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Back to the Real Economy: The Effects of Risk Mispricing on the Term Premium and Bank Lending*

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Abstract

Bond markets can plummet or rally on the back of sentiment-driven reactions which are unrelated to fundamentals. Therefore, changes in bond prices can not only be interpreted as reflecting risk but also mispricing of long-term assets. These perceived risks can often feed back into the economy by affecting the supply of credit. We construct a DSGE model with heterogeneous banks, asset pricing rules that generate a time-varying term premium, and introduce bond risk mispricing shocks to study their effects on the real economy. A risk mispricing shock, in which agents overprice perceived risk, increases term premia and lowers output by reducing the availability of credit, as banks rebalance portfolios in favor of longer-term bonds. However, when investors underprice risk, a compressed term premium leads to a ‘bad’ credit boom that results in a more severe recession once the snapback occurs.

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1 Introduction

Bond markets are generally thought to be driven by fundamentals, with prices reflecting the expected future path of short-term assets adjusted for risk. However, markets often plummet or rally on the back of changes to risk perceptions that do not necessarily stem from underlying actual risks in the economy, suggesting an occasional mispricing of risks in asset markets (e.g. Pflueger et al., 2020; Lewis et al., 2021). If market participants overprice or underprice long-term risk, can these ‘mispricing shocks’ affect credit markets and feed back to the real economy, potentially threatening financial stability?

In this paper, we develop a Dynamic Stochastic General Equilibrium (DSGE) model with a rich financial sector and bank lending that allows us to investigate the transmission mechanisms through which bond mispricing leads banks to reassess their lending behavior and ultimately impact economic activity. To this end, we introduce risk mispricing shocks, which influence the compensation for bearing long-term risk (the term premium) but are unrelated to economic fundamentals. An overpricing of risk prompts banks to rebalance their portfolios away from private sector loans and towards government bonds. We find that in addition to loans becoming more expensive, a risk mispricing shock also alters the conditions for bank credit approval, increasing the de-facto required collateral necessary to take out a loan, making access to credit yet more difficult. Even without any initial change in underlying economic fundamentals, bond mispricing can lead to a pronounced contraction in investment and economic activity, linking risk mispricing shocks to the real economy via the term premium, through changes in bank lending decisions.

Our contribution to the literature is three-fold: (1) We combine a banking sector that is subject to macroprudential regulation with asset pricing rules for long-term bonds in order to investigate how changes in financial markets affect credit allocation to the real economy. (2) The rich structure of our general equilibrium model and non-linear solution technique enable us to match both macroeconomic and term premium moments to the data. (3) By introducing a wedge to the stochastic discount factor of financial agents, we model a shock that mimics how financial markets and the real economy respond to the mispricing of long-term risk.

Our framework allows us to investigate lending conditions by differentiating between a ‘good’ credit boom driven by economic fundamentals versus a ‘bad’ credit boom driven by agents underpricing risk in the economy. We find that a bad credit boom that leads to a compressed term premium despite...
unchanged fundamentals, is less supportive of economic growth than a good credit boom. Moreover, once agents correct their mistake and price risk accordingly, the term premium snaps back and output falls more sharply. A bad credit boom has stronger effects on financial markets than a good credit boom. Nonetheless, 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. We conclude by highlighting the implications of different macroprudential policies targeted at reducing risk-taking behavior and promoting financial stability.

The paper is structured as follows. Section 2 describes the main assumptions and equations of the DSGE model that links the real economy and the financial sector via the term premium. Section 3 provides more information on the solution method and calibration exercise, the main transmission mechanism, and the model-implied responses of risk mispricing in the bond markets. It also includes a detailed robustness section to assess the role of the banking sector and other classic macroeconomic and financial shocks in explaining our results. Section 4 explores the richness of our model by simulating different credit boom scenarios to analyze the effectiveness of macroprudential policies in mitigating financial instability. Section 5 concludes.

2 A DSGE model with bank lending and risk mispricing

Our main setup is based on Gambacorta and Signoretti (2014)’s model to study augmented monetary policy rules with bank lending and firms’ balance sheet channels, which combines Iacoviello (2005)’s type of financial frictions with Gerali et al. (2010)’s heterogeneous banking sector. We extend their framework in several important dimensions in order to structurally analyze the effects of long-term risk mispricing shocks on the macroeconomy.

First, our model features households that choose consumption, labor, and savings to maximize their recursive utility with Epstein-Zin preferences as in Rudebusch and Swanson (2012) and Van Binsbergen et al. (2012). Intuitively, Epstein-Zin preferences imply that households are not just concerned with smoothing their consumption once sudden shocks are realized in the short term, but are also concerned with medium- and longer-term changes, allowing long-term risk to play a role in their decision-making process. As in Gambacorta and Signoretti (2014), competitive entrepreneurs (that are credit constrained) need to borrow from the banks by providing capital as collateral and therefore produce
intermediate goods that are sold to retailers. This feature introduces a collateral channel, generating the Bernanke and Gertler (1995) financial-accelerator effect that is subject to an LTV (loan-to-value) target ratio set by the monetary policy authority. Retailers differentiate the intermediate goods and sell them with a mark-up to households, who also own the retailers and keep their profits. In addition, there are capital producers who buy un-depreciated capital from entrepreneurs and re-sell it for a new price back to entrepreneurs taking into account a quadratic adjustment cost, necessary to derive the price for capital. As in Kiyotaki and Moore (1997), capital has many functions in this model and thus establishes an important feedback mechanism between the economy and the financial sector. Capital is used (i) in the production of intermediate goods, (ii) as a collateral for entrepreneurs’ loans, and (iii) as a source of funds for investment. Therefore capital, along with the LTV ratio and the bank’s borrowing rates, have a crucial impact on consumption and investment decisions made by entrepreneurs, which we subject to risk mispricing shocks.

Second, following Gambacorta and Signoretti (2014), banks have two branches: a wholesale and a retail branch, and all debt contracts are indexed in nominal terms in order to focus on the role of financial frictions, rather than inflation. While wholesale banks take deposits from households and operate under perfect competition, retail banks are monopolistic and give out loans to entrepreneurs charging a mark-up fee. We modify the banking problem to allow banks to choose between (a) keeping deposits at the short-term risk-free rate; (b) giving out loans to entrepreneurs and receive profits from the mark-up they charge over a long-term rate set by asset pricing rules; or (c) investing in long-term government bonds in the spirit of Gertler and Karadi (2013). Our extension exposes bank loan rates to risk mispricing shocks that make access to credit more difficult, a feedback mechanism that we identify as the loan price channel.

Third, the monetary policy authority determines the capital/asset ratio for banks, sets the LTV target ratio for entrepreneurs, and follows a more conventional monetary policy rule that minimizes output and inflation deviations from their targets, similar to Rudebusch and Swanson (2012). Moreover, the fiscal authority that issues long-term bonds to finance government spending is modeled exogenously as a stochastic process.

As in Gertler and Karadi (2011; 2013), Carlstrom et al. (2017), Sims and Wu (2021), and Sims et al. (2021) we incorporate long-term bonds rather than equity, in a general equilibrium framework with segmented markets. However, instead of exploring the role of unconventional monetary policies
on interest rates and ultimately the economy, we focus on mispricing of maturity risk. The fourth and final extension of the model—and our key contribution to understanding macro-financial linkages—is therefore the introduction of asset pricing rules where the nominal stochastic discount factor of investors (which prices long-term assets) is subject to risk mispricing shocks that endogenously elevate or compress the term premium, above and beyond economic fundamentals. We hence allow investors to misprice risk by introducing a wedge between the actual price of long-term bonds based on the level of risk in the economy versus the effective price that is driven by the perception of risk.

