLOOS) of the Federal Reserve.

[b] If yes, a variable is assumed to be slow-moving when estimated with a principal component approach.

[c] Variable transformations codes are as follows: 1 - no transformation, 2 - difference, 4 - logarithm, 5 - log-difference.

Table A.2: Data and Transformations Used in the Robustness Checks.

Series ID	**Transformation**[a]	**Description**
GB_RGDPdot	1	Greenbook projections for quarter-on-quarter growth in real GDP, chain weighted (annualized percentage points)
GB_PGDPdot	1	Greenbook projections for quarter-on-quarter growth in price index for GDP, chain weighted (annualized percentage points)
GB_UNEMP	1	Greenbook projections for the unemployment rate, (percentage points)
GB_CPIdot	1	Greenbook projections for quarter-on-quarter headline CPI inflation, (annualized percentage points)
GB_CORECPIdot	1	Greenbook projections for quarter-on-quarter core CPI inflation, (annualized percentage points)
GB_RCONSUMdot	1	Greenbook projections for quarter-on-quarter growth in real personal consumption expenditure, chain weighted (annualized percentage points)
GB_RNRESINVdot	1	Greenbook projections for quarter-on-quarter growth in real business fixed investment, chain weighted (annualized percentage points)
GB_RRESINVdot	1	Greenbook projections for quarter-on-quarter growth in real residential investment, chain weighted (annualized percentage points)
GB_RFEDGOVdot	1	Greenbook projections for quarter-on-quarter growth in real federal government consumption and gross investment, chain weighted (annualized percentage points)
GB_RSLGOVdot	1	Greenbook projections for quarter-on-quarter growth in real estate and local government consumption and gross investment, chain weighted (annualized percentage points)
GB_NGDPdot	1	Greenbook projections for quarter-on-quarter growth in nominal GDP (annualized percentage points)
GB_HOUSING	4	Greenbook projections for housing starts (millions of units)
GB_INDPRODdot	1	Greenbook projections for quarter-on-quarter growth in the industrial production index (annualized percentage points)
ADJLS	1	Supply component of SLOOS lending standards in Bassett et al. (2014) (Net percentage of banks tightening lending standards, adjusted for macroeconomic and bank-specific factors that also affect loan demand)
EBP	1	Excess Bond Premium in Gilchrist and Zakrajšek (2012) (annualized percentage points)
NFCICREDIT	1	Chicago Fed National Financial Conditions Credit Subindex (index)
MONPOL	1	Time series of monetary policy shocks in Barakchian and Crowe (2013) (quarterly aggregates of monthly observations)

[a] Variable transformations codes are as follows: 1 - no transformation, 2 - difference, 4 - logarithm, 5 - log-difference.

A.2. Bayesian Estimation of the FAVAR Model

In order to jointly estimate equations (1) and (2) using Bayesian methods it is convenient to rewrite the model in state-space form:

$$\begin{bmatrix} X_t \\ Y_t \end{bmatrix} = \begin{bmatrix} \Lambda^f & \Lambda^y \\ 0 & I \end{bmatrix} \begin{bmatrix} F_t \\ Y_t \end{bmatrix} + \begin{bmatrix} e_t \\ 0 \end{bmatrix} \tag{A.1}$$

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-1} \\ Y_{t-1} \end{bmatrix} + v_t, \tag{A.2}$$

where Y_t is the $M \times 1$ vector of observables, F_t is the $K \times 1$ vector of unobservable factors, and X_t is the $N \times 1$ vector of informational time series. We restrict the loading coefficient matrices Λ^f of dimension $N \times K$ and Λ^y of dimension $N \times M$ in order to identify the factors uniquely. The vector error terms e_t and v_t are assumed to be normally distributed and uncorrelated, i.e. $e_t \sim N(0, R)$ and $v_t \sim N(0, Q)$, where R is a diagonal matrix.

In one-step Bayesian estimation, all parameters are treated as random variables. The parameter vector θ contains the factor loadings and the variance-covariance matrix of the observation equation in (1) as well as the VAR coefficients and the variance-covariance matrix of the transition equation in (2) , i.e., $\theta = \left(\Lambda^f, \Lambda^y, R, vec(\Phi), Q\right)$. In addition, the unobservable factors are treated as random variables and sampled. The observation and transition equations can be rewritten as

$$\boldsymbol{X}_t = \Lambda \boldsymbol{F}_t + \boldsymbol{e}_t \tag{A.3}$$

$$\boldsymbol{F}_t = \Phi(L) \boldsymbol{F}_{t-1} + \boldsymbol{v}_t, \tag{A.4}$$

where Λ is the loading matrix, $\boldsymbol{X}_t = (X_t', Y_t')$, $\boldsymbol{e}_t = (e_t', 0)$, and $\boldsymbol{F}_t = (F_t', Y_t')$. Let $\tilde{\boldsymbol{X}}_t = (\boldsymbol{X}_1, \boldsymbol{X}_2, \ldots, \boldsymbol{X}_T)$ and $\tilde{\boldsymbol{F}}_t = (\boldsymbol{F}_1, \boldsymbol{F}_2, \ldots, \boldsymbol{F}_T)$ denote the respective histories from time 1 to T. Our goal is to obtain the marginal densities of the parameters and factors, which can be integrated out of the joint posterior density $p\left(\theta, \tilde{\boldsymbol{F}}_T\right)$. Hence, we are interested in the following objects:

$$p\left(\tilde{\boldsymbol{F}}_T\right) = \int p\left(\theta, \tilde{\boldsymbol{F}}_T\right) d\theta, \tag{A.5}$$

$$p(\theta) = \int p\left(\theta, \tilde{\boldsymbol{F}}_T\right) d\tilde{\boldsymbol{F}}_T. \tag{A.6}$$

A.2.1. The Gibbs Sampler

We use the multi-move Gibbs sampling approach of Carter and Kohn (1994), which alternately samples from the parameters and the factors as follows:

Step 1: Choose a starting value for the parameter vector θ_0.

Step 2: Draw $\tilde{\boldsymbol{F}}_T^{(1)}$ from the conditional density $p\left(\tilde{\boldsymbol{F}}_T|\tilde{\boldsymbol{X}}_T, \theta_0\right)$.

Step 3: Draw $\theta^{(1)}$ from the conditional density $p\left(\theta|\tilde{\boldsymbol{X}}_T, \tilde{\boldsymbol{F}}_T^{(1)}\right)$.

Repeat steps 2 and 3 until convergence.

A.2.2. Choice of Starting Values

An obvious choice for θ_0 is the solution implied by principal component analysis (compare Bernanke et al., 2005), which we use as a baseline in most runs. However, starting the chains (even very long ones) from the same point may not be sufficient to achieve the target distribution, in practice, even if the chain appears to have converged. Therefore, we experimented with "agnostic" starting values, e.g. $vec\,(\Phi) = 0$, $Q = I$, $\Lambda^f = 0$, Λ^y = OLS of the regression of X on Y and R = fitted residual covariance matrix from the OLS regression of X on Y, without substantial effects on our results. We furthermore ran multiple consecutive chains of 1 million draws each, setting the starting values of the subsequent to the values obtained in the last iteration of the previous chain. Given that the chains were highly autocorrelated for some of the parameters, we applied thinning and kept only every fifth draw.

A.2.3. Conditional Densities and Priors

In order to draw from $p\left(\tilde{\boldsymbol{F}}_T|\tilde{\boldsymbol{X}}_T, \theta\right)$, we apply Kalman filtering techniques (see Kim and Nelson, 1999). Due to the memoryless Markov property of $\boldsymbol{F}_t$, the conditional distribution of the history of factors can be expressed as a product of the conditional distributions of factors at date t:

$$p\left(\tilde{\boldsymbol{F}}_T|\tilde{\boldsymbol{X}}_T, \theta\right) = p\left(\boldsymbol{F}_T|\tilde{\boldsymbol{X}}_T, \theta\right) \prod_{t-1}^{T-1} p\left(\boldsymbol{F}_t|\boldsymbol{F}_{t+1}, \tilde{\boldsymbol{X}}_t, \theta\right). \tag{A.7}$$

The original model is linear-Gaussian, which implies

$$\boldsymbol{F}_T|\tilde{\boldsymbol{X}}_T, \theta \sim N\left(\boldsymbol{F}_{T|T}, \boldsymbol{P}_{T|T}\right) \tag{A.8}$$

$$\boldsymbol{F}_t|\boldsymbol{F}_{t+1}, \tilde{\boldsymbol{X}}_t, \theta \sim N\left(\boldsymbol{F}_{t|t,\boldsymbol{F}_{t+1}}, \boldsymbol{P}_{t|t,\boldsymbol{F}_{t-1}}\right), \tag{A.9}$$

where

$$\boldsymbol{F}_{T|T} = E\left(\boldsymbol{F}_T|\tilde{\boldsymbol{X}}_T,\theta\right), \tag{A.10}$$

$$\boldsymbol{P}_{T|T} = Cov\left(\boldsymbol{F}_T|\tilde{\boldsymbol{X}}_T,\theta\right), \tag{A.11}$$

$$\boldsymbol{F}_{t|t,\boldsymbol{F}_{t+1}} = E\left(\boldsymbol{F}_t|\boldsymbol{F}_{t+1}\tilde{\boldsymbol{X}}_t,\theta\right) = E\left(\boldsymbol{F}_t|\boldsymbol{F}_{t+1},\boldsymbol{F}_{t|t},\theta\right), \tag{A.12}$$

$$\boldsymbol{P}_{t|t,\boldsymbol{F}_{t-1}} = Cov\left(\boldsymbol{F}_t|\boldsymbol{F}_{t+1}\tilde{\boldsymbol{X}}_t,\theta\right) = Cov\left(\boldsymbol{F}_t|\boldsymbol{F}_{t+1},\boldsymbol{F}_{t|t},\theta\right). \tag{A.13}$$

$\boldsymbol{F}_{t|t}$ and $\boldsymbol{P}_{t|t}$ are calculated by the Kalman filter for $t = 1,\dots,T$, conditional on θ and the respective data history $\tilde{\boldsymbol{X}}_t$. The Kalman filter starting values are zero for the factors and the identity matrix for the covariance matrix. Further, a Kalman smoother is applied to obtain the updated values of $\boldsymbol{F}_{T-1|T-1,\boldsymbol{F}_T}$ and $\boldsymbol{P}_{T-1|T-1,\boldsymbol{F}_T}$.

The priors on the parameters in Λ and the variance-covariance matrix of the observation equation, R, are as follows. Since R is assumed to be diagonal, estimates of Λ and the diagonal elements R_{ii} of R can be obtained from OLS equation by equation. Conjugate priors are assumed to have the form

$$R_{ii} \sim iG\left(\delta_0/2,\eta_0/2\right) \tag{A.14}$$

$$\Lambda_i|R_{ii} \sim N\left(0,R_{ii}M_0^{-1}\right), \tag{A.15}$$

where, following Bernanke et al. (2005), we set $\delta_0 = 6$, $\eta_0 = 2\cdot 10^{-3}$ and $M_0 = I$. Given the above priors, it can be shown that the corresponding posterior distributions have the form

$$R_{ii}|\tilde{\boldsymbol{X}}_T,\tilde{\boldsymbol{F}}_T \sim iG\left(\delta_i/2,\eta/2\right) \tag{A.16}$$

$$\Lambda_i|R_{ii},\tilde{\boldsymbol{X}}_T,\tilde{\boldsymbol{F}}_T \sim N\left(\bar{\Lambda}_i,R_{ii}\bar{M}_i^{-1}\right), \tag{A.17}$$

where

$$\delta_i = \delta_0/2 + \hat{e}_i'\hat{e}_i + \hat{\Lambda}_i'\left[M_0^{-1} + \left(\tilde{\boldsymbol{F}}_T'^i\tilde{\boldsymbol{F}}_T^i\right)^{-1}\right]^{-1}\hat{\Lambda}_i, \tag{A.18}$$

$$\eta = \eta_0/2 + T, \tag{A.19}$$

$$\bar{\Lambda}_i = \bar{M}_i^{-1}\left(\tilde{\boldsymbol{F}}_T'^i\tilde{\boldsymbol{F}}_T^i\right)\hat{\Lambda}_i, \tag{A.20}$$

$$\bar{M}_i = M_0 + \tilde{\boldsymbol{F}}_T'^i\tilde{\boldsymbol{F}}_T^i, \tag{A.21}$$

and $\tilde{\boldsymbol{F}}_T^i$ are the regressors of the ith equation.

