

Financial Intermediary Leverage and Unemployment

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January 7, 2020

Job Market Paper

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Abstract

I establish that financial intermediary leverage and unemployment are closely related and build a model that combines frictions on financial intermediaries with labor search and matching to explain the relationship. Empirically, in response to a negative productivity shock, unemployment increases substantially when financial intermediary leverage is high, but not in other episodes. The model relies primarily on the stochastic discount factor (SDF) channel. Negative productivity shocks increase the financial intermediary leverage. Because the financial intermediary sector can't raise enough funds in high leverage states, the SDF increases sharply. Meanwhile, the matching surplus is low. The negative relationship between the SDF and the matching surplus decreases the present value of future matching surpluses. Consequently, vacancy posting and employment plummet in a high leverage state. The model implies that the unemployment rate would have been 2 percentage points lower if the 2008 recession had started with the early 2001 financial intermediary leverage.

Key words: Financial crisis, Unemployment, Great Recession.

JEL Codes: E23, E24, E32, E44, G01

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1 Introduction

Financial crises are usually associated with abnormally high unemployment. For example, the unemployment rate peaked at 10% in Oct 2009, the highest since 1982. Meanwhile, the equity-to-asset ratio (capital ratio¹) of the financial intermediary sector – represented by the primary dealers – reached the lowest level since 1970. On the contrary, the 2001 recession, which was a nonfinancial recession, witnessed the unemployment rate peaking at 6% and the primary dealer capital ratio was much higher than in 2008-2009. As Figure 1.1 shows, there is a strong negative correlation between the financial intermediary capital ratio and the unemployment rate. Such comparison suggests that disruptions in the financial intermediary sector are closely related to deep recessions in the labor market. In fact, high unemployment is a recurring feature of episodes with low financial sector capitalization. Muir (2017) uses a panel of 14 countries spanning 140 years to document that the discount rate and unemployment increase substantially in financial crises but not in non-financial recessions². Another puzzling fact is that other macroeconomic fundamentals, such as consumption and productivity, don't seem to behave so differently across financial crises and other recessions. Therefore, it seems hard to explain the excess unemployment during financial crises by contractions in real activities.

My paper studies why unemployment increases substantially in financial crises. First, I show empirically that low financial intermediary capitalization amplifies unemployment response to a productivity shock. The intermediary asset pricing literature has found evidence that the equity capital of financial intermediaries is crucial for understanding asset price behaviors³. My paper connects real activities, in particular, unemployment, to financial intermediary equity capital. Conditional on the initial capital ratio being in the bottom 10 percent of the sample, the peak response of the unemployment rate to a negative one standard deviation productivity shock is twice as large as that conditional on the top 10 percent capital ratio. However, the physical capital and the investment rate (investment/capital) impulse responses only vary by about 10% across these capital ratio

¹Following the convention in intermediary asset pricing models, I use the capital ratio – the reciprocal of the leverage ratio – as a measure of financial intermediary financial well-being.

²A financial crisis in Muir (2017) is defined as “events during which a country’s banking sector experiences bank runs, sharp increases in default rates accompanied by large losses of capital that result in public intervention, bankruptcy, or forced merger of financial institutions”. There are 67 country-year specific financial crises in the sample.

³For example, Adrian et al. (2014), He et al. (2017), Adrian et al. (2017), Lenel et al. (2019) and Haddad and Muir (2018).

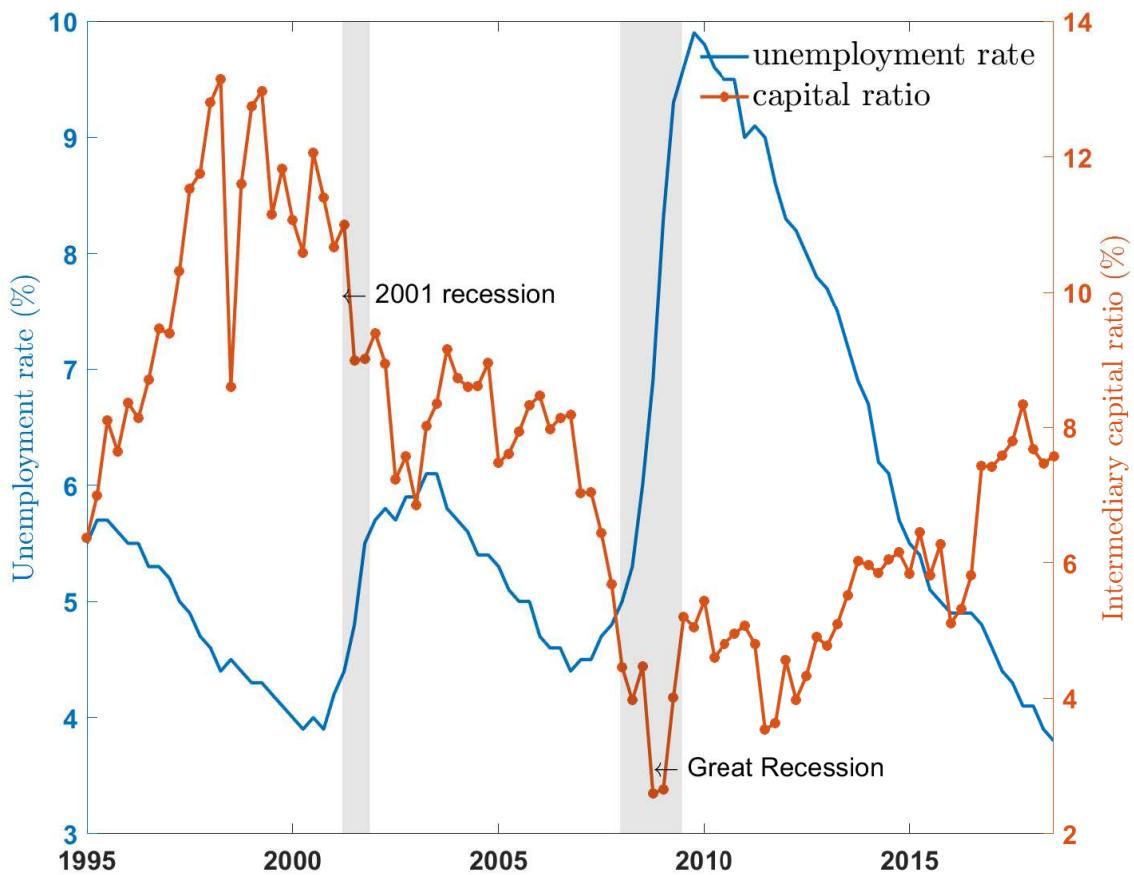


Figure 1.1: Unemployment rate and the financial intermediary capital ratio. Both series are expressed in percentage points. The financial intermediaries are the primary dealers. See Section 2 for more details about the primary dealers. The capital ratio is defined as the market value of equity divided by total assets. The two series are strongly negatively correlated with a correlation coefficient of -0.67.

states. The impulse responses are consistent with the fact that unemployment increases substantially in a financial crises. Interestingly, the capital accumulation channel does not seem to account for much of the spike in unemployment.

Then I build a model to explain two key empirical facts. First, unemployment increases much more in financial crises than in other recessions. Second, macroeconomic fundamentals behave less differently across financial crises and other recessions. For simplicity, the productivity process is the only exogenous process but my model mechanism applies to other shocks as well. Feeding in the productivity series from the Federal Reserve Bank of San Francisco, the model generates capital ratio and unemployment series that are similar to the data. The simulation also generates a moderate risk premium in the 2001 recession and an abnormally high one in the 2008 Great Recession.

My paper proposes the high discount rate as a key driving force of the high unemployment during financial crises. The discount rate is determined by financial intermediaries, who face a borrowing constraint when their equity falls too low relative to total assets. The intermediaries don't like being constrained, so they discount those states heavily. Employment is a dynamic decision because of the labor search and matching friction. The high discount rate decreases the present value of labor, thus labor demand falls. Relating to the empirical facts, the low financial intermediary capitalization is a defining feature of financial crises. The model that naturally links the low financial intermediary capitalization to the high discount rate and high unemployment. Furthermore, the discount rate serves as an additional channel that complements the low physical capital and productivity to generate the low demand for labor. The paths of the marginal product of labor and wage don't differ much across financial crises and nonfinancial recessions. It is the way in which the market evaluates those paths that leads to the low labor demand.

My model combines the Gertler-Karadi-Kiyotaki (GKK) intermediary friction and the Diamond-Mortensen-Pissarides (DMP) labor search and matching friction. Financial intermediaries purchase firm stocks and borrow deposits from households. The borrowing constraint prevents the financial intermediaries from raising enough deposits to invest in risky assets when they have low equity wealth relative to total assets. The representative firm hires labor and accumulates physical capital to maximize the market value of the firm on behalf of the financial intermediaries. Due to the search and matching friction, part of the vacancies can't be filled and it's costly for the firm to post more vacancies. The firm trades off the present value of benefits associated with hiring against the cost of posting vacancies. The financial intermediaries determine the discount rate, which the

firm uses to evaluate the present value of matches. Here, the “discount rate” for a long-term relationship is determined by the covariation between the stochastic discount factor (SDF) and the cash flow. The more negative the covariation, the higher the discount rate.

The first contribution of the model is to generate spikes in the discount rate and the unemployment rate in financial crises. The key mechanism is the endogenous interaction between the intermediary friction and the labor search and matching friction, which forms a vicious cycle only arising in financial crises. A series of negative productivity shocks decrease the stock price and the intermediary capital ratio. The intermediary borrowing constraint binds and the discount rate increases. The high discount rate decreases the present value of labor and labor demand falls. This is the first step of the vicious cycle. Secondly, the high unemployment further decreases the intermediary capital ratio and increases the discount rate. The labor search and matching friction is crucial for this step: high unemployment implies more vacancies to be posted in the future, which incur high costs and reduce the market value of the firm. Since the financial intermediaries hold the firm stocks as assets, the low stock price further decreases the capital ratio and increases the discount rate. This completes the vicious cycle.