2.1 Households

Households maximize their recursive utility function

\[ V_t = U(c_t, \ell_t) + \beta_h \left( E_t V_{t+1}^{1-\xi} \right)^{\frac{1}{1-\xi}}, \]

where \( c_t \) is consumption, \( \ell_t \) is labor supply, \( \beta_h \) is the household’s patience discount factor, and \( \xi \) is the Epstein-Zin parameter that captures risk aversion. The intra-period utility function is given by

\[ U(c_t, \ell_t) = \frac{c_t^{1-\psi}}{1-\psi} - \frac{\ell_t^{1+\phi}}{1+\phi}, \]

with \( 1/\phi \) representing the Frisch elasticity of labor and \( 1/\psi \), the intertemporal elasticity of substitution. Households choose consumption, labor, and deposit their savings \( (d_t) \) at wholesale banks, for which they receive a risk-free gross return \( 1 + i_t \). They also own retail firms, which are monopolistic and generate a profit, \( J_{h,t} \), such that they are subject to the following budget constraint

\[ c_t + d_t \leq w_t \ell_t + (1 + i_{t-1})d_{t-1} + J_{h,t}, \]

where \( w_t \) is the real wage and the short-term nominal interest rate \( i_t \) is set by the monetary policy authority. The central bank therefore has the potential to directly impact the household decision-making process, since an increase in the policy rate in Eq. (3) incentivizes households to increase their savings. The first-order condition yields the consumption Euler equation

\[ \frac{1}{c_t^{\psi}} = E_t \left[ \frac{\beta_h (1 + i_t)}{c_t^{\psi} e_{t+1}^{\psi}} \left( \frac{V_t'}{V_{t+1}} \right)^{\xi} \right], \]
where $V'_t$ constitutes the certainty equivalent, such that $V'_t = \left( E_t V_{t+1} \right)^{1-\xi}$. Households also provide labor to the entrepreneurs for the production of intermediate goods, which follows a standard labor supply schedule $\ell_t^\phi = \frac{w_t}{c_t^x}$.

2.2 Entrepreneurs

Entrepreneurs produce goods, employ households, and consume, but also need to borrow from banks by providing capital as collateral. 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 sides of the model. For simplicity, we assume that entrepreneurs have constant relative risk aversion, as they, unlike households, do not invest or price financial assets. The entrepreneurs therefore choose their consumption $(c_{e,t})$, labor demand $(\ell_{d,t})$, and bank loans $(b_{e,t})$ in order to maximize utility subject to a budget constraint,

$$
\max \{ c_{e,t}, \ell_{d,t}, b_{e,t} \} \quad \text{s.t.} \quad c_{e,t} + (1 + i_{b,t} - 1)b_{e,t-1} + w_t \ell_{d,t} + q_k k_{e,t} \leq \frac{y_{e,t}}{x_t} + b_{e,t} + q_k (1 - \delta_k) k_{e,t-1},
$$

where $i_{b,t}$ is the interest rate on bank loans, $k_{e,t}$ is the entrepreneurs’ stock of capital that depreciates at rate $\delta_k$ with price $q_k$, $y_{e,t}$ is the intermediate output produced by entrepreneurs, $\frac{1}{x_t} = \frac{P_{w,t}}{P_t}$ is the relative competitive price of the intermediate good, and $\beta_e$ represents their patience discount factor. For small enough shocks, $\beta_h > \beta_e$ makes entrepreneurs more impatient than households, ensuring that the borrowing constraint is binding and credit is constrained in the economy. The entrepreneurs are also subject to a borrowing constraint that determines how much they can borrow from banks (i.e. the collateral channel),

$$
 b_{e,t} \leq \frac{\Omega E_t [q_{k,t+1} k_{e,t}(1 - \delta_k)]}{1 + i_{b,t}},
$$

where $\Omega$ is the steady state of the stochastic LTV ratio $\Omega_t$, which is an AR(1) process with i.i.d. shock $\varepsilon_{\Omega,t}$ and variance $\sigma_\Omega$. A high LTV ratio implies that banks can lend more for the same amount of collateral and vice versa.

Entrepreneurs operate under perfect competition and their production function for intermediate
goods follows a standard Cobb-Douglas form

\[ y_{e,t} = A_t k_{e,t-1}^\alpha l_{d,t}^{1-\alpha}, \]  

(7)

where \( \alpha \) denotes the capital share and \( A_t \) is the stochastic AR(1) technology process with i.i.d. technology shock \( \varepsilon_{a,t} \) and variance \( \sigma_a \). Their optimal consumption Euler equation,

\[ \frac{1}{c_{e,t}} - \lambda_{e,t} = E_t \left[ \frac{\beta_e (1 + i_{b,t})}{c_{e,t+1}} \right], \]  

(8)

is similar to the households’ Euler equation but differs by the Lagrange multiplier on the borrowing constraint, \( \lambda_{e,t} \), which represents the marginal value of one unit of additional borrowing. Another important difference with respect to households is that entrepreneurs face the higher bank loan rate, \( i_{b,t} \), rather than the short-term risk-free rate, \( i_t \).

The labor demand schedule is \( \frac{(1-\alpha)w_{t}}{l_{d,t} \varepsilon_{t}} = w_t \) and the investment Euler equation equals the marginal benefit to the marginal cost of saving capital. Since capital serves as collateral, the equation also depends on the Lagrange multiplier of the borrowing constraint and the LTV ratio,

\[ E_t \left[ \frac{\lambda_{e,t} \Omega_k q_{k,t+1} (1 - \delta_k)}{1 + i_{b,t}} + \frac{\beta_e}{c_{e,t+1}} \left[ q_{k,t+1} (1 - \delta_k) + r_{k,t+1} \right] \right] = \frac{q_{k,t}}{c_{e,t}}, \]  

(9)

where \( r_{k,t} \) is the return to capital, defined as \( r_{k,t} \equiv \alpha \frac{A_t k_{e,t-1}^\alpha l_{d,t}^{1-\alpha}}{\varepsilon_{t}} \).

### 2.3 Banks

The banking sector is divided into a perfectly competitive wholesale branch and a monopolistic retail branch. The wholesale sector maximizes bank profits by optimizing the net interest margin between the wholesale loan rate \( (i_{w,t}) \) and the short-term rate \( (i_t) \), subject to the quadratic adjustment costs of deviating from a target capital/asset ratio, \( \nu \). The wholesale bank’s maximization problem is

\[ \max_{\{B_t, d_t\}} \left\{ i_{w,t} B_t - i_t d_t - \frac{\theta}{2} \left( \frac{K_{b,t}}{B_t} - \nu \right)^2 K_{b,t} \right\}, \]  

(10)

where \( B_t \) represents the total assets of the bank and \( K_{b,t} \) is the banks’ capital with adjustment cost \( \theta \). As the deposit rate is the same as the risk-free rate, banks’ demand for deposits is elastic, with
the amount of deposits being determined by the households. Wholesale banks are subject to a balance sheet constraint that can also be interpreted as a capital adequacy/leverage constraint, ensuring all loans are backed by sufficient bank capital and deposits at the beginning of the period. Combining Eq. (10) and the banks’ balance sheet identity, the first-order condition of the wholesale bank collapses to

\[ i_{w,t} = i_t - \theta \left( \frac{K_{b,t}}{B_t} - \nu \right) \left( \frac{K_{b,t}}{B_t} \right)^2. \]

