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"Search for Yield and Business Cycles"

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Search for Yield and Business Cycles *

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Abstract

In the ultra-low interest rate environment after the financial crisis, it has been often pointed out that the "search for yield" behavior of financial institutions might have been intensifying interest rate decreases. One hypothesis to explain search for yield is that banks try to buy longer-term bonds even when they recognize negative term premiums in long-term rates because they myopically care about current portfolio income, not just expected holding-period returns. I study the potential impacts of this behavior on U.S. business cycles and long-term bond's ex-post term premiums. I find that in an economy in which banks are exposed to the value-at-risk constraint, the existence of these myopic banks provides realistic moments of ex-post term premiums. In addition, their existence could generate higher output persistence under a productivity shock compared to an economy without them. This is because the difference between a myopic long-term bond pricing and a realized deposit rate path affects banks' net worth.

JEL classification: E32, E43, G11, G12

Keywords: Business cycle, Search for yield, Long-term real rates, Value-at-risk constraint

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1 Introduction

The purpose of this study is to investigate how search for yield by banks that take duration risks myopically caring about current portfolio income or yield, rather than about expected holding-period returns, affects term premiums of long-term bonds and business cycles. Search for yield means that financial institutions shift their fixed-income portfolios into riskier assets with higher yields as interest rates decline. Risks taken by financial institutions in this context usually include credit and duration risks. Major existing research on search for yield study credit risk-taking behaviors both empirically and theoretically, and its implication for business cycles.[1] In this study, on the other hand, I focus on search for yield in the context of duration risk-taking, and try to explain empirical behaviors of term premiums of long-term bonds and its implication for business cycles.[2]

The potential impact of search for yield on the business cycles of the recent U.S. economy, which started a policy rate hike process in December 2015 for the first time after the 2008 financial crisis, has not been discussed intensively. The federal funds rate level as of 2017 is still much lower than Federal Open Market Committee's projection of the longer-run median level.[3] As the Federal Reserve normalizes monetary policy and short-term real interest rates rise gradually, banks that have chosen to hold longer-dated assets will face a squeeze on their net interest margin. It is possibile that further increases in the policy rate toward the longer-run level as the economy recovers would cause adverse effects if banks that take large duration risks exist in the economy. Rajan (2006) points out that search for yield implies a greater tendency to allow asset price misalignments and creates more financial-sector induced procyclicality. Kohn (2010) argues the necessity for financial intermediaries to be prepared for duration risks associated with mismatch in asset and liability maturities as the economy recovers. Wang (2017) mentions the presence of duration risks in the financial sector under low interest rate environments after the 2008 financial crisis with empirical evidence. Paul (2018) suggests that monetary policy tightening could increase financial instability by changing equity values of banks.

To pursue this issue, I develop a real business cycle model that incorporates two types of banks, rational and myopic, with their demand for long-term government bonds. The

[1]For example, Dell'Ariccia et al. (2017) and Jiménez et al. (2014) study this issue empirically. Martinez-Miera and Repullo (2017) study this theoretically. These studies show that banks take more credit risks as interest rates become lower.

[2]Wang (2017) provides empirical evidence for duration risk-taking.

[3]The September 2017 Federal Open Market Committee projection of longer-run federal funds rate median is 2.8% while the target range for the federal funds rate is 1–1.25% in September 2017. (https://www.federalreserve.gov/monetarypolicy/fomcprojtabl20170920.htm)

rational banks, which I call "expected return-oriented banks" (EO banks), rationally expect the deposit rate path in bond pricing. EO banks care about expected holding-period returns. The myopic banks, I call "yield-oriented banks" (YO banks), expect that the deposit rate will stay flat over the maturity of long-term government bonds. I model the YO banks' flat deposit rate expectation to describe their myopic considerations about current portfolio income. The population share of YO banks is exogenously given in my model.[4] To investigate duration risks separately from credit risks, credit risks or credit bonds are outside the scope of this study. Both banks maximize expected terminal wealth. They decide their balance sheet size and asset portfolio allocation between two assets, capital and long-term government bonds, so as to satisfy the value-at-risk (VaR) constraint. I add the VaR constraint so that banks' net worth positions, which could be squeezed by myopic pricing of long-term bonds, affect portfolio choices including capital holding for production by banks and total balance sheet size. Without this kind of constraints associated with net worth, net worth positions do not matter to banks' portfolio choice and their behaviors, which is not realistic.[5]

The major implications of this study are as follows. Firstly, in my model with YO banks, volatility of ex-post term premiums and correlation between ex-post term premiums and output show realistic values, while the model with only EO banks fails to show them.[6] Secondly, when I assume the existence of YO banks, output shows more persistent and volatile responses to a productivity shock. In other words, when YO banks exist, recovery after a negative shock hits the economy becomes slower. The existence of YO banks lowers ex-post returns to banks' net worth because YO banks that priced long-term bonds based on expectations of flat deposit rate path later experience increases in realized deposit rates which are funding costs for the banks. This consequently reduces capital stock holdings by banks because the banks try to maintain their solvency by reducing the size of their balance sheets.

Management myopia would be one of the candidates to explain why banks take more duration risks by investing in longer maturity assets with term spreads. Based on a survey of more than 400 financial executives, Graham et al. (2005) find that firms are willing to sacrifice economic value to meet a short-run earnings target, because of the severe market

[4] A depiction closer to the reality should include the endogeneity of YO banks' population share. Nevertheless, I consider that my approach is a useful first step, before incorporating endogeneity in future research.

[5] Importance of banks' net worth position is discussed, for example, in Adrian and Shin (2014) and Gertler and Kiyotaki (2010).

[6] Because my interest lies in realized effects on banks' profitability, I focus on ex-post term premiums which I define as the difference between a long-term bond interest rate and short-term interest rates corresponding to the maturity of the long-term bond, rather than ex-ante term premiums.

reaction to missing an earnings target. In their survey, 78% of the surveyed executives would give up economic value in exchange for smoothing earnings. Major motivations behind it include credibility with the capital market and career concerns according to their survey. Cai et al. (2017), Guan et al. (2005), and Liu and Xuan (2016) show empirical evidence that when chief executive officers' job security is lower, companies tend to result in more earnings management. Mizik and Jacobson (2007) present empirical evidence that some firms engages in myopic marketing management by limiting marketing expenditures to inflate current-term accounting results at the time of a seasoned equity offering, because investors rely on current-term accounting measures to form expectations of future profits. Stein (1989) provides a theoretical model to illustrate how asymmetric information induces myopic behavior. In his model: (i) stock price is a function of expected future earnings: (ii) current stock price is a component of the manager's utility function: and (iii) current earnings are signals of future earnings. Managers can inflate current earnings by "borrowing" from future earnings, which results in costs in the future.

Several empirical studies show that banks have taken more duration risks since the financial crisis, even though the banks that have chosen to hold more duration risks for term spreads will face a squeeze on their net interest margin as the Federal Reserve normalizes monetary policy and short-term interest rates rise gradually. Wang (2017) provides empirical evidence that banks that faced less strict regulation after the financial crisis took on assets with longer maturities. Bednar and Elamin (2014a) and Bednar and Elamin (2014b) provide empirical evidence that U.S. banks' duration risk has increased since 2009. Memmel et al. (2018) empirically show that banks start to lengthen asset duration to obtain term premiums if the operative income falls below a certain threshold. This indicates that the prevalence of search for yield in terms of duration risks may increase if the current low interest rate environment persists though the literature often focuses on search for yield in terms of credit risk-taking. However, impacts of duration risks on business cycles are not discussed widely.

To describe these investors' near-term income considerations, Hanson and Stein (2015) propose a partial equilibrium model in which a myopic investor prices long-term (two-period) government bonds expecting that the short-term rate will stay flat over the maturity of bonds, while rational investors rationally expect the short-term rate. The sum of bond demand from both types of investors and the fixed supply of long-term bonds generate negative term premiums.[7] However, in their model, the impact on business cycles is not discussed.

[7] Hanson and Stein (2015) assume that there are two types of investors, "expected return-oriented investors" who maximize expected holding-period returns, and "yield-oriented investors" who maximize current income. Both investors purchase long-term bonds (two-period bonds) and finance this position by rolling-

Most studies on search for yield focus on credit risk-taking, rather than duration risks. Dell'Ariccia et al. (2017) find that ex-ante risk-taking by banks measured by internal rating of the bank' s new loans) is negatively associated with increases in short-term policy interest rates. Jiménez et al. (2014) empirically shows that banks take on more credit risk when rates are low. Martinez-Miera and Repullo (2017) present a theoretical model in which banks take more credit risks (lowering monitoring costs) as interest rates decline. In their model, they explain a positive correlation between credit spread and risk-free interest rate, and a negative correlation between risk-free rate and riskiness of banks' portfolio which results in boom and bust cycles associated with endogenous changes in monitoring level and default probabilities. My model explains procyclical ex-post term premium changes and riskiness of banks' balance portfolio in terms of duration risks.

The rest of the paper is organized as follows. Section 2 presents my model. Section 3 discusses quantitative results based on the model. Section 4 concludes the analysis and discusses the future extension of my analysis.

2 Model

The economy that I model consists of households, banks, firms (goods producers), capital producers, and the government. There are two types of banks: EO and YO banks. EO banks rationally form an expectation about deposit rates which are funding costs for them. YO banks expect that deposit rates will take flat paths over long-term government bond maturities each time a bond is purchased. I assume this specific formulation of expected deposit rate paths by YO banks to parsimoniously describe their concerns about current income, based on the two-period bond model of Hanson and Stein (2015). Both types of banks collect deposits from the households, and invest their own net worth and deposits in two types of assets: capital stock and long-term government bonds.