Compared with the financial frictions on the firm side (e.g. Bernanke et al. (1999) and Jermann and Quadrini (2012)) and the household side (e.g. Kehoe et al. (2019b)), an attractive feature of the intermediary friction is that the SDF consists of the marginal value of intermediary wealth in addition to the marginal utility of consumption. It reflects the fact that financial intermediaries dislike being constrained, and that they are the marginal investors in the financial markets. The additional component helps reconcile the tension between the stable consumption and volatile discount rate in the data. In particular, the construction is amenable to distinguishing nonfinancial recessions from financial crises⁴. In normal times, the financial intermediaries are not constrained and the marginal value of financial intermediary wealth is low. The SDF is mostly determined by the marginal utility of consumption and is low and stable. In financial crises, the financial intermediary wealth falls into the constrained region and the marginal value of wealth spikes up. The SDF is mostly determined by the marginal value of financial intermediary wealth and increases sharply. The covariation between the SDF and the matching surplus becomes more negative, increasing the discount rates. Therefore, unemployment increases substantially in financial crises relative to nonfinancial recessions.

⁴Muir (2017) shows that the Campbell-Cochrane habit formation and the long-run risk models both have difficulties distinguishing nonfinancial recessions from financial crises

My second contribution is to emphasize the feedback from the labor market to the financial sector, which is a new propagation channel for the financial accelerator literature⁵. Without the labor search and matching friction, the physical capital stock is the only asset pricing factor. Labor can only affect the stock price through general equilibrium effects, and the impact on financial intermediary capital ratio is much weaker than in my model. In my model, labor is an additional asset pricing factor. Unemployment can directly amplify fluctuations in the stock price, and the amplification is stronger in financial crises because the low stock price decreases the capital ratio and initiates vicious cycle. In my calibrated model, the risk premium is 5 times higher than that in a model without the labor search friction during a financial crisis.

The model predicts that, given the same sequence of exogenous shocks, unemployment is lower if the financial intermediaries have higher capital ratio. I simulate the 2008 Great Recession with different levels of initial capital ratio that are intended to represent the intermediary capital ratios at the onset of the 2001 and 2008 recessions. The results suggest that if the financial intermediary sector in 2008Q4 had been as well capitalized as in early 2001, the unemployment rate during the Great Recession would have been 2 percentage points lower thanks to a lower discount rate. I also consider a policy experiment in the spirit of Gertler and Karadi (2011). My model suggests that the QE1 reduced the unemployment rate by 1 percentage point during the 2008-2010 period because the policy reduces the intermediary wealth exposure to negative asset returns and increases the capital ratio.

Related literature The paper is related to three strands of literature. First, it is related to the financial accelerator literature. The “financial accelerator” is broadly defined to include frictions on the nonfinancial firm side, such as Kiyotaki and Moore (1997), Bernanke et al. (1999) and Jermann and Quadrini (2012); frictions on the household side, such as Mian and Sufi (2018), Mian and Sufi (2014), Mian et al. (2013), Kehoe et al. (2019b); and the more recent focus on the financial intermediary frictions, such as Gertler and Kiyotaki (2010), Gertler and Karadi (2011), Gertler et al. (2019), Ajello (2016), He and Krishnamurthy (2013), He and Krishnamurthy (2019), Brunnermeier and Sannikov (2014), Drechsler et al. (2018), and Bocola (2016). In those models, the wealth of the constrained sector serves as a key determinant of the total credit available in the economy. The financial frictions propagate to the real activities mainly by affecting the level of

⁵For example, Gertler et al. (2019), He and Krishnamurthy (2013), He and Krishnamurthy (2019), Brunnermeier and Sannikov (2014), and Bocola (2016)

capital for production. Technically, the recent financial accelerator literature has been emphasizing nonlinear dynamics induced by occasionally binding constraints (Gertler et al. (2019), He and Krishnamurthy (2013), He and Krishnamurthy (2019), Brunnermeier and Sannikov (2014), and Bocola (2016)). There is also rich empirical evidence that financial frictions can have real effects. For example, Schularick and Taylor (2012), Jordà et al. (2016), Mian et al. (2013), Mian and Sufi (2014), Mian and Sufi (2018), Mian et al. (Forthcoming), López-Salido et al. (2017) document that an increase debt predicts lower economic growth. Gilchrist and Zakrajšek (2012), Chodorow-Reich (2014), Giglio et al. (2016), Adrian et al. (2019) show that measures of distress in the financial sector predict economic contractions. My paper contributes to the financial accelerator literature a channel that does not depend on capital accumulation, through which a financial crisis can amplify unemployment by reducing the expected discounted value of future surpluses.

The second strand is the intermediary asset pricing literature. The central argument of this strand of literature is that the equity capital of the financial intermediaries has a critical role in determining asset prices. Theoretical models include He and Krishnamurthy (2012), He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), Bocola (2016), Maggiori (2017), Moreira and Savov (2017). Empirically, there is increasing evidence that financial intermediary equity capital has unique impacts on asset prices. For example, Adrian et al. (2014), He et al. (2017), Adrian et al. (2017), Lenel et al. (2019) study the cross-sectional asset returns, and Haddad and Muir (2018) study the time series of asset returns. Muir (2017) documents that risk premia only increase substantially in financial crises in a panel of 140 years and 14 countries, and suggests theories relating asset prices to the health of financial sector appear promising. Interestingly, Muir (2017) also documents abnormally high unemployment rate during financial crises relative to nonfinancial recession. My paper contributes to the intermediary asset pricing literature by studying the critical role of the financial intermediary capitalization in affecting unemployment, and rationalizing it in a general equilibrium model.

The third strand is the recent labor search literature that emphasizes the role of the SDF in unemployment fluctuations. A closely related paper is Hall (2017), which shows that an exogenous stochastic discount factor estimated from the S&P500 index is able to match U.S. unemployment quite well. Kilic and Wachter (2018) generate endogenous high discount rates using rare disasters. Petrosky-Nadeau et al. (2018) show that the canonical DMP model with a log-normal productivity process can generate rare disasters if solved globally. Kehoe et al. (2019a) reconciles asset pricing moments and unemployment fluctuations using habit formation in the preference. Kehoe et al.

(2019b) also combine financial frictions with a DMP model, but the financial friction is the household borrowing constraint instead of constraints on the financial intermediary sector and there is no aggregate uncertainty. A common feature of these models is that the SDF is derived from household consumption. My paper derives the SDF from the financial health of financial intermediaries. Thanks to the financial intermediary friction, the model can generate the contrasts between financial crises and nonfinancial recessions documented by Muir (2017) that the consumption-based models find hard to explain. This mechanism implies that the public authority can reduce unemployment by stabilizing the financial intermediary capital ratio.

Road Map The rest of the paper is organized as follows. Section 2 presents two sets of empirical exercises. The first compares correlations between capital ratios of different sectors and aggregate U.S. time series of real variables. The second exercise studies whether a low intermediary capital ratio amplifies impulse responses of different real variables to a given productivity shock. Section 3 presents the baseline model which combines an intermediary asset pricing model with a labor search model, and shows that the unemployment and risk premia do increase substantially when the intermediary capital ratio is low. Section 4 considers three experiments: 1) removing the search and matching friction in the labor market; 2) making the SDF exogenous; 3) government purchasing risky assets in a financial crisis. The overall goal of the exercises is to show that the endogenous interaction between the financial intermediary capitalization and the labor market friction is central for amplifying unemployment and the risk premium in a financial crisis. Section 5 concludes.

2 Empirical Evidence

This section presents two sets of empirical exercises. The first compares the correlations between time series of aggregate U.S. real variables and capital ratios of different sectors. The exercise finds that the primary dealer capital ratio has a stronger correlation with U.S. business cycle than other capital ratios, which justifies the focus on the primary dealer capital ratio. The second exercise studies state dependent impulse responses to a productivity shock using the primary dealer capital ratio as the state variable. The exercise finds that the unemployment rate has a significantly larger impulse response when the primary dealer capital ratio is low. Interestingly, the static labor demand is associated with a small fraction of the amplification of unemployment. This motivates the SDF channel to explain the amplification of unemployment in a financial crisis.

2.1 Data

This subsection describes the data used in the empirical exercise. The standard business cycle variables are from the FRED: Real Gross Domestic Product (GDPC1), Real Personal Consumption Expenditures (PCECC96), Civilian Unemployment Rate (UNRATE), Employment Level (CE16OV), 3-Month Treasury Bill: Secondary Market Rate (TB3MS), 10-Year Treasury Constant Maturity Rate (DGS10). Capital stock and investment are computed following Hall (2001), updated to the latest date available.

According to Duffie (2019), the failure of critical financial intermediaries was central to the propagation and magnification of initial adverse shocks. The critical financial intermediaries identified by Duffie (2019) are members of the primary dealers, which are trading counterparties of the New York Fed in its implementation of monetary policy. Currently, there are 24 primary dealers including Goldman Sachs, J.P. Morgan, Morgan Stanley, and others⁶. In terms of total assets, the primary dealers constitute 96% of the U.S. broker dealer sector. He et al. (2017) show that shocks to the capital ratio of the primary dealers have significant explanatory power for expected returns in many major asset classes. Capital ratio is the equity-to-assets ratio, which is the reciprocal of the leverage. Over the period 1960-2012, primary dealers account for 96% of total assets of the broker-dealers sector and 60% of total assets of all banks in the U.S.. The capital ratio is defined as the market value of equity divided by total asset at the holding company level:

$$\text{capital ratio}_t = \frac{\sum_{i \in \{\text{primary dealers}\}} \text{market equity}_{i,t}}{\sum_{i \in \{\text{primary dealers}\}} (\text{market equity}_{i,t} + \text{book debt}_{i,t})}.$$

The capital ratio is computed by He et al. (2017) from CRSP/Compustat and Datastream, and the updated time series are available on Asaf Manela's website. There are two reasons for choosing this series as the indicator of financial intermediation. First, the capital ratio is an important endogenous state variable for investment decisions in intermediary asset pricing theory, and the primary dealers are the dominant financial intermediaries in the United States. Second, the time series is based on the market value of equity, which is the empirical counterpart of capital ratio in intermediary asset pricing theory. Of course, the primary dealers are special in many other aspects that are worth studying, but this paper only emphasizes their dominant role in financial intermediation and takes them as a representative of all financial intermediaries in the U.S..

⁶The list of primary dealers can be found on New York Fed's website: <https://www.newyorkfed.org/markets/primarydealers>.

