BANK OF ENGLAND

Staff Working Paper No. 806
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June 2019

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Abstract

We develop a dynamic stochastic general equilibrium framework that can account for important macroeconomic and financial moments, given Epstein-Zin preferences, heterogeneous banking and third-order approximation methods that yield a time-varying term premium that feeds back to the real economy. A risk perception shock increases term premia, lowers output, and reduces short-term credit in the private sector in response to higher loan rates and constrained borrowers, as banks rebalance their portfolios. A 'bad' credit boom, driven by investors mispricing risk, leads to a more severe recession and is less supportive of economic growth than a 'good' credit boom based on fundamentals.

Key words: Stochastic discount factor, DSGE, long-term interest rate, risk mispricing, macro-financial linkages, bank lending.

JEL classification: E43, E44, E58, G12.

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. We would like to thank Roberto Billi, Ricardo Caballero, Fabio Canova, Martin Ellison, Mike Joyce, Luisa Lambertini, Ian Martin, Fred Malherbe, Evi Pappa, Glenn Rudebusch, Paul Shea, Eric Swanson, and Mathias Trabandt, for their helpful comments on this paper and Chi Hyun Kim and Gabriel Madeira for their helpful discussions. We also benefited from comments by the participants of the 2019 Women in Macro, Finance and Economic History Workshop at DIW Berlin; the 2nd Annual NuCamp Conference at Nuffield College, Oxford; the XIII Annual Conference on Financial Stability and Banking in Brazil; the 50th Money, Macro, and Finance Conference in Edinburgh; the 2018 European Economic Association Congress in Cologne; and the Bank of England Seminar series.

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ISSN 1749-9135 (on-line)

1 Motivation

Understanding bank lending and the factors that impact the availability of credit is of particular interest for financial stability and monetary policy transmission throughout the business cycle. While higher short-term rates lead to tighter financial conditions –a traditional central bank policy mechanism– risk perceptions, as captured by long-term rates, also play an important role in bank lending. When market participants are pessimistic about future economic conditions, or their willingness to bear risk diminishes and they therefore over-price risk, banks reassess their lending policies to reflect heightened risk perceptions. Furthermore, a risk perception shock can alter the conditions for bank credit approval, increasing the required collateral necessary to take out a loan, making access to credit even more difficult.

In this paper, we provide a structural framework to understand the macroeconomic and financial effects of risk perception shocks through bank lending. To this end, we develop a Dynamic Stochastic General Equilibrium (DSGE) model with a rich financial sector that accounts for banks' lending behaviour in response to changes in the market's perception of risk. We find that a risk perception shock leads banks to increase their holdings of long-term public debt and reduce short-term loans to the private sector as they rebalance their portfolios. The total contraction in overall credit leads to a reduction in investment and output.

Our model has three important features that allow us to study risk pricing in a general equilibrium context. First, we introduce a feedback loop between the financial sector and the economy via the term premium. In this set-up, when investors perceive more risk in the economy, their compensation for risk exposure leads to an increase in the term premium, which influences the demand and pricing of long-term bonds. Banks respond to this endogenous increase in the term premium by changing their willingness to lend money short-term to the private sector. This framework therefore allows for the term premium to feed back into the real economy through the banking sector, impacting credit availability through portfolio rebalancing.

Second, we extend a fully micro-founded DSGE model with heterogeneous banking (Gerali et al., 2010; Gambacorta and Signoretti, 2014) to incorporate the asset pricing insights from the term structure literature in finance (Vasicek, 2005; Le et al., 2010). In this combined framework, the monetary policy authority sets the short-term interest rate according to a standard Taylor rule that minimizes inflation and output deviations from their steady states, while long-term bonds issued by the government are priced by investors following general asset pricing rules (e.g. Rudebusch and Swanson, 2012). A novel feature of our setup is that the nominal stochastic discount factor of investors, which prices long-term assets, is subject to risk perception shocks that endogenously elevate the term premium.

Third, our model can match both, macroeconomic and term premium moments observed in the U.S. data during the 1961–2016 period. In particular, bond premium moments are notoriously difficult to match in standard linear DSGE models, as the term premium is assumed to be zero or constant in benchmark models. Instead, our model allows for a time-varying term premium, which is consistent with the risk pricing patterns documented in the literature (e.g. Shiller, 1979; Fama, 1984; Campbell, 1987; Longstaff, 1990). We accomplish this by separating households' risk aversion from their intertemporal elasticity of substitution with Epstein and Zin (1989) preferences as well as implementing third-order approximation solution methods. In this way, we not only study the impact of risk perception shocks, but also consistently identify classic macroeconomic shocks, without imposing unrealistic values on our model parameters.

We find that a risk perception shock that raises the term premium on long-term bonds (with a magnitude similar to the monthly increase during the Lehman crisis in 2008), leads banks to rebalance their portfolio holdings in favour of long-term public debt and away from short-term private loans to the corporate sector. There are two mechanisms at work, consistent with empirical and survey-based evidence on the effects of risk perception shocks. First, banks account for changes in risk perception through the "loan price" channel, by transferring the elevated perceived risk to the private sector in the form of higher borrowing rates, leading to tighter financial conditions in the economy. Second, as borrowers are subject to a binding credit constraint, an increase in the cost of borrowing also reduces the amount that entrepreneurs can borrow through the "collateral" channel. This channel acts as an important propagation mechanism, amplifying the effects of risk perception shocks and reducing the availability of credit even further. Overall, we find that the risk perception shock also has large, temporary, and negative effects on the macroeconomy, similar to a standard demand shock. Higher perceived risk in the economy induces households to save more and consume less, puts downward pressure on prices, and leads to a contraction in output and investment. This downturn then requires monetary stimulus from the central bank in an effort to ease economic conditions.

We next investigate the difference between a 'good' credit boom driven by economic fundamentals versus a 'bad' credit boom driven by agents under-pricing risk in the economy. We find that a bad credit boom is less supportive of economic growth than a good credit boom. Moreover, once agents correct their mistake and price risk accordingly, output falls more sharply. While a bad credit boom still drives investment, it is less supportive of consumption with wages remaining constant, as fundamentals and therefore productivity, remain unchanged. On the other hand, a bad credit boom has stronger effects on financial markets than a good credit boom. We conclude by highlighting the financial stability implications of different macroprudential policies targeted at reducing risk-taking behaviour.

Our paper relates to two strands of literature: a) the macro-finance literature on term structure models, and b) the macroeconomic literature on risk shocks. The literature on macro-finance term structure models is still evolving. While early studies were mostly limited to endowment economies, there has been a surge of models integrating the term structure into non-linear DSGE models. Earlier work has shown that the term premium can vary significantly over time (Piazzesi and Schneider, 2007). As in the previous literature (Rudebusch and Swanson, 2012; Rudebusch et al., 2007; Van Binsbergen et al., 2012; Caldara et al., 2012; Fuerst and Mau, 2019), our paper also uses third-order approximations to generate a time-varying term premium and uses Epstein-Zin preferences to help match finance moments. However, in addition to these papers, we introduce a banking sector, so we can measure the effects of risk on lending, and importantly, build in a feedback loop so that changes to the term premium have effects on the macroeconomy. This feature supports the reduced-form evidence found in the literature that identifies persistent effects in macroeconomic variables in response to term premia shocks (Gil-Alana and Moreno, 2012; Jardet et al., 2013; Joslin et al., 2014). As suggested by New Keynesian models, and empirical evidence in Rudebusch et al. (2007), a decrease in the term premium should be followed by an increase in output growth, implying that the term premium is counter-cyclical.[1]

The euro area bank lending survey, providing qualitative information on bank loan demand and supply across euro area enterprises and households, identified risk perceptions as one of the most important factors in periods of net tightening of credit standards on housing loans and loans to enterprises (Köhler Ulbrich et al., 2016). While recent papers have accounted for risk or uncertainty in a standard New Keynesian framework, a caveat of these models is that they often assume a specific form of shock (e.g. a second-moment supply shock) and do not account for its effect on bank lending. The risk perception shock allows for a flexible interpretation, as it affects long-term expectations of investors' future prospects or their appetite for risk. As such, it is related to several strands of the macroeconomic literature on 'risk' shocks: a) 'animal spirit' shocks (e.g. Azariadis, 1981; De Grauwe, 2011; De Grauwe and Macchiarelli, 2015) that affect the expectations of investors and skew it toward being optimistic or pessimistic; b) uncertainty shocks, which model uncertainty as a second moment shock to either Total Factor Productivity (TFP) to model supply uncertainty (e.g. Bloom, 2009; Christiano et al., 2014) or to the stochastic discount factor to model demand uncertainty (e.g. Bianchi et al., 2018), or calibrate it to time-varying volatility observed in the data (e.g. Fernández-Villaverde et al., 2011, 2015; Basu and Bundick, 2017); and c) disaster shocks (e.g. Rietz, 1988; Barro, 2006; Gourio, 2012) which can often be interpreted similar to discount factor shocks, as they affect aggregate demand. The uncertainty approach assumes that an uncertainty shock only affects the second moment of a variable, which means that real effects are often fairly small. The advantage of using a risk perception shock is that we remain as agnostic as possible about what drives risk perceptions: it could be a political or economic change that increases the likelihood of worsening economic conditions, an increase in uncertainty, or a change in the willingness to bear long-term risk. Moreover, by incorporating the term premium and solving the model using a third-order approximation, risk arises naturally in the model due to the risk-averse preferences of investors. Hence, the steady state level of the term premium is positive, even in the absence of shocks, leading to first order effects. Additionally, we make no assumptions about specific agents' beliefs, as is necessary to incorporate an 'animal spirit shock' into a DSGE model and are only focussed on agents' perception of financial risk. The shock we are interested in is similar in nature to Caballero and Simsek (2017), who looked at risk premium shocks driven by agents ex-ante optimistic or pessimistic expectations due to interest rate frictions. Modelling a shock to risk perceptions via the stochastic discount factor allows for a straight-forward way to test for the effects of shocks on long-term risk perceptions in a relatively standard DSGE framework.

The paper is structured as follows. As a first step, Section 2 provides intuition on what movements in the term premium represent and how they relate to investors' perceptions of long-term risk. We then study the empirical responses of an increase in the term premium in a Structural Bayesian Vector Autoregressive (VAR) model using zero and sign restrictions in Section 3. The empirical exercise confirms that a shock to risk perception behaves very similarly to other risk perception shocks identified in the literature (e.g. Bloom, 2009). We find that there is indeed a strong, short-lived, negative

[1] Further evidence on counter-cyclical risk premia can be found in Campbell and Cochrane (1999); Wachter (2006); Bauer et al. (2012); Lustig et al. (2014).

macroeconomic response with output decreasing and a less significant contraction in short-term private sector loans, while long-term bank lending to the public sector increases. Section 4 describes the main assumptions and mechanisms behind the DSGE model that links the real economy and the financial sector via the term premium. We provide details about the calibration and solution methods, as well as the model-implied macroeconomic implications of a risk perception shock, along with the term premium's response to classic macroeconomic shocks (TFP, government spending and monetary policy). Section 5 explores the richness of our model by simulating different credit boom scenarios to study the effects of risk mispricing and to assess the effectiveness of macroprudential policies in mitigating financial instability. Section 6 concludes.

2 The Term Premium

The term premium is the compensation that investors require in order to hold a long-term bond instead of a series of short-term bonds during the same horizon. As such, a high term premium reflects a perceived increase in financial risk over the life of a bond. This compensation for risk varies throughout time as investors update their beliefs about the future path of the economy, including changes in expected inflation, the course of monetary policy, and their tolerance for risk, among other factors. This section explores the most salient features of the term premium as well as its relationship to perceived risk. It is important to note that the term premium captures *expected* risk by market participants. Previous studies have documented that risk perceptions, unlike actual risk, decline during the build up of a boom and spike once the bust occurs, so that actual and perceived risks are actually negatively correlated (Danielsson et al., 2012).

For this paper, we utilise the ACM term premium measure developed by the Federal Reserve Bank of New York. For a short summary of the methodology and an overview of how it compares to other measures, refer to Adrian et al. (2013).[2] The evolution of the nominal ten-year term premium from 1961 to 2017 is shown in Figure 1 along with the ten-year U.S. Treasury yield. In December 2013, for example, a ten-year U.S. Treasury bond earned a 2.90 percent annualised yield. More than half of this return, 1.73 percentage points, reflected the compensation risk-neutral investors at that time would require in order to be exposed to long-term risk, i.e. the term premium. As can be observed from the figure, the term premium is substantial – around 1.63% for the past six decades – and varies significantly over time, ranging from –0.65% to 4.79%.