A very simple example of why a bank's manager becomes myopic, which is consistent with the survey evidence presented by Graham et al. (2005) is as follows. The performance evaluation of a manager is conducted based on performances over the past one year by an owner. There are two investment strategies. The first strategy is investing in short term bonds rolling over two years. Suppose that this generates returns of 0 dollar in year 1 and

over short-term (one-period) borrowing under mean-variance optimization with short-term rate uncertainty in the second period. To formulate an optimization problem in which yield-oriented investors maximize current income (first period's income), Hanson and Stein (2015) assume that these investors expect short-term rates are flat over the two periods. They show that negative term premiums arise depending on the share of yield-oriented investors and a rational path of short-term rates

5 dollar in year 2. The second strategy is investing in two-year maturity bonds with term spread. This generates returns of 2 dollar in each of year 1 and 2. The first strategy cannot generate any returns in the first year. If the manager chooses the first one, this manager is fired regardless of present values of expected profits at the end of the first year. Therefore, this manager myopically chooses the second strategy.

The households supply labor to goods producers, receives wages, and makes deposits at the banks. The households do not have access to the financial market other than through its deposits. The banks conduct asset allocations so that they do not violate the VaR constraint. Goods producers hire labor and borrow capital goods from banks in competitive markets. Capital producers sell capital goods to banks. The government collects lump-sum taxes from the households and issues long-term government bonds to finance government debts and expenditures.

2.1 Banks

At time t, banks collect deposits D_t from the households and purchase capital stock K_t and the long-term (two-period) bond B_t issued by the government.[8] The banks finance purchases of assets by deposits and net worth N_t. B_t provides the same real returns, $R_{B,t+1}$, over two periods after purchases, i.e., in $t+1$ and $t+2$. I assume that there is no secondary market for bonds. Therefore, the banks continue to hold them until they mature. Superscripts, e and y, indicate the variables of EO banks and YO banks, respectively. EO banks and YO banks are populated by portions of $1-\alpha$ and α, respectively, so that the sum of these is unity.

2.1.1 EO banks

EO banks' balance sheet at time t is given by

$$K_t^e + B_{t-1}^e + B_t^e = D_t^e + N_t^e. \tag{1}$$

I assume that N_t^e is a state variable that is pre-determined at the beginning of time t. Because output can be transformed to capital without adjustment costs, relative price does not appear in this equation.

[8] Woodford (2001) models long-term bonds as the exponentially decaying coupon perpetuity. This setting allows us to assume a single long-term bond regardless of issue dates under the rational expectation of the short-term interest rate path. However, when I consider flat short-term interest rate paths at each issue date of long-term bonds, a single long-term bond as modeled in Woodford (2001) cannot be utilized to describe my interest.

The banks receive returns from the two types of assets they invested in during the previous period, repay deposits to the households, and accumulate their own net worth. Therefore, banks' net worth evolves according to the following law of motion,

$$\begin{aligned} N_{t+1}^{e} =& R_{K,t+1}K_{t}^{e} + R_{B,t}B_{t-1}^{e} + R_{B,t+1}B_{t}^{e} \\ & - \frac{1}{2}\chi_{t}B_{t}^{e^{2}} - R_{D,t+1}D_{t}^{e}. \end{aligned} \tag{2}$$

$R_{K,t+1}$ is the real gross return on capital between time t and $t+1$. $R_{D,t+1}$ is the deposit rate between time t and $t+1$, which is risk free.[9] Because the government bond is over two periods, banks receive the same real returns over two periods after they purchase the bonds. I assume banks need to pay long-term bond holding costs, $\frac{1}{2}\chi_{t}B_{t}^{e2}$, where χ_t is a time-varying parameter for the cost.[10] This is governed by two equations shown below,

$$\chi_{t} = \overline{\chi}\exp(u_{t}^{\chi}). \tag{3}$$

and

$$u_{t}^{\chi} = \rho_{\chi}u_{t-1}^{\chi} + \epsilon_{t}^{\chi}, \tag{4}$$

where $\overline{\chi}$ is the steady-state level of χ and u_{t}^{χ} is a stochastic process for χ at time t. ϵ_{t}^{χ} is a stochastic shock at time t.

Banks choose their portfolio size and allocation between the two types of assets subject to the VaR constraint. This setting is similar to that used by Aoki and Sudo (2013). Banks adjust their balance sheet in period t so that they can repay all their debts to the households, even if the capital return becomes the worst-case scenario that they assume could occur in period $t+1$. The assumed worst-case return from capital holdings is $\underline{R_K}$, which is exogenously given. The VaR constraint is given by

[9]Here, "risk free" means that the rate is known in period t. In the VaR constraint (5) which will be shown later, it is possible that banks cannot repay all of their deposits without any transfer from the households if the realized bond and capital returns are sufficiently lower than banks' expectation. However, I construct my model so that banks receive positive transfers from the households and repay deposit costs in that case.

[10]This quadratic representation of bond holding costs is a device to generate bond supply effects on the bond's return under the first-order approximation. In Hanson and Stein (2015), the quadratic term of the bond demand function comes from the mean-variance specification of investors' utility. However, it requires normal distributions of returns. I avoid this issue in a general equilibrium model by assuming long-term bond holding costs. The time-varying parameter χ_t parsimoniously describe a non-systematic part of term premiums' movements.

$$\underline{R_K} K_t^e + R_{B,t} B_{t-1}^e + R_{B,t+1} B_t^e - \frac{1}{2}\chi_t B_t^{e2} - R_{D,t+1} D_t^e \geq 0. \tag{5}$$

Eliminating D_t^e yields

$$\begin{aligned} N_{t+1}^e =& (R_{K,t+1} - R_{D,t+1}) K_t^e + (R_{B,t} - R_{D,t+1}) B_{t-1}^e + (R_{B,t+1} - R_{D,t+1}) B_t^e \\ & - \frac{1}{2}\chi_t B_t^{e2} + R_{D,t+1} N_t^e \end{aligned} \tag{6}$$

and

$$\begin{aligned} & (\underline{R_K} - R_{D,t+1}) K_t^e + (R_{B,t} - R_{D,t+1}) B_{t-1}^e + (R_{B,t+1} - R_{D,t+1}) B_t^e \\ & - \frac{1}{2}\chi_t B_t^{e^2} + R_{D,t+1} N_t^e \geq 0. \end{aligned} \tag{7}$$

Next, I formulate a bank's maximization problem. Following Gertler and Karadi (2011) and others, I assume that banks maximize the discounted stream of payouts to the households. Therefore, the discount rate Λ is set to be the household's intertemporal marginal rate of substitution. Under financial market frictions, it is optimal for the bank to retain net worth until exiting, which occurs by probability $1-\theta$. The bank's objective is to maximize expected terminal wealth V_t at time t, given by,

$$V_t^e = \max_{\{B_{t+i}^e\}_{i=0}^{\infty}} E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i+1} \theta^i N_{t+i+1}^e \tag{8}$$

subject to the net worth evolution shown by (6) and the VaR constraint (7). The discount rate Λ is defined as

$$\Lambda_{t,t+i+1} = \beta^{i+1} \frac{U_c(C_{t+i+1}, L_{t+i+1})}{U_c(C_t, L_t)}, \tag{9}$$

where $U_c(C_t, L_t)$ is the first-order derivative of household utility with respect to C_t.

As noted, banks need to pay long-term bond holding costs given by $\frac{1}{2}\chi_t B_t^{e2}$, which is not a linear function. Therefore, I cannot necessarily guess V_t^e as a linear function of B^e, K^e, and/or N^e. Instead, I use backward iterations to obtain N_{t+i+1}^e as a function of B^e by eliminating K^e, given the initial value of N^e. I substitute this for N_{t+i+1}^e in (8) and solve the optimal choice of B_t^e by taking the first-order condition with respect to B_t^e. The details are shown in Appendix A.1. The government bond demand equation from EO banks is

$$B_t^e = \chi_t^{-1} E_t \left[\left\{ 1 + \frac{\Omega_{t+1}}{1+\Omega_{t+1}} R_{D,t+2} \left(\frac{R_{K,t+1} - \underline{\underline{R_K}}}{R_{D,t+1} - \underline{\underline{R_K}}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{\underline{R_K}}}{R_{D,t+2} - \underline{\underline{R_K}}} \right)^2 \right\} R_{B,t+1} \right.$$
$$\left. - R_{D,t+1} - \frac{\Omega_{t+1}}{1+\Omega_{t+1}} R_{D,t+2} \left(\frac{R_{K,t+1} - \underline{\underline{R_K}}}{R_{D,t+1} - \underline{\underline{R_K}}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{\underline{R_K}}}{R_{D,t+2} - \underline{\underline{R_K}}} \right)^2 R_{D,t+2} \right] \tag{10}$$

where

$$\Omega_{t+1} = \beta\theta \frac{U_c(C_{t+2}, L_{t+2})}{U_c(C_{t+1}, L_{t+1})} \{1 + \Omega_{t+2}\}. \tag{11}$$

The first line of (10) represents gross returns from government bonds. The second line indicates funding costs, namely, deposit rates over two periods. To finance bond purchases, banks need to pay costs incurred from deposit rates. Other things being equal, when deposit rates are high, the demand for government bonds decreases.