The labor status transition probabilities are computed following Shimer (2012). I update the time series to 2018Q3. The computation procedure is briefly described as following. Labor status can take one of the values in {employment (E), unemployment (U), out of the labor force (I)}. Observations are based on monthly CPS surveys of household labor status. The data are viewed as discrete observations of a continuous-time process, such that workers are allowed to switch labor statuses between observations. Assume that the transitions follow a three-state continuous-time Markov process. Let λ_t^{AB} denote the hazard rate of transitioning from state A to state $B \neq A$ where $A, B \in \{E, U, I\}$. $\Lambda_t^{AB} \equiv 1 - e^{-\lambda_t^{AB}}$ is the transition probability from A to B in the full month. Monthly transition probabilities are averaged to get quarterly transition probabilities. Details for estimating λ_t^{AB} can be found in Shimer (2012). Shimer (2012) finds that the unemployment-to-employment (UE) transition probability accounts for three quarters of the fluctuations in aggregate unemployment rate, so I only report findings for UE among all transition probabilities in the rest of the paper. For the same reason, I assume an exogenous job separation rate in the theoretical model.

2.2 Correlations with the business cycle

In addition to the financial intermediary leverage, previous research on financial frictions have emphasized the household leverage (Mian and Sufi (2018), Mian and Sufi (2014), Mian et al. (2013), Kehoe et al. (2019b)) and the corporate leverage (Bernanke et al. (1999)) as the financial accelerators. I estimate the following regressions to see if the primary dealer capital ratio is more correlated with the real variables. If so, this justifies the focus on financial intermediaries rather than, say, household's borrowing constraint. The regressions analyze the predictive power of the capital ratio over horizons $h = 1, 2, \dots, H$ in the spirit of Gilchrist and Zakrajšek (2012):

$$y_{t+h} = \alpha^h + \beta_1^h x_t + \beta_2^h r_{f,t} + \beta_3^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}, \quad (2.1)$$

where y_{t+h} is a measurement of real activity h periods ahead, x_t is one of the candidate capital ratios, $r_{f,t}$ is the risk-free interest rate measured by 3-month treasury zero-coupon yield, TS_t is term spread measured by the difference between zero-coupon yields on 10-year and 3-month treasury bonds, and y_{t-l} is lagged dependent variable. The risk-free rate and the term spread are included as controls for the forecasting regression because the yield curve is a commonly adopted predictor of business cycle fluctuations. Measures of real activities include the unemployment rate, the

UE transition probability, GDP, and consumption. The unemployment rate and the UE transition probability are expressed in levels, and GDP and consumption are expressed in cumulative growth rates: $(\ln Y_{t+h} - \ln Y_{t-1}) * 400/(h + 1)$. Capital ratios include the primary dealer capital ratio, households and nonprofit organizations capital ratio, and nonfinancial corporate business capital ratio. The primary dealer capital ratio is described in the previous subsection and other capital ratios are computed from Flow of Funds tables using analogues definitions. To facilitate interpretation, capital ratios are normalized to have mean 0 and standard deviation 1. The time frame is 1970Q1-2017Q3.

Table 1 presents the coefficient β_1^h obtained with the primary dealer capital ratio at horizons 1, 4, and 8 quarters. A higher primary dealer capital ratio is associated with a higher UE transition probability, a lower unemployment rate, higher GDP growth, and higher consumption growth. Consistent with intermediary asset pricing theory, the primary dealer capital ratio is procyclical. Controlling for the risk-free rate and slope of the yield curve, the primary dealer capital ratio still predicts the UE transition probability and the unemployment rate at 99% confidence level. The predictive coefficients are also economically significant at short, medium, and long horizons. For example, a one standard deviation increase in primary dealer's capital ratio is associated with a 0.237 percentage point (pp) lower unemployment rate 1 quarter ahead and a 0.781 pp lower unemployment rate 2 years in the future. The standard deviation of the sample unemployment rate is 2%.

In contrast to the results obtained with the primary dealer capital ratio, capital ratios of the households and nonprofit organizations sector and the nonfinancial business sector are not significantly correlated with the real variables. Table 2 presents coefficient β_1^h obtained with the households and nonprofit organizations capital ratio. The coefficients for the UE transition probability and the unemployment rate are both negative although not statistically significant. Intuitively, UE transition and unemployment rate are negatively correlated so the same signs of coefficients for the two dependent variables are hard to interpret. Moreover, the magnitudes of the point estimates are much smaller than those obtained with the primary dealer capital ratio. Table 3 presents β_1^h obtained with the nonfinancial business sector capital ratio. The nonfinancial business capital ratio has no significant correlation with labor market variables at any horizon. At one-year and two-year horizons, the nonfinancial business sector capital ratio is negatively correlated with cumulative GDP and consumption growth.

The results are consistent with Gilchrist and Zakrajšek (2012), who find that corporate bond

Table 1: Primary dealer capital ratio and real variables.

	UE	Unemployment rate	GDP	Consumption
$h = 1$				
capital ratio	1.732*** (0.38)	-0.237*** (0.07)	0.371*** (0.12)	0.461*** (0.11)
$h = 4$				
capital ratio	3.120*** (0.72)	-0.628*** (0.19)	0.153** (0.06)	0.203*** (0.06)
$h = 8$				
capital ratio	3.564*** (0.97)	-0.781*** (0.22)	0.052 (0.04)	0.070** (0.03)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha^h + \beta_1^h x_t + \beta_2^h r_{f,t} + \beta_3^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_t : the primary dealer capital ratio, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

credit spreads have strong predict power for future economic activity. They interpret the increase in credit spread as reflecting a reduction in the risk-bearing capacity of the financial sector. The primary dealer capital ratio and the credit spread in Gilchrist and Zakrajšek (2012) are negatively correlated, and it is straightforward that a low capital ratio reduces the financial intermediary risk-bearing capacity. Using the primary dealer capital ratio, my exercise confirms the broad finding that disruptions in the financial sector predict future economic contractions.

2.3 Empirical impulse responses

Motivated by the fact that the primary dealer capital ratio is strongly correlated with aggregate real variables, I use the primary dealer capital ratio as a state variable to study the transmission of productivity shocks. I choose the productivity shock among other exogenous shocks because it is relatively easily measurable and can account for joint movements of many business cycle variables. The primary dealer capital ratio is procyclical and reached the lowest level during the 2008 crisis. If a low capital ratio in the financial intermediary sector amplifies impulse responses to a given exogenous shock, it helps us understand why the recessions are deeper in financial crises.

Table 2: Households and nonprofit organization capital ratio and real variables.

	UE	Unemployment rate	GDP	Consumption
$h = 1$				
capital ratio	-0.199** (0.08)	-0.002 (0.01)	-0.017 (0.04)	-0.072 (0.04)
$h = 4$				
capital ratio	-0.087 (0.17)	-0.013 (0.03)	-0.004 (0.02)	0.001 (0.02)
$h = 8$				
capital ratio	-0.133 (0.37)	-0.006 (0.06)	-0.019 (0.01)	-0.002 (0.01)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha^h + \beta_1^h x_t + \beta_2^h r_{f,t} + \beta_3^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_t : the households and nonprofit organization capital ratio, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

Table 3: Nonfinancial corporate business capital ratio and real variables.

	UE	Unemployment rate	GDP	Consumption
$h = 1$				
capital ratio	-0.073 (0.16)	-0.011 (0.04)	-0.129 (0.12)	-0.005 (0.09)
$h = 4$				
capital ratio	-0.151 (0.28)	0.009 (0.09)	-0.243*** (0.04)	-0.094** (0.04)
$h = 8$				
capital ratio	-0.287 (0.22)	0.069 (0.06)	-0.060*** (0.02)	-0.059*** (0.01)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha^h + \beta_1^h x_t + \beta_2^h r_{f,t} + \beta_3^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_t : the Nonfinancial corporate business capital ratio, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

I estimate the following local projection regression equation

$$y_{t+h} = \alpha^h + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h \text{cap}_{t-1} \times \varepsilon_t^{TFP} + \beta_3^h r_{f,t} + \beta_4^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t+h}. \quad (2.2)$$

Here y_{t+h} is one of the following variables: the unemployment rate, log of the employment level, the UE transition probability, log of the level of physical capital, and the investment-to-capital ratio. The employment level and physical capital stock are detrended using the method of Hamilton (2017). The reason for using levels instead of growth rates is to facilitate the back-of-the-envelope calculation described below. h is the forecasting horizon. For each $h \in \{1, 2, \dots, H\}$, the regression is estimated separately. ε_t^{TFP} is the productivity shock based on the productivity time series from the Federal Reserve Bank of San Francisco. The productivity shock is computed in two steps: 1) Regress the log productivity time series on a linear time trend and a constant, keep the residual; 2) fit the residual into an AR(1) process and the residual of the AR(1) process is the productivity shock ε_t^{TFP} . cap_{t-1} is the primary dealer capital ratio in the previous quarter. It is lagged one period to ensure it is predetermined at the time of the productivity shock. The capital ratio and productivity shock are normalized to have zero mean and unitary standard deviation. β_1^h measures the linear response to the productivity shock, which is the impulse response when the capital ratio is at the mean level. β_2^h measures the state dependence, which is the additional impulse response when the capital ratio deviates from its mean. The sample ranges from 1970q1 to 2017q3.

The regression addresses two questions. First, do β_1^h and β_2^h have different signs? If the signs are different, a below-average capital ratio would amplify the impulse response to the productivity shock⁷. Second, how does the absolute value of β_2^h compare to β_1^h ? If it is relatively big, the impulse response is more sensitive to the level of the capital ratio. Previous literature on intermediary friction focuses on how disruptions in the intermediary sector discourage capital accumulation. This regression compares the magnitudes of state dependence for the labor market variables and the physical capital. The results suggest that the capital accumulation channel may not be sufficient to explain the large increase in the unemployment rate during the Great Recession.

Table 4 presents the local projection coefficients β_1^h and β_2^h at 1, 4, and 8 quarter horizons. Firstly, the linear effect β_1^h and the state dependence β_2^h have opposite signs for labor market variables and the investment rate, meaning that a lower capital ratio amplifies impulse responses

⁷Suppose capital ratio is below average, so enters the equation with a negative sign. A negative number multiplying β_2^h flips the sign, so the state-dependent effect has the same sign with the linear effect, amplifying the linear effect.

to a given productivity shock. For example, the unemployment rate increases by 0.16 pp ($-0.16 \times (-1)$) on impact of a one standard deviation negative productivity shock when the primary dealer capital ratio is at the mean level. When the capital ratio is one standard deviation below its mean at the time of shock, the unemployment rate further increases by 0.16 pp ($0.16 \times (-1) \times (-1)$). Secondly, estimates of the state dependence parameter β_2^h have comparable magnitudes with the linear effect β_1^h for labor market variables, but are relatively small for the investment rate. For example, β_2^4 is 75% of β_1^4 in absolute value (0.27/0.36) for the unemployment rate but only 25% (0.03/0.12) for the investment rate. Labor market variables seem to have much stronger “excess response” to a productivity shock than investment rate and capital stock do when the primary dealer capital ratio is low.