The retail bank buys the loans from the wholesale bank at price \( i_{w,t} \) and uses them either to (i) lend to the government by purchasing long-term bonds \( (b_{l,t}) \) at rate \( i_{l,t} \), or (ii) lend short-term to entrepreneurs at rate \( i_{b,t} \) set by the retail bank. It therefore maximizes profits for \( B_t = b_{e,t} + b_{l,t} \),

\[
\max_{\{i_{b,t}, b_{l,t}\}} \quad i_{b,t}b_{e,t} + i_{l,t}b_{l,t} - i_{w,t}B_t, \quad (11)
\]

with respect to loan demand, \( b_{e,t} = i_{b,t} - \epsilon_{b} \), where \( \epsilon_{b} \) is the demand elasticity. The first order condition of the retail bank becomes

\[ i_{b,t} = i_{l,t} \left( \frac{\epsilon_{b}}{\epsilon_{b} - 1} \right) \frac{\mu_{b}}{\mu_{b}}, \quad (12) \]

where \( \mu_{b} \) represents the markup over the long-term rate.

The retail banks have market power, which helps them adjust their lending in response to shocks or cycles. Notice that, everything else held constant, a shock that increases the long-term rate would also increase the loan rate charged by retail banks, making access to credit more difficult for entrepreneurs. This is effectively the “loan price” channel through which increases in long-term rates 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 \( \delta_{b} \) and accrues from past capital and retained earnings, \( J_{b,t} \), \( K_{b,t} = K_{b,t-1} (1 - \delta_{b}) + J_{b,t-1} \). Since it is pro-cyclical, bank capital worsens when output declines due to decreasing banks’ profits, defined as the sum of both the retail bank and wholesale bank sector profits on loans, long-term bond holdings, and deposits, respectively:

\[
J_{b,t} = i_{b,t}b_{e,t} + i_{l,t}b_{l,t} - i_{l}d_t - \theta \left( \frac{K_{b,t}}{B_t} - \nu \right)^2 K_{b,t}. \quad (13)
\]
2.4 Retailers and capital good producers

The monopolistic retailers differentiate the intermediate goods produced by 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 first order condition of the retailers generates the classic New Keynesian Philip’s curve

\[
0 = 1 - \frac{\mu_{y,t}}{\mu_{y,t} - 1} + \frac{1}{\mu_{y,t} - 1} x_t - \kappa \pi_t (\pi_t - 1) \pi_t + \beta \mathbb{E}_t \left[ \frac{c_t}{c_{t+1}} - \kappa \pi (\pi_{t+1} - 1) \pi_{t+1} \frac{Y_{t+1}}{Y_t} \right],
\]

(14)

where the marginal cost is \( \frac{1}{x_t} \), inflation is \( \pi_t = \log \left( \frac{P_t}{P_{t-1}} \right) \), \( \kappa \pi \) represents the degree of price stickiness, and \( Y_t \) is total output. The firm’s mark-up, \( \mu_{y,t} \), is stochastic and follows an AR(1) process with an autocorrelation coefficient \( \rho_{\mu_y} \) and an i.i.d. mark-up shock, \( \varepsilon_{\mu_y,t} \), with variance \( \sigma_{\mu_y} \).

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 \( P_{k,t} \), so that the relative price of capital is \( q_{k,t} \equiv \frac{P_{k,t}}{P_t} \). 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 parametrized by \( \kappa \), the investment \( (I_t) \) adjustment cost parameter. The first-order condition of capital good producers is

\[
1 = q_{k,t} \left[ 1 - \frac{\kappa}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \kappa \pi \left( \frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta \mathbb{E}_t \left[ \frac{c_{e,t}}{c_{e,t+1}} q_{k,t+1} \kappa \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 \right],
\]

(15)

with capital, \( K_t \), evolving according to

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

(16)
2.5 Monetary policy

Monetary policy follows a standard Taylor rule, in which the central bank sets the one-period nominal policy rate according to

\[
i_t = \rho_i i_{t-1} + (1 - \rho_i) \left[ \bar{i} + \phi_\pi (\pi_t - \bar{\pi}) + \phi_y (y_t - \bar{y}) \right] + \varepsilon_{i,t}, \tag{17}\]

where \(\rho_i\) is the interest-rate smoothing coefficient, \(\{\bar{i}, \bar{\pi}, \bar{y}\}\) are the interest rate, inflation and output steady states, respectively, and \(\phi_\pi\) and \(\phi_y\) are the inflation and output monetary policy parameters.\(^1\) \(\varepsilon_{i,t}\) is an i.i.d. monetary policy shock with variance \(\sigma_i\).

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.

2.6 Asset pricing equations and risk mispricing

Long-term bonds are default-free securities issued by the fiscal authority that pay a geometrically declining coupon every period in perpetuity.\(^2\) In the traditional finance literature, the price of a nominal long-term bond at time \(t\) maturing at \(t + l\), \(p_{l,t}\), can be decomposed into the risk-neutral present value of the bond, \(\hat{p}_{l,t}\) (i.e. discounted at the risk-free rate), and the covariance between future pay-offs and the bond-pricing stochastic discount factor, \(m_{l+1}^*\):

\[
p_{l,t} = \mathbb{E}_t[p_{l-1,t+1}] (1 + i_t)^{-1} + \text{cov}_t \left( m_{l+1}^*, p_{l-1,t+1} \right). \tag{18}\]

\(^1\)Fuerst and Mau (2019) pointed 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. Hördahl et al. (2008) showed that the degree of interest rate smoothing in the monetary policy rule is also important for matching bond and macroeconomic moments in their microfounded DSGE framework. Refer to Palomino (2012) for an analysis of the role of monetary policy regimes and central bank credibility in influencing bond risk premia in long-term bonds.

\(^2\)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.
The first term in Eq. (18) corresponds to the asset price in a risk-neutral world with constant consumption and linear utility. Notice that if \( \text{cov} (m_{t+1}^*, p_{t-1,t+1}) = 0 \) then the price of the long-term bond is exactly the risk-neutral price.\(^3\) 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.

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,

\[
 p_{l,t} = 1 + \delta_c E_t [m_{t+1}^* p_{t-1,t+1}],
\]

where \( \delta_c \) is the coupon decay rate that controls the duration of the bond. The continuously compounded yield for the bond, \( i_{l,t} \), and its risk-neutral counterpart, \( \hat{i}_{l,t} \), are therefore given by

\[
 i_{l,t} \equiv \log \left( \frac{\delta_c p_{l,t}}{p_{l,t} - 1} \right) \quad \text{and} \quad \hat{i}_{l,t} \equiv \log \left( \frac{\delta_c \hat{p}_{l,t}}{\hat{p}_{l,t} - 1} \right). \tag{20}
\]

As guaranteed by the absence of arbitrage in the bond markets, we compute the nominal term premium, \( t_{p_{l,t}} \), as the difference between the yield on the long-term bond and the yield on the equivalent risk-neutral bond defined in Eq. (20):

\[
 t_{p_{l,t}} = i_{l,t} - \hat{i}_{l,t}, \tag{21}
\]

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 mispricing, \( \epsilon_{m,t} \), such that

\[
m_{t+1}^* = \frac{\beta_h}{\pi_{t+1}} \left( \frac{c_t}{c_{t+1}} \right)^\psi \left( \frac{V_t'}{V_{t+1}} \right)^\xi + \epsilon_{m,t}, \tag{22}
\]

where \( \epsilon_{m,t} = \rho_m \epsilon_{m,t-1} - \epsilon_{m,t} \), for \( \epsilon_{m,t} \sim N(0, \sigma_m) \).