To interpret this equation intuitively, I rewrite this equation in the steady state as,

$$B_{ss}^e = \chi_t^{-1} \left[\left(1 + \beta\theta R_{D,ss} \frac{R_{K,ss} - \underline{\underline{R_K}}}{R_{D,ss} - \underline{\underline{R_K}}} \right) (R_{B,ss} - R_{D,ss}) \right], \tag{12}$$

where subscript ss denotes the steady-state value of each variable. In the case in which the banks' maximization problem is not subject to the VaR constraint, $\frac{R_{K,ss} - \underline{\underline{R_K}}}{R_{D,ss} - \underline{\underline{R_K}}}$ becomes 1. Therefore, I can interpret that $\frac{R_{K,ss} - \underline{\underline{R_K}}}{R_{D,ss} - \underline{\underline{R_K}}}$ represents the risk effects of the VaR constraint on bond demand. If the worst-case return from capital holdings $\underline{\underline{R_K}}$ decreases under the steady state where $R_{K,ss} > R_{D,ss}$ holds, this fraction on the right hand side of the equation decreases. An increase in $R_{K,ss}$ helps net worth accumulation and supports bond demand. Because lower deposit rates $R_{D,ss}$ alleviate insolvency risks, banks increase bond demand more than in a case without the VaR constraint as deposit rates are lower. Larger $R_{B,ss}$ increases bond demand more than a case without the VaR constraint, because $\frac{R_{K,ss} - \underline{\underline{R_K}}}{R_{D,ss} - \underline{\underline{R_K}}}$ is larger than 1 in the steady state. These effects are not incorporated in the case without the VaR constraint.

The aggregate net worth of EO banks evolves as shown in equation (13) below because only θ fraction of EO banks survive into the next period. I assume new entries of banks following Gertler and Karadi (2011). [11]

[11] Gertler and Karadi (2011) consider newly entering bankers receiving small amounts of "startup" funds from the households.

$$
\begin{aligned}
N_t^e = & \exp(v_t)\theta\{(R_{K,t} - R_{D,t})K_{t-1}^e + (R_{B,t-1} - R_{D,t})B_{t-2}^e + (R_{B,t} - R_{D,t})B_{t-1}^e - \frac{1}{2}\chi_t {B_{t-1}^e}^2 + R_{D,t}N_{t-1}^e\} \\
& + \varpi(K_{t-1}^e + B_{t-2}^e + B_{t-1}^e), \qquad (13)
\end{aligned}
$$

where v_t represents the net worth shock process. v_t is governed by

$$
v_t = \rho_v v_{t-1} + \epsilon_t^v. \qquad (14)
$$

ρ_v represents a persistency parameter of the net worth shock process and ϵ_t^v represents an exogenous shock to net worth.[12] The second line of (13) represents transfers from the households to newly born banks, where ϖ is a parameter of the fraction to the balance sheet size.

2.1.2 YO banks

According to Hanson and Stein (2015), YO banks price long-term bonds differently from EO banks. The difference is the expectation formation about the path of deposit rates, R_D. While EO banks rationally form expectations of R_D, YO banks consider at time t that the level of $R_{D,t+1}$ at time t continues over the next period, time $t+1$, too. Then, at time $t+1$, YO banks update their information about actual $R_{D,t+2}$ when they newly observe it and consider that the level will continue over the next period, $t+2$. Based on this assumption, I replace $R_{D,t+2}$ with $R_{D,t+1}$ in the EO banks' demand equation for B_t^e in (10) and obtain the YO banks' demand for the bond B_t^y as

$$
\begin{aligned}
B_t^y = \chi_t^{-1} E_t \Bigg[& \left\{ 1 + \frac{\Omega_{t+1}}{1+\Omega_{t+1}} R_{D,t+1} \left(\frac{R_{K,t+1} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^2 \right\} R_{B,t+1} \\
& - R_{D,t+1} - \frac{\Omega_{t+1}}{1+\Omega_{t+1}} R_{D,t+1} \left(\frac{R_{K,t+1} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^2 R_{D,t+1} \Bigg]. \qquad (15)
\end{aligned}
$$

This formulation implies that YO banks care about the spread between long-term bond yields and the current short-term interest rate, whereas EO banks care about spreads in expected returns.[13] Even though the yield curve is upward-sloping, long-term bonds would

[12] This setting of net worth shock follows that of Nolan and Thoenissen (2009).

[13] Although I replace $R_{D,t+2}$ with $R_{D,t+1}$ assuming YO banks' current income concern, the same model setting could be alternatively approached by extrapolative expectations in which the future short rate is the same as today's rate. The literature on extrapolative expectations includes Fuster et al. (2010) and Lansing

be more attractive to the YO banks as long as today's deposit rate is low, but not necessarily to EO banks. Thus, the demand for long-term bonds from YO banks depends more on current income.

By changing the superscript e in (7) and (13) to y, the VaR constraint and aggregate net worth evolution for YO banks become

$$(\underline{R_K} - R_{D,t+1})K_t^y + (R_{B,t} - R_{D,t+1})B_{t-1}^y + (R_{B,t+1} - R_{D,t+1})B_t^y - \frac{1}{2}\chi_t B_t^{y2} + R_{D,t+1}N_t^y \geq 0 \quad (16)$$

and

$$\begin{aligned} N_t^y =& \exp(v_t)\theta\{(R_{K,t} - R_{D,t})K_{t-1}^y + (R_{B,t-1} - R_{D,t})B_{t-2}^y + (R_{B,t} - R_{D,t})B_{t-1}^y - \frac{1}{2}\chi_t {B_{t-1}^y}^2 + R_{D,t}N_{t-1}^y\} \\ &+ \varpi(K_{t-1}^y + B_{t-2}^y + B_{t-1}^y), \end{aligned} \quad (17)$$

respectively. In the steady state, EO and YO banks are identical because both banks form the same deposit rate expectations that the rates are flat over time. The aggregate net worth of banks is given by

$$N_t = (1 - \alpha)N_t^e + \alpha N_t^y, \quad (18)$$

where α represents the portion of YO banks.

2.1.3 Definition of variables for asset returns and banks' balance sheets

For convenience, I define variables outside the model associated with asset returns and banks' balance sheet variables as follows. The ex-post term premium, tp, is

$$tp_t = R_{B,t+1} - \sqrt{R_{D,t+1}R_{D,t+2}}. \quad (19)$$

The spread between the bond return and the deposit return, bsp, is

$$bsp_t = R_{B,t+1} - R_{D,t+1}. \quad (20)$$

Banks' asset, bal, is

$$bal_t = B_{t-1} + B_t + K_t. \quad (21)$$

The leverage of banks, lev, is

(2006).

$$lev_t = bal_t / N_t. \tag{22}$$

The share of long-term bonds to total banks' asset, $bshare$, is

$$bshare_t = (B_{t-1} + B_t)/bal_t. \tag{23}$$

B_t and N_t are the aggregate amount of bonds and the aggregate net worth, respectively, as defined later in Section 2.6.

2.2 Households

The infinitely lived representative household makes decisions on consumption, savings in the form of bank deposit holdings, and labor supply. The households are excluded from access to financial markets of capital stock holdings and government bonds. The household's utility in each period is presented in the following function,

$$U(C_t, L_t) = \frac{1}{1-\sigma}\left(C_t - \psi\frac{L_t^{1+\nu}}{1+\nu}\right)^{1-\sigma}, \tag{24}$$

where C_t is consumption at time t, L_t is labor at time t, σ is the rate of relative risk aversion, ψ is the weight assigned to labor, and ν is the inverse of Frisch elasticity. I assume Greenwood-Hercowitz-Huffman (Greenwood et al. (1988)) preferences to eliminate wealth effects on labor supply.

The budget constraint of the household is given by the following equation.

$$C_t + D_t = w_t L_t + R_{D,t} D_{t-1} - T_t + \pi_t^F + \pi_t^B. \tag{25}$$

Here, w_t is the wage at time t, π_t^F is the profit from goods producers at time t, and π_t^B is net worth from exiting banks returned to the household at time t minus transfer from the household to newly born banks. T_t is a lump-sum tax at time t. I assume that the deposit rate is the risk-free rate. π_t^B is given by

$$\begin{aligned}
\pi_t^B =&(1-\alpha)(1-\exp(v_t)\theta)\{R_{K,t}K_{t-1}^e + R_{B,t-1}B_{t-2}^e + R_{B,t}B_{t-1}^e - \frac{1}{2}\chi_t B_{t-1}^{e^2} - R_{D,t}D_{t-1}^e\} \\
&- (1-\alpha)\varpi(K_{t-1}^e + B_{t-2}^e + B_{t-1}^e) \\
&+ \alpha(1-\exp(v_t)\theta)\{R_{K,t}K_{t-1}^y + R_{B,t-1}B_{t-2}^y + R_{B,t}B_{t-1}^y - \frac{1}{2}\chi_t B_{t-1}^{y^2} - R_{D,t}D_{t-1}^y\} \\
&- \alpha\varpi(K_{t-1}^y + B_{t-2}^y + B_{t-1}^y).
\end{aligned} \tag{26}$$