To illustrate the point that the capital accumulation channel is not sufficient for generating the amplified unemployment, consider the following back-of-the-envelope calculation. Suppose the labor market is the standard RBC labor market. The first-order-condition for employment is

$$\ln w(S) = \ln(1 - \alpha) + \alpha \ln K(S) - \alpha \ln A(S) - \alpha \ln L(S)$$

where S is the vector of state variables, w is the real wage, K is the physical capital, A is the productivity, and L is the level of employment. Following a productivity shock,

$$d \ln w(S) = \alpha d \ln K(S) - \alpha d \ln A(S) - \alpha d \ln L(S).$$

Suppose in a different state S' , the economy is hit by a productivity shock of the same sign and magnitude. Taking difference,

$$\Delta d \ln w(S) = \alpha \Delta d \ln K(S) - \alpha \Delta d \ln L(S)$$

where the Δ operator means $d \ln x(S) - d \ln x(S')$. The difference in the responses of the employment level should be

$$\Delta d \ln L(S) = \Delta d \ln K(S) - \frac{\Delta d \ln w(S)}{\alpha}. \quad (2.3)$$

Suppose that equation (2.2) gives the estimates of $d \ln L, d \ln w, d \ln K$ in different states. Take $\alpha = 1/3$, let S denote the average capital ratio state and S' denote the 1-standard-deviation-below-mean capital ratio state. According to Table 4, the differences in the impulse responses to a -1 standard

deviation productivity shock at horizon $h = 4$ are

$$\Delta \ln L = 0.40, \Delta \ln K = 0.11, \Delta \ln w = -0.06.$$

The $\Delta \ln L$ implied by the first-order condition is

$$0.11 - \frac{-0.06}{1/3} = 0.29.$$

That is, the state-dependent response of the log employment rate, β_2^4 , should be -0.29 instead of -0.40 . The measurement of real wage impulse response is noisy and it seems counter-intuitive that the impulse response of the real wage is dampened in a financial crisis. The calculation is only illustrative, but the crux of the exercise is that the impulse response of the physical stock, either measured by the response of $\ln K$ or the I/K ratio, has much weaker state-dependence than employment. For example, $\Delta \ln K$ is only 27.5% of $\Delta \ln L$ ($0.11/0.40$)).

Intuitively, labor demand in the standard RBC labor market solely depends on the contemporaneous marginal product of labor, which is proportional to the capital-labor ratio. Lower capital diminishes the marginal product of labor, so labor demand contracts more in response to a negative productivity shock. The point estimates suggest that in response to a negative productivity shock in a lower capital ratio state, capital falls more. If the wage impulse response does not change, employment should fall at the same rate with capital. Since wage also falls slightly more in the low capital ratio state, employment should fall at a lower rate than capital. However, the capital impulse response is not significantly sensitive to the capital ratio, making it hard to rationalize the strong state dependence of the labor market impulse responses. The simple calculation suggests that the capital accumulation channel does not fully explain the sharp recession in the labor market in a financial crisis. We should look for channels in addition to the contemporaneous marginal product of labor to understand the strong state dependence of the labor market impulse responses.

Figure 2.1 illustrates the state-dependent impulse responses in two specific cases. Impulse responses at a given horizon are averaged with two neighboring horizons to smooth out the graphs. The impulse responses are computed as $\beta_1^h + \beta_2^h \text{cap}_t$, where cap_t equals to the value of the capital ratio in 2001Q1 or 2008Q4. According to the NBER business cycle dates, 2001q1 and 2008q4 are starting dates of two recent recessions. The difference is that the 2001 recession was relatively mild and the capital ratio of the primary dealers was among the top 10 percent of the sample,

Table 4: State-dependent impulse responses.

	UE	Unemployment rate	I/K	$\ln K$	$\ln wage$	$\ln L$
$h = 1$						
ε_t^{TFP}	0.75*** (0.26)	-0.16*** (0.04)	0.07*** (0.01)	0.13 (0.10)	0.35* (0.16)	0.30*** (0.08)
$\varepsilon_t^{TFP} \times \text{cap}_t$	-0.84** (0.33)	0.16*** (0.04)	-0.02*** (0.01)	0.06 (0.07)	-0.19 (0.16)	-0.19** (0.08)
$h = 4$						
ε_t^{TFP}	1.90*** (0.49)	-0.36*** (0.09)	0.12*** (0.02)	0.44*** (0.13)	0.69*** (0.24)	0.68*** (0.17)
$\varepsilon_t^{TFP} \times \text{cap}_t$	-0.79** (0.38)	0.27*** (0.09)	-0.03 (0.02)	-0.11 (0.11)	0.06 (0.18)	-0.40** (0.16)
$h = 8$						
ε_t^{TFP}	1.38** (0.58)	-0.26** (0.13)	0.05* (0.03)	0.37** (0.15)	0.42* (0.24)	0.35* (0.20)
$\varepsilon_t^{TFP} \times \text{cap}_t$	-0.20 (0.51)	0.18 (0.12)	0.02 (0.02)	0.04 (0.12)	0.30* (0.17)	-0.19 (0.20)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h \text{cap}_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. cap_t : the primary dealer capital ratio, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

whereas the 2008 recession was deep and the capital ratio was among the bottom 10 percent of the sample. The purpose of the comparison is to represent the impulse responses in a normal recession and those in a deep recession following a financial crisis. Again, the magnitude of the productivity shock is irrelevant. It is the product $\beta_2^h \text{cap}_t$ that makes the impulse responses potentially differ across states.

In the first 15 quarters, the unemployment rate had significantly different responses in the two cases. The peak response to a one standard deviation negative productivity shock in the 2001 recession was a 0.3 percent increase, compared with a 0.6 percent increase in the 2008 recession. The difference in responses of job finding probability was less persistent, but still large for peak effects. The responses in both episodes peaked at 5 quarters after the shock. In the 2001 recession, the job finding probability declined 1.4 percentage points in response to a negative one standard deviation productivity shock at the peak. In the 2008 recession, the job finding probability declined 2.1 percentage points at the peak. In contrast, impulse responses of capital stock and investment rate in both episodes were indistinguishable. The peak response of capital stock was a 0.5 percent decrease in 2001 , and a 0.6 percent decrease in 2008. Investment rate declined by 0.1 percent in both episodes.

The state-dependent impulse responses are broadly consistent with the findings of Muir (2017). Figure III of Muir (2017) suggests that unemployment on average increases four times as much in financial crises as in normal recessions. Although I study the impulse responses while Muir (2017) studies average levels, the common point is that unemployment is abnormally high in a financial crisis, which is defined as an episode in which the financial sector is poorly capitalized. Muir (2017) also finds abnormally high risk premia in financial crises. The most natural way to think of the risk premium is the cost of borrowing, which reduces physical capital accumulation. However, my exercise suggests that this channel is not enough to generate the high unemployment observed in financial crises. The high risk premium can also be interpreted as an abrupt increase in the discount rate, and my model is going to emphasize the discount rate channel. The model in the next section argues that the high risk premia and high unemployment reinforce each other in general equilibrium, and the friction in the financial intermediary amplifies this vicious cycle in a financial crisis.

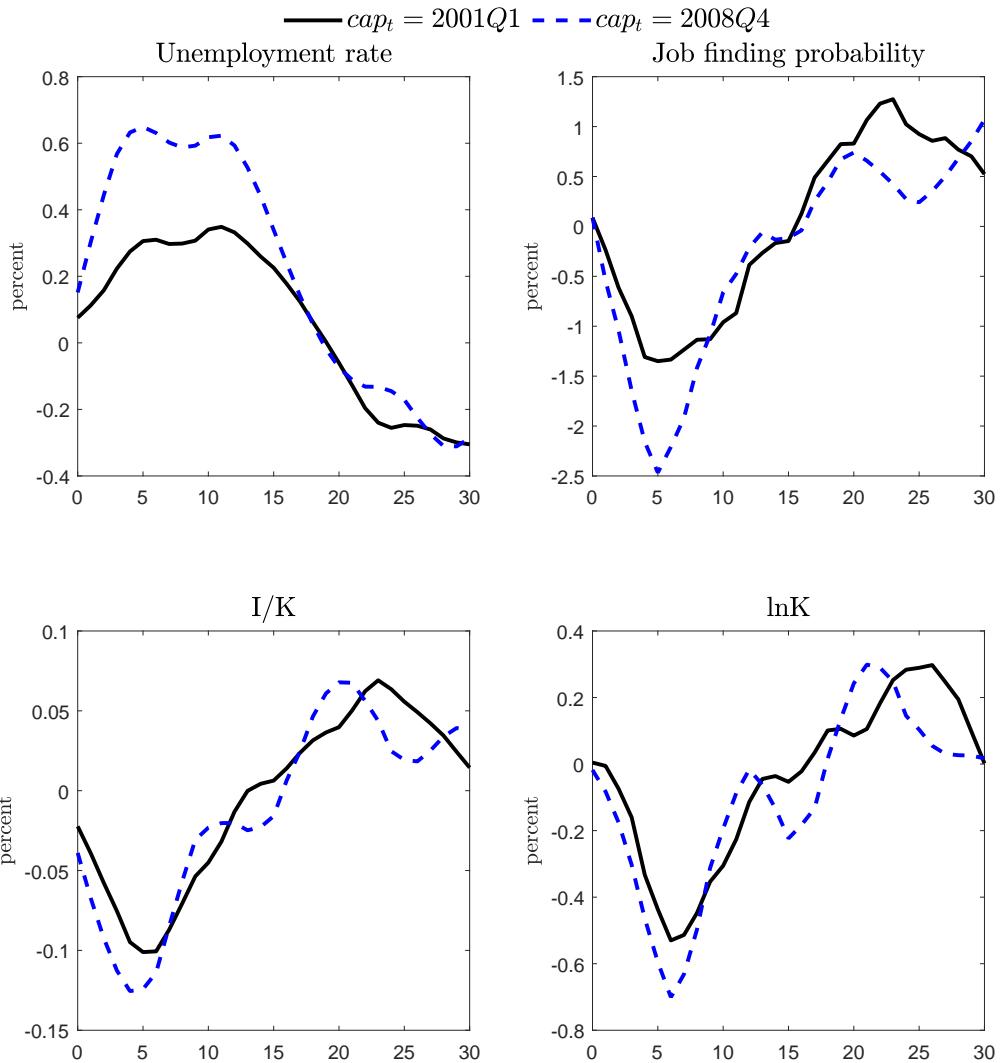


Figure 2.1: State-dependent impulse responses from local projection regressions. The figure plots estimates of $\beta_1^h + \beta_2^h \text{cap}_{t-1}$ for $h = 1, 2, \dots, 30$. The regression is $y_{t+h} = \alpha^h + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h \text{cap}_{t-1} \times \varepsilon_t^{TFP} + \beta_3^h r_{f,t} + \beta_4^h TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$, estimated separately for each h . $r_{f,t}$: 3-month zero-coupon treasury yield. TS_t : 10-year-3-month spread in zero-coupon treasury yields. Specifically, the capital ratio is assigned the observed value in 2001Q1 for the solid line and 2008Q4 for the dashed line.