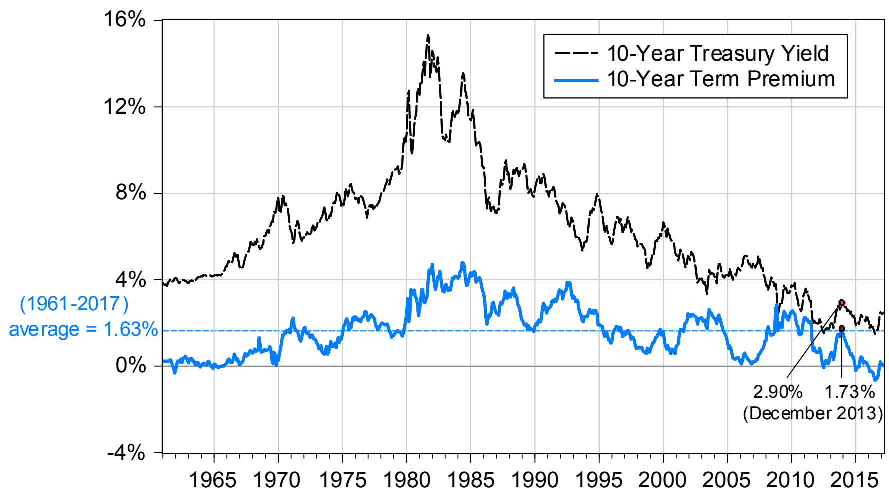
To provide economic intuition of what movements in the term premium represent, we compare its evolution to several economic variables, including different proxies for perceived risk and measures of uncertainty.[3] Figure 2(a) displays the term premium along with the unemployment rate. As has

[2] A measurement caveat is that the term premium is unobservable and as such, needs to be estimated or inferred from the term structure of interest rates, forecasts, or surveys of market participants. Swanson (2007), Rudebusch et al. (2007), and Li et al. (2017a) compared different estimates of the term premium and provide excellent overviews of the challenges faced when measuring the long-term expectation of short rates.

[3] Note that there is a common distinction in the literature between risk and uncertainty. 'Risk' is defined as an event occurring with measurable probability, while 'uncertainty' describes potential future events but the likelihood is indefinite or incalculable (Knight, 1921). Andreasen (2012) pointed out rare disasters increase the level of the term premium, while uncertainty increases the variance of the term premium. Bundick et al. (2017) found that a decline in the slope of implied

been established in the literature, the term premium is counter-cyclical, rising along with unemployment during economic downturns and falling during economic upswings (the correlation is 0.55). This counter-cyclicality suggests that the term premium should be negatively correlated with output and consumption; therefore, as households' future consumption prospects worsen, the term premium rises. In fact, the correlation between the term premium and year-over-year changes in personal consumption expenditures is –44%.[4] This interpretation is also consistent with the empirical evidence in Ludvigson and Ng (2009), indicating that agents seek compensation for macroeconomic risks associated with recessions.

Figure 1: Ten-Year Treasury Yield and the Term Premium (1961-2017)



Sources: Federal Reserve Bank of New York; Federal Reserve Board.

We use the Merrill Lynch MOVE Index, which summarises options-implied expected volatility of Treasury yields, in order to capture investors' perceived interest rate risk in Figure 2(b). During the overlapping period, the correlation between these two series is 50 percent.[5] The term premium is also positively correlated (50%) with the 3-month VIX, a proxy for financial risk in equity markets.[6]

Furthermore, as can be observed in Figures 2(c) and 2(d), the term premium is associated with fluctuations in policy (60% correlation) and inflation uncertainty (50% correlation), as measured by different components from the Baker et al. (2016) Uncertainty Index. Baker et al. (2016) estimate the dispersion among economic forecasters in the purchase of goods and services by state, local and the federal government, and the consumer price index (CPI) as a measure of policy and inflation uncertainty,

volatility also lowers the level of the term premium. We allow the term premium to capture both, changes in perceived risk and uncertainty over the life of the bond.

[4]Monthly estimates of market-based Personal Consumption Expenditures are available from 1988/01 to 2017/04 from the Bureau of Economic Analysis.

[5]Adrian et al. (2013) also showed that the term premium is correlated with the disagreement about the level of the federal funds rate four quarters ahead (as measured by the average forecast of the highest ten responses minus that of the lowest ten responses in the Blue Chip Financial Forecasts survey) from 1982 to 2013. The correlation between the term premium and the quarterly dispersion of professional forecasters 3-month T-bill rate estimates four quarters ahead is 53% during the 1981–2017 period.

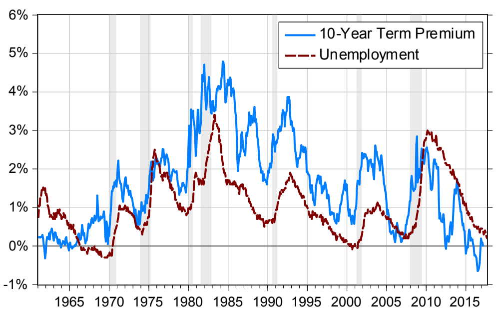
[6]NSA CBOE S&P 500 3-month volatility index (2008–2017).

respectively. A similar result is also identified by Bianchi et al. (2018), who found that changes in nominal term premia contain key identifying information for uncertainty shocks.[7]

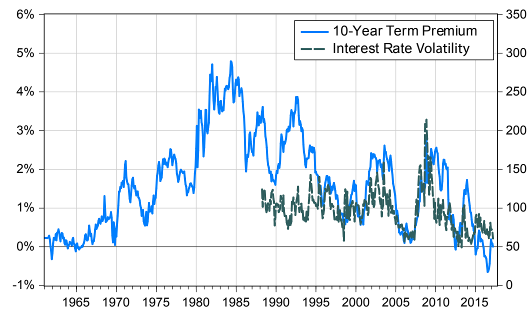
From this preliminary analysis, we therefore expect the term premium to be high when investors are more risk averse; the marginal rate of consumption is high; output is low; or there is more uncertainty about the future economic outlook (i.e. the path of interest rates, inflation, fiscal policy).[8]

Figure 2: Term Premium, Perceived Risk, and Uncertainty

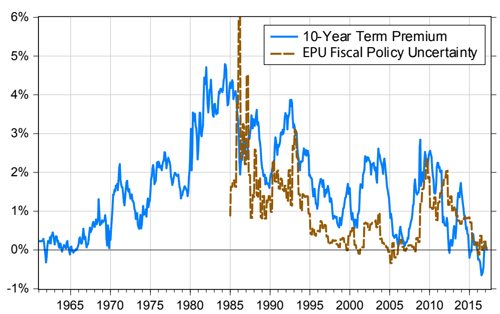
(a) Term Premium is Counter-cyclical



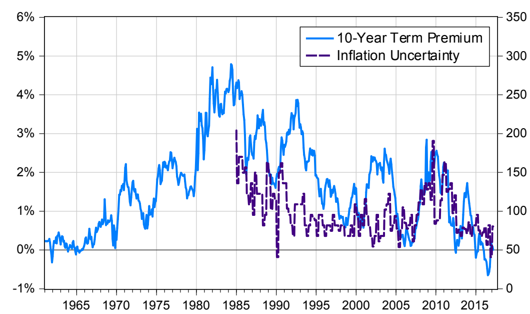
(b) Interest Rate Volatility (MOVE)



(c) Policy Uncertainty



(d) Inflation Uncertainty



Notes: Term premium is the ACM series from the Federal Reserve Bank of New York, as in Adrian et al. (2013), from January 1961 to March 2017. Unemployment rate is from the Bureau of Labor Statistics, and shaded areas indicate NBER recession periods. Interest Rate Volatility is proxied by the Merrill lynch Option Volatility Estimate (MOVE) Index. Policy and Inflation Uncertainty are obtained from the Baker et al. (2016) Uncertainty Index. All data are monthly. Refer to Appendix A.1 for details.

In the next sections, we explore the effects of risk perception shocks via the term premium on the macroeconomy and the financial sector, both empirically and in the context of a DSGE model. We define a 'risk perception shock' as an exogenous fluctuation in investors' perception of financial risk, when pricing risk premia via their stochastic discount factor. There is a multitude of potential real life occurrences that can alter our beliefs about the future, such as political events, new regulation, trade

[7]The term premium is also correlated with the Jurado et al. (2015) monthly (one-year ahead) macroeconomic uncertainty index (46%) and the quarterly dispersion of professional forecasters CPI estimates over the next ten years (64%).

[8]There are, of course, other explanations for movements in the term premium, such as the recent central bank purchases of bonds under Quantitative Easing, the use of explicit forward-rate guidance to reduce uncertainty about the future path of monetary policy, and the possible flight-to-quality flows that reflect preference for certain class of assets.

agreements, or similar events that change households' risk assessment exogenously. Understanding the effect of a risk perception shock on the economy through the term premium has important policy implications that we want to later interpret in the context of our model.

3 The Impact of a Risk Perception Shock: Empirical Approach

As a first step, we want to understand the role of a risk perception shock on both the macroeconomy and the financial sector in an empirical VAR model. This analysis allows us to obtain a benchmark from which we can evaluate the theoretical DSGE responses in the later section. Also, it provides us with an initial idea of the quantitative effects and persistence of an increase in the term premium, following a risk perception shock. The structural Bayesian VAR follows

$$\mathbf{A_0 x_t} = \mathbf{A_1 x_{t-1}} + \mathbf{e_t},$$

where $\mathbf{A_0}$ and $\mathbf{A_1}$ are the matrices of structural coefficients, and $\mathbf{e_t}$ is an orthogonal vector of structural innovations. The vector $\mathbf{x_{t-1}}$ also includes a constant. We use monthly U.S. data from 1961 until 2017 for output as measured by industrial production, inflation, the Wu-Xia shadow federal funds rate, commercial and industrial loans by commercial banks, Treasuries and Agency loans by commercial banks, and the term premium (see Appendix A.2 for a detailed description of the data). We choose the shadow federal funds rate to account for monetary policy during the zero lower bound period constraining the policy rate from below. Output and bank/government loans enter the model in annual growth rates, while the remaining variables are in percent. We interpret government debt as long-term debt, and commercial and industrial loans as short-term debt, as it aligns closely with the maturity composition of portfolio allocations by borrower.[9] We choose a Minnesota prior to improve the accuracy of our estimation, and follow the Bayesian information criteria for lag length by selecting two lags, accordingly.

3.1 Identification

We follow Canova and Nicolo (2002) and employ sign restrictions ex post on the impulse responses to structurally identify a risk perception shock in the data. We use sign restrictions to identify the risk perception shock, as it allows us to impose simultaneous restrictions on financial variables and avoids making overly strong assumption on the nature of the shock. A risk perception shock that raises the term premium (tp_t) implies that long-term expected risk in financial markets is increasing and/or that financial uncertainty is worsening. The contemporaneous sign restrictions are reported in Table 1. We restrict risk perceptions to be negatively correlated with output growth (y_t), consistent

[9] More than 90% of commercial loans have a maturity of less than a year and 70-80% of less than a month (source: E.2 Survey of Terms of Business Lending, Board of Governors of the Federal Reserve System). In contrast, more than 70% of privately-held public debt has a maturity greater than a year, with the average maturity of all government debt held by private investors being 5-6 years (source: Table FD-5, US Treasury Bulletin, Department of the Treasury).

with the counter-cyclical properties of the term premium shown in the previous section.[10] Another key identification assumption is that the monetary policy authority only sets the short-term rate (i_t) in response to macroeconomic conditions, so that the term premium has no contemporaneous effect on the short-term interest rate. To impose a combination of zero and sign restrictions, we use the algorithm of Binning (2013).

Table 1: Sign Restrictions

Variable/Shock	Demand	Supply	Monetary Policy	Loans	Risk Perception
y_t	> 0	< 0	< 0	0	< 0
π_t	> 0	> 0	< 0	0	
i_t	> 0	> 0	> 0		0
b_t^e, b_t^l				> 0	
tp_t					> 0

While we are only interested in a risk perception shock per se, we need to ensure that the shock is fully identified and cannot be misspecified as another shock in the model. We explicitly identify a demand, supply, monetary policy, and a private and public sector loan shock in the data to avoid mistaking the risk perception shock with other shocks in the model. We use standard sign restrictions on output and inflation (π_t): a demand shock increases output and inflation simultaneously, while a supply shock increases inflation, but decreases output (Kilian and Lütkepohl, 2017). As inflation rises in both cases, so does the interest rate. A contractionary monetary policy shock (hence an increase in the interest rate), leads to a decline in both output and inflation. Finally, a loan shock, i.e. banks lending more to either the private sector, b_t^e, or the public sector, b_t^l, increases the volume of loans (b_t) that are held by commercial banks but has no immediate effect on macroeconomic variables as any effect will likely be only felt with a delay. This set of identification restrictions is thus necessary and sufficient to ensure that we identify a shock to risk perception. To remain as agnostic as possible, we impose these restrictions only contemporaneously upon impact of the shock.