The risk mispricing shock enters the stochastic discount factor that prices long-term assets negatively,

\(^3\)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.
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 Eq. (21), as the risk-neutral yield remains unaffected by the shock. Notice that our risk mispricing 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 the household’s Euler Eq. (4), acting 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 investors to change their portfolio allocations immediately but still not alter their consumption patterns on impact. The idea that there is a wedge between the actual household stochastic discount factor and the discount factor used to price risk premia has been micro-founded for example by Barillas and Nimark (2017), who priced bonds subject to speculative behavior of individual traders, and Ellison and Tischbirek (2021), who decomposed the real term premium at any maturity into covariances of realized stochastic discount factors and covariances of expectations of stochastic discount factors which differ due to informational assumptions. Furthermore, we model risk mispricing as an AR(1) process following the empirical evidence supporting the idea that investors’ perceived changes in the term premium are persistent (see Adrian et al., 2013). This assumption is also consistent with the literature on uncertainty or credit risk shocks being persistent, as in Christiano et al. (2014).

2.7 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, $b_{t,t}$,

$$G_t + i_t b_{t,t-1} = b_{t,t}.$$  

(23)

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4Li et al. (2017b) empirically estimated 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 found that the effect of a U.S. term premium shock is persistent with a significant estimate of the autocorrelation coefficient of 0.78. Using a term structure model of interest rates, Osterrieder and Schotman (2017) found that when allowing for stronger persistence of interest rate shocks, e.g. with fractional integration $I(0.89)$, the correlation between risk prices and the spot rate becomes negative, matching the volatility observed in the data.
Government spending in Eq. (23) follows a stationary AR(1) process

\[ G_t = (1 - \rho_g)\bar{G} + \rho_g G_{t-1} + \varepsilon_{g,t}, \] (24)

where \( \bar{G} \) is the steady state value of government consumption, \( \rho_g \) captures the degree of autocorrelation in fiscal policy, and \( \varepsilon_{g,t} \) is a government spending i.i.d. shock with variance \( \sigma_g. \)\(^5\)

### 2.8 Market clearing and aggregation

Goods and labor markets clear with condition \( \gamma_e \ell_{d,t} = \gamma_h \ell_{t}; \) the aggregate banks’ balance sheet identity is \( B_t = D_t + K_{b,t}; \) and the resource constraint of the economy is

\[ Y_t = C_t + q_{k,t} (K_t - (1 - \delta_k) K_{t-1}) + \frac{\delta_b K_{b,t-1}}{\pi_t} + G_t, \] (25)

as it is a closed economy with Rotemberg adjustment costs, with the following variable definitions for aggregate output \( (Y_t) \), consumption \( (C_t) \), capital \( (K_t) \), and deposits \( (D_t) \) in Eq. (25):

\[
\begin{align*}
Y_t &= \gamma_e y_{e,t}, \\
C_t &= \gamma_h c_t + \gamma_e c_{e,t}, \\
K_t &= \gamma_e k_{e,t}, \\
D_t &= \gamma_h d_t.
\end{align*}
\]

### 3 Results

We describe the solution methods and the baseline calibration for our model in Section 3.1 and compare the fit of the simulated model moments to the data in Section 3.2. Section 3.3 showcases the impact of our risk mispricing shock on the economy, focusing on the role of the banking sector in propagating the shock in Section 3.4. We describe the impact of other classic macroeconomic shocks in Section 3.5 and evaluate the robustness of our results to different parametrization and shock specifications in Section 3.6.

\(^5\)Note that in this case, government debt is non-explosive, as the transversality (no Ponzi) condition for public debt applies, i.e., the growth of public debt is smaller than the real interest rate charged on this debt in the infinite horizon.
3.1 Solution and calibration

Since the dimension of the model is relatively high with 14 state variables, the most feasible option to solve the model is through perturbation methods.\textsuperscript{6} We use third-order solutions and 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. This feature occurs because first-order solutions imply that the expectation hypothesis holds and the term premium is zero, with second-order solutions generating a positive, yet constant term premium, both results inconsistent with empirical evidence on risk pricing dynamics (e.g. Shiller, 1979; Campbell, 1987; Longstaff, 1990; Cuthbertson, 1996; Piazzesi and Schneider, 2007). 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. A high term premium therefore reflects a perceived increase in financial risk over the life of a bond. Although unobservable, and therefore difficult to measure, it has been established in the literature that this compensation for risk varies throughout time as investors update their beliefs about the future path of the economy (e.g. Campbell and Shiller, 1991).\textsuperscript{7} Only by using third-order solutions, we manage to capture a time-varying term premium and match empirical bond moments. 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 based on standard parameters in the literature and to fit specific moments for both macroeconomic and financial variables.

Table 1 reports the values of the calibrated parameters for the baseline model based on previous estimates for U.S. data, as typically established in the literature. For households and entrepreneurs, the discount factors are set such that $\beta_h$ implies an annual interest rate of 2% and $\beta_h > \beta_e$ ensures that entrepreneurs are more impatient as in Gerali et al. (2010) and Gambacorta and Signoretti (2014).

\textsuperscript{6}Caldara et al. (2012) showed that perturbation methods provide equally accurate solutions to models with recursive preferences than Chebychev polynomials and value function iterations, but are considerably faster.

\textsuperscript{7}The term premium is typically 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. Importantly, despite the disagreement on what the level of the term premium is (e.g. Rudebusch and Swanson, 2012 report a mean of 106 b.p., whereas Adrian et al., 2013 report a mean of 169 b.p. for the 1961/2-2007/8 period), all measures broadly agree on the general movements of the term premium and are hence highly correlated.
For preferences, $\phi$ is based on the inverse of the Frisch elasticity being $1/2$ and $\psi$ is based on the intertemporal elasticity of substitution being 0.25, in line with previous micro-founded studies which have found $\psi^{-1}$ to be smaller than one (e.g. Vissing-Jørgensen, 2002) so that the utility function is everywhere positive and the certainty equivalence is well defined. We set the Epstein-Zin parameter $|\xi| = 2$ to match two term premium moments (mean and standard deviation). 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 and more consistent with the low estimates found in the macro literature (see Havranek et al., 2015 for a meta-study).