The household maximization problem is given by

$$\max\, E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t) \tag{27}$$

subject to (25), where E_0 denotes the expectation operator at time 0. $\beta \in (0, 1)$ is the discount factor. The first-order conditions associated with the household maximization problem are given by the Euler equation,

$$U_c(C_t, L_t) = \beta E_t R_{D,t+1} U_c(C_{t+1}, L_{t+1}), \tag{28}$$

where $U_c(C_t, L_t)$ is the derivative of utility by C_t,

$$U_c(C_t, L_t) = \left(C_t - \psi \frac{L_t^{1+\nu}}{1+\nu}\right)^{-\sigma}, \tag{29}$$

and the labor supply schedule,

$$-\frac{U_L(C_t, L_t)}{U_c(C_t, L_t)} = w_t, \tag{30}$$

where $U_L(C_t, L_t)$ is the derivative of utility by L_t,

$$U_L(C_t, L_t) = \left(C_t - \psi \frac{L_t^{1+\nu}}{1+\nu}\right)^{-\sigma} (-\psi L_t^{\nu}). \tag{31}$$

2.3 Firms/Goods producers

Goods producers produce consumption goods and investment goods, and sell them to the households and capital producers. They hire labor from the households and borrow capital from banks. Both the input and output markets of goods producers are assumed to be competitive. Production technology is given by

$$Y_t = \exp(A_t) K_{t-1}^{\xi} L_t^{1-\xi}. \tag{32}$$

Y_t is output at time t and A_t represents the technology level at time t. ξ is the capital share. The productivity shock process is formulated with a persistency parameter of ρ_A and an exogenous shock to productivity ϵ_t^A as,

$$A_t = \rho_A A_{t-1} + \epsilon_t^A. \tag{33}$$

The first-order condition for goods producers yields labor demand,

$$w_t = (1 - \xi)\frac{Y_t}{L_t}. \tag{34}$$

The return on capital is simply defined as

$$R_{K,t+1} = MPK_{t+1} + 1 - \delta, \tag{35}$$

where δ is the depreciation rate and MPK_t is the marginal productivity of capital given by

$$MPK_t = \xi\frac{Y_t}{K_{t-1}}. \tag{36}$$

2.4 Capital producers

Capital producers produce capital from investment goods, I_t, which are outputs from goods producers. They sell their outputs to banks. No adjustment costs are assumed here. Therefore, the output of capital producers becomes

$$K_t = (1 - \delta)K_{t-1} + I_t. \tag{37}$$

2.5 The government

The government collects lump-sum tax T_t from the households and issues long-term (two-period) government bonds B_t to finance its repayment of bonds issued in the previous period and the period before the previous one including interest rate costs, and government expenditure G_t. The government budget constraint is,

$$R_{B,t-1}B_{t-2} + R_{B,t}B_{t-1} + G_t = T_t + B_{t-1} + B_t. \tag{38}$$

The tax rule is given by the following two equations.

$$T_t = \tau_t Y_t. \tag{39}$$

$$\tau_t = \bar{\tau}^{\rho_\tau} \tau_{t-1}^{1-\rho_\tau} (\frac{B_{t-1}}{Y_t} / \frac{B_{ss}}{Y_{ss}})^\gamma. \tag{40}$$

The tax ratio to output, τ_t, reacts to the deviation of the ratio of government bonds to output from the steady state by a parameter, γ, with the baseline rate, $\bar{\tau}$. ρ_τ is the persistence parameter. Tax reactions to government debt amounts are necessary to avoid explosive paths of government debts and are usually seen in the literature. Government expenditures are given exogenously as

$$G_t = \bar{g}. \tag{41}$$

Because my interest is not in reactions to government expenditure shocks, for simplicity, I do not add the stochastic shock to the government expenditure process.

2.6 Market clearing

EO and YO banks are populated by portions of $(1-\alpha)$ and α, respectively. The market clearing condition of government bonds is,

$$B_t = (1-\alpha)B_t^e + \alpha B_t^y. \tag{42}$$

By the same logic, the market clearing condition of capital is,

$$K_t = (1-\alpha)K_t^e + \alpha K_t^y. \tag{43}$$

The supply of capital is given by capital producers' output.

Finally, because of long-term government bond holding costs for both EO and YO banks, the resource constraint of the entire economy becomes,

$$C_t + I_t + G_t + (1-\alpha)\frac{1}{2}\chi_{t-1}{B_{t-1}^e}^2 + \alpha\frac{1}{2}\chi_{t-1}{B_{t-1}^y}^2 = Y_t. \tag{44}$$

2.7 Equilibrium conditions

An equilibrium consists of a set of prices, $\{w_t, R_{K,t}, R_{D,t}, R_{B,t},\}_{t=0}^\infty$, and the allocations, $\{C_t, L_t, B_t^e, B_t^y, K_t^e, K_t^y, Y_t\}_{t=0}^\infty$, for a given government policy, $\{G_t, \tau_t\}_{t=0}^\infty$, realizations of exogenous variables, $\{\epsilon_t^A, \epsilon_t^v\}_{t=0}^\infty$, the expected worst-case return, $\{\underline{R_K}\}$, and initial conditions,

$\{B^e_{-1}, B^y_{-1}, K^e_{-1}, K^y_{-1}, D^e_{-1}, D^y_{-1}, N^e_{-1}, N^y_{-1}, R_{D,0}\}$ such that for all t: (i) the household maximizes its utility given prices; (ii) each type of banks maximizes their profits given prices and expected worst-case returns; (iii) goods producers maximize their profits given prices; (iv) capital producers maximize their profits given prices; (v) the government budget constraint holds; and (vi) all markets clear.

3 Quantitative analysis

In this section, I show the quantitative implications of my model economy. I solve this model by the first-order perturbation method around the steady state. Time frequency is annual. I check the model's performance by comparting theoretical moments with actual data moments and compute impulse responses under productivity shocks. I consider different population shares of the two types of banks and investigate how they change the dynamic paths of the economy.

In summary, the implications are as follows. The model in which YO banks exist works well to provide plausible theoretical moments of ex-post term premiums. Impulse responses of this model imply that the existence of YO banks generates higher output persistence under a productivity shock and makes the recovery path after a negative productivity shock hits the economy slower.

3.1 Calibration

Table 1 lists the choice of parameter values for my baseline model. Parameter values are calibrated in annual rates and assume those of the U.S. economy. I calibrate basic parameters, the rate of relative risk aversion σ, and the inverse of Frisch elasticity ν following Christiano et al. (2005). Discount rate β and depreciation rate δ are annualized by multiplying their quarterly calibration values by 4. My calibrated value for capital share ξ is different from theirs. This is because using their value, 0.36, results in a much higher investment ratio to output and a much lower consumption share to output in my model compared to the actual data. Therefore, I set this value at 0.25. This calibration provides reasonable shares of investment I and consumption C to output Y as shown in Table 2. The relative utility weight of labor ψ is set so that in the steady state one-third of the labor endowment is spent on productive activity.[14]

[14] De Paoli et al. (2010) calibrate the relative utility weight of labor so that labor supply becomes one third. In Christiano et al. (2005), it is chosen so that a steady-state value of aggregate labor equals 1.

Next, I calibrate government sector parameters and banking sector parameters. These parameters are important in this study because they affect the sensitivity of banks' net worth to changes of interest rates associated with assets and liabilities including returns on capital, long-term bond rates, and deposit rates. These parameters affect the steady-state balance sheet size and its components, average asset duration, and net worth ratio to total balance sheet. The calibrated model needs to have similar duration risks to the reality measured by impacts of changes of all interest rates (returns on capital, long-term bond rates, and deposit rates) on net worth to study effects of the existence of YO banks. The details are as follows. Drechsler et al. (2018) provide U.S. banks' repricing maturity estimate based on all U.S. commercial banks from 1984 to 2013. They define repricing maturity as the time until an asset's interest rate is reset. Their estimate of mean repricing maturity of aggregate assets is 3.360 years and that of liabilities repricing maturity is 0.441 years. The equity/assets ratio in their data is 0.097. Therefore, the repricing maturity mismatch is roughly estimated to be 2.96 years ($= 3.36 * 1 - 0.441 * (1 - 0.097)$). This can be considered a proxy of duration mismatch. Given this, when all interest rates of assets and liabilities increase equally by 1%, net worth is eroded by 30.5($= 2.96/0.097$)%. The maximum of the asset repricing maturity of my model is 2 years because the long-term government bond is two years while the estimate of mean repricing maturity of aggregate assets is 3.360 years in the data. With this model's constraint, I try to make the steady-state net worth sensitivity to the interest rate close to the data by calibrating both government sector parameters and banking sector parameters.[15]

I calibrate banks' survival probability θ at 0.8 and the worst-case gross return of capital $\underline{R_K}$ at 0.85.[16] θ affects the steady-state banks' net worth as implied by (13) and $\underline{R_K}$ affects the size of capital given the steady-state net worth as implied by (7). The parameter for transfer to the newly entering banks ϖ is set at a very small value. Gertler and Karadi (2011) calibrate the corresponding parameter so that it helps pin down the target steady

[15]Drechsler et al. (2018) argue that the federal fund rate sensitivity of banks' interest rate expense is not as large as repricing maturity of liability suggests because market power allows banks to keep deposit rate low even when market interest rates rise. They regress changes of quarterly interest expense over assets multiplied by four on quarterly changes of the Federal fund rates over the current, previous, and the quarter before the previous. They name the sum of the coefficients of the regressors over these three quarters as "interest rate expense beta". They estimate the interest rate expense beta as 0.36. If I annualized the beta, it would be $0.48 = 0.36 * 4/3$. In duration term, it could be interpreted as $2.08 = 1/0.48$. When I use 2.08 instead of 0.441 as the repricing maturity of liability, the repricing maturity mismatch becomes 1.48 years ($= 3.36 * 1 - 2.08 * (1 - 0.097)$). The sensitivity of net worth to all interest rates increase by 1% becomes 15.2($= 1.48/0.097$)% instead of 30.5%. Based on this consideration, the calibrated net worth sensitivity, 16% in Table 2 is not far from the reality.