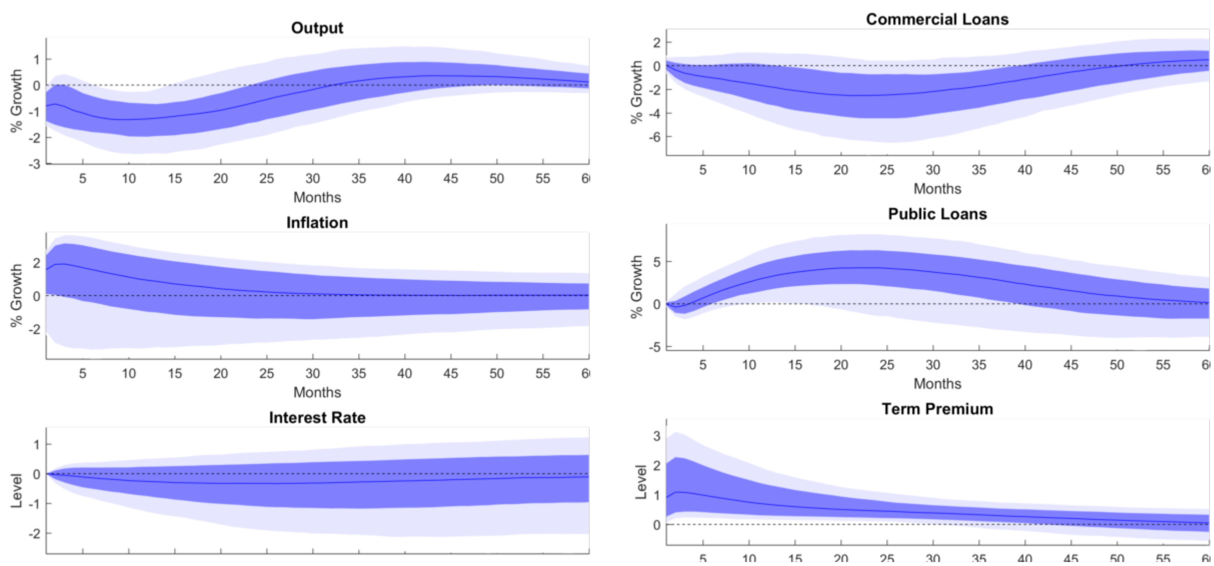
3.2 Results

Figure 3 shows the impulse responses to a one standard deviation positive increase in the monthly term premium. To provide some context, the size of this shock is similar to the increase in the term premium from September 2008 (1.6) to October 2008 (2.6), during the Global Financial Crisis. From the left column, we can see that an increase in the term premium of 90 basis points has a short-lived, yet very sizeable effect on the economy. Output declines by 1.3% in the first year and returns back to the steady state after two and a half years. Our risk perception shock has a similar effect on output, in terms of direction and magnitude, to uncertainty shocks empirically identified in the literature: –1.2% (Baker

[10] Rudebusch et al. (2007) show that in response to a monetary policy or a technology shock, a rise in the term premium is associated with current and future weakness in output and that a decline in the term premium is associated with stimulus to the economy. However, for a government spending shock, a rise in the term premium is associated with current and future output strength, thus finding that the correlation between output and the term premium depends on the nature of the shock itself.

et al., 2016); –1% during expansions and –2% during contractions (Caggiano et al., 2017). The response of inflation and the interest rate is not very strong and zero is included in the credible set, although there is a large probability that inflation might initially respond positively. This finding is consistent with the effects of an uncertainty shock on inflation found in the previous literature (e.g., Creal and Wu, 2017 and Bundick et al., 2017). Short-term commercial loans granted by banks decline by 2% and exhibit more persistent effects than output, with the median response only returning to the steady state after roughly five years. Interestingly, banks do increase their long-term lending to the public sector by more than 4% in response to the risk perception shock with a similar persistence.

Figure 3: Term Premium Shock and Lending



Notes: The solid line represents the median point estimate, while the dark and light shaded regions report point-wise 68% and 90% Monte Carlo credible sets, respectively. The shock size is a one standard deviation increase in the term premium. The estimates are based on 200,000 draws of which the first 25% are discarded.

3.3 Robustness

While the 90% credible sets are fairly large, this is partially driven by the uncertain response of the term premium itself. We therefore perform a series of robustness checks, which we report in the Appendix. First, we carry out the same analysis but use the junk-bond spread instead of the term premium to capture financial risk. A widening of the junk-bond spread, an indicator of the overall creditworthiness of the private sector, is often a signal of higher perceived risk in the financial markets. In response to a one-standard deviation shock that increases the junk-bond spread by 110 basis points, output and short-run commercial loans decline significantly, while long-term lending to the public sector increases (see Appendix Figure B.1). The effects seem to be quantitatively more than twice as large for output and loans, possibly as the junk-bond spread relates more closely to corporate short-term risk and is thus more volatile than the term premium, which incorporates much broader macroeconomic and long-term risk perceptions. Figure B.2 in the Appendix also reports the results for a one-standard deviation increase in the term premium excluding the financial crisis (left column) and using the VIX measure as a different proxy for risk (right column). In both cases results are qualitatively similar but with higher credible sets around the median response due to the decrease in data volume (the CBOE VXO/VIX is only available from July 1986).

To summarise, we (i) show that the term premium can be used as a measure of risk perceptions, and (ii) we find that banks reduce short-term lending to the private sector as a consequence of a risk perception shock, while increasing their long-term lending to the public sector. We hence empirically establish that there is indeed a link between risk perceptions and loan allocation that renders further investigation. Next, we develop a structural model to further analyse the relationship between risk perception, the financial sector, and the macroeconomy in a general equilibrium context.

4 The Impact of a Risk Perception Shock: DSGE Model

In this section, we construct a New-Keynesian DSGE model that can generate a positive and time-varying term premium to structurally analyse the effects of a long-term risk perception shock on the macroeconomy via the banking sector.[11] An important feature of our model is that by incorporating a financial sector into a general equilibrium framework, we are able to match macro and term premium moments, capturing the real and financial implications of risk perception shocks.

There are two key features that help us match the term premium moments: Epstein-Zin preferences and third-order solution methods. Firstly, Epstein and Zin (1989) preferences have the advantage that risk aversion can be modelled independently from the intertemporal elasticity of substitution (IES). Since Epstein-Zin preferences yield the same results using first-order approximations as standard utility functions, the model is still able to match macroeconomic moments. However, by introducing an additional parameter, α_{EZ}, the risk aversion of households can now be amplified to also match the empirical features of bond moments. Moreover, using higher order solution methods generates heteroskedasticity in the stochastic discount factor, which prices long-term assets in the economy. First-order solutions would imply that the expectation hypothesis holds and the term premium would be zero. Second-order solutions can improve upon this by generating a positive, yet constant term premium. Only by using third-order solutions, we manage to capture a time-varying term premium and match empirical bond moments.

In this setup, asset prices become relevant for real behaviour, giving the term premium a key role as a feedback mechanism between financial markets and the macroeconomy. Importantly, this framework allows us to structurally study the implications of a risk perception shock for bank lending in a general equilibrium context and thus understand the mechanisms by which the term premium affects the macroeconomy and vice-versa.

[11] The advantage of the New Keynesian model over a Real Business Cycle model is that inflation and inflation expectations are taken into account, which is crucial for the determination of the yield curve and thus, the term premium.

4.1 Model Description

As in Gerali et al. (2010) and Gambacorta and Signoretti (2014), the model contains several agents: patient households, impatient entrepreneurs, retailers, wholesale and retail banks, capital goods producers, and a monetary policy authority. We modify their baseline model by introducing non-defaultable long-term bonds that are issued by a fiscal authority to finance government spending. Long-term bonds are determined by standard asset pricing rules that allow for a time-varying term premium to arise endogenously in the model as in Rudebusch and Swanson (2012). This extension of the model allows us to have a more fleshed-out financial sector that is consistent with financial risk pricing.

Another novel feature of our setup is the implementation of a feedback loop between the financial sector and the real economy via the term premium. First, households are patient and provide labour to impatient entrepreneurs, while competitive entrepreneurs produce intermediate goods that are sold to retailers. These retailers differentiate the intermediate goods and sell them with a mark-up to households, who also own the retailers and keep their profits. Banks have two branches: a wholesale and a retail branch. Wholesale banks take deposits from households and can invest in long-term bonds. They operate under perfect competition. Retail banks are monopolistic and give out loans to entrepreneurs charging a mark-up fee. In addition, they take and monitor collateral from the entrepreneurs given a stochastic loan-to-value (LTV) ratio. To sum up, banks can choose between a) keeping deposits, which for households are equivalent to short-term T-Bills, as they pay the risk-free rate; b) give out short-term loans to entrepreneurs and receive profits from the mark-up they charge; or c) invest in long-term bonds which pay a term premium. The remaining profits are invested in bank capital, monitored by the monetary policy authority. The monetary policy authority sets the policy rate, determines the capital/asset ratio for banks, and the LTV target ratio for entrepreneurs. The fiscal authority issues long-term government bonds to finance government spending, which is modelled exogenously. In addition, there are capital producers who buy undepreciated capital from entrepreneurs and re-sell it for a new price back to entrepreneurs taking into account quadratic adjustment cost. This is necessary to derive a price for capital. Similar to Rudebusch and Swanson (2012), we focus on long-term bonds rather than equity, in order to capture changes in investors' perception of long-term risk. Since long-term bonds affect real behaviour and vice versa, the term premium has important policy implications for bank lending, which we further investigate in Section 5.

Households

Households maximise their recursive utility function

$$V_t = U(c_t^P, l_t) + \beta_P \left[\mathbb{E}_t(V_{t+1})^{(1-\alpha_{EZ})}\right]^{1/(1-\alpha_{EZ})}, \tag{1}$$

where c_t^P is consumption, l_t is labour supply, β_P is the patient discount factor, and α_{EZ} is the Epstein-Zin parameter that measures households' risk aversion. The intra-period utility function is given by

$$U(c_t^P, l_t) = \frac{(c_t^P)^{1-\psi}}{1-\psi} - \frac{l_t^{1+\phi}}{1+\phi}.$$

$1/\phi$ is the Frisch elasticity of labour and $1/\psi$ is the IES. Intuitively, Epstein-Zin preferences imply that households are not just concerned with smoothing their consumption once sudden shocks are realised in the short term, but also for medium- and longer-term changes in consumption, allowing long-term risk to play a role in households' decision-making process. Households deposit savings at wholesale banks, for which they receive a risk-free return. They also own retail firms, which are monopolistic and generate a profit, so that they are subject to the budget constraint

$$c_t^P + d_t \leq w_t l_t + (1 + r_{t-1}^{ib}) d_{t-1} + J_t^R,$$

where d_t are bank deposits, w_t is the real wage, and r_t^{ib} is the short-term rate set by the monetary policy authority. The central bank has therefore the potential to directly impact the household decision-making process, since an increase in the policy rate would induce households to increase their savings. J_t^R are the profits of the retail sector. The first-order condition yields the consumption Euler equation

$$\frac{1}{\left(c_t^P\right)^{\psi}} = \mathbb{E}_t \left[\frac{\beta_P (1 + r_t^{ib})}{\left(c_{t+1}^P\right)^{\psi}} \left(\frac{V_{t+1}}{V_t'} \right)^{(-\alpha_{EZ})} \right],$$

where V_t' constitutes the certainty equivalent and V_{ss} is the steady state, such that

$$V_t' = V_{ss} \mathbb{E}_t \left[\left(\frac{V_{t+1}}{V_{ss}} \right)^{(1-\alpha_{EZ})} \right]^{\frac{1}{1-\alpha_{EZ}}}.$$

Households also provide labour to the entrepreneurs for the production of intermediate goods, which follows the usual labour supply schedule

$$l_t^{\phi} = \frac{w_t}{\left(c_t^P\right)^{\psi}}.$$

Entrepreneurs

Entrepreneurs need to borrow from banks by providing capital as collateral, but also produce goods, employ households and consume. They form the link between the real economy and the banking sector and are thus important for generating a feedback loop between the financial and macroeconomic side of the model. The entrepreneurs maximise

$$\max_{c_t^E, l_t^d, b_t^E} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_E \log(c_t^E),$$

with respect to their consumption, c_t^E, labour demand, l_t^d, and bank loans, b_t^E. The optimisation problem is subject to a budget constraint,

$$c_t^E + (1 + r_{t-1}^b) b_{t-1}^E + w_t l_t^d + q_t^k k_t^E \leq \frac{y_t^E}{x_t} + b_t^E + q_t^k (1 - \delta_k) k_{t-1}^E, \tag{2}$$

where r_t^b is the interest rate on bank loans, k_t^E is the entrepreneurs stock of capital, q_t^k is the price of capital, and y_t^E is the intermediate output produced by entrepreneurs. $\frac{1}{x_t} = \frac{P_t^W}{P_t}$ is the relative competitive price of the intermediate good produced by the entrepreneur, and δ_k is the depreciation rate of capital. The entrepreneurs are also subject to a borrowing constraint,

$$b_t^E \leq \frac{m_t^E \mathbb{E}_t \left[q_{t+1}^k k_t^E (1-\delta^k)\right]}{1+r_t^b}, \tag{3}$$

where m_t^E is the stochastic LTV ratio which follows an AR(1) process with an i.i.d. shock ε_t^{me} and variance σ_{me}. A high LTV ratio implies that banks can lend more for the same amount of collateral and vice versa. The borrowing constraint determines how much entrepreneurs can borrow from banks (i.e. the collateral channel). For small enough shocks, $\beta_P > \beta_E$ ensures that the borrowing constraint is binding and credit is constrained in the economy.