The priors on the transition (state) equation are as follows. As the transition equation corresponds to a standard VAR, it can be estimated by OLS equation by equation to obtain $vec\left(\hat{\Phi}\right)$ and $\hat{Q}$. We impose a conjugate Normal-Inverse-Wishart prior,

$$Q \sim iW\left(Q_0, K + M + 2\right) \tag{A.22}$$

$$vec\left(\Phi\right)|Q \sim N\left(0, Q \otimes \Omega_0\right), \tag{A.23}$$

where the diagonal elements of Q_0 are set to the residual variances of the corresponding univariate regressions, $\hat{\sigma}_i^2$, as in Kardiyala and Karlsson (1997). The diagonal elements of Ω_0 are set in the spirit of the Minnesota prior, i.e. the prior variance of the coefficient on variable j at lag k in equation i is $\sigma_i^2/k\sigma_j^2$. This prior yields the following conjugate posterior:

$$Q|\tilde{\boldsymbol{X}}_T, \tilde{\boldsymbol{F}}_T \sim iW\left(\bar{Q}, T + K + M + 2\right) \tag{A.24}$$

$$vec\left(\Phi\right)|Q, \tilde{\boldsymbol{X}}_T, \tilde{\boldsymbol{F}}_T \sim N\left(vec\left(\bar{\Phi}\right), Q \otimes \bar{\Omega}\right), \tag{A.25}$$

where

$$\bar{Q} = Q_0 + \hat{V}'\hat{V} + \hat{\Phi}'\left[\Omega_0 + \left(\tilde{\boldsymbol{F}}_{T-1}'\tilde{\boldsymbol{F}}_{T-1}\right)^{-1}\right]^{-1}\hat{\Phi} \tag{A.26}$$

$$\bar{\Phi} = \bar{\Omega}\left(\tilde{\boldsymbol{F}}_{T-1}'\tilde{\boldsymbol{F}}_{T-1}\right)\hat{\Phi} \tag{A.27}$$

$$\bar{\Omega} = \left(\Omega_0^{-1} + \tilde{\boldsymbol{F}}_{T-1}'\tilde{\boldsymbol{F}}_{T-1}\right)^{-1} \tag{A.28}$$

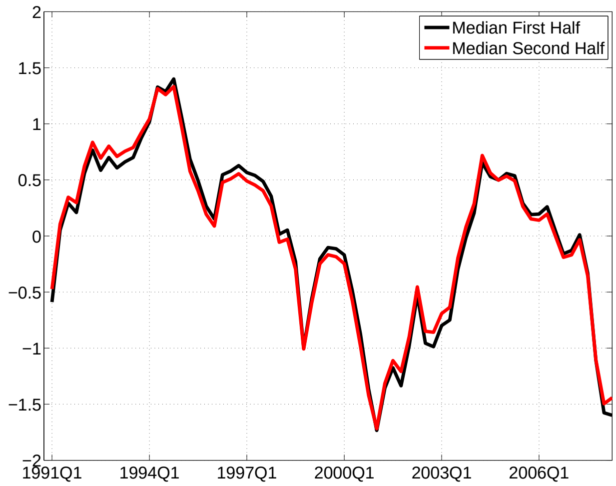
and $\hat{V}$ is the matrix of OLS residuals.

Following Bernanke et al. (2005) and Amir Ahmadi and Uhlig (2009), we enforce stationarity by truncating draws of Φ where the largest eigenvalue exceeds 1 in absolute value.

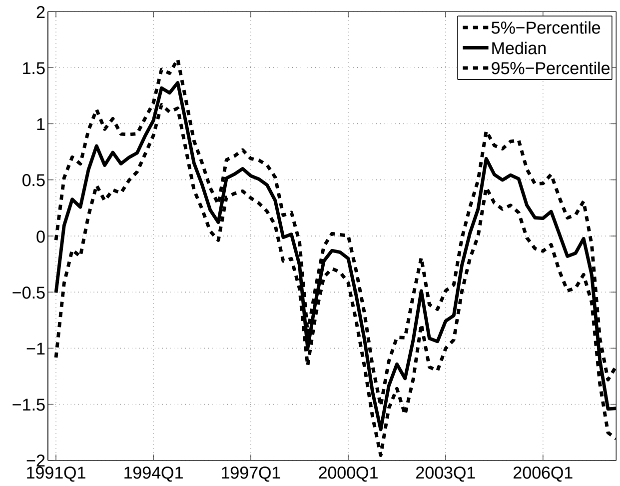
A.2.4. Monitoring Convergence

Geman and Geman (1984) show that both joint and marginal distributions will converge to their target distributions at an exponential rate as the number of replications approaches infinity. In practice, however, the Gibbs sampler may converge slowly and requires careful monitoring. We monitor convergence by (i) plotting the coefficients against the number of replications (level shifts and trends should not occur); (ii) comparing the medians and means of the coefficients at different parts of the chain (large differences should not occur); (iii) plotting and comparing the medians of the factors obtained from first and second half of the chain (large and frequent deviations should not occur). The corresponding figures for our baseline model with 3 factors are reported below. It turns out that convergence is quite slow and becomes increasingly difficult to achieve, if we increase the number of unobserved factors.

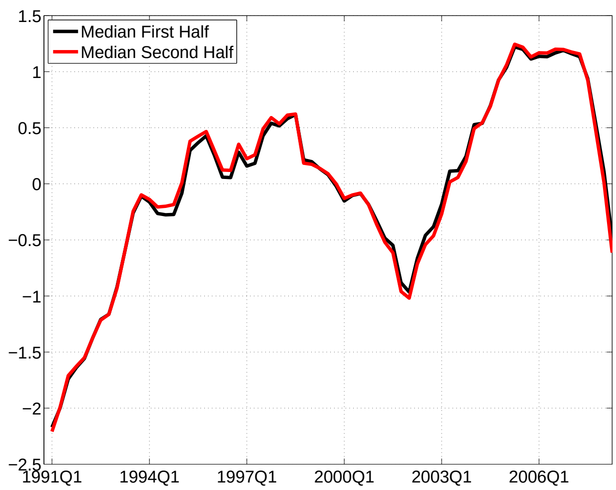
Figure A.1: Monitoring of Factor Convergence and Factor Uncertainty for the Baseline FAVAR Model.



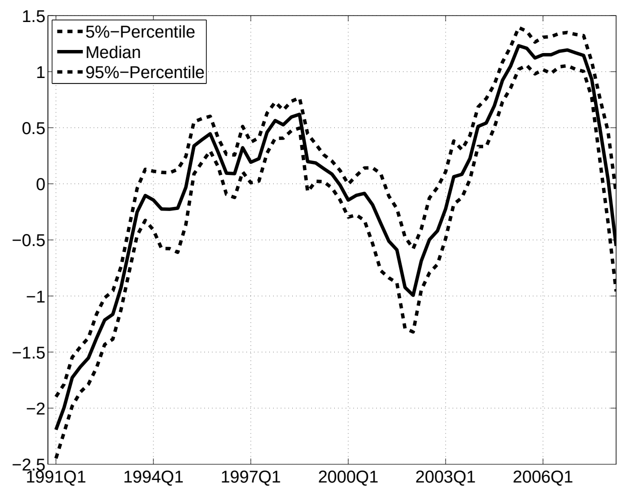
(a) Factor 1: Median of first & second half of draws post burn-in.



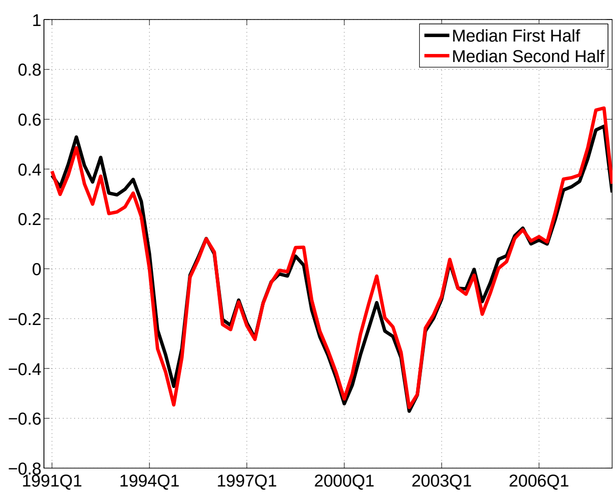
(b) Factor 1: Median of all draws after burn-in & 90% coverage.



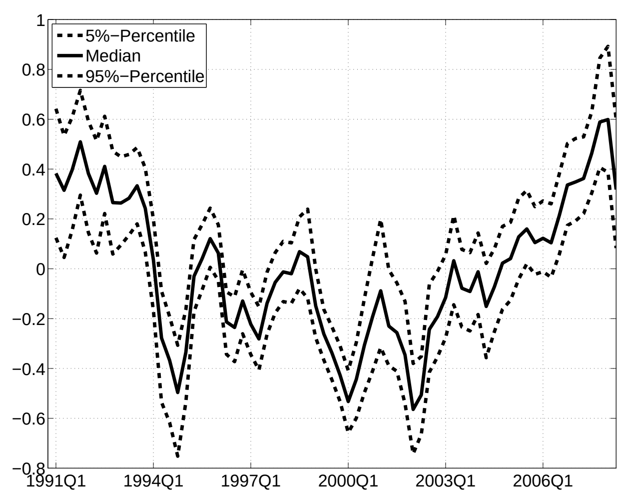
(c) Factor 2: Median of first & second half of draws post burn-in.



(d) Factor 2: Median of all draws after burn-in & 90% coverage.



(e) Factor 3: Median of first & second half of draws post burn-in.



(f) Factor 3: Median of all draws after burn-in & 90% coverage.

Appendix B. The Optimal Loan Contract

This appendix provides details on the optimal financial contract, following the logic in Bernanke et al. (1999). Given the different assumptions about the roles of borrowers and lenders, however, we deviate from the latter, where this is necessary.

B.1. Without Aggregate Risk

In the absence of aggregate risk, the loan contract between the bank and entrepreneur i is only affected by the entrepreneur's idiosyncratic risk ω^i. Consequently, the bank's constrained profit maximization problem can be formulated as in equation (9), where all terms are defined in the main text.

Given the borrower's net worth, the bank chooses the volume of the loan and thus k. For any value of k, the entrepreneur's participation constraint (PC) pins down the default threshold $\bar{\omega}^i$, which splits the expected total profits from the investment project between the borrower and the lender. Given $\bar{\omega}^i$, the non-default rate of return on the loan to entrepreneur i, Z^i_{t+1}, will then be determined by (6).

For notational convenience, we suppress any time subscripts and index superscripts throughout the appendix, while our aim remains to derive the properties of the optimal contract between the bank and entrepreneur i.

B.1.1. The EFP and Loan Supply

In what follows, we establish a positive relation $k = \psi(s)$, $\psi'(s) > 0$, between the *external finance premium* (EFP) $s \equiv R^k/R$ and the bank's optimal choice of the capital/net worth ratio $k \equiv R^k/$. The Lagrangian corresponding to the problem in (9) is given by

$$\mathcal{L} = [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, sk - (k - 1 - n) + \lambda\{[1 - \Gamma(\bar{\omega})]\, sk - s\},$$

where $n \equiv N^b/N$ and λ is the Lagrangian multiplier on the borrower's PC. The corresponding first-order conditions (FOCs) are

$$\begin{aligned}
k: &\quad [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1 + \lambda[1 - \Gamma(\bar{\omega})]\, s = 0,\\
\bar{\omega}: &\quad [\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]\, sk - \lambda\Gamma'(\bar{\omega})\, sk = 0,\\
\lambda: &\quad [1 - \Gamma(\bar{\omega})]\, sk - s = 0.
\end{aligned}$$

Note that the assumptions made about $\Gamma(\bar{\omega})$ and $\mu G(\bar{\omega})$ imply that the bank's expected profit share net of expected default costs satisfies

$$\Gamma(\bar{\omega}) - \mu G(\bar{\omega}) > 0 \quad \text{for} \quad \bar{\omega} \in (0, \infty)$$

and

$$\lim_{\bar{\omega}\to 0} \Gamma(\bar{\omega}) - \mu G(\bar{\omega}) = 0, \qquad \lim_{\bar{\omega}\to\infty} \Gamma(\bar{\omega}) - \mu G(\bar{\omega}) = 1 - \mu.$$

In order for the bank's profits to be bounded in the case where the borrower defaults with probability one, we therefore assume that $s < 1/(1-\mu)$ (compare Bernanke et al., 1999).