[16]Gertler and Karadi (2011) set banks' survival probability parameter at 0.972, the annualized level of which is 0.89.

state leverage ratio of banks' balance sheet. I followed their logic for calibration of ϖ to have the target net worth sensitivity. The steady-state tax rate $\bar{\tau}$ affect the government bond supply and banks' holding of government bonds. I set the steady-state tax rate $\bar{\tau}$ at 0.40, given that the steady-state government expenditure $\bar{g}$ is set as mentioned later.

By these calibrations, the model repricing maturity mismatch in year term is, $(1B_{ss} + 2B_{ss} + 1K_{ss})/(B_{ss} + B_{ss} + K_{ss}) - 1 * (B_{ss} + B_{ss} + K_{ss} - N_{ss})/(B_{ss} + B_{ss} + K_{ss}) = 0.44$. The model's steady-state equity/assets ratio is 2.8%. The net worth sensitivity to the interest rate becomes $15.8(= 0.44/0.028)\%$. This sensitivity level is smaller than that of the data, 30.5%. However, I do not make efforts to increase it further because increasing the model's sensitivity could bring lower steady-state capital return than the steady-state bond's return. I compromise this deviation from the reality in order to have reasonable levels of the steady-state asset returns. The size parameter of long-term bond holding cost $\overline{\chi}$ is set so as to have the similar steady-state value of the term premium to the data.

The steady-state government expenditure $\bar{g}$ is set so that this share in output is 0.18 following Smets and Wouters (2007).[17] It is difficult for calibrations of the tax response parameter γ and autoregressive parameter of tax rule ρ_T to find specific values. I set these so that second moments of tax become close to actual data moments and the model can avoid explosive paths of bond amounts. The autoregressive parameter of productivity shock ρ_A is set to 0.8. I refer to Smets and Wouters (2007) who estimate the autoregressive parameter of productivity shock in quarter frequency as 0.95.

To examine robustness, I test other structural parameter values for the rate of relative risk aversion, the capital share, and the inverse of Frisch elasticity based on estimates by Smets and Wouters (2007), keeping the steady-state net worth sensitivity to the interest rate and steady-state labor very close to those of the baseline model values by adjusting the steady-state tax rate, relative utility weight of labor, and worst-case gross return of capital. By these calibrations, I obtain similar relationships among the impulse responses of the three economies to those discussed in Section 3.4.

3.2 Steady-state values

Table 2 shows the steady-state values of my model, which are again in annual rates. These values do not depend on the share of YO banks, α, because EO and YO banks form the same deposit rate expectations in the steady-state, where deposit rates are flat over time. For comparison, this table shows recent actual data values averaged over 1990–2017. These

[17] Gertler and Karadi (2011) set this at 0.2.

Parameters	Value	Description
β	0.98	Discount rate
σ	1.0	The rate of relative risk aversion
ψ	2.82	Relative utility weight of labor
ν	1	Inverse of Frisch elasticity
$\underline{R_K}$	0.85	Worst-case gross return of capital
$\overline{\chi}$	0.008	Size parameter of long-term bond holding cost
θ	0.8	Survival rate of banks
ξ	0.25	Capital share
δ	0.1	Depreciation rate
$\bar{\tau}$	0.40	Steady state tax ratio to output
$\bar{g}$	0.071	Steady state government expenditure
ϖ	0.0001	Proportional transfer to the entering banks
γ	0.8	Response parameter of $\bar{\tau}$ to bond to output ratio
ρ_A	0.8	Autoregressive parameter of productivity shock
ρ_v	0.8	Autoregressive parameter of new worth shock
ρ_T	0.6	Autoregressive parameter of tax rule

Table 1: Parameters

values are before detrending. The details of the data source are presented in Appendix A.2. To compare the steady-state values of the model and data, I show the adjusted Y of the model from (44) to make the model and data output components consistent. For Table 2, I exclude $(1-\alpha)\frac{1}{2}\chi_{t-1}{B^e_{t-1}}^2 + \alpha\frac{1}{2}\chi_{t-1}{B^y_{t-1}}^2$ from (44) because I construct actual output data by adding C, I, and G.

Historical allocation ratio data are stable except $2B_{ss}/Y_{ss}$. Because B_{ss}/Y_{ss} in the actual data has an upward trend even in recent observations, I cannot regard its historical average value as a steady-state value for direct comparison with the model's steady-state value. Regarding actual data of net worth ratio to assets, I directly use data of net worth ratio to total assets from the U.S. commercial banks' balance sheet instead of constructing asset amounts as $2B_{ss} + K_{ss}$ from the data. I do so because actual asset data include assets other than those I assume in the model and actual banks' asset components are not necessarily the same as those modeled. Another key value is net worth value sensitivity to interest rate, which implies by what percent net worth is affected by a change in interest rate. The model's steady-state level is smaller than the data. However, it is a necessary compromise given this model structure. Having a smaller number for this value does not result in over-evaluation of duration impact on net worth when compared to the actual impact.

Steady-state interest rate levels are higher than the actual data mostly because of the

Variables	Steady state value	Actual data
C_{ss}/Y_{ss}	0.63	0.64
I_{ss}/Y_{ss}	0.19	0.16
Net worth value sensitivity to interest rate	16%	31%
$2B_{ss}/Y_{ss}$	8.31	1.15
K_{ss}/Y_{ss}	1.85	2.19
$N_{ss}/(2B_{ss}+K_{ss})$, Net worth ratio to assets*	0.03	0.10
$R_{D,ss}$	1.02	1.01
$R_{B,ss}$	1.03	1.02
tp_{ss}	0.007	0.005

Table 2: Steady state values

Note: Subscript ss means a steady-state value. Actual data are the average of 1990:1–2017:3 quarterly data. Data of K_{ss} are the average of 1990:1–2016:4 due to data availability. Term premium data are those of ex-post 2-year U.S. treasury interest rate term premiums. Real interest data are deflated by actual inflation rates. * For actual data, I directly take the net worth to total assets ratio.

calibrated discount rate value and recent actual data, which are considered as being affected by recent monetary policy loosening. For actual term premium data, I use ex-post term premium data which are the 2-year U.S. treasury real interest rate minus the average of the 1-year U.S. treasury real interest rates over the corresponding 2 years.

3.3 Second moments

Table 3 compares second moments of my model and actual data to check the model's performance. Moments are calculated on an annual basis. I show three theoretical moments depending on YO banks' populations. The first is the economy in which all banks are YO ($\alpha = 1$), the second is the economy in which the share of EO and YO bank are each 50% ($\alpha = 0.5$), and the third is the economy in which all banks are EO ($\alpha = 0$). The theoretical moments of the models are based on three stochastic shocks: productivity, net worth, and bond holding cost (χ) shock. In this analysis, the sizes of these two shocks are 0.4%, 0.8%, and 30% on an annual basis, respectively.[18] To compare the second moments between the model and the data, I show the adjusted Y's moments for the model by excluding long-term bond holding costs, $(1-\alpha)\frac{1}{2}\chi_{t-1}{B^e_{t-1}}^2 + \alpha\frac{1}{2}\chi_{t-1}{B^y_{t-1}}^2$, from (44) to make the model and data output components consistent in Table 3.

[18] Nolan and Thoenissen (2009) estimate quarterly standard deviation of productivity shock and financial shocks as 0.8% and 0.9%, respectively. I calibrated the sizes of these shocks so that $SD[\log Y]$ and $SD[\log N]$ become close to data moments. I calibrated the size of shock to bond holding cost parameter χ to have standard deviation of ex-post term premium close to the data.

The empirical moments cover 1990–2017. I take natural logs of allocation data and detrend them by third-order time polynomial regression. I do not detrend interest rate data and ex-post term premium data. The details of the data source are presented in Appendix A.2. Actual long-term rate data are those of 2 year U.S. treasury interest rate considering the model. As mentioned, I use ex-post term premium data for actual term premiums. This is because consequent impacts on banks' net worth are considered to come from ex-post term premiums rather than ex-ante term premiums.[19]

Incorporating the existence of YO banks indicates benefits over a model with EO banks only. The ex-post term premium is an important variable to generate persistence of output responding to shocks in the model. Figure 1 plots historical data of ex-post term premiums of 2, 3, and 5-year bond interest rates and detrended output. This figure visually shows that ex-post term premiums move procyclically with lags. As shown in Table 3, a positive share of YO banks helps to generate more realistic correlation of ex-post term premiums and output, as shown in $Corr[\log Y, tp]$ and $Corr[\log Y(-1), tp]$. The case with only EO banks shows low correlation between output and term premium because volatility of term premiums are mostly driven by shocks to bond holding cost χ. On the other hand, bond pricing based on expectation of flat deposit rates by YO banks increases cyclical movement of ex-post term premiums, which is not produced by a case with only EO banks. This is how the model with YO banks has more realistic correlations between output and term premium than a case that only EO banks exist.