Entrepreneurs do not work but use capital and labour in the production of intermediate goods. As in Kiyotaki and Moore (1997), capital has many functions in this model and thus establishes another important feedback mechanism between the real economy and the financial sector. Capital is used (i) in the production of intermediate goods, (ii) as a collateral for the entrepreneurs, and (iii) as a source of funds for investment. The production function for intermediate goods follows a standard Cobb-Douglas form

$$y_t^E = A_t^e (k_{t-1}^E)^{\alpha} (l_t^d)^{(1-\alpha)},$$

where α denotes the capital share, and A_t^e technology. A_t^e is stochastic and follows an AR(1) process with an i.i.d. technology shock ε_t^a with variance σ_a. Entrepreneurs operate under perfect competition. Their optimal consumption Euler equation is

$$\frac{1}{c_t^E} - \lambda_t^E = \mathbb{E}_t \left[\frac{\beta_E (1+r_t^b)}{c_{t+1}^E}\right].$$

This is similar to the households' Euler equation but differs by the Lagrange multiplier on the borrowing constraint, λ_t^E, which represents the marginal value of one unit of additional borrowing. Another difference to households is that entrepreneurs have a higher deterministic discount factor, and face the higher bank loan rate, r_t^b, rather than the risk-free rate, r_t^{ib}. The labour demand schedule is

$$\frac{(1-\alpha) y_t^E}{l_t^d x_t} = w_t.$$

The investment Euler equation equalises the marginal benefit with the marginal cost of saving capital. As capital serves as collateral, the equation also depends on the Lagrange multiplier of the borrowing constraint and the LTV ratio. It follows that

$$\mathbb{E}_t \left[\frac{\lambda_t^E m_t^E q_{t+1}^k (1-\delta^k)}{1+r_t^b} + \frac{\beta_E}{c_{t+1}^E}\left[q_{t+1}^k (1-\delta^k) + r_{t+1}^k\right]\right] = \frac{q_t^k}{c_t^E},$$

where r_t^k is the return to capital which is defined by the marginal product of capital as

$$r_t^k \equiv \alpha \frac{A_t^E (k_{t-1}^E)^{(\alpha-1)} (l_t^d)^{(1-\alpha)}}{x_t}.$$

Banks

The banking sector is divided into a perfectly competitive wholesale and a monopolistic retail sector. The wholesale sector maximises bank profits by optimising the net interest margin between the loan rate and the long-term bond rate subject to the quadratic adjustment costs of deviating from a target capital/asset ratio, ν. As the deposit rate is the same as the risk-free rate, banks' demand for deposits is elastic and the amount of deposits is determined by households. The wholesale bank's maximisation problem is

$$\max_{B_t, d_t} R_t^b B_t - r_t^{ib} d_t - \frac{\theta}{2} \left(\frac{K_t^b}{B_t} - \nu \right)^2 K_t^b, \tag{4}$$

where $B_t = b_t^E + b_t^l$ represents the total assets of the bank. K_t^b is the banks' capital and θ is the parameter for the capital adjustment costs.

Wholesale banks are subject to a balance sheet constraint that can also be interpreted as a capital adequacy/leverage constraint.[12] Loans and bonds have to be backed up by sufficient bank capital and deposits at the beginning of the period

$$b_t^E + b_t^l = d_t + K_t^b. \tag{5}$$

Combining (4) and (5), the first-order condition of the wholesale bank collapses to

$$R_t^b = r_t^{ib} - \theta \left(\frac{K_t^b}{b_t} - \nu \right) \left(\frac{K_t^b}{B_t} \right)^2.$$

The retail bank buys the loans from the wholesale bank at price R_t^b and uses it either to (i) lend to the government via long-term bond holdings, b_t^l , at the long-term bond rate determined by the stochastic discount factor, r_t^l, or (ii) lend short-term to entrepreneurs. The retail bank maximises

$$\max_{b_t^E, b_t^l} r_t^b b_t^E + r_t^l b_t^l - R_t^b B_t \tag{6}$$

with respect to loan demand which is $b_t^E = \left(r_t^b\right)^{-\epsilon_B}$, where ϵ_B is the demand elasticity. The first order condition of the retailer becomes

$$r_t^b = \frac{\epsilon_B}{1 - \epsilon_B} r_t^l,$$

which can simply be expressed as a mark-up, $\overline{\mu}_b$, on the long-term rate, so that the retail loan rate becomes $r_t^b = r_t^l + \overline{\mu}_b$.

[12] Note that capital and leverage ratios differ, as the capital ratio is risk-weighted. As such, the leverage ratio indicates the maximum loss that can be absorbed by the bank's equity, while the capital ratio is a measure of the potential loss than can be absorbed (Gambacorta and Karmakar, 2018).

The retail banks have market power, which help them to adjust their lending in response to shocks or cycles. Notice that, everything else held constant, a higher term premium that increases the long-term rate, also increases the loan rate charged by retail banks, making access to credit more expensive for entrepreneurs. This is effectively the loan price channel through which increases in the term premium make borrowing less attractive.

Another crucial determinant for the feedback loop between the banking sector and the real economy is bank capital. Bank capital depreciates at rate δ_b and accrues from past capital and retained earnings, J_t^B,

$$K_t^b = K_{t-1}^b(1-\delta_b) + J_{t-1}^B.$$

Since it is pro-cyclical, bank capital worsens when output declines due to decreasing banks' profits. The latter is defined as the sum of both the retail and wholesale sector profits on loans, long-term bonds, and deposits, respectively, and depends on the state of the macroeconomy, i.e.

$$J_t^B = r_t^b b_t^E + r_t^l b_t^l - r_t^{ib} d_t - \frac{\theta}{2}\left(\frac{K_t^b}{B_t} - \nu\right)^2 K_t^b.$$

Retailers and Capital Good Producers

The monopolistic retailers differentiate the intermediate goods produced by the entrepreneurs at no cost and sell them with a mark-up. However, retailers face quadratic price adjustment cost, which causes prices to be sticky (Rotemberg, 1982). The parameter κ_P represents the degree of price stickiness. The first order condition of the retailers generates the classic New Keynesian Philip's curve

$$0 = 1 - \frac{mk_t^y}{mk_t^y - 1} + \frac{mk_t^y}{mk_t^y - 1} mc_t^E - \kappa_P(\pi_t - 1)\pi_t + \beta_P \mathbb{E}_t\left[\frac{c_t^P}{c_{t+1}^P}\kappa_P(\pi_{t+1} - 1)\pi_{t+1}\frac{Y_{t+1}}{Y_t}\right], \tag{7}$$

where the marginal cost is $mc_t^E \equiv \frac{1}{x_t}$, $\pi_t = log\left(P_t/P_{t-1}\right)$, and Y_t is total output. The firm's mark-up, mk_t^y, is stochastic and follows an AR(1) process with an autocorrelation coefficient ρ_{mk} and an i.i.d. mark-up shock, ε_t^{mk}, with variance σ_{mk}.

Capital good producers are perfectly competitive and their main task is to transform the old, undepreciated capital from entrepreneurs to new capital without any additional costs. They then resell the new capital to the entrepreneurs in the next period at price P_t^k, so that the relative price of capital is $q_t^k \equiv \frac{P_t^k}{P_t}$. In addition, capital producers 'invest' in the final goods bought from retailers, which are not consumed by households, and also transform these into new capital.

The final goods to capital transformation is subject to quadratic adjustment costs that are parametrised by κ_i, the investment (I_t) adjustment cost parameter. The first-order condition of capital good producers is

$$1 = q_t^k\left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa_i\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + \beta_E\mathbb{E}_t\left[\frac{c_t^E}{c_{t+1}^E}q_{t+1}^k\kappa_i\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \tag{8}$$

with capital, K_t, evolving according to

$$K_t = (1-\delta_k)K_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t. \tag{9}$$

Monetary Policy

Monetary policy follows a standard Taylor rule, so that the policy rate is set according to

$$r_t^{ib} = \rho_{ib} r_{t-1}^{ib} + (1-\rho_{ib})\left[\overline{r}^{ib} + \phi_\pi (\pi_t - \overline{\pi}) + \phi_y (y_t - \overline{y})\right] + \varepsilon_t^r, \tag{10}$$

where ρ_{ib} is the interest-rate smoothing coefficient, $\{\overline{r}^{ib}, \overline{\pi}, \overline{y}\}$ are the interest rate, inflation and output steady states, respectively, and ϕ_π and ϕ_y are the inflation and output monetary policy parameters.[13] ε_t^r is an i.i.d. monetary policy shock with variance σ_r.

The monetary policy authority is also responsible for setting a target capital/asset ratio for banks to avoid an over-leveraging of the economy similar to the Basel Tier 1 leverage ratios. Moreover, the central bank also sets the LTV target ratio for entrepreneurs.

Asset Pricing Equations

Long-term bonds are default-free securities issued by the fiscal authority that pay a geometrically declining coupon every period in perpetuity.[14] In the traditional finance literature, the price of a nominal long-term bond at time t maturing at $t+l$, p_t^l, can be decomposed into the risk-neutral present value of the bond, $\widehat{p}_t^l$ (i.e. discounted at the risk-free rate), and the covariance between future pay-offs and the bond-pricing stochastic discount factor, m_{t+1}^*:

$$p_t^l = \underbrace{\mathbb{E}_t[p_{t+1}^{l-1}]\left(1 + r_t^{ib}\right)^{-1}}_{\text{risk neutral price}=\widehat{p}_t^l} + \underbrace{cov_t\left(m_{t+1}^*, p_{t+1}^{l-1}\right)}_{\text{risk discount}}.$$

The first term is the asset price in a risk-neutral world with constant consumption and linear utility. Notice that if $cov_t\left(m_{t+1}^*, p_{t+1}^{l-1}\right) = 0$ then the price of the long-term bond is exactly the risk-neutral price.[15] The second term is a risk adjustment, such that a large negative covariance lowers the price of the bond. Therefore, investors must be compensated to hold assets that pay poorly during bad times, and vice-versa.

[13] Fuerst and Mau (2019) point out that the exact monetary policy rule specification is important to generate variability in the term premium in response to macroeconomic shocks. In order to achieve greater variability in the term premium, the monetary authority should respond to the level of output relative to the steady state rather than the output gap (see Rudebusch and Swanson, 2012). As an output level rule means the central bank is committing to a contractionary policy for longer, thus reducing inflation by more, the term premium is more affected than in the case of an output gap rule.

[14] This is equivalent to assuming that long-term bonds are infinitely-lived *consol-style* bonds as in Chin et al. (2015). The purpose of this assumption is to reduce the pricing relationship to just one recursive equation in the model, rather than having to solve for each maturity level. As shown in Rudebusch and Swanson (2012), this simplification still generates equivalent results to using ten-year zero-coupon bonds, while significantly reducing the computational burden.

[15] An important assumption for a positive, time-varying term premium is that the expectations hypothesis therefore does not hold and households are allowed to be risk averse.

Following the fundamental asset pricing equation, the price of a long-term bond is determined by the risk-adjusted expected valuation of future pay-offs,

$$p_t^l = 1 + \delta_c \mathbb{E}_t[m_{t+1}^* p_{t+1}^{l-1}],$$

where δ_c is the coupon decay rate that controls the duration of the bond.[16] The continuously compounded yield for the bond, r_t^l, and its risk-neutral counterpart, $\hat{r}_t^l$, are therefore given by

$$r_t^l \equiv log\left(\frac{\delta_c p_t^l}{p_t^l - 1}\right) \qquad \text{and} \qquad \hat{r}_t^l \equiv log\left(\frac{\delta_c \hat{p}_t^l}{\hat{p}_t^l - 1}\right).$$

As guaranteed by the absence of arbitrage in the bond markets, we compute the nominal term premium, tp_t^l, as the difference between the yield on the long-term bond and the yield on the equivalent risk-neutral bond:

$$tp_t^l = r_t^l - \hat{r}_t^l, \tag{11}$$

hence the term premium reflects the compensation that risk-averse investors require in order to be exposed to maturity risk.

A novel feature of our setup is that the valuation of long-term bonds depends on the nominal stochastic discount factor of the households, subject to risk perception shocks, ϵ_t^{rp}, such that

$$m_{t+1}^* = \frac{\beta_P}{\pi_{t+1}}\left(\frac{c_t^P}{c_{t+1}^P}\right)^{\psi}\left(\frac{V_t'}{V_{t+1}}\right)^{\alpha_{EZ}} + \epsilon_t^{rp},$$

where $\epsilon_t^{rp} = \rho_{rp}\epsilon_{t-1}^{rp} - \varepsilon_t^{rp}$, for $\varepsilon_t^{rp} \sim N(0, \sigma_{rp})$. The risk perception shock enters the stochastic discount factor that prices long-term assets negatively, so that a positive shock lowers the marginal utility growth rate, as prospects for the future valuation of bonds worsen. Since the demand (and hence price) of long-term bonds goes down, long-term yields increase via the term premium, as the risk-neutral yield remains unaffected by the shock. Notice that our risk perception shock is not a preference shock, as it only enters the nominal stochastic discount factor that prices bonds, m_{t+1}^*, i.e. 'investors' stochastic discount factor', and not m_{t+1}, so it acts more like a wedge when it comes to asset prices rather than a fundamental change in agents' beliefs. This setup is intuitive in that one can imagine how an event or news that trigger a higher perception of risk might cause households to change their portfolio allocations immediately but still not alter their consumption patterns. The idea that there is a wedge between the actual household stochastic discount factor and the discount factor used to price risk premia is similar to Ellison and Tischbirek (2018), who decomposed the real term premium at any maturity into covariances of realised stochastic discount factors and covariances of expectations of stochastic discount factors which differ due to informational assumptions. Furthermore, we model the risk perception shock as an AR(1) process following the empirical evidence supporting the idea that investors' perceived declines

[16] We use an adjusted formula of Macaulay duration $D = \frac{(1+i)}{(1+i-\delta_c)}$ and solve it for δ_c with $D = 40$ periods to mimic a ten-year zero-coupon bond for which duration is equal to maturity. Note that $\delta_c < \beta^{-1}$ is the upper bound that defines an infinite duration bond.

in the term premium are persistent (see Adrian et al., 2013).[17] This assumption is also consistent with the literature on uncertainty or credit risk shocks being persistent, as in Christiano et al. (2014).

Government Sector

For simplicity, we assume that all government spending, G_t, is financed exclusively via long-term bonds. The budget constraint of the fiscal authority is thus expressed as current government spending plus the repayment of interest on the previous debt which cannot exceed the value of current long-term bonds, b_t^l,

$$G_t + r_t^l b_{t-1}^l = b_t^l.$$

Government spending follows a stationary AR(1) process

$$G_t = (1 - \rho_g) G^{SS} + \rho_g G_{t-1} + \varepsilon_t^g,$$

where G^{ss} is the steady state value of government consumption, ρ_g captures the degree of autocorrelation in fiscal policy, and ε_t^g is a government spending i.i.d. shock with variance σ_g.