We further assume that $\bar{\omega}h(\bar{\omega})$ is increasing in $\bar{\omega}$, where $h(\omega)$ denotes the *hazard rate* $f(\bar{\omega})/[1-F(\bar{\omega})]$.[34] Hence, there exists an $\bar{\omega}^*$ such that

$$\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) = [1 - F(\bar{\omega})][1 - \mu\bar{\omega}h(\bar{\omega})] \gtreqqless 0 \quad \text{for} \quad \bar{\omega} \lesseqqgtr \bar{\omega}^*,$$

i.e., the bank's expected net profit share reaches a global maximum at $\bar{\omega}^*$. Moreover, the above assumption implies that

$$\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega}) = \frac{d[\bar{\omega}h(\bar{\omega})]}{d\bar{\omega}}[1-F(\bar{\omega})]^2 > 0 \quad \forall\bar{\omega}.$$

Consider first the FOC w.r.t. $\bar{\omega}$, which implies that

$$\lambda(\bar{\omega}) = \frac{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})}{\Gamma'(\bar{\omega})}.$$

Taking the partial derivative w.r.t. $\bar{\omega}$, we obtain

$$\begin{aligned}\lambda'(\bar{\omega}) &= \frac{\Gamma'(\bar{\omega})[\Gamma''(\bar{\omega}) - \mu G''(\bar{\omega})] - \Gamma''(\bar{\omega})[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{[\Gamma'(\bar{\omega})]^2}. \\ &= \frac{\mu[\Gamma''(\bar{\omega})G'(\bar{\omega}) - \Gamma'(\bar{\omega})G''(\bar{\omega})]}{[\Gamma'(\bar{\omega})]^2} < 0,\end{aligned}$$

because $\Gamma'(\bar{\omega}) = 1 - F(\bar{\omega}) > 0$ and $\Gamma''(\bar{\omega})G'(\bar{\omega}) - \Gamma'(\bar{\omega})G''(\bar{\omega}) < 0$ for all $\bar{\omega}$.

[34] Given that we borrow the definitions of $\Gamma(\bar{\omega})$ and $\Gamma(\bar{\omega}) - \mu G(\bar{\omega})$ from Bernanke et al. (1999), our assumption about the hazard rate and its implications are identical to those in their Appendix A.

Taking limits,

$$\lim_{\bar{\omega}\to 0}\lambda(\bar{\omega}) = 1, \qquad \lim_{\bar{\omega}\to\bar{\omega}^*}\lambda(\bar{\omega}) = 0.$$

In contrast to Bernanke et al. (1999), $\lambda(\bar{\omega})$ is therefore a decreasing function of the cutoff. This is a logical consequence of the borrower's PC, since the borrower's expected share of total profits is decreasing in $\bar{\omega}$.

From the FOC w.r.t. k, we can furthermore define a function

$$\rho(\bar{\omega}) \equiv \frac{1}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega}) + \lambda[1 - \Gamma(\bar{\omega})]} = s.$$

Taking the partial derivative w.r.t. $\bar{\omega}$, we obtain

$$\begin{aligned}
\rho'(\bar{\omega}) &= -\rho(\bar{\omega})^2\{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) + \lambda'(\bar{\omega})[1-\Gamma(\bar{\omega})] - \lambda(\bar{\omega})\Gamma'(\bar{\omega})\} \\
&= -\rho(\bar{\omega})^2\{\lambda(\bar{\omega})\Gamma'(\bar{\omega}) + \lambda'(\bar{\omega})[1-\Gamma(\bar{\omega})] - \lambda(\bar{\omega})\Gamma'(\bar{\omega})\} \\
&= \underbrace{-\rho(\bar{\omega})^2}_{<0}\underbrace{\lambda'(\bar{\omega})}_{<0}\underbrace{[1-\Gamma(\bar{\omega})]}_{>0} > 0,
\end{aligned}$$

where the second equality uses the FOC w.r.t. $\bar{\omega}$. In the limit, as $\bar{\omega}$ goes to 0 and $\bar{\omega}^*$, respectively,

$$\begin{aligned}
\lim_{\bar{\omega}\to 0}\rho(\bar{\omega}) &= 1 \qquad \text{(due to } \lim_{\bar{\omega}\to 0}\lambda(\bar{\omega}) = 1 \text{ and } \lim_{\bar{\omega}\to 0}G(\bar{\omega}) = 0\text{)}, \\
\lim_{\bar{\omega}\to\bar{\omega}^*}\rho(\bar{\omega}) &= \frac{1}{\Gamma(\bar{\omega}^*) - \mu G(\bar{\omega}^*)} \equiv s^* \qquad \text{(due to } \lim_{\bar{\omega}\to\bar{\omega}^*}\lambda(\bar{\omega}) = 0\text{)}.
\end{aligned}$$

Accordingly, there is a one-to-one mapping between the optimal cutoff, $\bar{\omega}$, and the premium on external funds, s, as in Bernanke et al. (1999). Inverting the function $s = \rho(\bar{\omega})$, we can therefore express the cutoff as $\bar{\omega} = \bar{\omega}(s)$, where $\bar{\omega}'(s) > 0$ for $s \in (1, s^*)$.

From the FOC w.r.t. λ, i.e. the borrower's PC, we finally define

$$\Psi(\bar{\omega}) = \frac{1}{1 - \Gamma(\bar{\omega})} = k.$$

Taking the partial derivative w.r.t. $\bar{\omega}$, we obtain

$$\Psi'(\bar{\omega}) = -\Psi(\bar{\omega})^2[-\Gamma'(\bar{\omega})] = \underbrace{\Psi(\bar{\omega})^2}_{>0}\underbrace{[1 - F(\bar{\omega})]}_{>0} > 0.$$

Hence, the qualitative implications are the same as in Bernanke et al. (1999). Taking limits,

$$\lim_{\bar{\omega}\to 0} \Psi(\bar{\omega}) = 1, \qquad \lim_{\bar{\omega}\to\bar{\omega}^*} \Psi(\bar{\omega}) = [1-\lambda(\bar{\omega}^*)]^{-1} < \infty.$$

Combining $k = \Psi(\bar{\omega})$ and $\bar{\omega} = \bar{\omega}(s)$, where $\Psi'(\bar{\omega}) > 0$ and $\bar{\omega}'(s) > 0$, we can thus express the capital/net worth ratio $k = QK/N$ as a function $k = \psi(s)$, where $\psi'(s) > 0$ for $s \in (1, s^*)$.

B.1.2. Proof of Interior Solution

Bernanke et al. (1999) use a general equilibrium argument to justify the assumption of an interior solution, i.e. an optimal contract with $\bar{\omega} < \bar{\omega}^*$ and $s < s^*$. In particular, they argue that "as s approaches s^* from below, the capital stock becomes unbounded. In equilibrium this will lower the excess return s." (compare Bernanke et al., 1999, p.1384).

Here, we follow an analytical argument instead. Recall that the lender's iso-profit curves (IPC) and the borrower's PC in $(k, \bar{\omega})$-space can be written as

$$\begin{aligned} k_{IPC} &= \frac{\pi^b - 1 - n}{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1}, \\ k_{PC} &\geq \frac{1}{1-\Gamma(\bar{\omega})}, \end{aligned}$$

where π^b denotes an arbitrary level of bank profits.

Recall further that, in $(k, \bar{\omega})$-space, the optimal contract is determined by the tangential point of the borrower's PC with the lender's IPC (from below). Consider first the borrower's PC. Since $\Gamma'(\bar{\omega}) > 0$, k_{PC} is a strictly increasing function for $\bar{\omega} \in [0, \infty)$, so that the borrower's PC has a positive slope everywhere in $(k, \bar{\omega})$-space.

Consider next the lender's IPC. Taking the partial derivative of k_{IPC} w.r.t. $\bar{\omega}$,

$$\left.\frac{\partial k}{\partial \bar{\omega}}\right|_{IPC} = \left(1 - \pi^b + n\right) \frac{[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]\, s}{\{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1\}^2} \quad \begin{cases} > 0 & \text{for} \quad \bar{\omega} \in [0, \bar{\omega}^*) \\ = 0 & \text{for} \quad \bar{\omega} = \bar{\omega}^* \\ < 0 & \text{for} \quad \bar{\omega} \in (\bar{\omega}^*, \infty) \end{cases},$$

i.e., the lender's IPC has a positive slope in $(k, \bar{\omega})$-space *left of* $\bar{\omega}^*$ but a negative slope *right of* $\bar{\omega}^*$.

Since the optimal contract requires that

$$\left.\frac{\partial k}{\partial \bar{\omega}}\right|_{IPC} = \left.\frac{\partial k}{\partial \bar{\omega}}\right|_{PC},$$

at the tangential point, and we already know that

$$\left.\frac{\partial k}{\partial \bar{\omega}}\right|_{PC} = \frac{\Gamma'(\bar{\omega})}{[1-\Gamma(\bar{\omega})]^2} > 0 \quad \text{for} \quad \bar{\omega} \in [0, \infty),$$

the optimal contract can only be obtained for $\bar{\omega} < \bar{\omega}^*$, which implies an *interior solution* to the bank's constrained profit maximization problem.[35]

B.1.3. Proof of Uniqueness

As was shown above, the tangential point of the borrower's participation constraint (PC) and the lender's iso-profit curve (IPC) is located on the interval $[0, \bar{\omega}^*)$. To show uniqueness, we proceed in two steps. First, we show that at the tangency point the curvature of the participation constraint is higher than the curvature of the iso-profit curve. Second, we discuss under which conditions the convexity (concavity) of PC and IPC are warranted on the interval $[0, \bar{\omega}^*)$. Given the differences in curvature at the tangency point shown in step 1, convexity implies a unique solution at $\bar{\omega} > 0$, whereas concavity implies a unique solution at $\bar{\omega} = 0$.

Step 1: At the tangency point, it holds that

$$\frac{1}{1-\Gamma(\bar{\omega})} = \frac{\pi^b - 1 - n}{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1},$$

i.e., the levels of k implied by PC and IPC are equal. Furthermore, it holds that

$$\frac{\Gamma'(\bar{\omega})}{[1-\Gamma(\bar{\omega})]^2} = \frac{\left(1 - \pi^b + n\right) s\, [\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{\{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\, s - 1\}^2},$$

i.e. $\partial k/\partial\bar{\omega}|_{PC} = \partial k/\partial\bar{\omega}|_{IPC}$ at the tangency point. Denote $A(\bar{\omega}) = \left(\partial^2 k/\partial\bar{\omega}^2\right)|_{PC}$ and $B(\bar{\omega}) = \left(\partial^2 k/\partial\bar{\omega}^2\right)|_{IPC}$.

[35] Note that this argument also applies to the formulation of the financial contract in Bernanke et al. (1999), likewise implying an interior solution.

In what follows, we suppress the dependence of Γ and G on the argument $\bar{\omega}$ to simplify the notation:

$$A(\bar{\omega}) = \frac{\Gamma''(1-\Gamma)^2 + 2(1-\Gamma)(\Gamma')^2}{(1-\Gamma)^4}$$

$$B(\bar{\omega}) = \left(1-\pi^b+n\right)s\frac{(\Gamma''-\mu G'')[(\Gamma-\mu G)s-1]^2 - 2s(\Gamma'-\mu G')^2[(\Gamma-\mu G)s-1]}{[(\Gamma-\mu G)s-1]^4}.$$

We need to know whether $A(\bar{\omega}) \lessgtr B(\bar{\omega})$. After some algebra and using the two relations holding at the tangency point stated above, we get

$$\begin{aligned}
A(\bar{\omega}) \lessgtr B(\bar{\omega}) \quad &\Leftrightarrow \quad \Gamma'' + \frac{2(\Gamma')^2}{1-\Gamma} \lessgtr \frac{\Gamma'(\Gamma''-\mu G'')}{\Gamma'-\mu G'} - \frac{2s(\Gamma'-\mu G')\Gamma'}{(\Gamma-\mu G)s-1} \\
&\Leftrightarrow \quad \frac{\mu(G''\Gamma'-\Gamma''G')}{\Gamma'-\mu G'} + 2\left[\frac{(\Gamma')^2\left(\pi^b-1-n\right)-(\Gamma'-\mu G')s\Gamma'}{(\Gamma-\mu G)s-1}\right] \lessgtr 0 \\
&\Leftrightarrow \quad \frac{\mu(G''\Gamma'-\Gamma''G')}{\Gamma'-\mu G'} + \frac{2(\Gamma')^2\left(\pi^b-1-n\right)}{(\Gamma-\mu G)s-1} + \frac{2(\Gamma'-\mu G')s\Gamma'}{1-(\Gamma-\mu G)s} > 0 \\
&\Rightarrow \quad A(\bar{\omega}) > B(\bar{\omega})
\end{aligned}$$

In particular, note that

$$\frac{\mu(G''\Gamma'-\Gamma''G')}{\Gamma'-\mu G'} > 0,$$

since $G''\Gamma' - \Gamma''G' > 0\ \forall\bar{\omega}$ and $\Gamma' - \mu G > 0$ for $\bar{\omega} \in [0, \bar{\omega^*})$.[36]

Furthermore,

$$\frac{2(\Gamma')^2\left(\pi^b-1-n\right)}{(\Gamma-\mu G)s-1} > 0,$$

since $\left(\pi^b-1-n\right) < 0$ and $[(\Gamma-\mu G)s-1] < 0$.