3 The Baseline Model

3.1 Description of the model

I adopt the financial friction framework of Gertler-Karadi-Kiyotaki. The framework explicitly allows for financial intermediation yet preserves the tractability of the representative agent setup. Households are unable to directly invest in the representative firm stocks. Instead, they set up financial intermediaries to invest in the stocks. Financial intermediaries take deposits from households and combine the deposits with their wealth to buy the stocks. Unemployment is modeled by a Diamond-Mortensen-Pissarides labor search and matching block. The firm hires labor by posting vacancies. Each vacancy can be matched with a worker according to a probability determined by the matching function. The fact that posting vacancy is costly and that the vacancy may not be filled makes the hiring decision dynamic. Since the firm maximizes the stock value to the financial intermediaries, it uses the financial intermediary stochastic discount factor to evaluate the present value of uncertain future matching surpluses. The only source of uncertainty is the productivity shock to the representative firm's production function. The challenge is to generate the joint dynamics of unemployment and intermediary capital ratio as observed in the data. One important endogenous mechanism that connects unemployment and the intermediary capital ratio is the fact that the stock price is an increasing function of labor. This generates a strong feedback effect from the labor market to the financial sector, which is absent in the existing financial accelerator literature.

Households A fraction ω of the household members are bankers. Each banker within a household manages a financial intermediary. The remaining fraction $1 - \omega$ of the household members are workers. Workers supply labor and earn wages for the household. I normalize the mass of workers to 1 such that the mass of (un)employed workers is the same as the (un)employment rate. Workers deposit funds into the financial intermediary owned by other households. Household members do not invest in risky assets directly. Instead, the financial intermediaries hold equity claims on firms using deposits and their own net wealth. There is complete risk sharing within the household. Bankers and workers pool their wealth together to make intertemporal optimization decisions.

At any time, a fraction $1 - \Xi$ of randomly selected existing bankers exit and become workers, and give all their wealth to the household. Meanwhile, a fraction $\frac{\omega}{1-\omega}(1 - \Xi)$ of workers within each household become bankers, so that the population remains constant. When becoming

a banker, each worker brings $\frac{\chi}{\omega(1-\Xi)}$ fraction of aggregate financial wealth of the economy into the intermediary sector. This exogenous role-switching is a simple way to prevent the financial intermediary sector from accumulating sufficient wealth to permanently escape the financial constraint described below.

The household problem is given by

$$\max_{C_t, B_t} \mathbf{E} \left[\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\gamma}}{1-\gamma} \right]$$

$$\text{s.t. } C_t = w_t L_t + b(1 - L_t) + \Pi_t + R_{f,t-1} B_{t-1} - B_t - T_t$$

where β is the time discount rate, γ is the coefficient of relative risk aversion, C is consumption, w is the real wage, L is the mass of employed workers, b is the unemployment benefit, Π is the net transfer from the exiting intermediaries, R_f is the risk-free gross interest rate, B is the quantity of risk-free bank deposit, and T is a lump sum tax to finance the unemployment benefit. Suppose there is an agency in the background that collects lump sum tax from all households and redistributes to all unemployed workers. The agency always runs a balanced budget. The determinants of Π will be described later in the financial intermediary problem. Workers are either employed or unemployed. Thanks to the complete insurance within a household, it suffices for the household's optimization to keep track of aggregate employment. Households don't value leisure, so labor supply is inelastic with respect to wage. Due to search friction in the labor market, however, households can influence the level of equilibrium employment through wage bargaining.

The intertemporal Euler equation for the risk-free rate is

$$1 = \mathbf{E}_t [\Lambda_{t,t+1} R_{f,t}], \text{ where } \Lambda_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}.$$

Financial intermediaries The setup for financial intermediation is the same as Gertler and Karadi (2011). Each intermediary has access to two assets: the risk-free deposit and shares of the representative firm stock. The balance sheet of each intermediary i at the end of period t (after rebalancing portfolio) is

$$P_t S_{i,t} = N_{i,t} + B_{i,t},$$

where $S_{i,t}$ is the number of the representative firm shares held by the intermediary, $N_{i,t}$ is the intermediary wealth, and $B_{i,t}$ is the deposit raised from the household, P_t is the ex-dividend price of the representative firm stock, and D_t is the dividend. The return on the firm stock is defined as

$$R_{K,t+1} = \frac{P_{t+1} + D_{t+1}}{P_t}.$$

All intermediaries treat the asset prices as given, so the dividend and asset prices don't have a subscript i . Let the intermediary wealth of the intermediary at the beginning of period $t+1$ before rebalancing the portfolio be $N_{i,t+1}^*$, which is simply the total return on the risky asset minus the deposit payment:

$$\begin{aligned} N_{i,t+1}^* &= R_{K,t+1} P_t S_{i,t} - R_{f,t} B_{i,t} \\ &= (R_{K,t+1} - R_{f,t}) P_t S_{i,t} + R_{f,t} N_{i,t}. \end{aligned}$$

The financial intermediary portfolio is self-financing, so rebalancing the portfolio does not affect the intermediary wealth: $N_{t+1}^* = N_{t+1}$. This leads to the law of motion for individual financial intermediary wealth:

$$N_{i,t+1} = (R_{K,t+1} - R_{f,t}) P_t S_{i,t} + R_{f,t} N_{i,t}.$$

Each financial intermediary earns the risk-free return on its wealth plus the exposure to the excess return on the risky asset. If $R_{K,t+1}$ turns out to be less than $R_{f,t}$ in period $t+1$, the intermediary would suffer a loss on its wealth. Ex ante, the realization of $R_{K,t+1}$ is uncertain to the intermediary when it makes portfolio decisions in period t . The uncertainty makes the financial intermediaries less willing to hold the risky asset when the wealth is low because the downside risk becomes more worrisome. This is a major difference from the model presented by Kehoe et al. (2019b), which does not have aggregate uncertainty. Recall that Ξ is the probability that the intermediary stays to the next period. The intermediary maximizes its wealth upon exit. The intermediary's value function, $W_{i,t}$, is

$$W_{i,t} = \max_{S_{i,t}, B_{i,t}} \mathbf{E}_t \left\{ \Lambda_{t,t+1} [(1 - \Xi) N_{i,t+1} + \Xi W_{i,t+1}] \right\} \quad (3.1)$$

subject to the financial constraint

$$W_{i,t} \geq \lambda P_t S_{i,t}$$

and the law of motion for the net wealth

$$N_{i,t+1} = R_{K,t+1}P_tS_{i,t} - R_{f,t}B_{i,t}.$$

The financial constraint can be motivated by the fact that the financial intermediary can divert a fraction λ of its assets into its own pocket. When that happens, the intermediary defaults on its deposit obligations but the depositors will force the intermediary into bankruptcy at the beginning of the next period. The intermediary's decision on whether to divert funds boils down to comparing the present value of not cheating, $W_{i,t}$, with the value of divertible assets, $\lambda P_t S_{i,t}$. Rational depositors will not deposit in the intermediary if $W_{i,t}$ is less than $\lambda P_t S_{i,t}$, in which case the intermediary has the incentive to cheat.

The following proposition summarizes the results of intermediary maximization problem.

Proposition 1. *The value function of the intermediary is*

$$W_{i,t} = \Omega_t N_{i,t}. \quad (3.2)$$

Let the Lagrange multiplier on the financial constraint be μ_t , and the intertemporal marginal rate of substitution be $\Lambda_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}$. The asset returns satisfy

$$1 - \mu_t \left(1 - \frac{\lambda}{\Omega_t} \right) = \mathbf{E}_t \left[\Lambda_{t,t+1} \frac{1 - \Xi + \Xi \Omega_{t+1}}{\Omega_t} R_{K,t+1} \right], \quad (3.3)$$

$$1 - \mu_t = \mathbf{E}_t \left[\Lambda_{t,t+1} \frac{1 - \Xi + \Xi \Omega_{t+1}}{\Omega_t} R_{f,t} \right], \quad (3.4)$$

$$1 = \mathbf{E}_t \left[\Lambda_{t,t+1} R_{f,t} \right]. \quad (3.5)$$

The complementary slackness conditions for the financial constraint are

$$\begin{aligned} \Omega_t N_{i,t} &\geq \lambda P_t S_{i,t}, \\ \mu_t &\geq 0, \\ \mu_t (\Omega_t N_{i,t} - \lambda P_t S_{i,t}) &= 0. \end{aligned}$$

Proof. See Appendix A. □

Equation (3.2) states that the value of an intermediary is linear in its wealth. The marginal value of intermediary wealth, Ω_t , depends only on aggregate state variables that individual intermediaries take as given. This can be proved by guess and verify, as Appendix A shows. To understand the meaning of Ω_t , start with the case without the financial constraint. In this case, the marginal value of intermediary wealth is always 1. This is because the net wealth is simply the market value of intermediary portfolio, the asset pricing Euler equations imply that the discounted market value of portfolio is a martingale: $N_{i,t} = \mathbf{E}_t [\Lambda_{t,t+1} N_{i,t+1}]$. Comparing this with equation (3.1), $W_{i,t} = N_{i,t}$ is obviously a solution to the value function. With the financial constraint, however, the martingale condition does not hold in general. This is because there are arbitrage opportunities that the intermediary can't exploit when the constraint binds. The point can be seen by taking the difference between equations (3.3) and (3.4):

$$\mu_t \frac{\lambda}{\Omega_t} = \mathbf{E}_t \left[\Lambda_{t,t+1} \frac{1 - \Xi + \Xi \Omega_{t+1}}{\Omega_t} (R_{K,t+1} - R_{f,t}) \right].$$

The left-hand side is positive, meaning that the expected discounted excess return is positive – there are positive expected gains from buying the stocks and raising deposits. If that case, a marginal increase in the intermediary wealth loosens the financial constraint and the intermediary can increase its portfolio value. Therefore, the marginal value of intermediary wealth is greater than 1 under the financial constraint.