Market Clearing and Aggregation

Goods and labour markets clear. The resource constraint of the economy is

$$Y_t = C_t + q_t^k \left(K_t - \left(1 - \delta^k \right) K_{t-1} \right) + \frac{\delta^b K_{t-1}^b}{\pi_t} + G_t,$$

as it is a closed economy with Rotemberg pricing.

4.2 Solution and Calibration

Since the dimension of the model is relatively high with 14 state variables, our only feasible option to solve the model is through perturbation methods. As the term premium needs to be time-varying, we use third-order solutions to ensure realistic dynamics.[18] We apply pruning to cut out unstable higher-order explosive terms. The advantage of using third-order solutions is that the macroeconomic responses remain mostly unchanged, and thus correspond to results in the previous literature, while the responses for the bond markets can be rendered more realistically. A potential disadvantage of this methodology is that the solution method is inherently local and is only valid around the steady state, so that larger shock variances might lead to more inaccurate results. As estimation of larger-scale, non-linear models is still difficult, we follow Rudebusch and Swanson (2012) and calibrate our model to fit specific moments for both macroeconomic, as well as financial variables. Table 2 reports the values of the calibrated parameters for the baseline model.

[17] Li et al. (2017b) empirically estimate the effect of changes in U.S. term premia, concurrent with changes in implied U.S. equity volatility and the broad dollar exchange rate index, and find that the effect of a U.S. term premium shock is persistent with a significant estimate of the autocorrelation coefficient of 0.78.

[18] Caldara et al. (2012) show that perturbation methods provide equally accurate solutions to models with recursive preferences than Chebychev polynomials and value function iterations, but are considerably faster.

Most of these values are standard and based on previous estimates for U.S. data. For the households, the discount factors are set such that β_P implies an annual interest rate of 2% and $\beta_P > \beta_E$ ensures that entrepreneurs are more impatient. ϕ is based on the inverse of the Frisch elasticity being 1/2. ψ is based on the IES being 0.25, in line with previous micro-founded studies which find the IES to be smaller than one (e.g. Vissing-Jørgensen, 2002). We set the Epstein-Zin parameter $|\alpha_{EZ}| = 2$ to match the term premium moments. Using the constant relative risk aversion (CRRA) formula in Swanson (2010), this number implies an overall CRRA of 4. This is a remarkable low result in the macro-finance literature –in which estimates often range from 30 to 110 (e.g. Rudebusch and Swanson, 2012)– being consistent with the low estimates found in the macro literature (see Havranek et al., 2015 for a meta-study). One of the reasons why we can match bond premium moments without a particularly large CRRA is by having a larger model with more shocks including a shock to the stochastic discount factor.

Table 2: Calibrated Parameters

Parameters	Value	Parameters	Value	Parameters	Value
Households		Finance		Shocks	
β_P	0.995	θ	11	ρ_a	0.9
β_E	0.96	ν	0.09	ρ_{mk}	0.9
ϕ	2	$\overline{\mu}_b$	0.0050	ρ_g	0.9
ψ	4	δ_c	0.9848	ρ_{me}	0.9
α_{EZ}	-2			ρ_{ib}	0.6
				ρ_{rp}	0.9
Production		Monetary Policy			
mk^{ySS}	1.2	ϕ_π	2	σ_a	0.007
α	0.3	ϕ_y	0.5	σ_{mk}	0.005
κ_P	28.65			σ_g	0.005
κ_i	0.5	Steady State Ratios		σ_{me}	0.005
δ_k	0.050	$\frac{K^{ss}}{Y^{ss}}$	$\frac{10}{3}$	σ_{ib}	0.003
π^{ss}	1	$\frac{G^{ss}}{Y^{ss}}$	0.19	σ_{rp}	0.005

The production parameters are standard. The price elasticity of demand is assumed to be 6, which implies $mk^{ySS} = 1.2$. The adjustment cost for prices, modelled via Rotemberg pricing, follows the estimated values by Gerali et al. (2010), as do the adjustment cost for investment, κ_i, and the adjustment cost for banks, θ. The capital share is assumed to be 0.3, and the rate of depreciation follows an annual depreciation rate of 20% (5% quarterly). The banking parameter, ν, is set to match the Basel capital target ratio of 0.09. The decay rate for consol bonds, δ_c, is set to match the 10-year bond duration. The monetary policy rule parameters reflect that the central bank targets both inflation and output with a stronger weight on inflation in line with the literature. The shock parameters are set to standard values, with the persistence of shocks being 0.9. The standard deviations of the shocks are set between 0.3–0.7 percentage points, depending on the volatility of the respective variable. Finally, the steady state capital/output and government spending/output ratios are set to reflect the long-run macroeconomic relationship between those variables.

To evaluate the fit of the model, we compare both macroeconomic as well as asset price moments implied by the DSGE model to the data. We use quarterly U.S. data for chained GDP, consumption, investment, and labour. The Hodrick-Prescott filter is used to compute the business cycle component of the log of these macroeconomic variables. We also include the standard deviations of quarterly private and public loan growth used in Section 3. For inflation, the interest rate, and the term premium annualised data are used. The interest rate is the shadow Federal Funds rate, and inflation is calculated using the GDP deflator. The term premium is the ten-year Treasury term premium from the Federal Reserve Bank of New York (Adrian et al., 2013). Details can be found in the Data Appendix A.3.

Since we use third-order approximations, theoretical moments are infeasible to compute analytically, so we use simulated moments instead. Table 3 shows the results for the baseline calibration. The model performs very well in matching all the key moments: the standard deviation of output and the term premium are under 0.5% of their data variation. Investment, consumption and labour deviate within 20% from the data moments. However, the variance of the interest rate is slightly further away from its data standard deviation, as we use the shadow rate and find more volatility in the interest rate than is reflected empirically, which explains the small discrepancy when matching the variance generated by the model.

Table 3: Comparing Simulated Model Moments with Actual Data

	Unconditional Moments	U.S. Data 1961--2016 (1961--2007)	Model
Output	$SD[Y]$	1.46 (1.46)	1.46
Consumption	$SD[C]$	0.85 (0.83)	0.99
Investment	$SD[I]$	4.08 (3.95)	4.53
Labour	$SD[l]$	2.10 (1.97)	1.66
Inflation	$SD[\pi]$	2.45 (2.52)	2.36
Short-term rate	$SD[r^{ib}]$	3.20 (2.70)	1.76
Term premium	$\mu[tp^l]$	1.62 (1.74)	1.69
	$SD[tp^l]$	1.19 (1.20)	1.20

Notes: All variables are reported in quarterly percentage points except for inflation, the interest rate, and the term premium which are converted into annual frequency. For robustness, we compute the unconditional moments for both data from 1961-2016 and data excluding the financial crisis from 1961-2007 in parentheses. The model moments are computed by simulating the data 224 times to be consistent with the duration of the actual data.

Our calibration also manages to match the term premium mean very closely within 4% of the data mean. Matching both the term premium mean and variance so closely is in itself remarkable, as a linear model or a model without Epstein-Zin preferences would not generate a positive term premium at all, and even with Epstein Zin preferences, the risk aversion parameter would often have to be very high to get any meaningful variation in the model.[19]

[19]Note that Rudebusch and Swanson (2012) use fourth-order solutions to compute the variances of finance moments

4.3 Results for a Risk Perception Shock: When investors Panic

We begin by analysing how a risk perception shock affects the macroeconomy. As in the empirical section, we interpret a risk perception shock as a temporary, exogenous change in the nominal stochastic discount factor of investors. Figure 4 reports the results for a risk perception shock that generates a 90 bps increase in the term premium, which corresponds to the size of the empirical one standard deviation shock in Section 3. This shock is comparable to the increase in the term premium that was experienced in the initial stages of the Global Financial Crisis.[20]

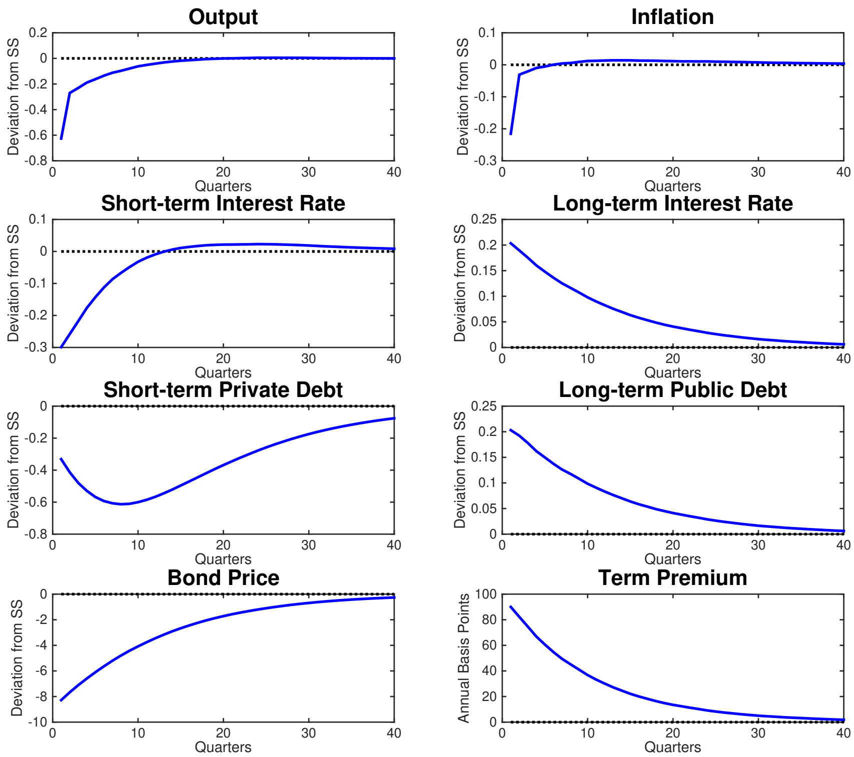
A 90 bps rise in the term premium has a negative effect on the macroeconomy with both output and inflation declining. The central bank reacts to this shock by decreasing the short-term interest rate, while the long-term interest rate, as a consequence of the rise in the term premium, increases. With the long-term rate increasing, acquiring long-term public debt becomes more profitable and increases. Moreover, with the price of government bonds decreasing, banks pass on the higher rates in form of higher borrowing rates to the private sector, which leads to a decline in short-term loans to the private sector, as borrowers are less willing to take out a loan at higher rates. This would constitute a loan price channel. Another channel in our model that would amplify this effect and reduce borrowing, is the collateral channel. As borrowers are subject to a binding credit constraint, an increase in the cost of borrowing would reduce the amount that entrepreneurs can borrow in Equation (3). These results are consistent with the idea that an increase in the long-term rate that is orthogonal to the expected path of average future short-term rates, reflects higher perceived risk in financial markets, inducing households to save more and consume less, prices to go down, and output and investment to contract. The persistence of the response suggests that a risk perception shock has long-term consequences for financial stability. These results are also in line with the responses observed in Section 3. While inflation and the short-term interest rate do not respond with statistical significance in the empirical model, they are both negative in the DSGE model, suggesting that the risk perception shock behaves similar to a demand shock. This interpretation is consistent with short-term private debt both decreasing in the empirical and the DSGE model as a consequence of the higher cost of private borrowing. In contrast, both empirically and in the model, long-term lending to the government increases. The economic mechanism is as follows: as risk perceptions in the economy increase, agents demand a higher term premium to be compensated for the risk of holding longer-term assets. With the term premium increasing, the return on the long-term bond increases, and the price decreases. As banks optimise between lending short term out to entrepreneurs and buying long-term government bonds, they adjust their loan rate in line with the increase in the return, so that the rate on private loans increases, as well. While the higher return on government debt implies an increase in the demand from banks to purchase these higher yielding assets (demand effect: price and quantity increase), the increase in the rate for private loans can be understood as an upwards

and achieve a standard deviation of 0.47.

[20]Note that we use linear scaling to make the theoretical responses comparable to the empirical shock size of 90 bps, as the shock variance in the baseline calibration is much lower at 0.005 in order to match the correct moments. Technically, using higher-order solutions allows for different shock sizes to results in asymmetric responses. However, larger variances are also likely to cause oscillating behaviour. We indeed find a slightly more oscillating response in bond prices, and the short term interest rate, when using a shock variance of 90 bps, indicating that the model solution might be more unstable for larger variances. However, most other responses are both quantitatively and qualitatively very similar.

shift of the bank's supply curve for private loans (supply effect: price increases and quantity decreases). With higher repayments rate, borrowers are less willing to borrow and thus reduce the quantity of private loans. The persistence of the monthly empirical model is matched for most variables, however, the magnitudes for loans are much smaller than for the empirical model.