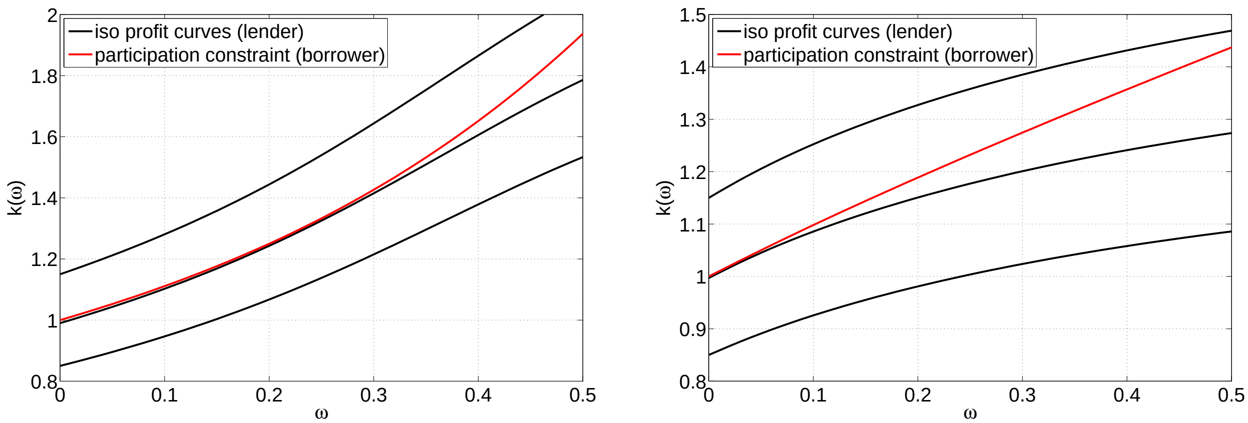
And finally,

$$\frac{2(\Gamma'-\mu G')s\Gamma'}{1-(\Gamma-\mu G)s} > 0,$$

since $(\Gamma'-\mu G') > 0$ on $[0, \bar{\omega}^*)$, $[1-(\Gamma-\mu G)s] > 0$, and $\Gamma' = 1-F > 0$. This proves that, at the tangency point, the participation constraint has a higher curvature than the iso-profit curve.

[36]The former follows from the assumption in Bernanke et al. (1999) that the product of the default threshold and the hazard rate, $\bar{\omega}\cdot h(\bar{\omega})$, is increasing in $\bar{\omega}$.

Figure B.1: Illustration of the Optimal CSV Contract without Aggregate Risk and the Effects of σ.



(a) $\sigma^2 = 0.28$ (compare Bernanke et al., 1999)

(b) $\sigma^2 = 2.28$

Step 2: Note that the sign of second partial derivatives $A(\bar{\omega})$ and $B(\bar{\omega})$ defined above is generally dependent on the parameters of the log-normal distribution assumed for ω. In particular, the sign of $A(\bar{\omega})$ on $[0, \bar{\omega^*})$ is determined by the sign of the following expression:[37]

$$\Gamma''(1-\Gamma)+2(\Gamma')^2 \lesseqgtr 0 \quad \Leftrightarrow \quad -f(\bar{\omega})[1-\Gamma(\bar{\omega})]+2[1-F(\bar{\omega})]^2 \lesseqgtr 0 \quad \Leftrightarrow \quad f(\bar{\omega})[1-\Gamma(\bar{\omega})] \lesseqgtr 2[1-F(\bar{\omega})]^2$$

While $0 < [1-\Gamma(\bar{\omega})] < 1$ and $0 < [1-F(\bar{\omega})] < 1$ for all distributional parameters of $F(\bar{\omega})$, the size of $f(\bar{\omega})$ can vary substantially depending on the mean and variance of $F(\bar{\omega})$. Given the distributional assumptions in Bernanke et al. (1999), i.e. $\ln\bar{\omega} \sim N\left(-0.5\sigma^2, \sigma^2\right)$, one can show that there is a threshold $\bar{\sigma}$ such that

$$f(\bar{\omega})[1-\Gamma(\bar{\omega})] > 2[1-F(\bar{\omega})]^2 \quad \Leftrightarrow \quad A(\bar{\omega}) < 0 \quad \text{for} \quad \sigma > \bar{\sigma}$$
$$f(\bar{\omega})[1-\Gamma(\bar{\omega})] < 2[1-F(\bar{\omega})]^2 \quad \Leftrightarrow \quad A(\bar{\omega}) > 0 \quad \text{for} \quad \sigma > \bar{\sigma}$$

In other words, the participation constraint is *concave* for $\sigma > \bar{\sigma}$ and *convex* for $\sigma < \bar{\sigma}$.

As Figure B.1 illustrates, the solution is unique and $\bar{\omega} > 0$ in the first case, whereas the solution is unique and $\bar{\omega} = 0$ in the second case. For realistic parameterizations of σ, such as in Bernanke et al. (1999), where $\sigma^2 = 0.28$, the convex case applies and there is a unique solution on $(0, \bar{\omega}^*)$.

[37]The analysis for the IPC is similar, as the sign of $B(\bar{\omega})$ depends on the sign of $(\Gamma'' - \mu G'')[(\Gamma - \mu G)s - 1] - 2s(\Gamma' - \mu G')^2 \lesseqgtr 0$.

B.2. With Aggregate Risk

In the presence of aggregate risk, the loan contract between the bank and entrepreneur i is affected both by the entrepreneur's idiosyncratic risk ω^i and by the ex-post realization of R^k_{t+1}. In this appendix, we establish a positive relation between the capital/net worth ratio $Q_t K^i_{t+1}/N^i_{t+1}$ and the ex ante (expected) EFP $s_t \equiv E_t\left(R^k_{t+1}/R_{t+1}\right)$. Again, we suppress any time subscripts and index superscripts.

For this purpose, it is convenient to write the profits per unit of capital expenditures as $\tilde{u}\omega R^k$, where $\tilde{u}$ denotes an aggregate shock to the gross rate of return on capital, and ω continues to denote the idiosyncratic shock, with $E(\tilde{u}) = E(\omega) = 1$. Using the definitions from the main text and Appendix B.1, we can then rewrite the bank's constrained profit maximization problem in equation (9) as

$$\max_{k,\bar{\omega}} \quad E\left\{\left[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\right]\tilde{u}sk - (k-1-n)\right\} \quad \text{s. t.} \quad E\left\{\left[1-\Gamma(\bar{\omega})\right]\tilde{u}sk - \tilde{u}s\right\} \geq 0$$

The corresponding Lagrangian,

$$\mathcal{L} = E\left\{\left[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\right]\tilde{u}sk - (k-1-n) + \lambda\left(\left[1-\Gamma(\bar{\omega})\right]\tilde{u}sk - \tilde{u}s\right)\right\},$$

yields the first-order conditions (FOC)

$$\begin{aligned}
k: &\quad E\left\{\left[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\right]\tilde{u}s - 1 + \lambda\left[1-\Gamma(\bar{\omega})\right]\tilde{u}s\right\} = 0,\\
\bar{\omega}: &\quad E\left\{\left[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})\right]\tilde{u}sk - \lambda\Gamma'(\bar{\omega})\tilde{u}sk\right\} = 0,\\
\lambda: &\quad E\left\{\left[1-\Gamma(\bar{\omega})\right]\tilde{u}sk - \tilde{u}s\right\} = 0.
\end{aligned}$$

As discussed in the main text, we assume that the borrower's PC must be satisfied *ex post*, i.e. conditional on the realization of $\tilde{u}$. As a consequence, $\bar{\omega}$ and all functions thereof, such as $\Gamma(\bar{\omega})$ and $\Gamma'(\bar{\omega})$, are independent of $\tilde{u}$. Using this assumption, the FOCs simplify to

$$\begin{aligned}
k: &\quad E\left\{\left[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\right]\tilde{u}s + \lambda\left[1-\Gamma(\bar{\omega})\right]\tilde{u}s\right\} = 1,\\
\bar{\omega}: &\quad \left[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})\right] = \lambda\Gamma'(\bar{\omega}),\\
\lambda: &\quad \left[1-\Gamma(\bar{\omega})\right]k = 1.
\end{aligned}$$

Taking partial derivatives of the borrower's *ex-post* PC w.r.t. k and $\bar{\omega}$, we obtain

$$\frac{\partial}{\partial k} = 1 - \Gamma(\bar{\omega}) - \Gamma'(\bar{\omega}) k \frac{\partial \bar{\omega}}{\partial k} = 0 \qquad \Rightarrow \qquad \frac{\partial \bar{\omega}}{\partial k} = \frac{1 - \Gamma(\bar{\omega})}{\Gamma'(\bar{\omega}) k} > 0$$

and

$$\frac{\partial}{\partial s} = -\Gamma'(\bar{\omega}) k \frac{\partial \bar{\omega}}{\partial s} = 0 \qquad \Rightarrow \qquad \frac{\partial \bar{\omega}}{\partial s} = 0.$$

Following Bernanke et al. (1999), define $\Upsilon(\bar{\omega}) \equiv \Gamma(\bar{\omega}) - \mu G(\bar{\omega}) + \lambda [1 - \Gamma(\bar{\omega})]$. Then totally differentiating the FOC w.r.t. k,

$$\begin{aligned}
& E\left\{\tilde{u}\Upsilon(\bar{\omega}) + \tilde{u}s\Upsilon'(\bar{\omega})\left(\frac{\partial \bar{\omega}}{\partial s}ds + \frac{\partial \bar{\omega}}{\partial k}dk\right)\right\} = 0 \\
\Leftrightarrow \qquad & E\left\{\tilde{u}s\Upsilon'(\bar{\omega})\frac{\partial \bar{\omega}}{\partial k}\right\}dk = -E\left\{\tilde{u}\Upsilon(\bar{\omega}) + \tilde{u}s\Upsilon'(\bar{\omega})\frac{\partial \bar{\omega}}{\partial s}\right\}ds \\
\Rightarrow \qquad & \frac{dk}{ds} = -\frac{E\left\{\tilde{u}\Upsilon(\bar{\omega}) + \tilde{u}s\Upsilon'(\bar{\omega})\frac{\partial \bar{\omega}}{\partial s}\right\}}{E\left\{\tilde{u}s\Upsilon'(\bar{\omega})\frac{\partial \bar{\omega}}{\partial k}\right\}} = -\frac{E\left\{\tilde{u}\Upsilon(\bar{\omega})\right\}}{E\left\{\tilde{u}s\Upsilon'(\bar{\omega})\frac{\partial \bar{\omega}}{\partial k}\right\}} > 0,
\end{aligned}$$

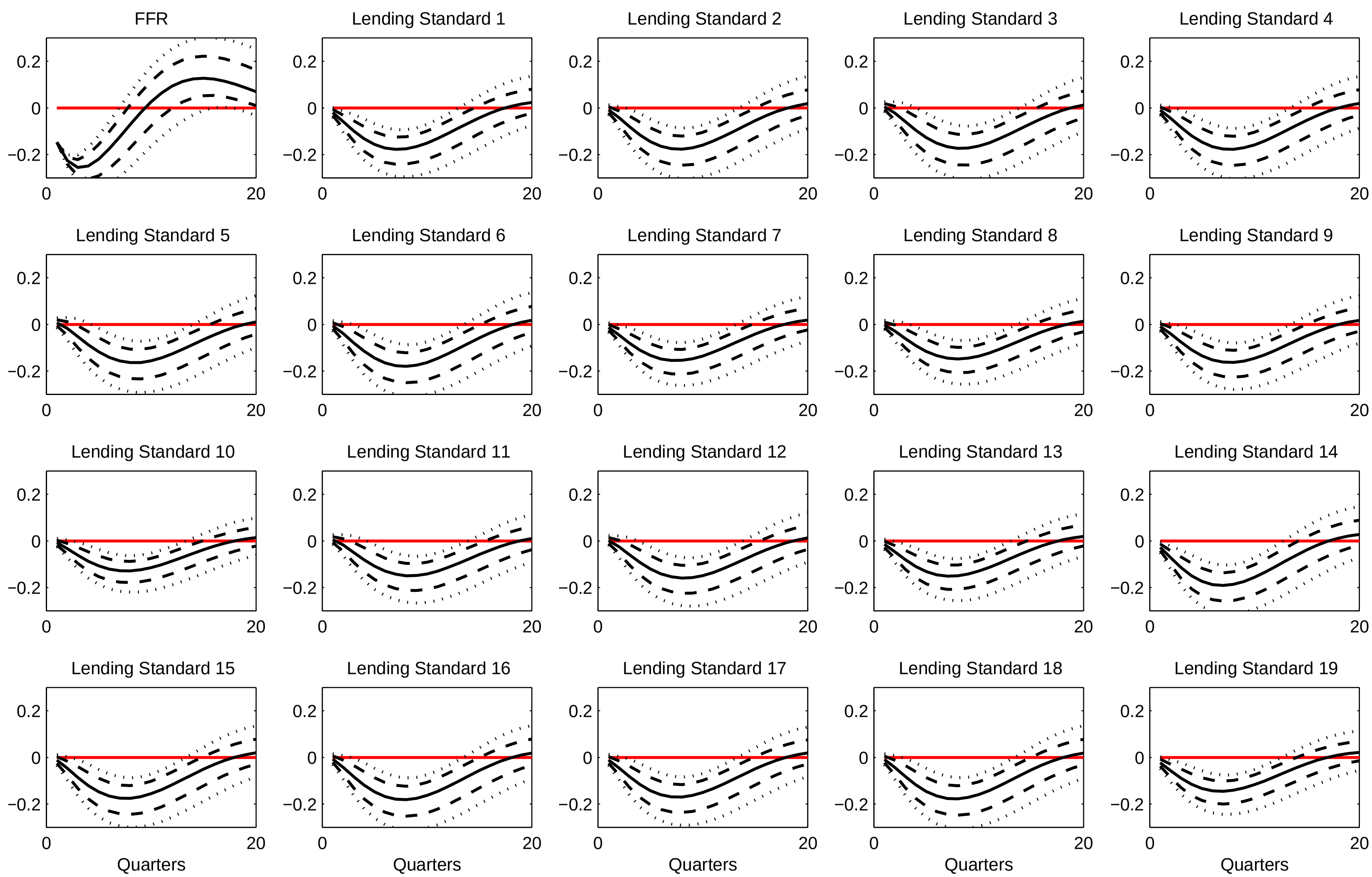
where we use the previous findings that $\partial\bar{\omega}/\partial k > 0$, $\partial\bar{\omega}/\partial s = 0$, and