<table>
<thead>
<tr>
<th>Table 1: Calibrated parameters</th>
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<tbody>
<tr>
<td>parameters</td>
</tr>
<tr>
<td>households</td>
</tr>
<tr>
<td>$\beta_h$</td>
</tr>
<tr>
<td>$\beta_e$</td>
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<tr>
<td>$\phi$</td>
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<tr>
<td>$\psi$</td>
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<tr>
<td>$</td>
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<td>production</td>
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<tr>
<td>$\bar{\mu}_y$</td>
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<td>$\alpha$</td>
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<tr>
<td>$\kappa_{\pi}$</td>
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<tr>
<td>$\kappa$</td>
</tr>
<tr>
<td>$\delta_k$</td>
</tr>
<tr>
<td>$\pi$</td>
</tr>
</tbody>
</table>

The production parameters are also standard. The price elasticity of demand is assumed to be 6, which implies a steady-state markup in the goods market $\bar{\mu}_y = 1.2$. The adjustment cost for prices $\kappa_{\pi}$, modeled via Rotemberg pricing, follows the estimated values by Gambacorta and Signoretti (2014), as do the adjustment cost for investment $\kappa$ in Eq. (15), and the adjustment cost for banks $\theta$. The capital share $\alpha$ is assumed to be 0.3, and $\delta_k = 0.05$ implies an annual depreciation rate of 20% in Eq. (16). The banking parameter $\nu$ is set to match the Basel capital target ratio of 0.09 and the decay rate for consol bonds, $\delta_c$ in bond pricing Eq. (19), is set to match the 10-year bond adjusted formula of Macaulay duration. The monetary policy rule parameters in Eq. (17) 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 also set to standard values, with the persistence of the autoregressive processes \( \rho \) being 0.6–0.9. The standard deviations of the shocks \( \sigma \) are calibrated between 0.3–0.7 percentage points, depending on the volatility of the respective variable when we do the moment matching exercise. Finally, the steady state capital/output \( \left( \frac{K}{Y} \right) \) and government spending/output \( \left( \frac{G}{Y} \right) \) ratios are set to reflect the long-run macroeconomic relationships between those variables.

### 3.2 Model fit

To evaluate the fit of the model, we compare both macroeconomic as well as term premium moments implied by the DSGE model to the data. We use the Hodrick-Prescott filter to compute the business cycle component of log quarterly U.S. data for chained GDP, consumption, investment, and labor. We also include the standard deviations of private and public loan growth for all commercial banks. The interest rate is the Wu and Xia (2016) annualized shadow Federal Funds rate and inflation is calculated using the GDP deflator. The term premium is the Adrian et al. (2013) nominal ten-year Treasury term premium from the Federal Reserve Bank of New York. Details and sources can be found in the Data appendix A.

Table 2 shows the results for the moments observed in the U.S. data during the 1961–2016 period in column (a) and the simulated moments using the baseline calibration in column (b). The model performs very well in matching all the key macroeconomic moments: the standard deviation of output is under 0.5% of the data variation, and consumption, investment, labor, and inflation deviate within 20% from their data moments. 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.

Our calibration also manages to match the term premium within 4% of the data mean and under 0.5% of the data variation. 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 modeled independently from the intertemporal elasticity of substitution. Since Epstein-Zin preferences yield the same results using first-order approximations.

---

8Note that Rudebusch and Swanson (2012) used fourth-order solutions to compute the variances of finance moments and achieved a standard deviation of 0.47. One of the reasons we can match bond premium moments without a particularly large CRRA coefficient is by having a larger model with more shocks including our new risk mispricing shock.
as standard utility functions, the model is still able to match macroeconomic moments. However, by introducing an additional parameter, $\xi$, the risk aversion of households can now be amplified to also match the empirical features of bond moments. Fuerst and Mau (2019) explored business cycle moments for different model specifications with and without segmented markets and Epstein-Zin preferences, and found these features to also help deliver a counter-cyclical term premium. We find, consistent with their results and empirical evidence (e.g. Campbell and Cochrane, 1999; Wachter, 2006; Bauer et al., 2012; Lustig et al., 2014), that the model-implied correlation between output and term premia is $-0.61$. This counter-cyclical suggests that we expect the term premium to rise along with unemployment during economic downturns and fall during economic upswings, as compensation for risk increases during bad times and vice versa.

Table 2: Comparing data with simulated model moments

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
<th>(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD[Y_t]$</td>
<td>1.46</td>
<td>1.46</td>
<td>1.18</td>
<td>1.33</td>
<td>0.87</td>
<td>0.88</td>
<td>0.29</td>
<td>1.20</td>
</tr>
<tr>
<td>$SD[C_t]$</td>
<td>0.85</td>
<td>0.99</td>
<td>0.80</td>
<td>0.81</td>
<td>0.67</td>
<td>0.84</td>
<td>0.25</td>
<td>0.74</td>
</tr>
<tr>
<td>$SD[I_t]$</td>
<td>4.08</td>
<td>4.53</td>
<td>2.74</td>
<td>2.86</td>
<td>3.94</td>
<td>2.95</td>
<td>1.87</td>
<td>3.39</td>
</tr>
<tr>
<td>$SD[\ell_t]$</td>
<td>2.10</td>
<td>1.66</td>
<td>1.53</td>
<td>1.27</td>
<td>1.24</td>
<td>1.32</td>
<td>0.47</td>
<td>1.44</td>
</tr>
<tr>
<td>$SD[\pi_t]$</td>
<td>2.45</td>
<td>2.36</td>
<td>1.98</td>
<td>2.14</td>
<td>1.31</td>
<td>1.95</td>
<td>0.36</td>
<td>1.93</td>
</tr>
<tr>
<td>$SD[i_t]$</td>
<td>3.20</td>
<td>1.76</td>
<td>1.63</td>
<td>0.97</td>
<td>1.50</td>
<td>2.05</td>
<td>0.80</td>
<td>1.56</td>
</tr>
<tr>
<td>$M[tp_{l,t}]$</td>
<td>1.62</td>
<td>1.69</td>
<td>1.92</td>
<td>1.22</td>
<td>1.41</td>
<td>1.39</td>
<td>1.13</td>
<td>1.50</td>
</tr>
<tr>
<td>$SD[tp_{l,t}]$</td>
<td>1.19</td>
<td>1.20</td>
<td>0.35</td>
<td>1.09</td>
<td>0.94</td>
<td>0.87</td>
<td>0.70</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Notes: Moments for aggregate output ($Y_t$), consumption ($C_t$), investment ($I_t$), and labor ($\ell_t$) are reported in quarterly percentage points; whereas inflation ($\pi_t$), short-term interest rate ($i_t$), and term premium ($tp_{l,t}$) are reported in annual frequency. The model moments are computed by simulating the data 224 times to be consistent with the duration of the time series. Refer to the Data appendix A for details on the moments reported in column (a). Column (b) moments correspond to the model with the baseline calibration from Table 1. Model moments when there is no risk mispricing shock ($\varepsilon_{m,t} = 0$) are reported in column (c), no TFP shock ($\varepsilon_{a,t} = 0$) in column (e), no government spending shock ($\varepsilon_{g,t} = 0$) in column (f), no macroeconomic shocks ($\varepsilon_{a,t} = \varepsilon_{g,t} = \varepsilon_{\mu y,t} = 0$) in column (g), and no financial or LTV ratio shock ($\varepsilon_{\Omega,t} = 0$) in column (h). Column (d) corresponds to the moments of a model without banking feedback, defined as $i_{b,t} = i_{w,t} \left( \frac{\lambda_b}{\lambda_w} \right)$. 

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3.3 The impact of a risk mispricing shock: When investors panic

We begin by analyzing how a risk mispricing shock affects the macroeconomy as a temporary, exogenous change in the nominal stochastic discount factor of investors pricing long-term bonds. Figure 1 reports the results for a shock that underprices long-term bonds by generating a 90 bps increase in the term premium (a), a magnitude comparable to the increase experienced from September to October 2008, during the initial stages of the Global Financial Crisis.\(^9\) This shock lowers the price of long-term bonds by 8 percent on impact (b) and increases the long-term interest rate by 0.2 percentage points (c), as participants demand higher compensation due to the perceived elevated risk.