Figure 4: Impulse Responses to a Risk Perception Shock



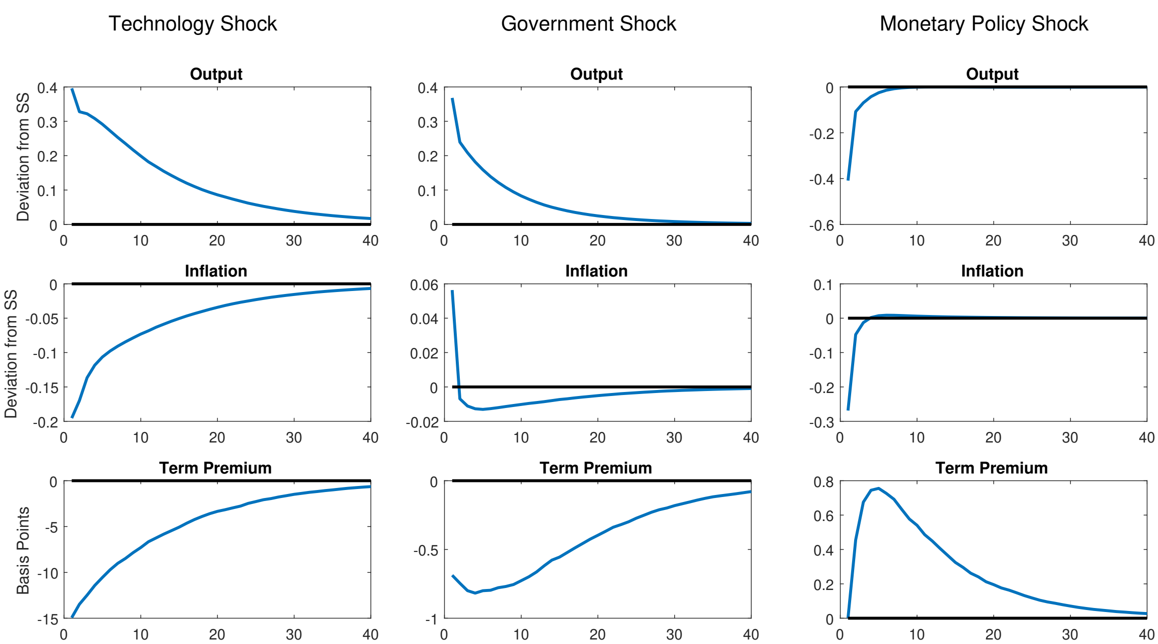
Notes: The blue line represents the impulse responses from the theoretical DSGE model using the baseline calibration.

Overall, the results of the theoretical model are in line with the previous literature on uncertainty shocks (e.g. Leduc and Liu, 2016) in that the risk perception shock seems to correspond with a demand shock. The macroeconomic responses to the risk perception shock are also consistent with recent findings in the finance literature, in which Joslin et al. (2014) identify that both economic activity and inflation significantly decline when a canonical term structure model of interest rates incorporates macroeconomic fundamentals beyond the information spanned by the yield curve. Although not a general equilibrium framework, their model allows future bond prices to be influenced by yield curve factors as well as macroeconomic risks, which in turn account for variation in the term premium. Finally, the DSGE model responses to an increase in the term premium confirm and refine the findings in our empirical section, which show that a risk perception shock lowers output, and short-term private loans, while increasing long-term bank lending to the government sector.

4.4 Robustness

In order to validate our results, we conduct a number of robustness checks. First, we analyse the impulse responses of traditional macroeconomic shocks as well as their effect on the term premium to cross-check that their responses are consistent with economic theory. The responses to a positive, one standard deviation technology, government spending, and monetary policy shock are reported in Figure 5. The left column shows the results for a technology shock, which can also be interpreted as a supply-side shock. As is standard in the literature, a technology shock increases output and lowers inflation. Consistent with the findings outlined in Rudebusch et al. (2007), a technology shock reveals a negative relationship between output and the term premium, which declines as a result of stronger economic activity associated with higher productivity.

Figure 5: Impulse Responses to Classic Macroeconomic Shocks



Notes: The blue line represents the impulse responses from the theoretical DSGE model using the baseline calibration. The shock size is a positive one standard deviation shock to the corresponding macroeconomic variable. The y-axis represents percentage deviation from steady state with the exception of the term premium, which is presented in basis points. The x-axis indicates quarters.

In the middle panel, a government spending shock that represents a shock on the demand side, raises both output and inflation, while the term premium declines. The term premium declines, as the average expected future short-term rate due to the monetary policy response to higher output and inflation is higher than the increase in the long-term rate.

The right-hand-side column shows the responses to a contractionary monetary policy shock. A contractionary monetary policy shock induces less persistent responses and implies, as expected, a decrease in output and inflation, with a positive term premium response.[21]

We next check the sensitivity of the responses with respect to the calibrated parameters. Interestingly, changing the banking or production parameters has very little effect on the term premium. Instead, it seems that the term premium moments are mostly driven by household parameters. The dynamics of the model are, however, relatively robust to changes in the parameters, as seen in Figure C.1 in the Appendix. By solving the model using standard first-order solutions, the Epstein-Zin preferences are equivalent to a standard CRRA preference function. Note that in our case, the expectation hypothesis will not necessarily hold even for the first-order approximation, as the term premium can still move due to exogenous shocks, although it will be zero on average.

The shock to risk perception, in this case, has larger effects on both short-term private and long-term public debt, however the transmission to output is marginally weaker, as the macro-financial linkages are simplified under the first-order conditions. Changing the Epstein-Zin risk preference parameter to be smaller, so that the implied CRRA coefficient would be 2, does not change the responses significantly. Increasing the IES parameter implies a stronger response of the term premium which is then translated into the other variables. The investment adjustment cost parameter matters quite significantly for the transmission. Changing it by a factor of 10 from 0.5 to 5, unsurprisingly implies that the drop in lending is far less severe, although the short-term rate drops by more, causing a sharper decline in the macroeconomic variables. Also, increasing the Frisch parameter means a faster recovery in private debt, although it does not transmit to the macroeconomic responses, which again only marginally change. The response is similar if increasing the impatience factor of borrowers.

We can conclude that our model manages to capture a) the basic macroeconomic dynamics, (b) the term premium moments, and c) the effects of long-term risk perception shocks. Our framework conforms with standard macroeconomic theory and is robust to different parameter specifications. The main transmission channel of a risk perception shock is still present when using first order solutions, although the implied term premium mean would be zero in the model which is at odds with the data. Unlike previous studies, we do not have to make any specific assumptions on the type of risk perception that feeds into investors' valuation of assets and how it might affect the macroeconomy.

5 Financial Stability and Credit Booms

5.1 When Investors Under-Price Risk

With the unfolding of the Financial Crisis, there has been a surge in both empirical and theoretical models trying to explain the underlying causes of financial market fluctuations. While recessions are a normal feature of business cycle dynamics, a consensus emerged that recessions following a credit fuelled boom are particularly damaging to the economy (Minsky, 1986; Borio and Lowe, 2002; Kindleberger and Aliber, 2011; Claessens et al., 2012; Jordà et al., 2013). Dell'Ariccia et al. (2016) found that one

[21] Mallick et al. (2017) investigate the role of monetary policy shocks on the term premium, where pre-2008 they use the Federal funds rate as the main monetary policy instrument and post-2008 they instead use Fed asset purchases and three-month Federal funds futures. Both empirical identification strategies of monetary policy shocks lead to statistically significant effects on the term premium, although through different mechanisms.

third of all credit booms are followed by a financial crisis and 60% are followed by lower economic performance. As such, a distinction that is often made is between a 'good' credit boom and a 'bad' credit boom. While both booms increase output and the availability of credit, a good boom is based on fundamentals in the economy improving, such as higher productivity or technological innovation (e.g. Kydland and Prescott, 1982). In contrast, we define a bad boom as a credit boom that is solely based on sentiment or 'animal spirits' and is thus likely to mean revert, once agents realise their mistake. An event that triggers the reversal in expectation, i.e. a Minsky moment, could likely set off a chain reaction that could induce a financial crisis and/or a recession. From a financial stability perspective, a bad boom could therefore have devastating consequences on financial markets and the real economy. Beaudry and Willems (2018), for example, found cross-country empirical evidence that over-optimism about the economic prospects of a country that later on fail to materialize, lead to excessive borrowing and is therefore associated with future economic recessions.

We model these two different types of booms using the baseline calibration from Section 4.2. To give a fair comparison, we calibrate both good and bad booms to peak at 10% after seven periods of consecutive growth. Figure 6 reports the results for a bad credit boom driven by risk perception shocks that lead investors to under-price risk as the blue, solid line, whereas the good credit boom, driven by real economy productivity shocks, is depicted with the red-dashed line.

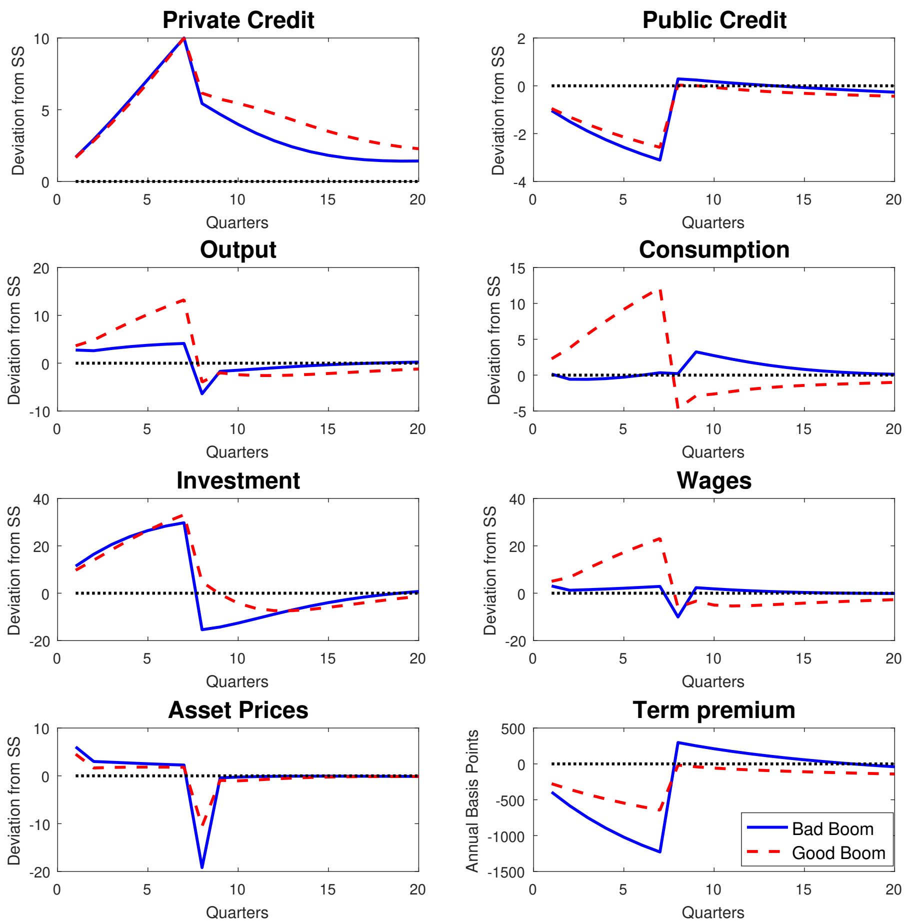
For the bad boom scenario, agents under-price the actual risk in the economy because they perceive risks, for some exogenous reason, to be lower. In modelling terms, the economy is hit by a series of small positive risk perception shocks for the duration of 7 quarters. We then assume that an exogenous event occurs making them realise that they have not priced risk correctly, which means they reverse their risk perception to the original baseline (i.e. a negative risk perception shock that equals the sum of the positive shocks hits in period 7). For a good boom, economic fundamentals improve due to a series of positive technology shocks, and, to give a comparison, then reverse back to the baseline in period 7. The path of private credit is calibrated to be similar in both cases. This also leads investment to follow a similar path, although this is where the similarities end. Most notably, the response of output is much weaker during the bad boom than for the good boom. However, for the reversal, the bad 'bust' is more severe than for the good boom equivalent. This would indicate that the transmission from the financial sector to the real economy in terms of credit is weaker during a bad boom, while worse during a bust.[22]

Some of the explanation for this result lies in the response of consumption and wages. While the increase in fundamentals during the good boom improves productivity, which in turn increases wages and consumption, the bad boom shows neither of these macroeconomic effects. Instead, the main effects of the bad boom are present in financial markets with the term premium dropping significantly and asset prices marginally increasing more in the boom, but then also contracting more in the bust. These simulation exercises can be used to highlight how crucial it is for policy makers to distinguish between a good and a bad credit boom. While both are characterised by higher private sector credit growth, their effects on the real economy are very different. From a financial stability perspective, intervening in a

[22]It should also be noted that the only non-linearity we assume in the model is the one arising due to the higher order perturbation method with which we solve the model. The effects of a bust are likely to be larger when accounting for other non-linearities like occasionally binding constraints (see e.g. Bluwstein, 2017).

bad boom would therefore has less macroeconomic implications for output than previously thought.

Figure 6: A Bad Credit Boom versus a Good Credit Boom Scenario

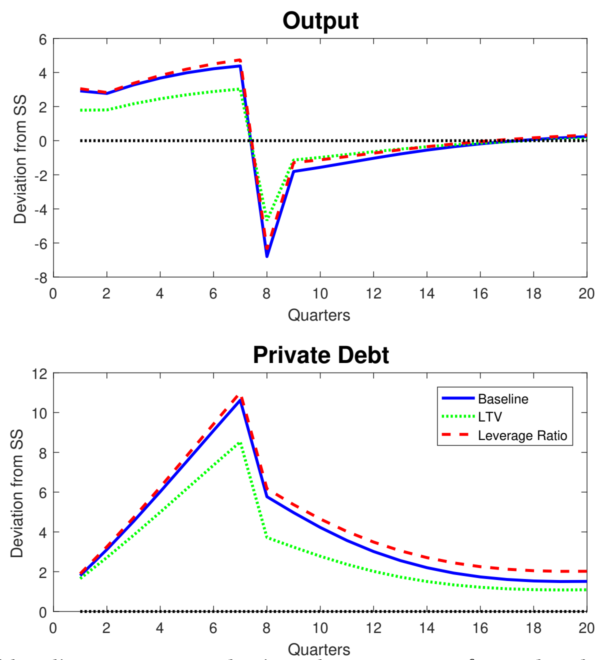


Notes: The blue line represents the impulse responses from the theoretical DSGE model using the baseline calibration and the bad credit boom scenario. The red dotted line represents good credit boom scenario. The scenario corresponds to 7 consecutive periods of a positive risk perception shock/ positive technology shock, with a reversal shock in the 7th period.