Term premium volatilities are close to the data in both the EO and YO cases, as shown in the row of $SD[tp]$. Autocorrelations of ex-post term premiums, $Autocorr[tp(-1)]$ and $Autocorr[tp(-2)]$, also become closer to the data when I assume a positive share of YO banks. By these observations, assuming a positive value of α is beneficial for explaining procyclical volatility of ex-post term premiums.

Standard deviation of output, $SD[\log Y]$, shows higher value when YO banks exist. Autocorrelations of output, $Autocorr[\log Y(-1)]$ and $Autocorr[\log Y(-2)]$, become higher as well. This is mainly because ex-post term premiums move procyclically when myopic banks exist and the term premiums consequently change banks' net worth which is a state variable. A change in banks' net worth persistently affects capital demand via the VaR constraint. This implies that the existence of YO banks makes the output path after a productivity shock

[19] One caveat of this method is that I lose recent 2 year term premium data, because term premiums can only be known in an ex-post way. An alternative method is to supplement the lacking parts of the ex-post term premiums by inserting recent ACM term premium (Adrian et al. (2013)) numbers in the FRB New York data base. However, the moments of actual data do not materially change by this operation. Therefore, I use only ex-post term premiums for data clarity.

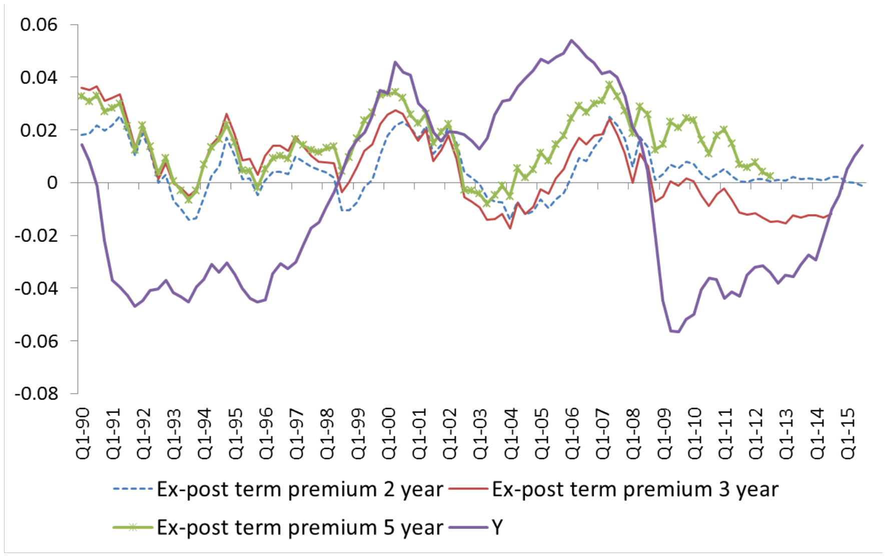

Figure 1: Ex-post term premiums of U.S. treasury rates and U.S. output

Note: The figure shows historical ex-post term premiums and output data. Data details are provided in Appendix A.2. The unit on the vertical axis for term premiums is percentage points, where 0.01 corresponds to 1%. The unit on the vertical axis for output is the log difference from its trend calculated by third-degree time polynomial regression of the natural log of output.

hits the economy more persistent and volatile.

I solve this model by the first-order perturbation method. This approach implies that movements of term premiums in the model are symmetric with respect to signs of productivity shocks. However, the analysis here implies that the existence of YO banks in the U.S. economy especially improves the theoretical moments of ex-post term premiums. Although output persistence becomes higher than the empirical data when the model has a high value of α, the overall fit to the data improves when I assume a positive value of α.

Variables	Model (YO)	Model (EO/YO)	Model (EO)	Actual data
$SD[\log Y]$	0.027	0.025	0.024	0.025
$SD[\log C]$	0.023	0.020	0.019	0.028
$SD[\log I]$	0.095	0.077	0.063	0.125
$SD[\log T]$	0.153	0.127	0.105	0.122
$SD[\log N]$	0.042	0.035	0.030	0.032
$SD[\log R_D]$	0.009	0.008	0.007	0.021
$SD[\log R_B]$	0.009	0.008	0.007	0.019
$SD[tp]$	0.006	0.006	0.005	0.005
$Corr[\log Y, tp]$	0.23	0.13	0.06	0.36
$Corr[\log Y(-1), tp]$	0.21	0.13	0.07	0.42
$Autocorr[\log Y(-1)]$	0.92	0.89	0.85	0.84
$Autocorr[\log Y(-2)]$	0.87	0.82	0.78	0.51
$Autocorr[tp(-1)]$	0.25	0.18	0.10	0.72
$Autocorr[tp(-2)]$	0.21	0.13	0.05	0.35

Table 3: Second moments

Note: Actual data are 1990–2017 annual data. Term premium data are those of ex-post 2-year U.S. treasury interest rate term premiums.

3.4 Impulse response

Figures 2 and 3 indicate impulse responses to a 1% negative productivity shock under the calibrations shown in Section 3.1. The time frequency is annual. On the vertical axis scale, 1 corresponds to 1% deviation from the steady state. As my interest lies in studying the potential impact of search for yield on business cycles of the recent U.S. economy, in which a policy rate hike process started in 2015 for the first time since the financial crisis. Therefore, by looking at responses to the negative productivity shock, I aim to visually check whether banks' myopic behavior could cause any adverse effects on the economy as the economy recovers. Solid lines denote responses observed in the EO economy ($\alpha = 0$), dash-dot lines denote those in the EO/YO economy ($\alpha = 0.5$), and dashed lines denote those in the YO economy ($\alpha = 1$). According to Figure 2, the YO economy shows more volatile and slower recovery following the negative productivity shock than the cases with a lower population share of YO banks. Furthermore, term premiums show larger drops as the share of YO banks in an economy increases.

First, I describe responses commonly observed in the three economies. The negative productivity shock leads to a lower capital return, R_K, because the marginal productivity of capital decreases as seen in Figure 3. Because of the reduced capital return, net worth of the next period has to decrease through the net worth evolution, as in the box for N

in Figure 2. The lowered net worth tightens the VaR constraint. To satisfy this tighter VaR constraint, there are primarily two variables to adjust given bond supply amounts. The amount of capital stock that banks hold, K, needs to be smaller and the deposit rate, R_D, needs to be lower as observed in Figure 2.

The bond rate, R_B, reacts as follows. From the bond demand side, a lowered deposit rate affects bond pricing. The long-term bond interest rate is mainly determined by a risk-neutral deposit rate path and the risk-associated term. To see this, R_B can be written as follows in the steady-state from equations (10) and (11), where subscript ss denotes the steady-state values of each variable.

$$R_{B,ss} = R_{D,ss} + \frac{\chi B_{ss}}{1 + \beta\theta \frac{R_{K,ss} - \underline{\underline{R_K}}}{1 - \frac{\underline{R_K}}{R_{D,ss}}}}. \tag{45}$$

In the first term, a lower deposit rate directly reduces the bond rate. In the second term, a lower deposit rate alleviates the risk of insolvency and allows the bond return to decline. Therefore, a decrease in the deposit rate lowers the long-term bond interest rate both from the first term (risk-neutral costs of funding) and the second term (risk premium parts associated with the VaR constraint).[20] In the EO economy, ex-post term premiums decrease only from the second term effect of (45) in response to the negative productivity shock because EO banks rationally expect paths of deposit rates. In the YO economy, ex-post term premiums decrease from both the first and second term effects because differences between expected and realized paths of deposit rates in the first term are a part of term premiums. The deviation from the steady state in the EO case is very small, as seen by the blue solid line of the tp box in Figure 2, because the first term effect of (45) is the key to generate ex-post term premiums in the model.

Next, I describe the differences between YO and EO economies. These come from the difference in bond pricing and ex-post behavior of deposit rates. Even though YO banks expect a flat path of deposit rates over two periods, the deposit rate gradually recovers over time, contrary to YO banks' expectations, as observed in the box for R_D in Figure 2. Because of the pricing difference and the realized deposit rate path, ex-post bond spreads in the YO economy become smaller than in the EO economy. This outcome reduces YO banks' profits and erodes net worth, N, for the next period, as shown by the red dashed line in Figure 2. Since lower net worth is a state variable, the banks choose a smaller level of capital, which makes investment smaller as shown by the red dashed line in I in Figure 3. As a result,

[20] More precisely, the second term includes bond holding costs as well.

output Y in the YO economy is lower than in the EO case. In addition, YO banks need to decrease the deposit rate more than EO banks need because of the realized tighter VaR constraint.[21] Therefore, bond interest rates stay lower than in the EO economy and continue to generate differences between the two economies.

In the YO economy, the term premium decreases by about 20 basis points initially. This is in contrast to the EO economy, in which the term premium decreases by only about 3 basis points. The flat expectation of the deposit rate by YO banks mainly drives the ex-post term premium decreases, in addition to the risk effects shown in equation (45). As mentioned in Section 3.3, the correlation between lagged term premiums and output is too small in the EO case. In the EO/YO and YO cases, myopic pricing generates both more realistic term premiums' volatility and correlations with output at the same time.

By these model mechanisms, the impulse responses of the YO economy to a negative productivity shock show lower ex-post term premiums, lower deposit rates, lower bond rates, and slower recovery of output than those of the EO economy. In this way, the existence of YO banks generates higher persistence and volatility in business cycles. In addition, the presence of YO banks provides more realistic movements of the ex-post term premiums.