With the long-term rate increasing, purchasing government bonds becomes more profitable and bank holdings increase by 0.2 percent (e). Moreover, with the price of bonds decreasing, banks pass on the elevated rates in form of higher borrowing rates to the private sector, which leads to a decline in loans to entrepreneurs (d), as borrowers are less willing to take out a loan at a higher rate. This constitutes a loan price channel, indicating a potential flight to safety, as risk perceptions in the economy increase.

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 shift of the bank’s supply curve for private loans (supply effect: price increases and quantity decreases). With higher repayment rates, borrowers are less willing to borrow and thus reduce the quantity of private loans.\(^10\) Another channel in our model that amplifies this effect and reduces borrowing, is the collateral channel. As borrowers are subject to a binding credit constraint, an increase in the cost of borrowing further reduces the amount that entrepreneurs can borrow in Eq. (6). We therefore see loans to entrepreneurs decline by more than 0.6 percent over subsequent quarters, with effects on the private credit market being much more persistent than on the public sector.

\(^9\)We use linear scaling since higher-order solutions allow for different shock sizes to result in asymmetric responses. However, larger variances are also likely to cause oscillating behavior. 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, although most other responses are both quantitatively and qualitatively very similar.

\(^10\)Notice that modeling commercial and industrial loans as short-term debt aligns closely with the maturity composition of portfolio allocations by borrowers in the data: 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).
Figure 1: Impulse responses to risk mispricing shock

Notes: The blue solid line represents the impulse responses to a shock that misprices long-term bonds by rising the term premium 90 bps, using the baseline calibration from Table 1.

Bond mispricing also has a negative effect on the macroeconomy with output declining by 0.6 percent on impact (g), returning to the steady state after 4 years. The response in output is mostly driven by a large fall in investment (i), which drops by more than 2%, rather than consumption (h), which only falls modestly. We therefore find that a risk mispricing shock, unlike a preference shock, does not cause consumption to respond significantly on impact and only generates a small decline with a trough around 3 years after the shock. 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, can reflect mispriced risk in financial markets, inducing prices to go down and output and investment to contract. The central bank reacts to this decline in output by lowering the short-term interest rate on impact (f), and since prices
go down, we find that the risk mispricing shock behaves similar to a demand shock.

There is recent anecdotal evidence to support the importance of both the loan price and collateral channels in restricting credit availability during the early 2020 outbreak of the COVID-19 pandemic. Between March 9th and March 19th, the 10-year U.S. Treasury yield rose by 60 bps, reflecting a pronounced increase in the Kim and Wright (2005) daily 10-year term premium of almost 40 bps, as estimated by the Board of Governors.\textsuperscript{11} During the following weeks, consumer lending by all commercial banks declined while holdings of Treasuries increased, part of the portfolio-rebalancing strategies towards safer assets that traditionally follow heightened risk perceptions. At the same time, a higher percentage of banks tightened their standards for issuing all types of loans (e.g. commercial, consumer, credit card, mortgage) as well as increased the spread of loan rates over the cost of funds, further restricting the availability of credit between 2020-Q1 and 2020-Q2.\textsuperscript{12} While the COVID-19 shock is not necessarily a bond mispricing shock—and was followed by lock-down policies that we do not model in our framework—it is a clear recent example of a disruption to the economy whose origins were unrelated to fundamentals, yet generated sudden portfolio rebalancing changes that at least partially impacted the availability of credit via the loan price and collateral channels, as described by our model.

Table 2 (c) reports the simulated model moments when we turn off the risk mispricing shock ($\varepsilon_{m,t} = 0$) in Eq. (22). In terms of macroeconomic variables, the model does a worse job at matching investment fluctuations when this shock is missing, in line with the fact that risk mispricing affects bank lending and therefore entrepreneurs’ ability to get funding and invest. This is more pronounced than if we were to turn off the other financial shock in the model in Table 2 (h), the LTV ratio shock $\varepsilon_{\Omega,t}$ in Eq. (9), with a more muted decline in the model’s ability to match investment volatility. We also find our shock to be important for matching term premia volatility, particularly given our baseline calibration featuring such a small value for the Epstein-Zin parameter. Otherwise, the ability of our model to match the remaining moments without risk mispricing shocks is still within 20\% of our baseline specification. In terms of variance decompositions, we compute the empirical moments as we are using third-order solutions and there is no unique way to decompose the overall variance into the contribution of individual shocks, because of the interaction effects due to non-linearities. We find that the risk mispricing shock only explains a small fraction of output fluctuations and loans to the government, but

is the most important source of fluctuation for loans to entrepreneurs. Although it is only modestly important for the real economy as a whole (with around 6% of output fluctuations being explained by it), it represents a quarter of investment movements, and the vast majority of fluctuations in financial markets within the model.

We find that, overall, the results of our theoretical model are in line with the previous empirical literature identifying sizable effects on economic activity resulting from uncertainty shocks (e.g., 1.2% decline in output in Baker et al., 2016; −1% change in output during expansions and −2% during contractions in Caggiano et al., 2017; a persistent effect on industrial production Carriero et al., 2018) and in that our risk mispricing shock seems to correspond with a demand shock (e.g. Leduc and Liu, 2016). Our shock also supports the reduced-form evidence found in the literature that identifies persistent effects in macroeconomic variables in response to term premia shocks (e.g. Gil-Alana and Moreno, 2012; Jardet et al., 2013). Joslin et al. (2014), for example, identified 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.

3.4 The role of banking feedback effects

We further explore the importance of the banking sector in allowing risk mispricing shocks to feed back to the real economy, by considering a model in which its role is instead more muted. To this end, we change the banking problem in Eq. (11) such that risk mispricing shocks do not affect the bank’s borrowing rate, effectively removing the feedback mechanism. This implied change in the banking optimization problem leads to a new retail bank’s first order condition in which Eq. (12) is now given by

\[
\hat{i}_{b,t} = \hat{i}_{w,t} \left( \frac{\epsilon_b}{\epsilon_b - 1} \right),
\]

13The term premium is highly correlated with measures of volatility and uncertainty, such as the Merrill Lynch MOVE Index, which summarizes options-implied expected volatility of Treasury yields and hence represents interest rate risk, as well as policy and inflation uncertainty measures as estimated by Baker et al. (2016). We therefore expect the term premium to be high when investors are more risk averse; output is low; or there is more uncertainty about the future economic outlook (i.e. the path of interest rates, inflation, fiscal policy).
such that the long-term rate—and therefore risk mispricing shocks impacting term premia—no longer influence borrowing rates via the loan price channel. Table 2 (d) displays the simulated model moments when turning off the banking feedback effect. Although most macro moments remain close to the baseline results, investment volatility becomes particularly difficult to match without the feedback mechanism that arises from the loan price channel, with term premia exhibiting lower mean and volatility than the data. Figure 2 highlights the importance of the mechanism through which risk mispricing shocks can feed back to the real economy. While loans to the government increase at a similar magnitude than in the baseline model as a result of a risk mispricing shock (b), loans to entrepreneurs are no longer affected (a), with risk mispricing shocks having no longer any impact on investment (f) and therefore output (d), and hence no need for the monetary policy authority to lower the policy rate (c).