$$\Upsilon'(\bar{\omega}) = \underbrace{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) - \lambda(\bar{\omega})\Gamma'(\bar{\omega})}_{=0 \text{ from the FOC w.r.t. } \bar{\omega}} + \lambda'(\bar{\omega})[1 - \Gamma(\omega)] = \lambda'(\bar{\omega}) k^{-1} < 0.$$

Similar to Bernanke et al. (1999), the optimal loan contract therefore implies a positive relation between the capital/net worth ratio k and the ex-ante EFP s also in the case *with* aggregate risk.

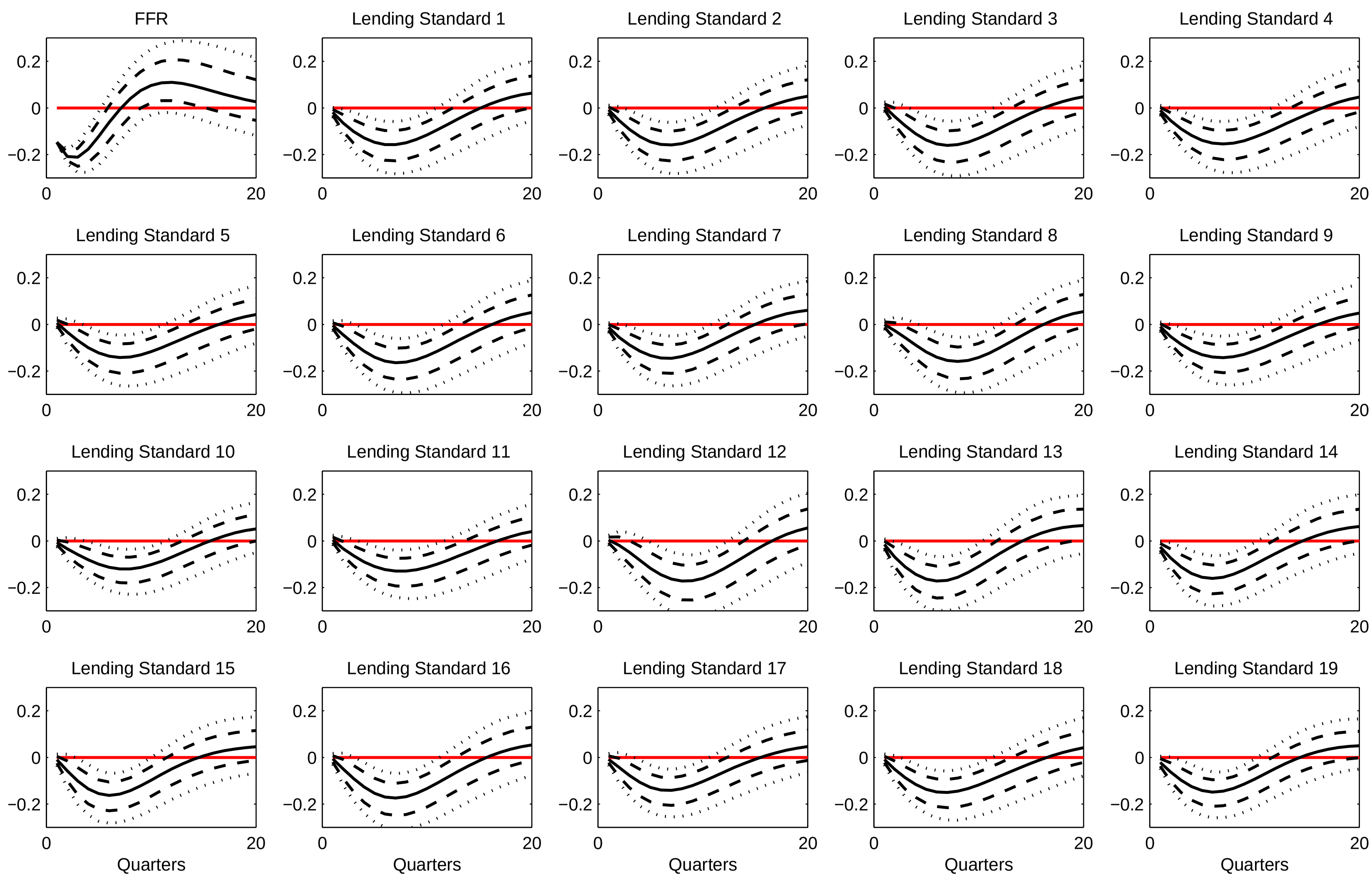
Appendix C. Robustness of Empirical Evidence

Figure C.1: Impulse Responses of Lending Standard Measures to a 25bps Expansionary Monetary Policy Shock in the Model with One Unobserved Factor.



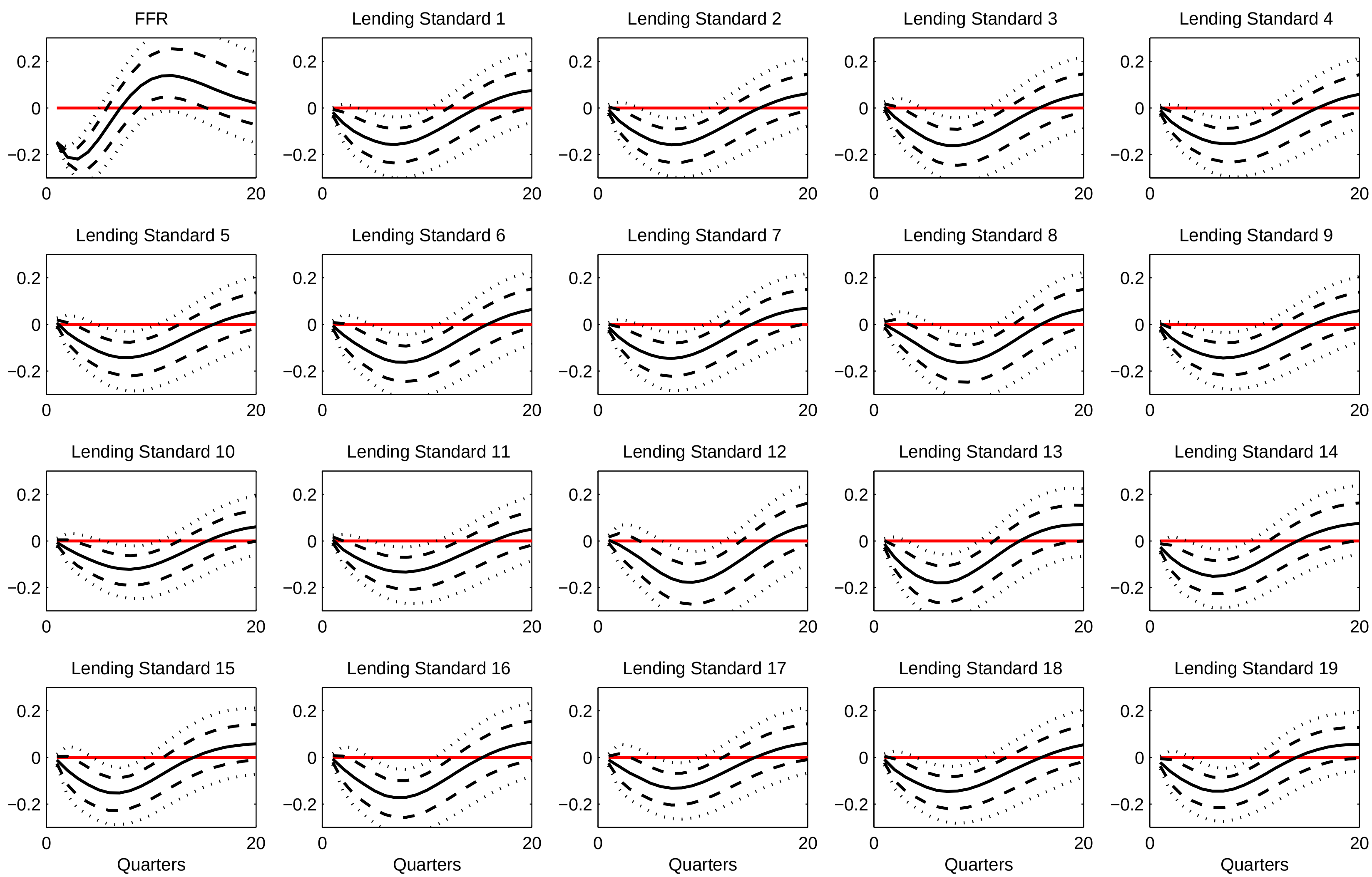
Notes: Median responses with pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles. See Appendix A.1 for a detailed description of lending standard measures.

Figure C.2: Impulse Responses of Lending Standard Measures to a 25bps Expansionary Monetary Policy Shock in the Model with Five Unobserved Factors.



Notes: Median responses with pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles. See Appendix A.1 for a detailed description of lending standards.

Figure C.3: Impulse Responses of Lending Standard Measures to a 25bps Expansionary Monetary Policy Shock in the Model with Seven Unobserved Factors.



Notes: Median responses with pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles. See Appendix A.1 for a detailed description of lending standards.

Tables

Table 1: Adjusted R^2 for the Measures of Lending Standards, sample 1991Q1-2008Q2.

No.	Lending Standard Description	1 factor	3 factors	5 factors	7 factors
1	domestic banks tightening standards on C&I loans to large and middle firms	0.91	0.93	0.95	0.95
2	domestic banks increasing the costs of credit lines to large and middle firms	0.93	0.92	0.92	0.92
3	domestic banks tightening loan covenants for large and middle firms	0.97	0.97	0.97	0.97
4	domestic banks reducing the maximum size of credit lines to large and middle firms	0.92	0.92	0.93	0.92
5	domestic banks increasing collateral requirements for large and middle firms	0.91	0.92	0.92	0.92
6	domestic banks increasing spreads of loan rates over banks' cost of funds to large and middle firms	0.93	0.93	0.93	0.94
7	domestic banks tightening standards for C&I loans to small firms	0.82	0.85	0.90	0.90
8	domestic banks increasing the cost of credit lines to small firms	0.85	0.85	0.90	0.90
9	domestic banks tightening loan covenants for small firms	0.88	0.88	0.90	0.90
10	domestic banks reducing the maximum size of credit lines to small firms	0.77	0.79	0.84	0.83
11	domestic banks increasing collateral requirements for small firms	0.84	0.84	0.87	0.87
12	domestic banks increasing spreads of loan rates over banks' cost of funds to small firms	0.88	0.90	0.93	0.93
13	domestic banks tightening standards for commercial real estate loans	0.67	0.74	0.89	0.92
14	foreign banks tightening standards for approving C&I loans	0.81	0.84	0.85	0.86
15	foreign banks increasing costs of credit lines	0.79	0.80	0.84	0.86
16	foreign banks tightening loan covenants	0.86	0.86	0.87	0.87
17	foreign banks reducing the maximum size of credit lines	0.76	0.77	0.81	0.84
18	foreign banks increasing collateral requirements	0.82	0.82	0.83	0.83
19	foreign banks tightening standards for commercial real estate loans	0.48	0.49	0.51	0.51

Table 2: Benchmark Calibration of Parameter Values.