The Euler equations (3.3) and (3.4) imply that the stochastic discount factor, $M_{t,t+1}^I$, is

$$M_{t,t+1}^I = \Lambda_{t,t+1} \frac{1 - \Xi + \Xi \Omega_{t+1}}{\Omega_t}.$$

The intermediaries dislike two risks: consumption risk and financial risk. An asset that pays less when consumption is low is less valuable. This effect is captured by $\Lambda_{t,t+1}$, as in a standard consumption-based asset pricing model. An asset that pays less when the intermediary has low wealth is also less valuable because it does not help relax the financial constraint. This effect is captured by $(1 - \Xi + \Xi \Omega_{t+1}) / \Omega_t$. As described above, when the intermediary has low wealth, it can't invest in high return assets as much as in an unconstrained case, and thus the marginal value of intermediary wealth is large. A marginal payoff in those states are valuable to the intermediary.

The net transfer, Π_t , from the intermediary sector to the worker sector is

$$\Pi_t = (1 - \Xi) \int_{i \in \mathcal{I}} N_{i,t} di - \chi P_t S_t.$$

Recall that Ξ is the survival rate of the intermediaries and χ is the fraction of the total asset value that the new intermediaries bring into the intermediary sector as wealth. The first part measures the aggregate wealth of exiting intermediaries, which is brought into the household. The second part measures the aggregate wealth of new intermediaries, which is brought into the intermediary sector. Dropping subscripts to denote aggregate variables, the law of motion of the aggregate intermediary wealth of the intermediary sector is

$$N_{t+1} = \Xi [(R_{K,t+1} - R_{f,t}) P_t S_t + R_{f,t} N_t] + \chi P_{t+1} S_{t+1}.$$

The terms in the bracket measure the return on the wealth of the survival intermediaries, which consists of the aggregate stock return net of deposit paid back to the depositors. The second term is the wealth contributed by entrant intermediaries.

Since the marginal value of intermediary wealth, Ω_t , does not depend on individual intermediary wealth, individual intermediary value functions can be added up to get the value of the aggregate intermediary sector. Since the intermediaries take asset prices as given, asset prices only depend on aggregate intermediary wealth. Normalizing by the value of total asset, $P_t S_t$, and let $n_t = N_t / P_t S_t$ denote the capital ratio, the constraint on aggregate net wealth becomes

$$\Omega_t n_t \geq \lambda,$$

and the law of motion for the capital ratio is

$$n_{t+1} = \Xi [(R_{K,t+1} - R_{f,t}) + R_{f,t} n_t] \frac{P_t S_t}{P_{t+1} S_{t+1}} + \chi. \quad (3.6)$$

The aggregate capital ratio n_t is the counterpart of the intermediary capital ratio in the empirical exercise. In equilibrium, $S_t = 1$ for all t . A lower capital ratio implies a tighter financial constraint for financial intermediaries, increasing Ω_t and μ_t , resulting in larger wedges in the stochastic discount factor and the Euler equation. The capital ratio summarizes the financial condition of the intermediary sector, and thus it is an important state variable for the model economy.

Firm and labor search Let the labor market tightness be $\theta_t \equiv U_t/V_t$, where U_t denotes the number of unemployed workers before matching and V_t denotes the number of vacancies. The matching function is

$$G(U_t, V_t) = \frac{U_t V_t}{(U_t^{\sigma_m} + V_t^{\sigma_m})^{\frac{1}{\sigma_m}}},$$

which characterizes the total number of matches, G , given the levels of unemployment before matching, U , and vacancy, V . The vacancy filling probability is $Q_t = G(U_t, V_t)/V_t$ and the job finding probability is $f_t = G(U_t, V_t)/U_t$, which is the model counterpart of the UE transition probability in the empirical exercise. This functional form ensures that the job finding rate and vacancy filling rate are bounded between 0 and 1. The law of motion for aggregate employment is

$$L_t = \rho L_{t-1} + Q_t V_t, \quad (3.7)$$

where ρ is the probability that a match survives from the previous period. Notice that the newly matched workers L_t are immediately available for producing output in the current period. Since the model period is one quarter, it is plausible that new hires are available in the current period. More importantly, the productivity shock (will be defined later) has contemporaneous effect on employment as in the RBC model. Due to the timing assumption, unemployment before matching is

$$U_t = \underbrace{(1 - \rho)L_{t-1}}_{\text{separated from previous match}} + \underbrace{1 - L_{t-1}}_{\text{previously unemployed}} = 1 - \rho L_{t-1}.$$

In the numerical exercise, the unemployment rate is measured as $1 - L_t$, which is the unemployment rate after matching in period t .

A representative firm hires workers, L_t , owns capital, K_t , and uses workers and capital to produce final goods. The firm produces output Y_t with a Cobb-Douglas production function:

$$Y_t = K_t^\alpha \left(e^{\zeta_t} L_t \right)^{1-\alpha}.$$

The log level of productivity follows an AR(1) process:

$$\zeta_t = \rho_\zeta \zeta_{t-1} + \sigma_\zeta \varepsilon_t^{TFP}, \varepsilon_t^{TFP} \sim \mathcal{N}(0, 1). \quad (3.8)$$

The productivity process is the only exogenous process in the model. Labor is hired by posting

vacancies. One vacancy can be matched with one worker. Posting each vacancy is associated with a cost $\kappa_t = \kappa_0 + \kappa_1 Q_t$. κ_0 is a fixed cost that has to be paid whether the vacancy is filled or not, and κ_1 is paid only when the vacancy is matched with a worker. New capital is produced by a concave function

$$K_{t+1} = (1 - \delta) K_t + \Phi(i_t) K_t \quad (3.9)$$

where $i_t \equiv I_t/K_t$ is the investment rate. The functional form of Φ is ⁸

$$\Phi(i) = \frac{1}{\phi} \left(\sqrt{2\phi i + 1} - 1 \right).$$

The firm's dividend, D_t , is defined as

$$D_t = Y_t - w_t L_t - i_t K_t - \kappa_t V_t.$$

The firm chooses vacancies V_t , labor L_t , investment rate i_t , and next-period capital K_{t+1} to maximize the cum-dividend stock price⁹, \tilde{P}_t of the firm:

$$\tilde{P}_t = \max_{V_t, L_t, i_t, K_{t+1}} D_t + \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t} \right)} \mathbf{E}_t [M_{t,t+1}^I \tilde{P}_{t+1}] \quad (3.10)$$

$$\text{s.t. } L_t = \rho L_{t-1} + Q(\theta_t) V_t \quad (3.11)$$

$$K_{t+1} = (1 - \delta) K_t + \Phi(i_t) K_t. \quad (3.12)$$

Consistent with the intermediary evaluation, the cum-dividend market value of the firm satisfies the Euler equation (3.3) for the stock return. Let J_t be the Lagrange multiplier on the law of motion for L_t . The first order condition of the firm maximization problem (3.10) with respect to V_t is

$$J_t = \frac{\kappa_t}{Q_t}, \quad (3.13)$$

which is the same as the zero-profit condition for vacancy posting under competitive entry in the canonical DMP model. Therefore, J_t can also be interpreted as firm's surplus from matching. The

⁸The law-of-motion for capital is equivalent to investment with quadratic adjustment cost: an investment of $\Phi + \frac{\phi}{2}\Phi^2$ generates new capital at rate Φ , $\frac{\phi}{2}\Phi^2$ is adjustment cost.

⁹Since the total number of shares is always 1 and the firm is an all-equity firm, the stock price is the same as the market value of the firm.

first-order condition with respect to L_t is

$$J_t = (1 - \alpha) \frac{Y_t}{L_t} - w_t + \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I \rho J_{t+1}] . \quad (3.14)$$

The condition suggests that the firm surplus from matching consists of two parts. The first part is the difference between contemporaneous marginal product of labor and wage, which is the current cash flow generated by a match. The second part is the continuation value of the match, which is the expected discount value of future streams of cash flows. Driven by the productivity process, the marginal product of labor is low when the marginal utility is high. When the financial intermediary sector has a low capital ratio, the stochastic discount factor further increases because the marginal value of financial intermediary wealth, Ω , is high. In a financial crisis, the negative relationship between the SDF, $M_{t,t+1}^I$, and the shadow value of labor, J_{t+1} , is more pronounced. The firm surplus is more sensitive to a negative productivity shock and the firm is less willing to post vacancies.

Let q_t denote the Lagrange multiplier on the law of motion for capital. The first-order condition with respect to investment rate i_t is

$$\Phi'(i_t) = \frac{1}{q_t} . \quad (3.15)$$

Since $\Phi'(\cdot)$ is a decreasing function, i_t increases with q_t . The dynamics of i_t is determined by q_t , which is determined by the curvature of $\Phi(\cdot)$. Suppose $\Phi(i) = i$ as in the basic RBC setting, the firm will always invest until the the shadow price of capital is equal to 1. As the curvature of $\Phi(\cdot)$ increases, investment becomes more sensitive to the shadow value of capital and there is more state dependence in the investment rate. In the numerical exercise, I calibrate the curvature of $\Phi(\cdot)$ to match the volatility of i_t in U.S. data. The first-order condition with respect to K_{t+1} implies the Euler equation for q_t :

$$q_t = \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t \left[M_{t,t+1}^I \left(\alpha \frac{Y_{t+1}}{K_{t+1}} - i_{t+1} + q_{t+1} (1 - \delta + \Phi(i_{t+1})) \right) \right] . \quad (3.16)$$

The shadow value of labor, J_t , and the shadow value of capital, q_t , relate labor and capital to the firm stock price. The following proposition shows that the stock price is endogenously affected by employment and capital stock.