5.2 Macroprudential Policies

Financial stability policy makers are tasked with identifying bad credit booms in advance and build up resilience against a potential burst that could be harmful for the economy, as we have seen with the 2008-2009 Great Recession. Policy makers are hence given powers over macroprudential policies to ensure the resilience of the financial system. We test two specific types of macroprudential policies that the financial stability authority can implement in our model: (a) a macroprudential policy that changes the banks' required capital/asset ratio, ν, and (b) a macroprudential policy that decreases the steady state of the LTV ratio of entrepreneurs, $m^{E,SS}$. Capital ratios are targeted in particular at lenders' solvency, whereas LTV ratio aims to improve borrowers' solvency and should help to avoid unsustainable debt levels. As an illustrative example, we assume an increase of the capital/asset ratio from 0.09 to 0.12, so that banks are encouraged to have a larger capital buffer with respect to their assets. In a similar vein, we analyse a reduction of the LTV target ratio for entrepreneurs from 0.35 to 0.2625 implying that entrepreneurs need to back up the same quantity of loans with more collateral than before. Both measures, a contractionary change in the baseline values by 25%, are intended to make the financial system more resilient.

Figure 7: A Bad Boom under Different Macroprudential Policy Scenarios



Notes: The blue line represents the impulse responses from the theoretical DSGE model using the baseline calibration. The red dotted line represents a scenario under a higher leverage ratio, whereas the blue dashed line corresponds to a scenario under a lower LTV target ratio. The scenario corresponds to 7 consecutive periods of a positive risk perception shock, with a reversal shock in the 7th period.

As Figure 7 shows, both tighter LTV and leverage ratio restrictions help to reduce the drop in output. The increase in the leverage ratio means that banks hold more capital. In this scenario, the increase in capital is not enough to induce banks to decrease credit to the private sector, so that private debt and output only change marginally. The LTV tightening, on the other hand, works directly via a reduction in the quantity of loans that borrowers can take out, which also reduces output volatility more significantly. A similar result is found by Caballero and Simsek (2017) who showed that macroprudential policies can be welfare improving by reducing the risk-taking behaviour of overly optimistic agents. In this simulation, macroprudential policy targetting borrowers is more effective in reducing the volatility of the bad boom and bust than policy aimed at lenders. Which policy is preferred will depend on the exact specification of the calibration and the policy makers preference function which is beyond the scope of this paper.

6 Conclusion

We construct a novel unifying model of asset pricing and bank lending and show that incorporating a feedback loop via the term premium is an important feature to help quantify the effects of long-term risk perception shocks in financial markets via the stochastic discount factor of investors. Both empirically, as well as in a DSGE model, risk perception shocks have real macroeconomic consequences and can affect lending conditions in the financial sector. Our model generates a time-varying term premium, which allows us to match both macro and finance moments. It confirms that risk perception shocks, which can occur during a panic and lead investors to over-price risk, reduce the volume of riskless short-term private loans in favour of long-term government bonds due to the loan price and collateral channels, and reduce output by a significant amount.

Our simulation also shows that a bad credit boom driven by agents under-pricing risks is very different from a credit boom driven by economic fundamentals. Whereas a good boom increases wages and consumption and translates very positively to output, a bad boom has only muted effects on output, consumption, and wages, and induces a more severe recession, when a reversal occurs. Furthermore, we demonstrate how our model can be used for macroprudential policy analysis using the example of an increase in the leverage ratio and a reduction in the loan to value ratio.

There are many avenues in which the model can be extended. In terms of the banking sector, one useful addition to explore another risk channel would be to allow for private loans to default endogenously and thus generate another source of risk in the model beyond duration risk. By introducing the possibility of corporate default, one could endogenise the risk premium that is charged on top of private loans based on the relative riskiness of private debt over government debt. An example could be the extension proposed by Swanson (2016) incorporating defaultable debt or equity risk. Note also that in our current version, the reason for changes to risk perceptions, and thus the under- or over-valuation of bond prices, is completely exogenous. In reality, these perception might have an endogenous cyclical nature. Another interesting avenue to pursue would be to estimate the model formally. Especially, the household parameters, which are crucial to pin down both the macroeconomic, as well as asset price behaviour, would benefit from estimation. As methods that allow to estimate a model to the third order (see e.g. Andreasen et al., 2018) are still difficult to implement for high-dimensional models, we shall leave this possible extension for future investigation.

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Appendix

A Data Appendix

A.1 The Term Premium as a Measure of Risk Perception

- The term premium is the ten-year Treasury average term premium from the Federal Reserve Bank of New York, developed by Tobias Adrian, Richard Crump, and Emanuel Moench, which can be downloaded at https://www.newyorkfed.org/research/data_indicators/term_premia.html. For details on the methodology refer to Adrian et al. (2013). Data from January 1961 to May 1961 are extended back using the growth rate of the ten-year Treasury note yield at constant maturity from the Federal Reserve Board.

- The civilian unemployment rate for individuals 16 years of age and older is seasonally adjusted and obtained from the Bureau of Labor Statistics.

- The monthly economic policy uncertainty index was developed by Scott Baker and Nicholas Bloom of Stanford University and Steven Davis of the University of Chicago. For more details refer to Baker et al. (2016). Inflation Uncertainty and Policy Uncertainty are proxied by the dispersion in the consumer price index, purchase of goods and services by state and local governments, and purchases of goods and services by the federal government.

- Interest rate volatility is proxied by the Merrill lynch Option Volatility Estimate (MOVE) Index, which is a yield curve weighted index of the normalised implied volatility on one-month Treasury options which are weighted on the 2, 5, 10, and 30 year contracts.

A.2 The Impact of a Risk Perception Shock: Empirical Approach

Monthly from 1961-M01 to 2016-M12, expressed in annual terms.

- Output is the seasonally adjusted annual log change of the industrial production index (2012=100) from the Federal Reserve Bank of St. Louis.

- Inflation is the annual percentage change in the U.S. Consumer Price Index (SA, 1982-84=100) from the Bureau of Labor Statistics.

- The nominal shadow short-term interest rate is computed as the average discount rate from 1961-M01 to 1961-M12; the end-of-period discount rate from the Federal Reserve Bank of New York from 1962-M01 to 1982-M06; the Federal Funds Target rate from 1982-M07 to 2008-M12 and from 2015-M10 to 2016-M12; and the Wu-Xia shadow Federal Funds rate from 2009-M01 to 2015-M09.

- Commercial and Industrial loans is the annualised log growth of end-of-period loans for all commercial banks (SA, Bil.$) from the Federal Reserve Bank of St. Louis.

- Public loans is the annualised log growth of end-of-period loans Treasuries and Agency Securities for all commercial banks (SA, Bil.$) from the Federal Reserve Bank of St. Louis.
- The junk-bond spread is the Moody's seasoned Baa corporate bond yield (% p.a.) minus the ten-year Treasury note yield at constant maturity (% p.a.) from the Federal Reserve Board.
- The Chicago Board Options Exchange Volatility Index (VIX) from Bloomberg, 1990–2017, reflects a market estimate of future volatility, based on the weighted average of the implied volatilities for a wide range of strikes. 1st & 2nd month expirations are used until 8 days from expiration, then the 2nd and 3rd are used.

A.3 The Impact of a Risk Perception Shock: DSGE Model

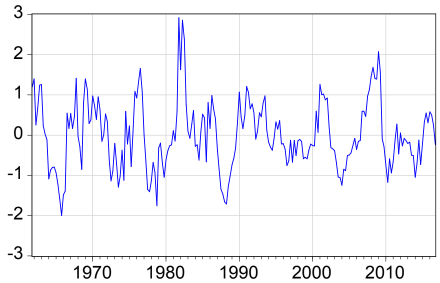
Quarterly from 1961-Q1 to 2016-Q4, expressed in annual terms. * HP filtered to extract the cyclical component.

1. Consumption*. Real personal consumption is computed as the period-to-period log growth rates of real expenditures of non-durable goods and services (SAAR, Bil.$), averaged using their shares in nominal expenditures. The weighted average growth rate is applied to the sum of nominal expenditures in both categories in 1961-Q1 to produce chained real consumption with a base of 1961-Q1.
2. Investment*. SSAR, Chn.2009$ log growth of the private domestic investment of chained real GDP.
3. Labour*. Computed as the amount of aggregate weekly hours of total private production and non-supervisory employees (SA, Thous.), multiplied by number of weeks in the quarter to produce quarterly hours of labour. Since the data start in 1964-Q1, business sector compensation per hour (SA) from the Bureau of Labor Statistics is used to extend the series backwards to the start of the dataset.
4. Inflation. Inflation is annualised log growth rate of the chain price index of GDP.
5. Output*. Seasonally adjusted annual log growth rate of chained real GDP.
6. Short Rate. The short-term nominal interest rate is computed as the average discount rate from 1961-Q1 to 1961-Q4; the end-of-period discount rate at Federal Reserve Bank of New York from 1962-Q1 to 1982-Q2; the Federal Funds target rate from 1982-Q3 to 2008-Q4 and 2015-Q4 to 2016-Q4; and the Wu-Xia shadow Federal Funds rate from 2009-Q1 to 2015-Q3.

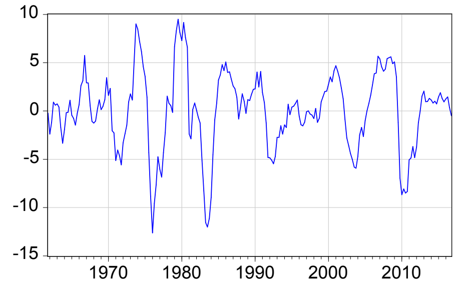
Table A.1: Data Sources and Summary Statistics (1961-2016)

Variable	Name	N	Mean	St. Dev.	Min	Max	Source
Quarterly Data							
C_t	Consumption	224	0.00	0.85	-2.00	2.92	Bureau of Economic Analysis
I_t	Investment	224	0.00	4.08	-12.62	9.50	FRB St. Louis
l_t	Labour	224	0.00	2.10	-6.71	4.71	Bureau of Labor Statistics
π_t	Inflation	224	3.42	2.45	-0.62	12.77	Bureau of Economic Analysis
Y_t	Output	224	0.00	1.46	-4.78	3.75	FRB St. Louis
r_t^{ib}	Short Rate	224	4.79	3.51	-2.92	14.00	FRB, FRB Atlanta
tp_t^l	Term Premium	224	1.64	1.19	-0.59	4.94	Federal Reserve Board
Monthly Data							
y_t	Output	672	1.41	3.85	-15.89	7.44	FRB St. Louis
π_t	Inflation	672	3.85	2.89	-1.96	14.59	Bureau of Labor Statistics
i_t	Short Rate	672	4.77	3.49	-2.99	14.00	FRB, FRB Atlanta
b_t^E	Private Loans	672	7.5	7.7	-20.2	25.4	FRB St. Louis
b_t^L	Public Loans	672	7.1	8.7	-13.4	38.2	FRB St. Louis
tp_t	Term Premium	672	1.64	1.19	-0.65	4.79	Federal Reserve Board

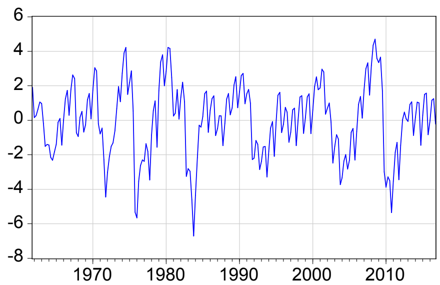
Figure A.1: Macroeconomic Variables From 1961 to 2016