Household and production sector	Parameter	Value
coefficient of relative risk aversion	σ	2
Frisch elasticity of labor supply	η	3
relative weight of labor in the utility function	χ	5.19
quarterly discount factor of households	β	0.995
elasticity of substitution between retailer varieties	ϵ	10
quarterly depreciation rate of physical capital	δ	0.025
coefficient of quadratic investment adjustment costs	ϕ	0.1
elasticity of output with respect to capital	α	0.35
Calvo probability of quarterly price adjustments	θ	0.75
Monetary policy	Parameter	Value
interest-rate persistence in the monetary policy rule	ρ	0.95
responsiveness of monetary policy to inflation deviations	ϕ_π	1.5
responsiveness of monetary policy to output deviations	ϕ_y	0.5
standard deviation of unsystematic monetary policy shocks	σ_ν	0.25
Optimal financial contract	Parameter	Value
exogenous consumption rate of entrepreneurial net worth	$1 - \gamma^e$	0.015
exogenous consumption rate of bank net worth	$1 - \gamma^b$	0.05
monitoring costs as a fraction of total return on capital	μ	0.20
variance of idiosyncratic productivity draws	σ_ω^2	0.18
steady-state default threshold of entrepreneurs	$\bar{\omega}$	0.35

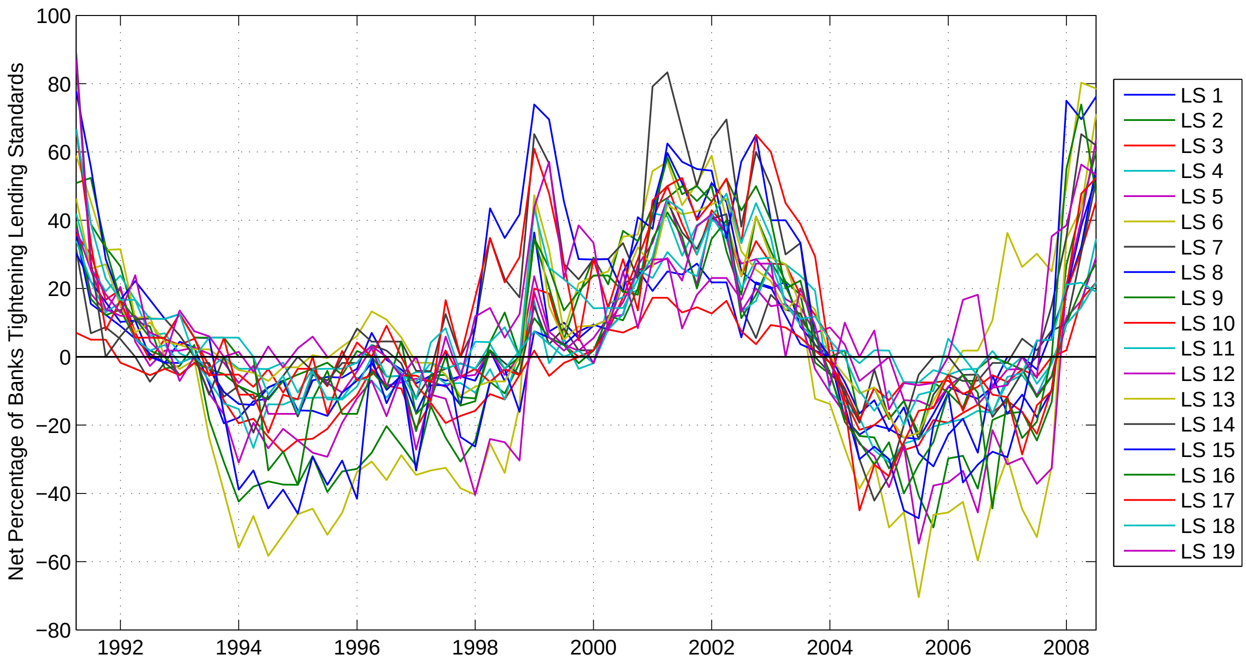
Table 3: Selected Steady-State Values for Benchmark Parameter Calibration.

Steady-State Variable or Ratio	Computation	Value
capital-output ratio	$K/(4 \cdot Y)$	1.9451
household consumption relative to output	C/Y	0.6963
entrepreneur consumption relative to output	C^e/Y	0.0784
bank consumption relative to output	C^b/Y	0.0251
capital investment relative to output	I/Y	0.1945
employment as a share of time endowment*	H	1/3
gross price markup of retailers*	$\epsilon/(\epsilon - 1)$	1.1111
leverage ratio of entrepreneurs*	QK/N	1.5372
default monitoring costs relative to output	$\mu G(\bar{\omega}) R^k QK/Y$	0.0057
annualized default rate of entrepreneurs*	$4 \cdot F(\bar{\omega})$	4.735%
annualized risk-free policy interest rate*	$4 \cdot (R^n - 1)$	2.010%
annualized interest rate on bank loans*	$4 \cdot (Z - 1)$	6.816%
annualized rate of return on capital	$4 \cdot \left(R^k - 1\right)$	6.195%
annualized external finance premium	$4 \cdot \left(R^k/R^n - 1\right)$	4.164%

* indicates steady-state values targeted in the benchmark calibration.

Figures

Figure 1: Lending Standard Measures, 1991Q1-2008Q2.



Notes: See Appendix A.1 for a detailed description of lending standard measures.

Figure 2: Reasons of Domestic Banks for Adjusting their Lending Standards, 1997Q1-2008Q2.

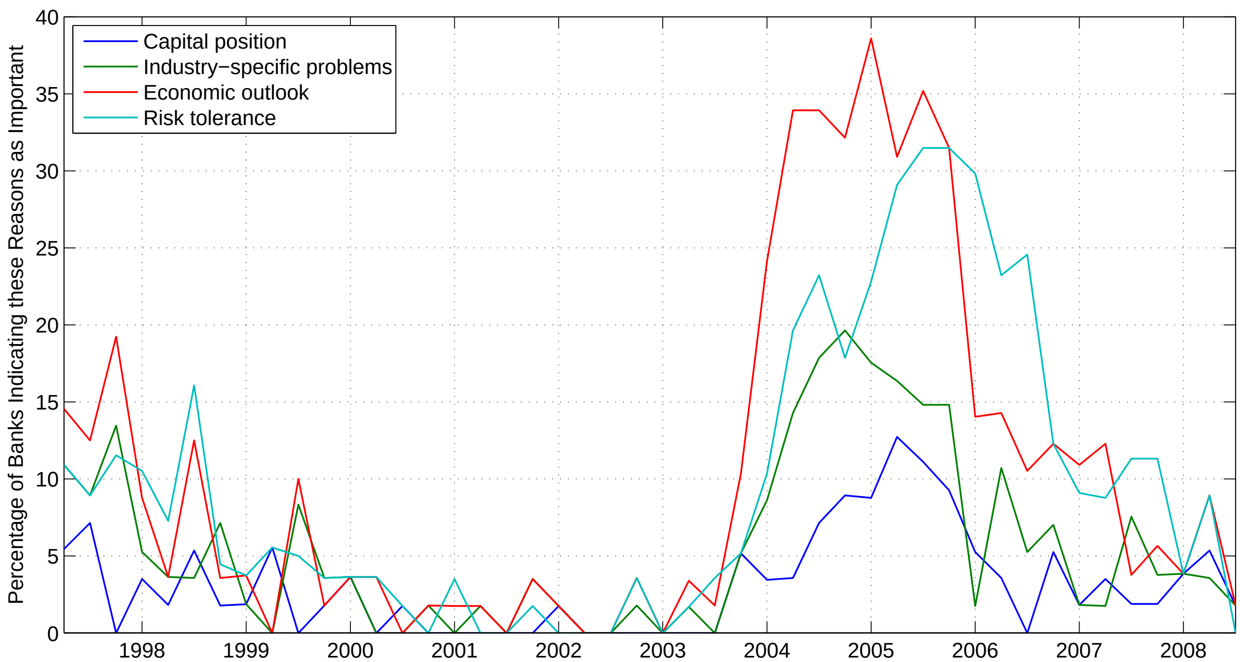
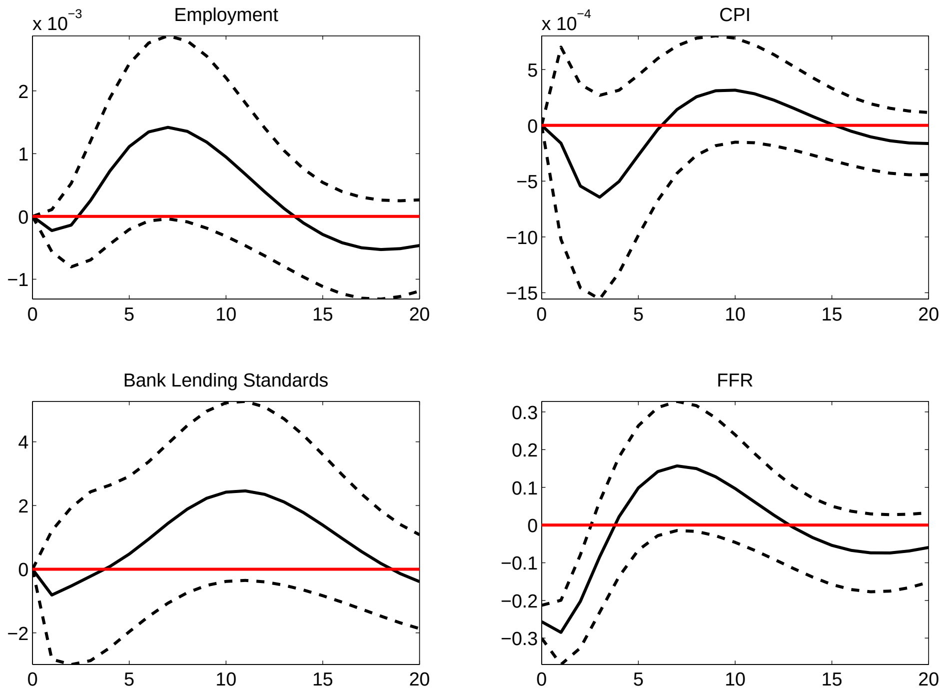
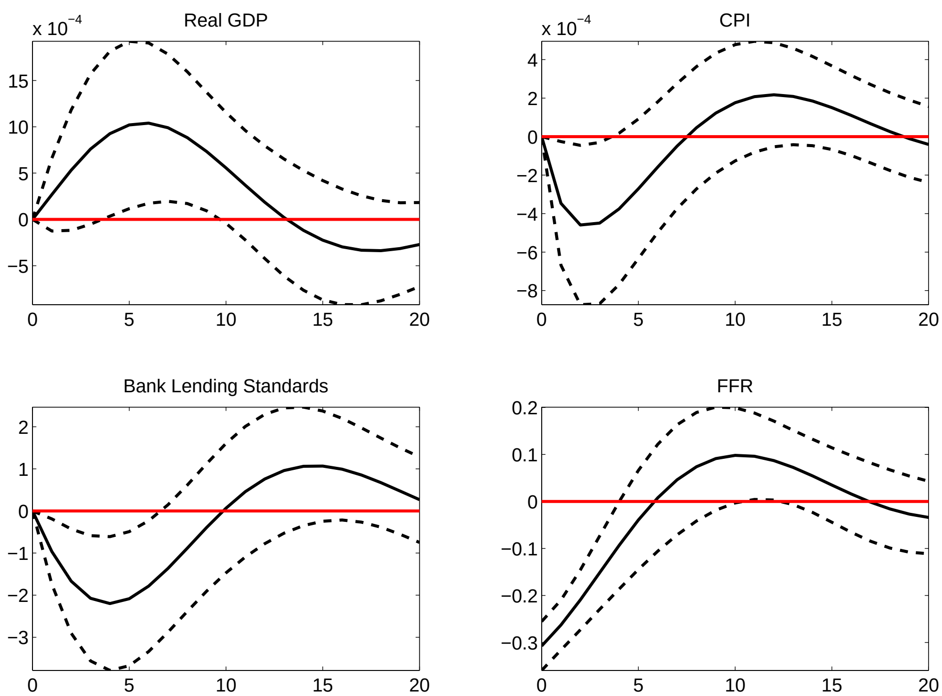


Figure 3: Impulse Responses to an Expansionary Monetary Policy Shock in a Small VAR.