Proposition 2. Given the $\{q_t\}_{t=0}^{\infty}$ and $\{q_t\}_{t=0}^{\infty}$ processes, the cum-dividend price is

$$\tilde{P}_t = \alpha Y_t - i_t K_t - \kappa_t V_t + q_t K_{t+1} + J_t L_t,$$

the ex-dividend price is

$$P_t = (\alpha - 1) Y_t + w_t L_t + q_t K_{t+1} + J_t L_t, \quad (3.17)$$

and the stock return is

$$R_{K,t+1} = \frac{P_{t+1} + D_{t+1}}{P_t} = \frac{\alpha Y_{t+1} - i_{t+1} K_{t+1} - \kappa_{t+1} V_{t+1} + q_{t+1} K_{t+2} + \mu_{L,t+1} L_{t+1}}{(\alpha - 1) Y_t + w_t L_t + q_t K_{t+1} + \mu_{L,t} L_t}. \quad (3.18)$$

Proof. See Appendix A. □

The term $(\alpha - 1) Y_t + w_t L_t$ shows up in the ex-dividend stock price because the matched workers are available for production in the current period. If they are available from the next period onward, then $(\alpha - 1) Y_t + w_t L_t$ does not show up in equation (3.17) and the ex-dividend stock price is $P_t = q_t K_{t+1} + J_t L_{t+1}$. In that case, the ex-dividend stock price is a two-factor version of Hayashi (1982). It follows that a lower employment rate decreases the stock price. Intuitively, since vacancy posting is costly, lower current employment implies more future vacancies needed to meet the desired employment level, and thus increasing future vacancy posting costs.

Labor's value from matching, E_t , is

$$E_t = w_t + (1 - \rho) \mathbf{E}_t [M_{t,t+1}^I (f_{t+1} E_{t+1} + (1 - f_{t+1}) F_{t+1})] + \rho \mathbf{E}_t [M_{t,t+1}^I E_{t+1}], \quad (3.19)$$

and value from unemployment, F_t , is

$$F_t = b + \mathbf{E}_t [M_{t,t+1}^I (f_{t+1} E_{t+1} + (1 - f_{t+1}) F_{t+1})]. \quad (3.20)$$

Here, w_t is the real wage, b is the unemployment benefit, ρ is the probability of remaining matched next period, $M_{t,t+1}^I$ is the stochastic discount factor, and f_{t+1} is the job finding probability. Labor's surplus from matching is

$$E_t - F_t = w_t - b + \rho \mathbf{E}_t [M_{t,t+1}^I (1 - f_{t+1}) (E_{t+1} - F_{t+1})].$$

Labor's surplus is discounted by $M_{t,t+1}^I$ instead of household's intertemporal marginal rate of substitution, $\Lambda_{t,t+1}$. Intuitively, $M_{t,t+1}^I$ is the stochastic discount factor in the financial market, so any uncertainty future payoff should be discounted by $M_{t,t+1}^I$. Alternatively, one could view the worker and financial intermediary as two subsidiaries of a consolidated decision maker. Complete insurance between the worker and financial intermediary justifies this view, and the wage bargaining can be viewed as made by the consolidated decision maker. The intermediary's wealth constraint restricts flow of funds within the decision maker. Without the financial friction, the consolidated decision maker acts exactly the same as the representative household in a textbook labor search model. With the financial friction, the consolidated decision maker can't move funds between assets as it wishes so it can't fully exploit arbitrage opportunities to the extent the intertemporal marginal rate of substitution suggests. The stochastic discount factor should reflect the fact that the decision maker can't fully optimize in the financial distress states, and put more weights on those states.

Finally, I use Nash bargaining to pin down the wage

$$(1 - \eta)(E_t - F_t) = \eta J_t, \quad (3.21)$$

where η is the labor bargaining power.

Equilibrium The resource constraint is

$$Y_t = C_t + i_t K_t + \kappa_t V_t. \quad (3.22)$$

In this economy, output is equal to the sum of consumption, investment in physical capital, and vacancy posing cost.

An equilibrium is characterized by the asset pricing Euler equations (3.3), (3.4), (3.5), stock price return equation (3.18), shadow price of labor (3.14), shadow price of physical capital (3.16), first-order conditions for physical capital investment (3.15) and vacancy posting (3.13), labor value functions (3.19) and (3.20), wage bargaining rule (3.21), laws-of-motion for the intermediary capital ratio (3.6), labor (3.7), capital (3.9), and productivity (3.8), resource constraint (3.22), and the stock market clearing condition $S_t = 1$. The complementary slackness conditions characterizing an equilibrium are $\Omega_t n_t \geq \lambda$, $\mu_t \geq 0$, $\mu_t (\Omega_t n_t - \lambda) = 0$.

A new propagation mechanism The interaction between the marginal value of intermediary wealth, Ω , and employment, L , is the key mechanism for generating the substantial increase in unemployment *and* risk premium in a financial crisis. When the intermediary capital ratio falls close to the binding region, Ω increases. This increases the stochastic discount factor because the term related to intermediary friction, $(1 - \Xi + \Xi\Omega_{t+1})/\Omega_t$, increases. Labor demand decreases because of the negative relationship between the matching surplus and the SDF. Equilibrium employment falls and the stock price decreases because of the $J_t L_t$ term in the stock pricing equation. This further decreases the intermediary capital ratio and creates a vicious cycle. This channel is stronger when the financial constraint binds more tightly, or, in a deep financial crisis. In normal times the constraint does not bind, and the channel is muted.

Thanks to the spikes in Ω , my model does not have to rely on the dynamics of aggregate consumption to generate large fluctuations in the SDF and hence unemployment (for example, Kilic and Wachter (2018), Petrosky-Nadeau et al. (2018), Kehoe et al. (2019b)). This relates to Muir (2017), who finds that aggregate consumption behaves similarly across financial crises and nonfinancial recessions. Therefore, a consumption-based SDF has hard time explaining the abnormal behaviors of unemployment and risk premia in financial crises.

Interestingly, the fluctuations in employment also substantially increase the risk premium in my model. In the standard financial accelerator literature, the ex-dividend stock price is $P_t = q_t K_{t+1}$ (for example, Brunnermeier and Sannikov (2014), Gertler and Karadi (2011), Gertler et al. (2019)). The stock price is much less volatile without the fluctuations in employment as an additional pricing factor, so the risk premium is lower.

3.2 Numerical solution

I solve for a recursive Markov equilibrium. Numerically, I project the policy functions and value functions on a set of Chebyshev polynomials to find a global solution. This method allows for an occasionally-binding financial constraint. See Appendix C for details.

Calibration The model is calibrated in quarterly frequency. Parameters for household preference are standard. The coefficient for relative risk aversion is $\gamma = 2$. The time discount rate is $\beta = 0.99$, which implies 4% annualized risk-free rate in the non-stochastic steady state. Capital's share in the Cobb-Douglas production function is $\alpha = 0.3$. The curvature parameter for capital accumulation

function is $\phi = 2$, which matches the volatility of investment-to-capital ratio in the U.S. data. Depreciation rate of capital is 0.025.

The share of divertible asset is $\lambda = 0.2$. This implies an annualized risk premium $\mathbf{E}_t R_{K,t+1} - R_{f,t} = 3\%$ in a financial crisis, close to the Effective Bond Premium 2.87% in 2008 Q4 estimated by Gilchrist and Zakrajšek (2012). The proportional transfer to new bankers, χ , is taken from Gertler et al. (2019). The intermediary survival rate, $\Xi = 0.96$, implies an average capital ratio of 10%.

Curvature parameter of the labor matching function is $\sigma_m = 1.25$, close to that in den Haan et al. (2000). The worker's bargaining weight, η , is 0.17, which implies a wage elasticity to labor productivity of 0.44, close to 0.47 in the postwar U.S. data. The flow value of unemployment, b , is 0.81. It is close to 0.88 estimated by Christiano et al. (2016).

The cost parameters $\kappa_0 = \kappa_1 = 1.8$ are larger than those in Petrosky-Nadeau et al. (2018). Because newly matched workers are immediately available for production in my model, current profit are added to firm's value of matching. Cost parameters should be larger to offset the additional profit. Merz and Yashiv (2007) estimate the marginal cost of hiring, $\kappa_0/Q(\theta_t) + \kappa_1$, to be 1.5 times the average output per worker with a standard error of 0.6. This ratio in my baseline model is 1.6, which is plausible.

Simulations and moments Since the focus of this paper is on the close relationship between the financial intermediary capital ratio and the unemployment rate, it is crucial that the model matches the correlations between the capital ratio and labor market variables. In U.S. data, the share of credit provided via capital markets increased sharply from 50% in the late 1980s to over 60% in the early 1990s (Duffie (2019)). Meanwhile, the correlation between the primary dealer capital ratio and real variables such as the I/K ratio and the unemployment rate also became much stronger. Therefore, I compare the model generated moments with the data moments based on the period from 1990q1 to 2017q3. The model moments are based on simulations with the same number of periods and 500 repetitions. I report the average of time series means and the average of time series standard deviations of each repetition. The targeted moments are: the mean capital ratio, the mean unemployment rate, and the standard deviation of the I/K ratio. The model matches the mean level of the unemployment rate, and the standard deviation of the I/K ratio, but the capital ratio is 4 pp higher than the target. The job finding probability does not match the data well. This could be improved by assuming a different matching function in the labor market, e.g., a Cobb-Douglas

Table 5: Parameter Values for the Baseline Model

Parameter	Symbol	Value	Target	Model
Household preference				
Relative risk aversion	γ	2	Literature	
Time discount rate	β	0.99	Literature	
Financial intermediary				
Wealth constraint	λ	0.2	Risk premium in 2008 max. 3% p.a.	3% p.a.
Proportional transfer to new bankers	χ	0.001	Gertler et al. (2019)	
Survival rate of bankers	Ξ	0.96	Capital ratio = 0.07	0.11
Final good firm				
Capital share	α	0.3	Capital share = 0.3	
Adjustment cost	ϕ	2	Volatility of $I/K = 0.3\%$	0.2%
Depreciation rate	δ	0.025	Starndard	
Search and matching				
Curvature of matching function	σ_m	1.25	den Haan et al. (2000)	
Fixed cost of posting vacancies	κ_0	1.8	Marginal cost of vacancy / output = 1.5	1.7
Fixed cost of matching	κ_1	1.8	Marginal cost of vacancy / output = 1.5	1.7
Unemployment benefit	b	0.81	Mean unemployment rate = 0.55	0.55
Survival rate of a match	ρ	0.9	Standard	
Labor's bargaining power	η	0.17	Elasticity of wage w.r.t productivity = 0.47	0.45
Exogenous processes				
Persistence of the productivity	ρ_ζ	0.95	TFP series from SF Fed	
Volatility of the productivity	σ_ζ	0.0168	TFP series from SF Fed	

Table 6: Basic Moments in the Baseline Model

	Data		Model	
	Mean	Std.	Mean	Std.
Capital ratio	7%	2%	11%	1%
Unemployment rate	6%	2%	6%	1%
Job finding probability	46%	7%	62%	4%
I_t/K_t	4%	0.3%	3%	0.2%
corr(unemployment rate, capital ratio)	-67%	-	-64%	-
corr(job finding probability, capital ratio)	73%	-	67%	-
corr(I_t/K_t , capital ratio)	80%	-	74%	-

matching function. However, I choose the functional form as in den Haan et al. (2000) to ensure the matching probabilities between zero and one.