Figure 2: Impulse responses to risk mispricing shock with and without banking feedback

![Figure 2: Impulse responses to risk mispricing shock with and without banking feedback](image)

*Notes:* The blue solid line represents the impulse responses to a shock that misprices long-term bonds by rising the term premium 90 bps, using the baseline calibration from Table 1. The purple dashed line shows the responses to the same baseline shock after the banking feedback channel is deactivated by not allowing risk mispricing shocks to enter the banking problem and therefore set the borrowing rates as in Eq. (26).

This mechanism is consistent with anecdotal evidence on bank behavior. The euro area bank lending survey providing qualitative information on bank loan demand and supply across euro area enterprises and households, for example, identifies ‘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).

3.5 Other classic macroeconomic shocks

We analyze the impulse responses of traditional macroeconomic shocks, including their effect on the term premium, to cross-check that their responses are consistent with economic theory and our model reproduces standard results that are well studied in the literature. The responses to a positive, one standard deviation technology (a), government spending (b), and monetary policy (c) shocks are reported in Figure 3.

As is standard in the literature, a technology shock—interpreted as a supply-side shock—persistently increases output and lowers inflation, see Figure 3 (a). 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 15 bps as a result of stronger economic activity associated with higher productivity.\textsuperscript{14} When we turn off the TFP shock that enters the production function Eq. (7) in Table 2 (e), we find TFP shocks to be particularly important for matching output volatility, and to a certain extent, fluctuations in consumption.

In Figure 3 (b), a one standard deviation, positive government spending shock that represents a shock on the demand side, raises both output and inflation on impact as expected, while the term premium declines by less than a basis point. The small decline in term premium is mechanical, 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. We therefore find almost no impact on the term premium from such a shock. We can see from Table 2 (f) that the government spending shock in Eq. (24) helps account for both fluctuations in output and investment. If we consider our model without any macroeconomic shocks (i.e., no TFP $\varepsilon_{n,t}$, no government spending $\varepsilon_{g,t}$, no firm’s mark-up $\varepsilon_{\mu y,t}$ in Eq. (14) shocks), then we are not able to match the volatility of any macroeconomic variable in the model, see Table 2 (g).

Finally, Figure 3 (c) shows the responses to a one standard deviation contractionary monetary policy shock. A contractionary monetary policy shock induces less persistent responses and implies, as Huh and Kim (2020) showed that financial frictions can play a role in amplifying the effects of TFP shocks on the term premium and the economy.
expected, a decrease in output and inflation, with a positive yet very small term premium response.\footnote{Mallick et al. (2017) investigated the role of monetary policy shocks on the term premium, where pre 2008 they used the Federal Funds rate as the main monetary policy instrument and post 2008 they instead used 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.}

Figure 3: Impulse responses to classic macroeconomic shocks

Notes: The solid lines represent the impulse responses using the baseline calibration from Table 1 to a positive one standard deviation technology shock in column (a), a government spending shock in column (b), and a monetary policy shock in column (c).

3.6 Robustness to parametrization and shock specification

We next check the sensitivity of the responses to a risk mispricing shock when changing key preference and banking parameters. For reference, Figure 4 displays the impulse response functions for the baseline model calibration in solid blue. We solve the model using first-order solution methods instead, which is
comparable to a model without an Epstein-Zin risk aversion parameter, such that household preferences collapse to a standard CRRA specification in Eq. (1). Responses to the risk mispricing shock do not change in any significant way relative to the baseline model (pink line with circles), since the term premium can still move due to risk mispricing shocks, although it now becomes zero on average. We also allow for a non-zero yet small Epstein-Zin parameter so that the CRRA coefficient decreases by half, with yet marginal changes to the responses to mispricing shocks (not shown). In the absence of shocks to the term premium, a larger Epstein-Zin parameter allows for risk aversion to increase and help match bond pricing moments. Fuerst and Mau (2019), for example, found macroeconomic moments to remain fairly unchanged when comparing a model with \((\xi = 200)\) and without \((\xi = 0)\) risk aversion, but with important consequences for term premia level and cyclicality. We also increase the entrepreneur’s patience parameter in their utility maximization problem Eq. (5), in order to lower the marginal value of one unit of additional borrowing in Eq. (8). The term premium response to a risk mispricing shock is 10 bps lower on impact than the baseline model (pink dashes), with a smaller increase on government loans and a smaller on impact—but more persistent over time—decline in private-sector credit. The macroeconomic responses, however, remain relatively unchanged (inflation, output, consumption, and therefore the short term rate).

Since the term premium is mostly driven by household parameters, we focus on changing the elasticities of substitution relative to interest rates and wages next. First, we double the intertemporal elasticity of substitution in households’ intra-period utility function Eq. (2), increasing consumption growth’s sensitivity to changes in the short-term interest rate. With a high intertemporal elasticity, risk mispricing shocks lead to a higher term premium increase on impact (120 bps instead of 90 bps), yielding a higher increase in loans to the government (light blue dashes). Private sector credit contracts more sharply and persistently, declining 0.4 percent on impact but also reaching a 0.8 percent decline 2 years later, remaining persistently lower throughout subsequent years. Yet, output’s response to the shock is similar to the benchmark, although persistently slightly lower, which can be also observed in the response in consumption. Second, we double the elasticity of substitution of labor supply, increasing households’ willingness to work as wages increase. The response of term premia to risk mispricing shocks becomes more muted, similar on impact to changing the entrepreneur’s patience parameter but less persistent over time (light blue line with circles). The lower increase in long-term interest rates translates into a slightly smaller increase in bank holdings of government debt, with credit to the private
sector declining just as much as the baseline on impact, but recovering much more quickly. Since output and inflation decline by less, the monetary policy authority’s response to the shock is also more muted than the baseline.

Figure 4: Impulse responses to risk mispricing shock: Robustness

Notes: The blue solid line represents the impulse responses to a shock that misprices long-term bonds by rising the term premium 90 bps, using the baseline calibration from Table 1. The pink line with circles shows the responses to the model when solved using first-order solutions; the pink dashes correspond to increasing entrepreneurs’ patience factor from 0.96 to 0.97; light blue dashes indicate an increase in the intertemporal elasticity of substitution (IES) from 0.25 to 0.50; the light blue line with circles, an increase in the Frisch elasticity of labor from 0.5 to 1; and green dashes represent the responses when increasing the investment adjustment cost parameter from 0.5 to 5.

Finally, we increase the investment adjustment cost parameter by a factor of 10. Although the term premium, long-term interest rate, and loans to the government responses to risk mispricing remain relatively unchanged, we see the same decline on private credit on impact followed by a steady increase to the baseline in subsequent years (green dashed line). The shock generates a pronounced decline in consumption with a short lived yet deeper decline in output and inflation, triggering a more aggressive response from the monetary policy authority.

Our risk mispricing shock enters the stochastic discount factor of investors in an additive fashion, which entails generating an up or downward parallel shift in the term premium. We therefore allow this shock to act as a wedge between the pricing kernel and the price of the bond. We test whether this
additive specification drives our results by changing Eq. (22) such that the shock multiplies the pricing kernel instead. This modification generates two changes in the interpretation of our risk mispricing shock. First, the shock still affects the level of the pricing kernel, but it also alters its slope, steepening or flattening the rate of growth instead of adding a wedge. Second, because a multiplicative shock is proportional to the pricing kernel, when the pricing kernel is very high (the good times), then the effect of the risk mispricing shock is larger than during the bad times, when the pricing kernel is smaller. Therefore, the impact of a risk mispricing shock on the term premium is no longer independent from the level of the pricing kernel. Unlike Kim (2000) additive vs. multiplicative TFP shock to firms’ production function, for example, we find our results to be robust to either shock specification, with model moments being practically the same and impulse response functions to either shock remaining unchanged, even if we increase the size of the shocks by a factor of 10. The reason this change does not alter our results is because our shock only affects the pricing kernel that is used to price assets (i.e., risk is mispriced by investors, reflected in the bond term premium) rather than affecting the stochastic discount factor of the households more broadly. As such, the shock does not alter the households’ problem either way, since their utility, preferences, and risk aversion remains the same. A shock to the households’ stochastic discount factor would instead be more of a preference-type of shock, altering their consumption patterns immediately, as opposed to mispricing risk.