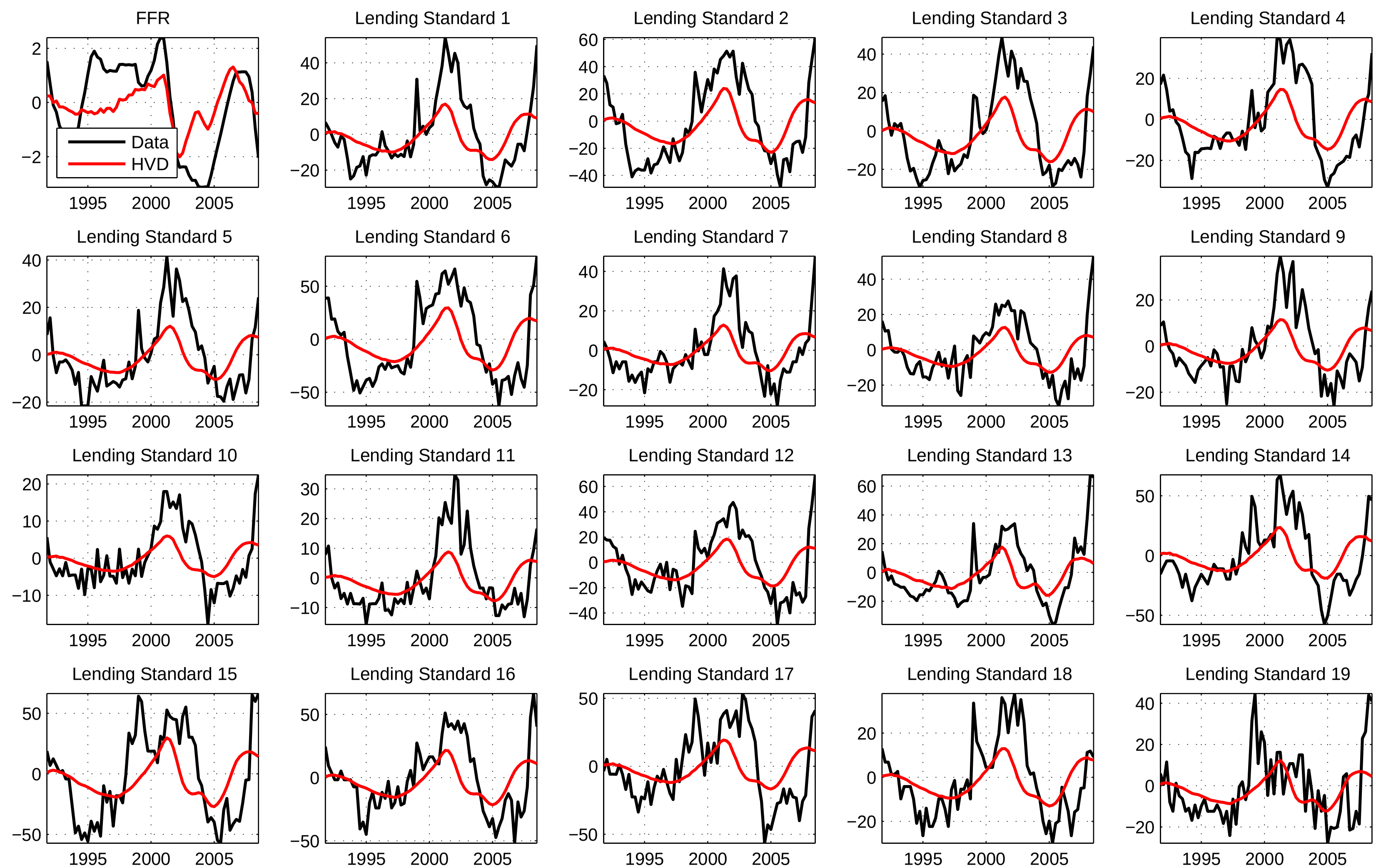
(a) Using employment as the measure of real economic activity.



(b) Using real GDP as the measure of real economic activity.

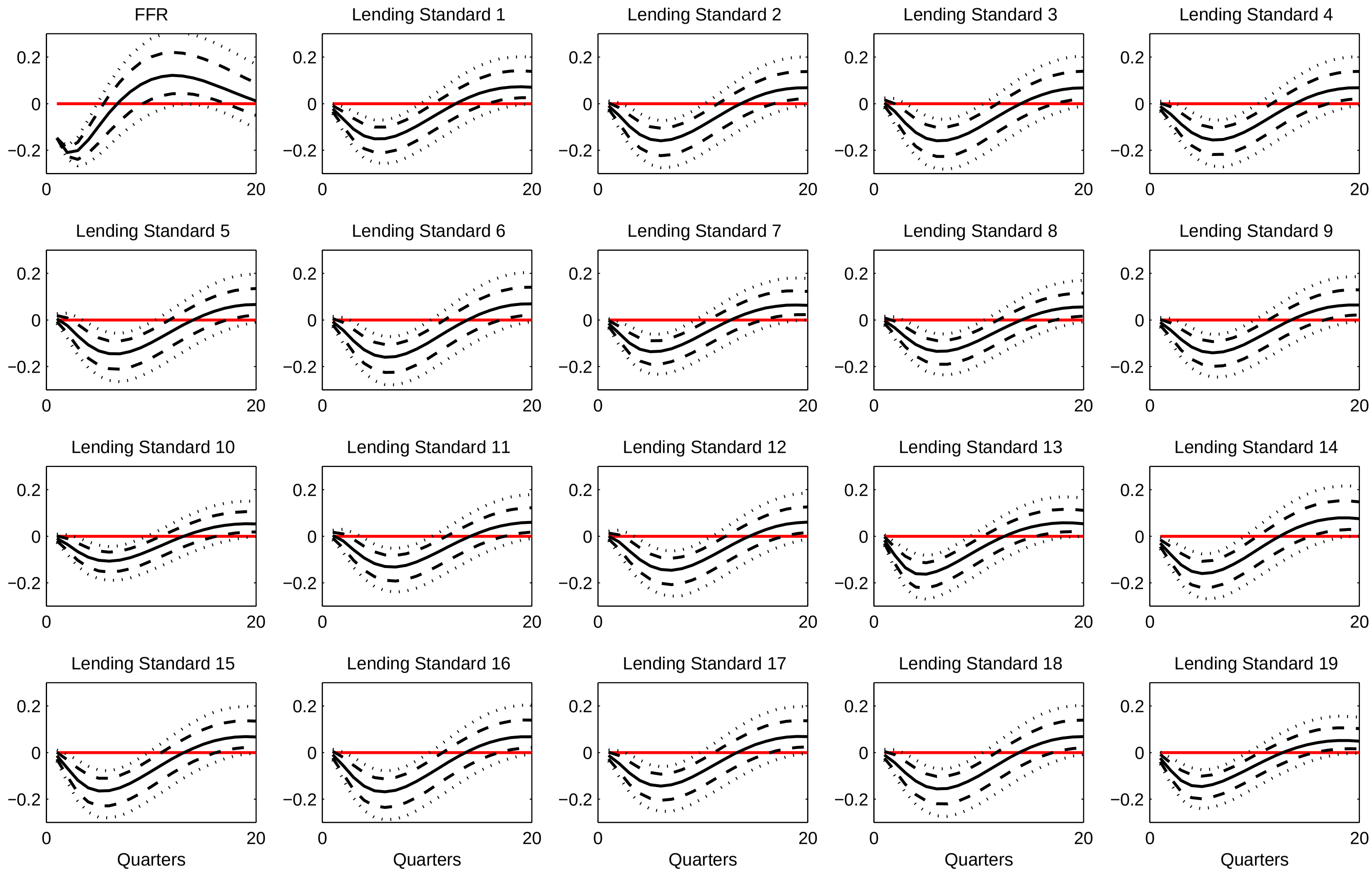
Notes: Point estimates with two standard error confidence bands.

Figure 4: Cumulative Contribution of Monetary Policy Shocks to the Historical Variance Decomposition of FFR and Lending Standards in the Model with Three Unobserved Factors.



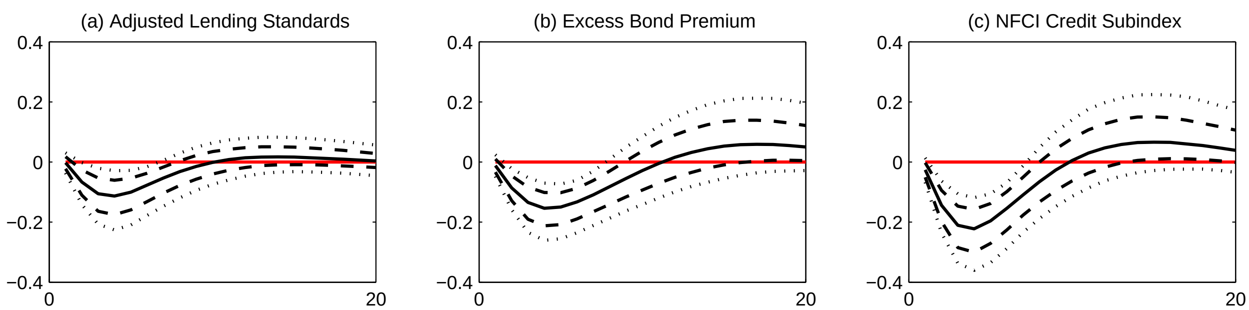
Notes: Point estimates for a single candidate draw from the Gibbs sampler. See Appendix A.1 for a detailed description of lending standard measures.

Figure 5: Impulse Responses of Lending Standard Measures to a 25bps Expansionary Monetary Policy Shock in the Model with Three Unobserved Factors.



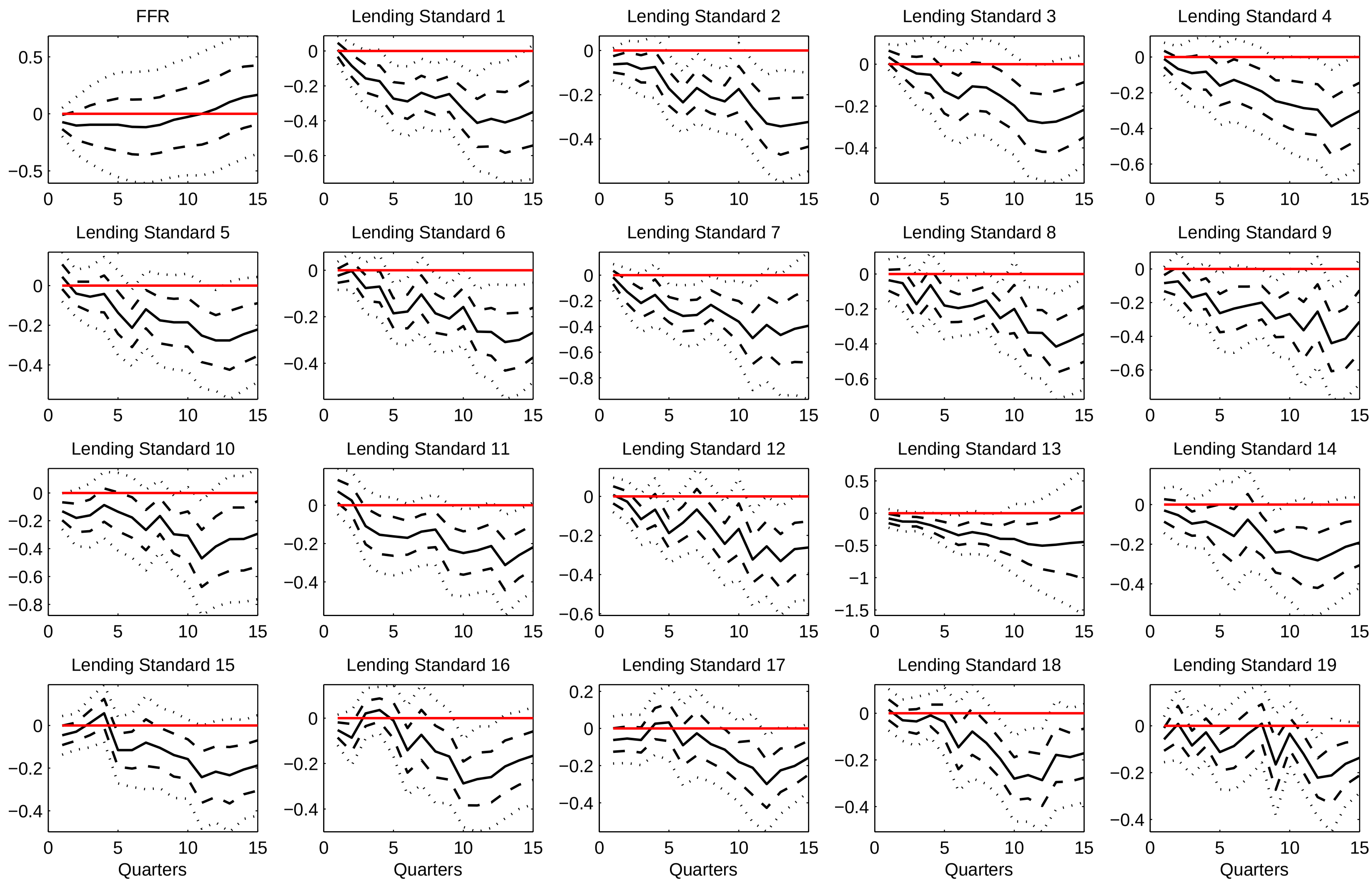
Notes: Median responses with pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles. See Appendix A.1 for a detailed description of lending standard measures.