[21] By the crowding-in effect between investment and consumption, consumption needs to offset an investment drop to some extent. This offsetting effect of consumption needs to accompany a deeper interest rate drop in the YO economy than in the EO economy. Consumption in the YO economy is higher than in the EO economy for this reason during early periods after the negative productivity shock hits the economy. In the longer run, less output implies less lifetime labor income. Long-run consumption in the YO economy is lower than in the EO economy.

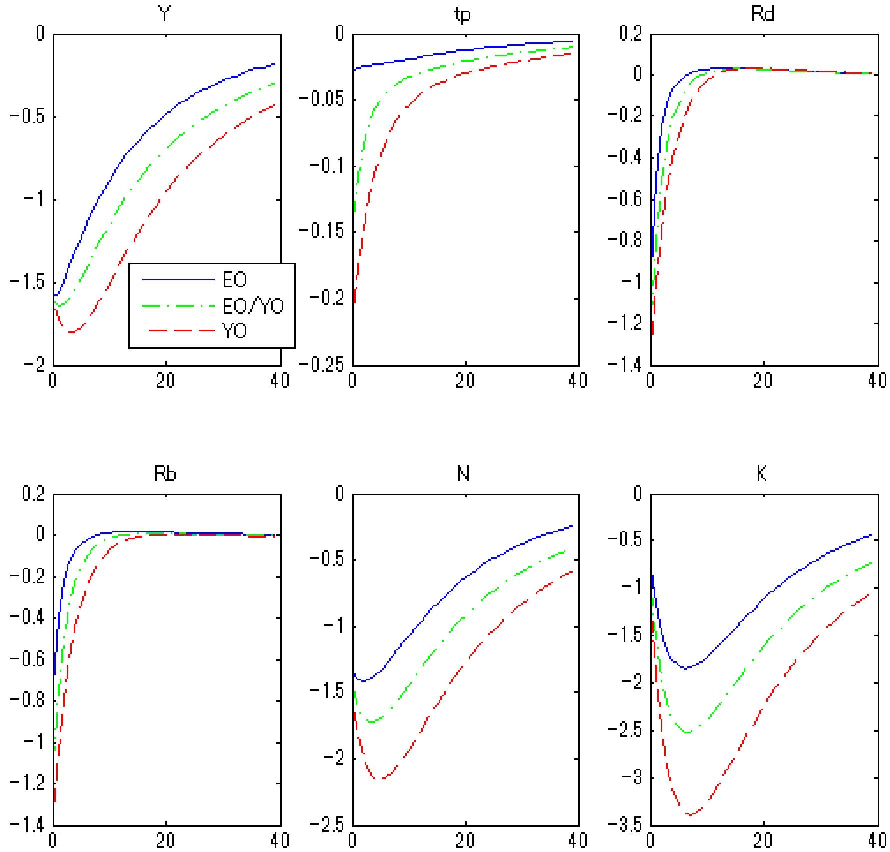

Figure 2: Impulse response to negative productivity shock

Note: This figure shows impulse responses to a 1% negative productivity shock. Time frequency is annual. The solid line indicates the economy in which all banks are EO type (EO economy, $\alpha = 0$). The dash-dot line indicates the economy in which 50% of banks are EO type and 50% are YO type (EO/YO economy, $\alpha = 0.5$). The dashed line indicates the economy in which all banks are YO type (YO economy, $\alpha = 1$). The value 1 on the vertical axis scale is equal to 1%. Return and spread variables, R_K, R_D, R_B, and tp, are in percentage point differences from their steady states. Otherwise, variables are shown as % deviation from their steady-state levels.

4 Conclusion

I investigated how search for yield by banks in terms of taking duration risks affects business cycles. The two key assumptions in this study are the existence of YO banks which expect that the deposit rate will stay flat over the maturity of long-term bonds and the VaR constraint for banks. I used this flat expectation assumption about YO banks to describe their myopic near-term income considerations rather than expected holding-period returns. I found that output recovery after the negative productivity shock becomes slower and ex-post term premiums move more procyclically in an economy with YO banks than in those without YO banks. This finding implies that the existence of YO banks potentially intensifies banks'

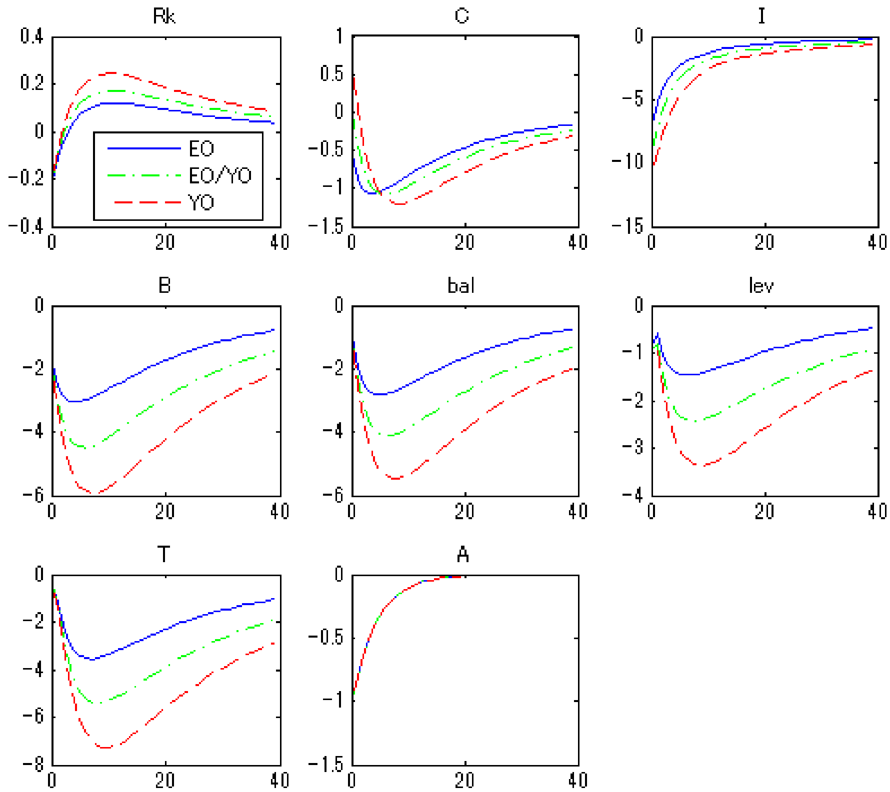

Figure 3: Impulse response to negative productivity shock (Cont'd)

Note: This figure shows impulse responses to a 1% negative productivity shock. Time frequency is annual. The solid line indicates the economy in which all banks are EO type (EO economy, $\alpha = 0$). The dash-dot line indicates the economy in which 50% of banks are EO type and 50% are YO type (EO/YO economy, $\alpha = 0.5$). The dashed line indicates the economy in which all banks are YO type (YO economy, $\alpha = 1$). The value 1 on the vertical axis scale is equal to 1%. Return and spread variables, R_K, R_D, R_B, and tp are in percentage point differences from their steady states. Otherwise, variables are shown as % deviation from their steady-state levels.

asset maturity mismatch risks and affects business cycles because it causes lower ex-post term premiums, resulting in higher degrees of net worth erosion as the economy recovers. For this reason, output of an economy with YO banks shows higher persistence and volatility under the productivity shock. In addition, my model with YO banks improves the theoretical moments of ex-post term premiums. This quantitative result implies that the possibility of YO banks existing in the U.S. economy should not be excluded.

Finally, this model is a real business cycle model that abstracts nominal aspects. A nominal model has the advantage of being able to examine the effects of a monetary policy shock on business cycles with YO banks. In addition, credit facilities, such as long-term credit bonds, have longer repricing maturities in reality, although I did not explicitly incorporate these for the sake of the model's simplicity. Incorporating long-term credit bonds enables analysis not only of the pure duration risks discussed in this study, but also of the consequences of myopic pricing of credit risks. These considerations remain for further research.

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A Appendix

A.1 Derivation of bond demand

This section shows the derivation of EO banks' bond demand. As mentioned in Section 2.1.1, I use backward iterations to obtain N^e as a function of B^e given the initial value of N^e. Then I take the first-order condition with respect to B^e.