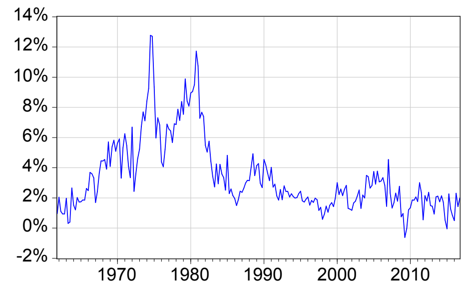
(a) Consumption



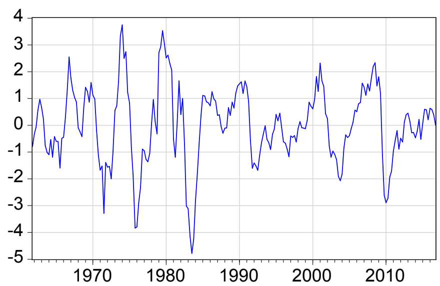
(b) Investment



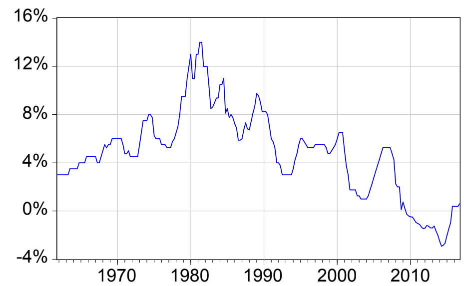
(c) Labour



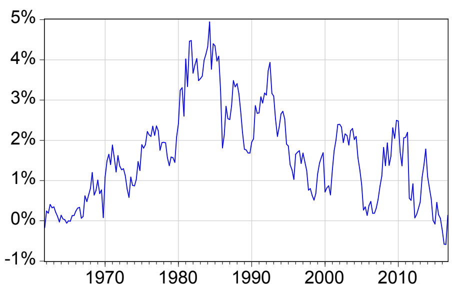
(d) Inflation



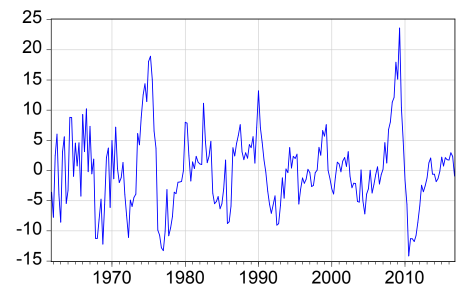
(e) Output



(f) Short Rate



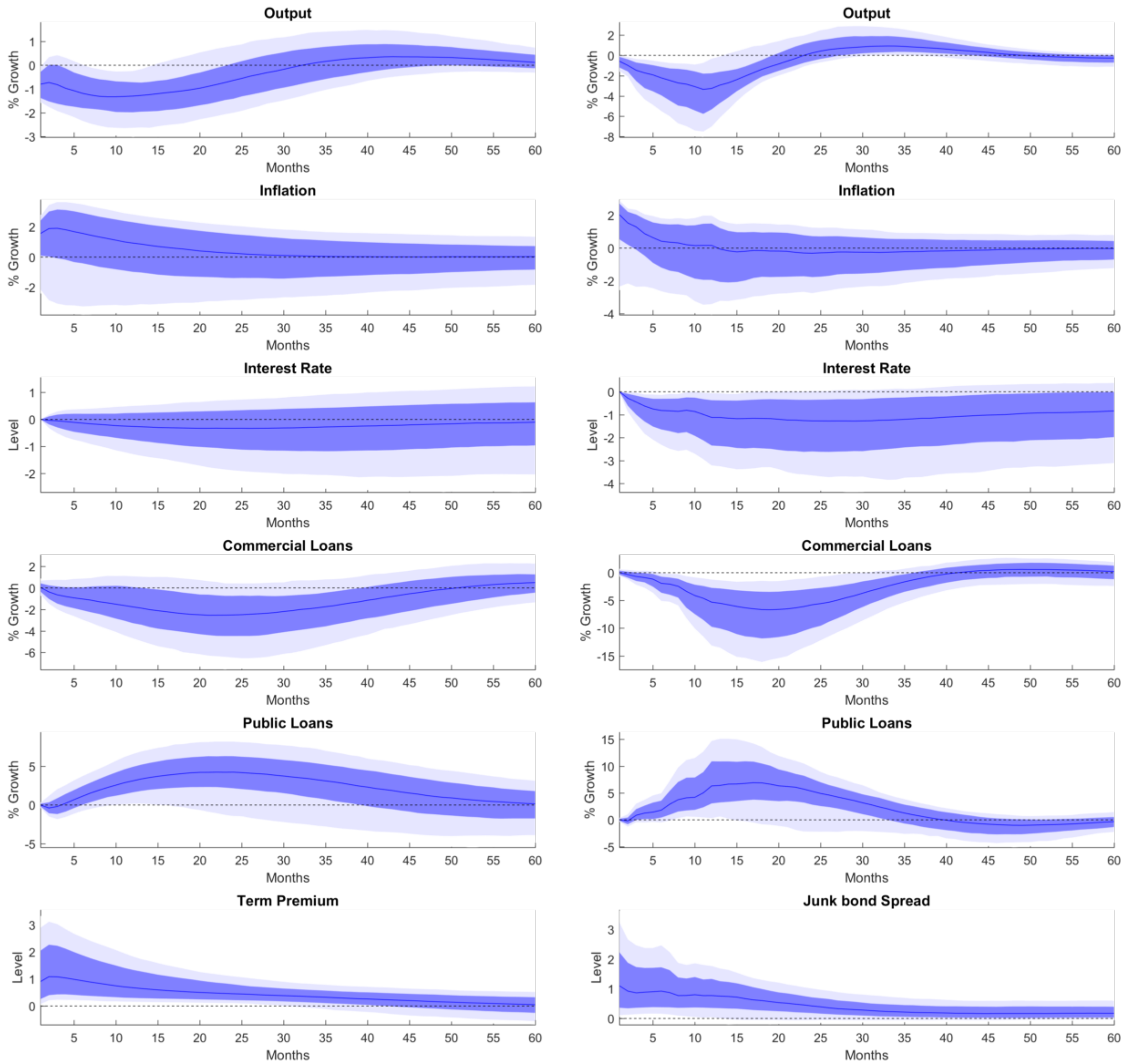
(g) Term premium



(h) Loans

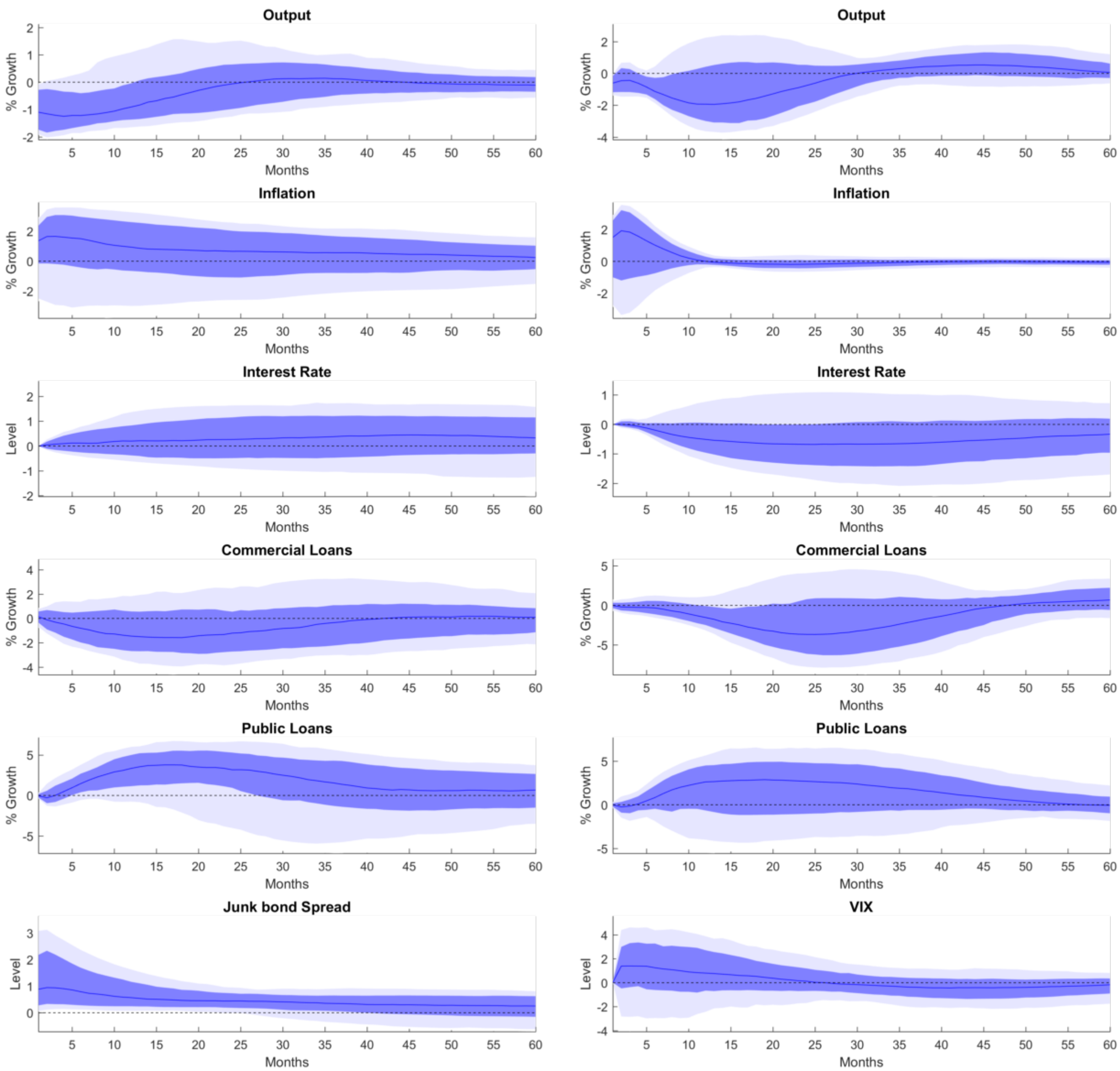
B Empirical Robustness

Figure B.1: Risk Perception Shock that Increases the Term Premium (left) and Junk-Bond Spread (right)



Notes: The solid line represents the median point estimate, while the dark and light shaded regions report point-wise 68% and 90% Monte Carlo credible sets, respectively. The shock size is a one standard deviation increase in the term premium (left column) and junk-bond spread (right column). The estimates are based on 200,000 draws of which the first 25% are discarded. For the junk-bond spread, we use 12 lags as suggested by the Bayesian information criteria.

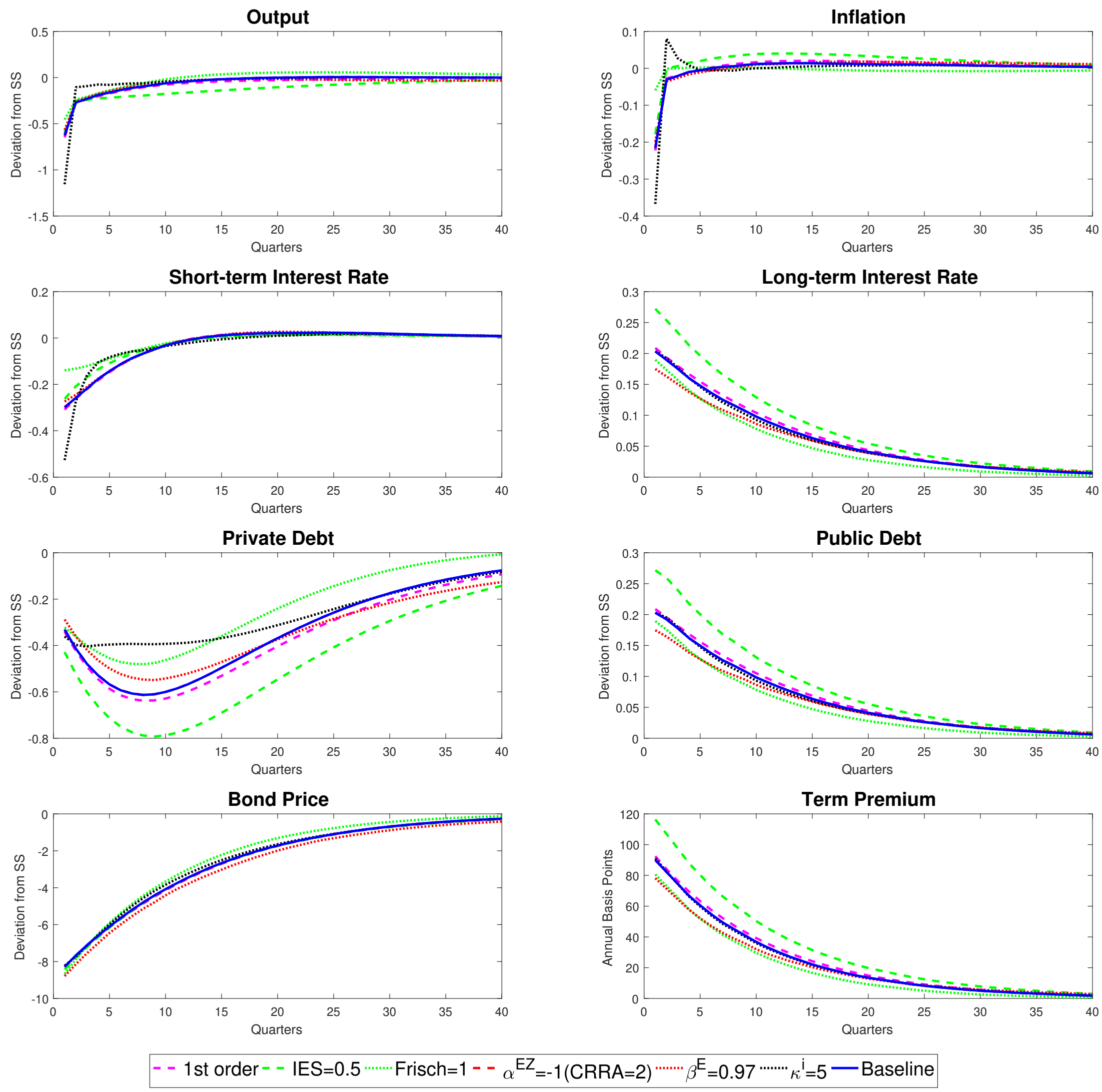
Figure B.2: Impulse Responses Excluding Financial Crisis (left) and using the VIX (right)



Notes: The solid line represents the median point estimate, while the dark and light shaded regions report point-wise 68% and 90% Monte Carlo credible sets, respectively. The shock size is a one standard deviation increase in the term premium excluding the financial crisis (left column) and the VIX (right column).

C Model Parameter Sensitivity

Figure C.1: Responses to a Risk Perception Shock under different Parametrisation



Notes: The blue line represents the impulse responses from the theoretical DSGE model using the baseline calibration. The risk perception shock increases the term premium by 90 basis points. The dotted and slash lines represent the median response under different parametrisation as specified in the legend.