Figure 6: Impulse Responses of Alternative Measures of Lending Standards to a 25bps Expansionary Monetary Policy Shock.



Notes: Median responses with pointwise $16^{th}/84^{th}$ and $5^{th}/95^{th}$ percentiles, based on the FAVAR Model with three unobserved factors, in which the 19 SLOOS lending standard measures have been replaced by (a) the credit supply indicator proposed by Bassett et al. (2014) (b) the excess bond premium proposed by Gilchrist and Zakrajšek (2012) (c) the NFCI credit subindex published by the Federal Reserve Bank of Chicago. See Appendix A.1 for a detailed description of the data.

Figure 7: Impulse Responses of Lending Standard Measures to an Expansionary Monetary Policy Shock Based on the Exogenous Shocks in Barakchian and Crowe (2013).



Notes: Point estimates with pointwise one- and two-standard-error HAC-robust bootstrap confidence intervals based on distributed lag regressions of each variable on $P = 4$ own lags as well as contemporaneous and $Q = 12$ lagged observations of the shock series in Barakchian and Crowe (2013). See Appendix A.1 for a detailed description of lending standards.

Figure 8: Illustration of the Optimal CSV Contract without Aggregate Risk and the Effects of Expansionary Monetary Policy.

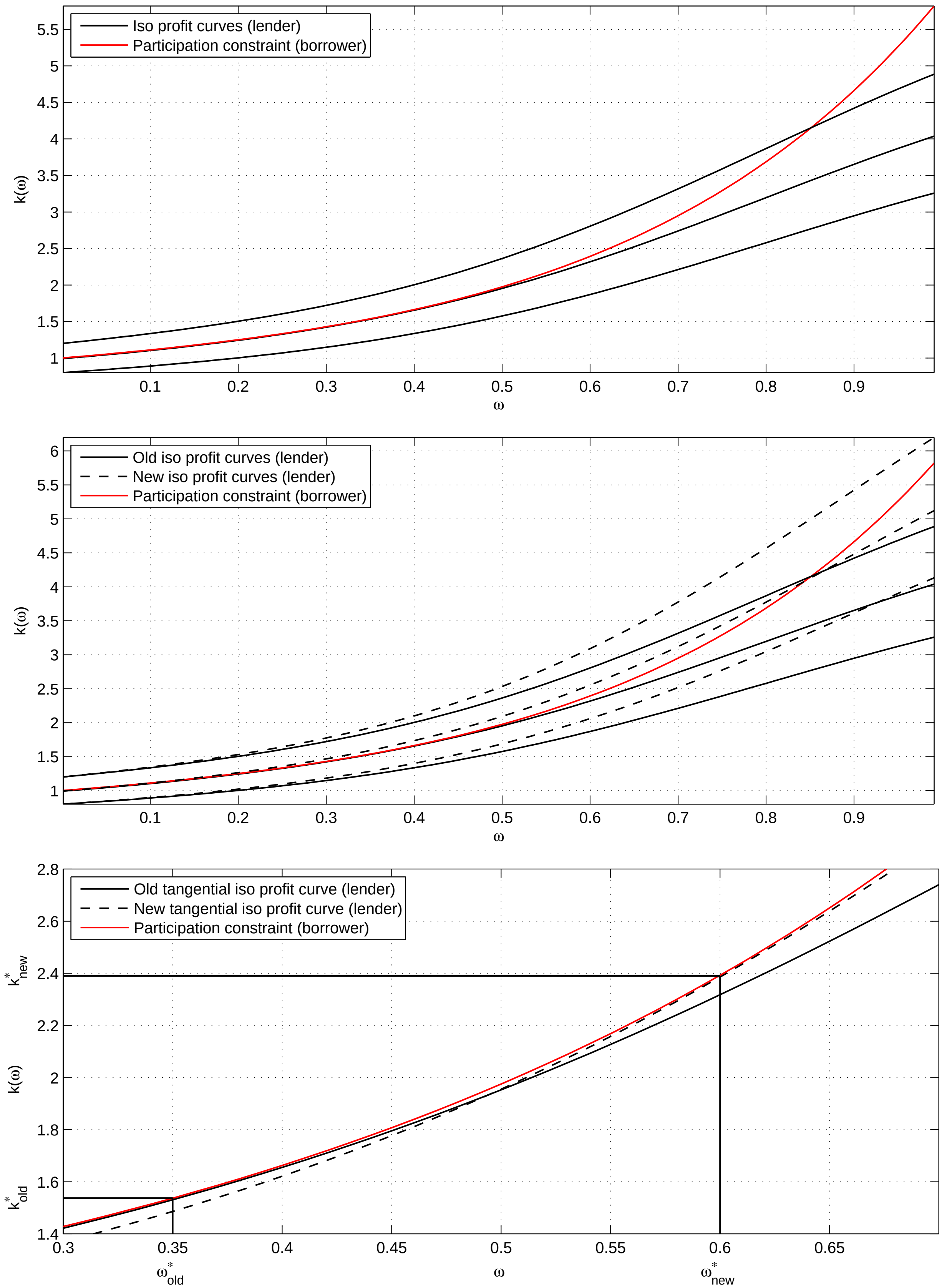


Figure 9: Selected Impulse Response Functions to an Expansionary Monetary Policy Shock of 25 Basis Points for $\rho = 0.95$.

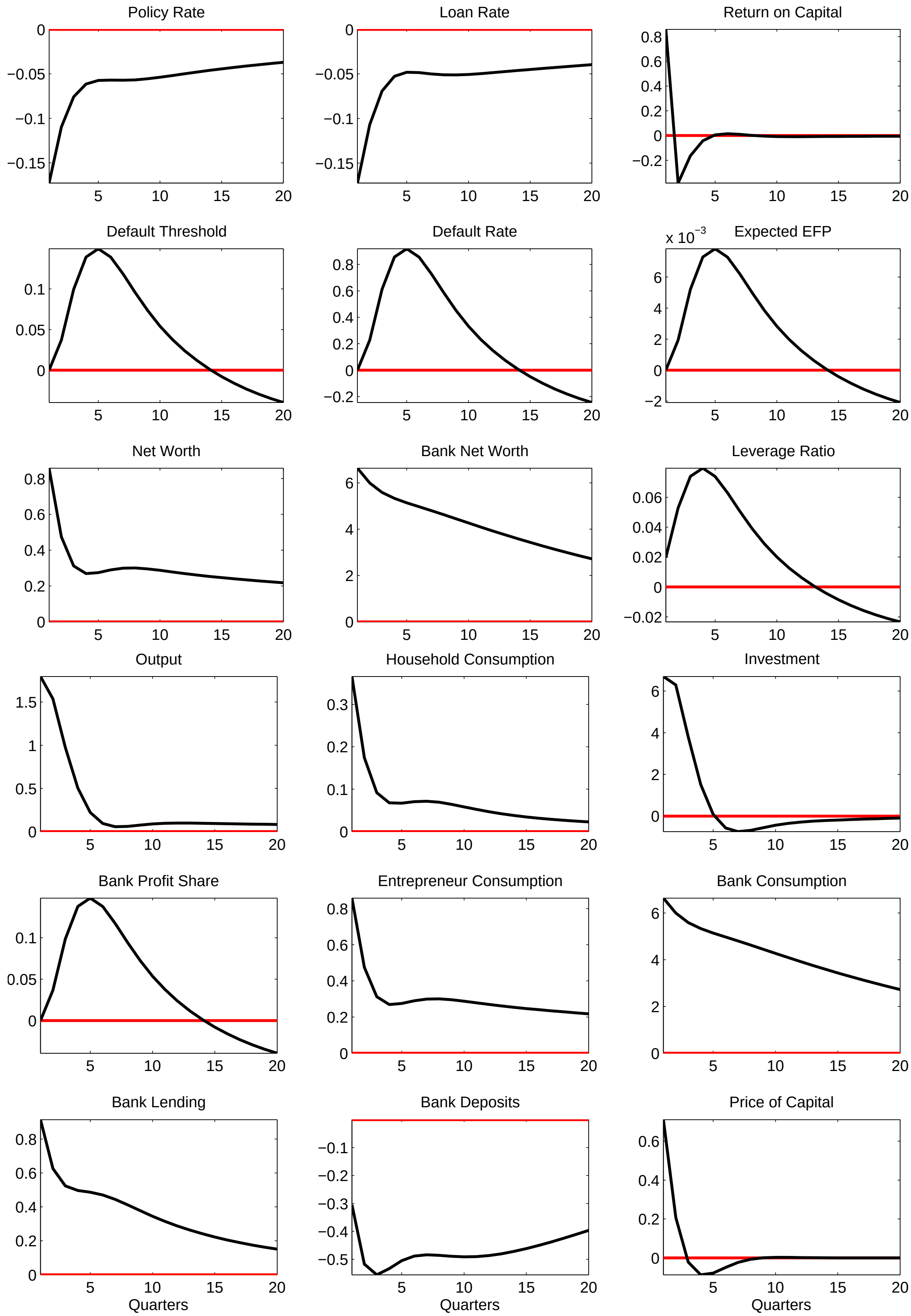


Figure 10: Selected Impulse Response Functions to an Expansionary Monetary Policy Shock for Different Optimal Debt Contracts.

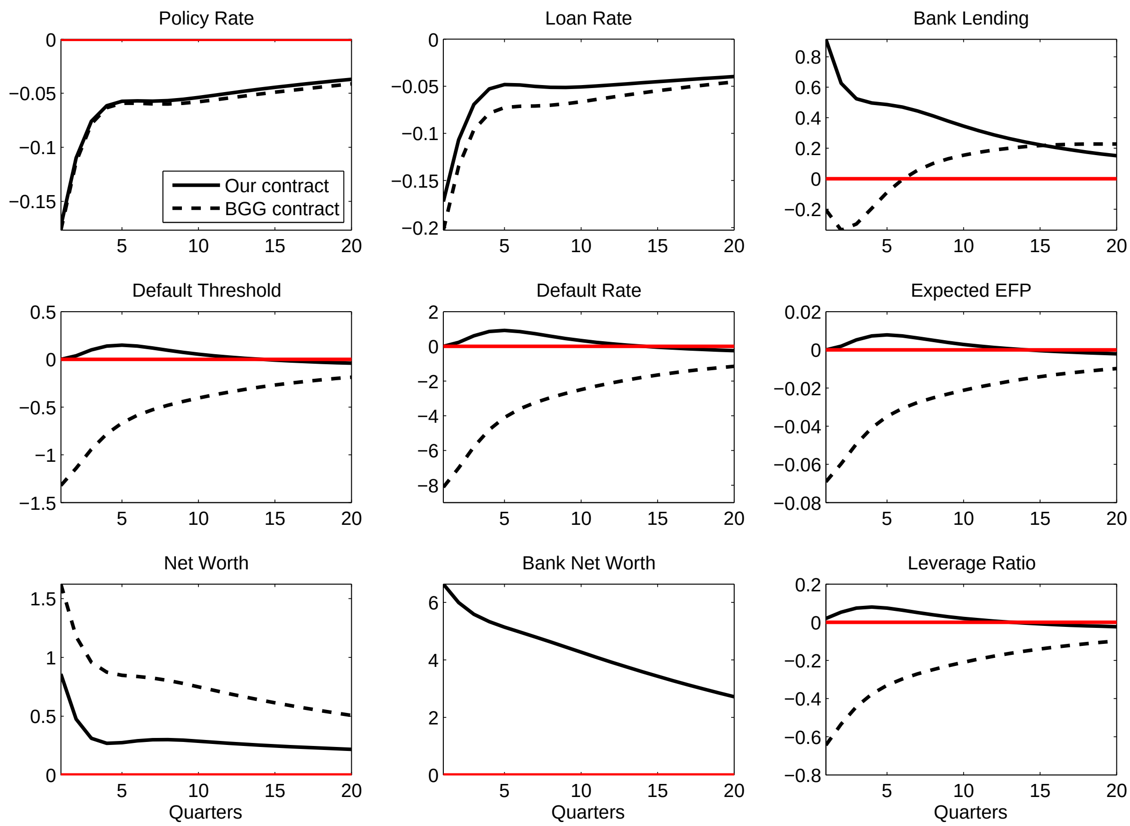


Figure 11: Selected Impulse Response Functions to an Expansionary Monetary Policy Shock of 25 Basis Points for $\rho = 0.90$ and $\rho = 0.95$.