We explore this point further by comparing our risk mispricing shock to a preference shock that impacts Eq. (4) instead. An example in the literature of such shock would be the classic Smets and Wouters (2007) risk premium shock, which affects households’ willingness to hold one-period bonds and can be interpreted as a structural shock to the demand for safe and liquid assets, as pointed out in Fisher (2015). Another micro-founded type of risk premium shock is detailed in Caballero and Simsek (2020), which generated shocks driven by agents ex-ante optimistic or pessimistic expectations due to interest rate frictions. Unlike our risk mispricing, preference shocks are similar to disaster shocks in the literature (e.g., Rietz, 1988; Barro, 2006; Gourio, 2012) in that they affect aggregate demand on impact. Figure 5 shows that because preference shocks enter the households’ problem directly, the effects on bank lending become even more pronounced, with the reduction in loans to entrepreneurs being more persistent over time (a) and long-term bond holdings increasing by more on impact (b), entailing very different responses (in sign and magnitude) for macroeconomic variables and therefore the central bank’s response. In this case, the model is very sensitive to whether the preference shock
enters the Euler equation additively or multiplicatively with respect to wealth and helps differentiate our shock as one that decouples households’ preferences from financial investors pricing risk, requiring no assumptions about what drives agents to do so: it could be a political or economic change that increases the perception of worsening economic conditions, an increase in uncertainty, or any exogenous change in the willingness to bear long-term risk, none of these reflected in economic fundamentals.

Figure 5: Impulse responses to risk mispricing vs. preference shocks

Notes: The blue solid line represents the impulse responses to a shock that misprices long-term bonds by rising the term premium 90 bps, using the baseline calibration from Table 1. The blue dashes show the responses a stochastic discount factor shock instead.

4 Application: When investors underprice 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 fueled 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 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, a bad boom can be defined as a credit boom that is solely
based on sentiment or ‘animal spirits’ and is thus likely to mean revert, once agents realize their mistake (e.g., Azariadis, 1981; De Grauwe, 2011; De Grauwe and Macchiarrelli, 2015; Bianchi and Melosi, 2016). An event that triggers the reversal in expectation, i.e., a Minsky moment, could likely set off a chain reaction ultimately inducing 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 (2022), 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.

4.1 Good and bad and credit booms

We model these two different types of booms using the baseline calibration from Table 1. 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 shocks that lead investors to underprice risk as the red line, whereas the good credit boom, driven by real economy productivity shocks, is depicted with the green line.

For the bad boom scenario, agents underprice the actual risk in the economy because they perceive risks, for some exogenous reason, to be lower. In modeling terms, the economy is hit by a series of small positive risk mispricing shocks for the duration of 7 quarters that compress the term premium (a). We then assume that an exogenous event occurs making agents realize that they have not priced risk correctly, which means they reverse their risk mispricing 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 (b), and, to give a comparison, then reverse back to the baseline in period 7. The path of private credit is calibrated to be similar during the boom in both cases (d). This also leads investment to follow a similar path (i), 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 (g). 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 is weaker during credit booms led by risk mispricing, yet can generate a more pronounced drop in output during a bust.\(^6\)

\(^6\)It should also be noted that the only non-linearity we assume in the model is the one arising due to the higher order
Some of the explanation for this result lies in the response of consumption (h) and wages (f). 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 (c) 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 characterized by higher private sector credit growth, their effects on the real economy are very different. From a financial stability perspective, intervening in a bad boom would therefore have a milder effect on output than previously thought.

Figure 6: Impulse responses to good and bad credit booms

Notes: The red line represents the impulse responses to a bad credit boom scenario: 7 consecutive periods of risk underpricing shocks, followed by a complete reversal shock in the 7th period. The green line represents the impulse responses to a good credit boom scenario: 7 consecutive periods of positive technology shocks, followed by a complete reversal shock in the 7th period. The 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).
4.2 Macroprudential policies

Financial stability policy makers are tasked with identifying bad credit booms in advance, and building up resilience against a potential burst that could be harmful for the economy, such as experienced in 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, \( \nu \) in Eq. (13), and (b) a macroprudential policy that decreases the steady state of the LTV ratio of entrepreneurs, \( \Omega \). Capital ratios are targeted in particular at lenders’ solvency, whereas the 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 analyze 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.

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 (gray dashes). In this scenario, the increase in capital is not enough to induce banks to decrease credit to the private sector, so that loans to entrepreneurs 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 (solid gray line).

A similar result is found by Caballero and Simsek (2020), who showed that macroprudential policies can be welfare improving by reducing the risk-taking behavior of overly optimistic agents. In this simulation, macroprudential policy targeting 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.
Figure 7: Impulse responses to bad credit boom under different macroprudential policies

Notes: The red solid line represents the impulse responses to a bad credit boom scenario using the baseline calibration: 7 consecutive periods of risk underpricing shocks, followed by a complete reversal shock in the 7th period. The gray dashes represent a bad boom scenario under a 25% higher leverage ratio (from 0.09 to 0.12), whereas the gray solid line corresponds to a scenario under a 25% lower LTV target ratio (from 0.35 to 0.2625).

5 Conclusion

We construct a unifying model of the macroeconomy with a financial sector and show that incorporating a feedback loop via bank lending helps quantify the general equilibrium effects of long-term risk mispricing shocks. Our model generates a time-varying term premium, consistent with empirical evidence, which allows us to match both macro and finance moments. We find that shocks that might occur during a panic and lead investors to overprice risk, reduce the volume of short-term private loans in favor of holding long-term government bonds due to the loan price and collateral channels, and significantly reduce credit availability, investment, and output.

Our simulation also shows that a bad credit boom driven by agents underpricing risks is very different from a credit boom driven by economic fundamentals. Whereas a good boom increases wages and consumption and translates positively to economic growth, 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 to foster financial stability over the business cycle.
There are many avenues in which the model can be extended. In terms of the banking sector, one useful addition 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 endogenize 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 modeling the empirical relationship between credit spreads and economic activity found in Faust et al. (2013), in the spirit of Görtz and Tsoukalas (2017). Note also that in our setup, the reason for risk mispricing, and thus the under- or over-valuation of long-term bond prices via the term premium, is exogenous. In reality, these perceptions 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 macroeconomic as well as asset price behavior, 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.
References


Appendix

A Data appendix

Quarterly from 1961-Q1 to 2016-Q4, expressed in annual terms.

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. Labor*. 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 labor. 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 annualized 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. We choose the shadow federal funds rate to account for monetary policy during the zero lower bound period constraining the policy rate from below, see Wu and Xia (2016) and refer to https://sites.google.com/view/jingcynthiawu/shadow-rates?authuser=0 for more details.

7. Term Premium. 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.

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

9. Government loans. Public loans is the annualized 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.

* HP filtered to extract the cyclical component.

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