Eliminating K_t^e from equation (6) and (7) with changing the time subscripts from t to $t+i$ yields

$$\begin{aligned} N^e_{t+i+1} &= \left\{ \frac{R_{K,t+i+1} - R_{D,t+i+1}}{\underline{R_K} - R_{D,t+i+1}} (R_{D,t+i+1} - R_{B,t+i}) + (R_{B,t+i} - R_{D,t+i+1}) \right\} B^e_{t+i-1} \\ &+ \left\{ \frac{R_{K,t+i+1} - R_{D,t+i+1}}{\underline{R_K} - R_{D,t+i+1}} (R_{D,t+i+1} - R_{B,t+i+1}) + (R_{B,t+i+1} - R_{D,t+i+1}) \right\} B^e_{t+i} \\ &- \frac{1}{2} \chi_{t+i} \frac{R_{K,t+i+1} - \underline{R_k}}{R_{D,t+i+1} - \underline{R_k}} B^{e^2}_{t+i} + \frac{R_{K,t+i+1} - \underline{R_K}}{R_{D,t+i+1} - \underline{R_K}} R_{D,t+i+1} N^e_{t+i}. \end{aligned} \tag{46}$$

Iterate backward for N^e_{t+i} and obtain

$$N^e_{t+i+1} \tag{47}$$

$$\begin{aligned} &= \sum_{j=0}^{i} \prod_{j=1}^{i} \left\{ \frac{R_{K,t+j+1} - \underline{R_K}}{R_{D,t+j+1} - \underline{R_K}} R_{D,t+j+1} \right\} \left\{ \frac{R_{K,t+j+1} - R_{D,t+j+1}}{\underline{R_K} - R_{D,t+i+1}} (R_{D,t+j+1} - R_{B,t+j}) + (R_{B,t+j} - R_{D,t+j+1}) \right\} B^e_{t+j-1} \\ &+ \sum_{j=0}^{i} \prod_{j=1}^{i} \left\{ \frac{R_{K,t+j+1} - \underline{R_K}}{R_{D,t+j+1} - \underline{R_K}} R_{D,t+j+1} \right\} \left\{ \frac{R_{K,t+j+1} - R_{D,t+j+1}}{\underline{R_K} - R_{D,t+i+1}} (R_{D,t+j+1} - R_{B,t+j+1}) + (R_{B,t+j+1} - R_{D,t+j+1}) \right\} B^e_{t+j} \\ &+ \sum_{j=0}^{i} \prod_{j=1}^{i} \left\{ \frac{R_{K,t+j+1} - \underline{R_K}}{R_{D,t+j+1} - \underline{R_K}} R_{D,t+j+1} \right\} \left\{ -\frac{1}{2} \chi_{t+j} \frac{R_{K,t+j+1} - R_{D,t+j+1}}{R_{D,t+i+1} - \underline{R_K}} \right\} B^{e^2}_{t+j} \\ &+ \prod_{j=0}^{i} \left\{ \frac{R_{K,t+j+1} - \underline{R_K}}{R_{D,t+j+1} - \underline{R_K}} R_{D,t+j+1} \right\} N^e_t, \end{aligned} \tag{48}$$

where

$$\prod_{j=1}^{i} \left\{ \frac{R_{K,t+j+1} - \underline{R_K}}{R_{D,t+j+1} - \underline{R_K}} R_{D,t+j+1} \right\} = 1 \text{ for } i = 0$$

Thus, I have N^e_{t+i+1} as a function of bonds and return rates. I substitute this representation into N^e_{t+i+1} in (8) and take the first-order condition with respect to B_{t+i}. After this calculation, by taking the case of $i = 0$, I obtain

$$
\begin{aligned}
&E_t \left\{\Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + \Lambda_{t,t+4}\theta^3 + ...\right\} \frac{R_{K,t+2} - \underline{R_K}}{R_{D,t+2} - \underline{R_K}} R_{D,t+2} \\
&\qquad\qquad\qquad\qquad\qquad\qquad \left\{ \frac{R_{K,t+2} - R_{D,t+2}}{\underline{R_K} - R_{D,t+2}} (R_{D,t+2} - R_{B,t+1}) + (R_{B,t+1} - R_{D,t+2}) \right\} \\
&+ \left\{\Lambda_{t,t+1}\theta^0 + \Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + ...\right\} \left\{ \frac{R_{K,t+1} - R_{D,t+1}}{\underline{R_K} - R_{D,t+1}} (R_{D,t+1} - R_{B,t+1}) + (R_{B,t+1} - R_{D,t+1}) \right\} \\
&+ \left\{\Lambda_{t,t+1}\theta^0 + \Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + ...\right\} \left\{ -\chi_t \frac{R_{K,t+1} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right\} B_t = 0.
\end{aligned} \tag{49}
$$

To have a recursive representation for $\{\Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + \Lambda_{t,t+4}\theta^3 + ...\}$ in (49), it is convenient to define Ω as

$$
\begin{aligned}
\Omega_{t+1} &= \frac{\Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + \Lambda_{t,t+4}\theta^3 + ...}{\Lambda_{t,t+1}\theta^0} \\
&= \beta \frac{U_c(C_{t+2}, L_{t+2})}{U_c(C_{t+1}, L_{t+1})}\theta + \beta^2 \frac{U_c(C_{t+3}, L_{t+3})}{U_c(C_{t+1}, L_{t+1})}\theta^2 + \beta^3 \frac{U_c(C_{t+4}, L_{t+4})}{U_c(C_{t+1}, L_{t+1})}\theta^3 + ... \, .
\end{aligned} \tag{50}
$$

By taking a one-period forward expression of (50) and taking the difference of these, Ω can be written as

$$
\Omega_{t+1} = \beta\theta \frac{U_c(C_{t+2}, L_{t+2})}{U_c(C_{t+1}, L_{t+1})} \{1 + \Omega_{t+2}\}. \tag{51}
$$

By using Ω to substitute for $\{\Lambda_{t,t+2}\theta^1 + \Lambda_{t,t+3}\theta^2 + \Lambda_{t,t+4}\theta^3 + ...\}$ in (49), I have the government bond demand equation from EO banks as

$$
\begin{aligned}
B_t^e = \chi_t^{-1} E_t \Bigg[&\left\{ 1 + \frac{\Omega_{t+1}}{1 + \Omega_{t+1}} R_{D,t+2} \left(\frac{R_{K,t+1} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{R_K}}{R_{D,t+2} - \underline{R_K}} \right)^2 \right\} R_{B,t+1} \\
&- R_{D,t+1} - \frac{\Omega_{t+1}}{1 + \Omega_{t+1}} R_{D,t+2} \left(\frac{R_{K,t+1} - \underline{R_K}}{R_{D,t+1} - \underline{R_K}} \right)^{-1} \left(\frac{R_{K,t+2} - \underline{R_K}}{R_{D,t+2} - \underline{R_K}} \right)^2 R_{D,t+2} \Bigg]
\end{aligned} \tag{52}
$$

A.2 Data Sources

Actual data construction is conducted by the following procedures. Actual data used in this study are those of United States. Real consumption, real investment, real government expenditure, real wage, and tax revenue data are from the Federal Reserve Bank of St. Louis FRED economic data base (`https://fred.stlouisfed.org/`). FRED series IDs for these variables are PCECC96, GPDIC1, GCEC1, LES1252881600Q, and W006RC1Q027SBEA, respectively. For real output data, I divide the sum of nominal consumption, investment, and government expenditure by the implicit price deflator for gross domestic purchases. The corresponding FRED series ID are PCEC, GPDI, GCE, and A712RD3A086NBEA, respectively. Real capital stock data are real net stock (private fixed assets) from the Bureau of Economic Analysis. Total employment data are employed civilians aged 16 years and over from the Bureau of Labor Statistics.

For real output, real consumption, real investment, and real wage in Section 3.3, I detrend the natural log of seasonally adjusted quarterly values using third-order time polynomial regression. I choose third-order regression because the Akaike information criterion shows the lowest value when I examine fit up to the fourth order. To be consistent, I use the same order in the time polynomial regressions for the other variables as well. Real capital data are real net private fixed assets provided on an annual basis. I translate these data to a quarterly basis by interpolation for detrending. Because the capital data are only available up to 2016, I extrapolate 2017 data from 2016:4. Seasonally adjusted total civilian employment numbers are provided on a monthly basis. Therefore, I translate them to a quarterly basis. For tax revenue, I use seasonally adjusted federal government current tax receipts and deflate it by the implicit gross domestic product deflator. I take the natural log of these quarterly numbers and detrend them using third-order time polynomial regression.

For government debt, I multiply seasonally adjusted quarterly total public debt as the percent of gross domestic product (FRED series ID: GFDEGDQ188S) by seasonally adjusted nominal gross domestic product (FRED series ID: GDP). I deflate quarterly changes of the nominal value of the debt by the implicit quarterly gross domestic product deflator and accumulate these real changes to have real government debt value. I take the natural log of this and detrend it using third-order time polynomial regression.

I take banks' net worth and a ratio of net worth to balance sheet from the Assets and Liabilities of Commercial Banks in the United States H.8 in the Board of Governors of the Federal Reserve System data base. (`https://www.federalreserve.gov/releases/H8/default.htm`) Data are on a monthly basis and I transform them to a quarterly basis. I deflate the nominal net worth changes by a quarterly implicit gross domestic product deflator and accumulate the real changes to obtain real net worth data. In Section 3.3, I take the natural log of quarterly real net worth numbers and detrend them using third-order time polynomial regression. For the net worth ratio, I perform direct detrending by third-order time polynomial regression without taking the natural log.

The interest rate data are based on the Federal Reserve Bank of New York's treasury term premia data base (`https://www.newyorkfed.org/research/data_indicators/term_premia.html`). For the deposit rate, I use the 1-year fitted zero coupon market yield of U.S. treasury. I use 5-year fitted zero coupon market yield of U.S. treasury for the long-term bond rate. I deflate both rates by the actual inflation rates of personal consumption expenditure core price index. In Section 3.2, I use gross yield data. Both rates in Section 3.3 are natural log of gross yields. Term premium data used here are those of ex-post term premiums, not ex-ante term premiums. I subtract the 1-year interest rates over the long-term rate maturity, 5 years, from the 5-year interest rate. I do not use ex-ante term premiums because the actual and consequent impacts on banks' net worth are considered to come from ex-post term premiums rather than ex-ante term premiums.

After preparing the quarterly data sets noted above, I annualize them to obtain annual frequency moments over 1990–2017 for consistency with the theoretical model, which assumes annual rates.