I am mainly interested matching the correlations between the intermediary capital ratio and the real variables, which are all untargeted. Recall that the only exogenous force in the model is the productivity process, so it could be challenging to match the multiple correlations at the same time. Nevertheless, the model is successful at matching the strong correlations between the capital ratio and the labor market dynamics measured by the unemployment rate and the job finding probability. In order to assess the importance of the capital accumulation channel for unemployment, it is also important to match the moments for the I/K ratio. Consistent with the data, the model also generates a strong correlation between the capital ratio and the I/K ratio.

Figure 3.1 shows the simulated time series. The model is initialized from the steady state, which is computed by feeding in a sequence of zero productivity shocks and simulate until convergence. Then I feed in the productivity shock series estimated from SF Fed productivity data, which starts from 1947Q2. The figure takes the snapshot from 2000Q1 to 2009Q2. The dynamics are solely driven by the productivity process and there are definitely other important exogenous processes driving the observed data. It is implausible to expect a decent match, but the simulation matches the quantitative features of the 2001 recession and the 2008 financial crisis. The unemployment rate increased mildly in 2001, but increased sharply in 2008. The risk premium, which is $\mathbf{E}_t [R_{K,t+1}] - R_{f,t}$, seemed normal in 2001 but skyrocketed in 2008. The simulated risk premium pattern is broadly consistent with a measure of risk premium in the data, which is the excess bond premium from Gilchrist and Zakrajšek (2012). The simulation is broadly consistent with the findings in Muir (2017): unemployment and risk premium are abnormally high in a financial crisis.

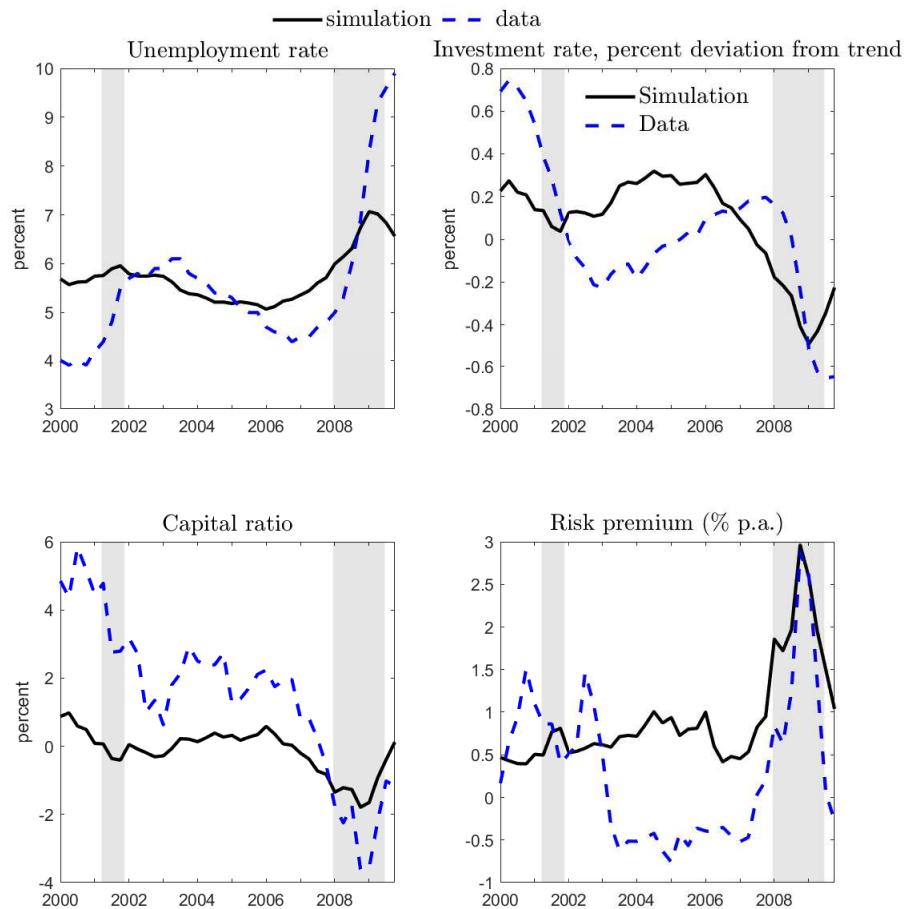


Figure 3.1: Simulated time series. The simulation starts in 1947Q2 from the steady state, and feeds in the SF Fed productivity series since then. The figure takes the snapshot from 2000Q1 to 2009Q2.

3.3 Nonlinear dynamics

Empirical impulse responses in Section 2 show that impulse responses to a given productivity shock are larger when the capital ratio is lower. This subsection shows that the baseline model is able to generate the relative magnitudes of impulse responses where the “high capital state” and “low capital state” are defined analogously. Importantly, the model generates significant state dependence for the unemployment rate and indistinguishable state dependence for the I/K ratio in response to a given productivity shock.

Conditional generalized impulse response functions The model counterpart of the state dependent impulse response function is the generalized impulse response function (GIRF). The generalized impulse response function is defined as

$$GIRF(y, S_t, h, v) = \mathbf{E}[y_{t+h} | \bar{S}_t, \varepsilon_t = v] - \mathbf{E}[y_{t+h} | \bar{S}_t, \varepsilon_t = 0].$$

The response variable is y , which could either be a control variable or a state variable. \bar{S}_t is the vector of state variables, h is the horizon of the impulse response function, and v is the size of the exogenous shock. The conditioning information consists of the state vector $\bar{S}_t = (K_t, n_t, L_{t-1}, \zeta_t)$ and the shock realized at t .

Computing the GIRF First, I simulate the model for 5000 periods and keep the last 1000 periods. Select the simulated state vectors $\bar{S}_t = (K_t, n_t, L_{t-1}, \zeta_t)$ whose capital ratio belongs to the top 10 percent of the 1000 simulated capital ratio. These state vectors serve as the initial states for the “high capital ratio” conditioning set. Similarly, select the simulated vectors whose capital ratio belongs to the bottom 10 percent as initial states for the “low capital ratio” conditioning set. Second, for each given initial state, fix the initial shock as -1 or 0 , simulate the model for H periods and repeat M times. For each initial shock, average over the M simulations to get an estimate of $\mathbf{E}[y_{t+k} | \bar{S}_t, \varepsilon_{t+1} = -1] - \mathbf{E}[y_{t+k} | \bar{S}_t, \varepsilon_{t+1} = 0]$ for the given initial state. Finally, repeat for each given initial states. Average the GIRFs within the “high capital ratio” and the “low capital ratio” conditioning sets separately.

GIRF in a financial crisis vs. a normal recession The conditioning sets are the bottom and top 10 percents of the capital ratio. Empirically, the 2008 crisis (financial crisis) witnessed the

bottom 10 percent of capital ratio of the primary dealers, and the 2001 recession (normal recession) witnessed the top 10 percent. The choice of conditioning sets is intended to be consistent with the two recessions and the local projection results.

Figure 3.2 shows the impulse responses of labor market variables and capital stock to a negative one standard deviation productivity shock. The solid line depicts average impulse responses in the high capital ratio state, and the dashed line depicts average impulse responses in the low capital ratio state. Consistent with the empirical state-dependent impulse responses in Figure 2.1, the impulse responses unemployment rate and the job finding probability strongly depend on the initial capital ratio whereas impulse responses of the I/K ratio and physical capital barely depend on the initial capital ratio. The peak impulse response of the unemployment in the low capital ratio state is twice as large as that in the high capital ratio state. Similarly, the peak impulse response of the job finding probability in the low capital ratio state is 1.5 times as large as in the high capital ratio state. On the contrary, the impulse responses of the I/K ratio and the physical capital are almost indistinguishable in the two states.

To understand the stark difference in the responses of labor market variables in the two states, it is helpful to look at the determinants of matching surpluses. The contemporaneous matching surpluses for the firm and workers are determined by the marginal product of labor and wage. The continuation values of the surpluses are the expected discounted value of future contemporaneous matching surpluses. For example, recall that the value of a match to the firm is

$$J_t = (1 - \alpha) \frac{Y_t}{L_t} - w_t + \rho \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t \left[\Lambda_{t,t+1} \frac{1 - \Xi + \Xi \Omega_{t+1}}{\Omega_t} J_{t+1} \right].$$

The contemporaneous matching surplus is $(1 - \alpha) \frac{Y_t}{L_t} - w_t$, the difference between the marginal product of labor and wage. The discount rate for future matching surpluses is affected by Ω_t and μ_t . Figure 3.3 shows the impulse responses of the variables determining the discount rate (the first row) and the variables determining the contemporaneous surpluses (the second row). In general, the impulse responses of μ_t and Ω_t are more sensitive to the capital ratio than the matching the marginal product of labor and wage. On impact of the negative productivity shock, the financial constraint tightens because the stock price decreases. The shadow value of the intermediary's wealth increases, but the magnitude is way bigger when the intermediary has a low capital ratio

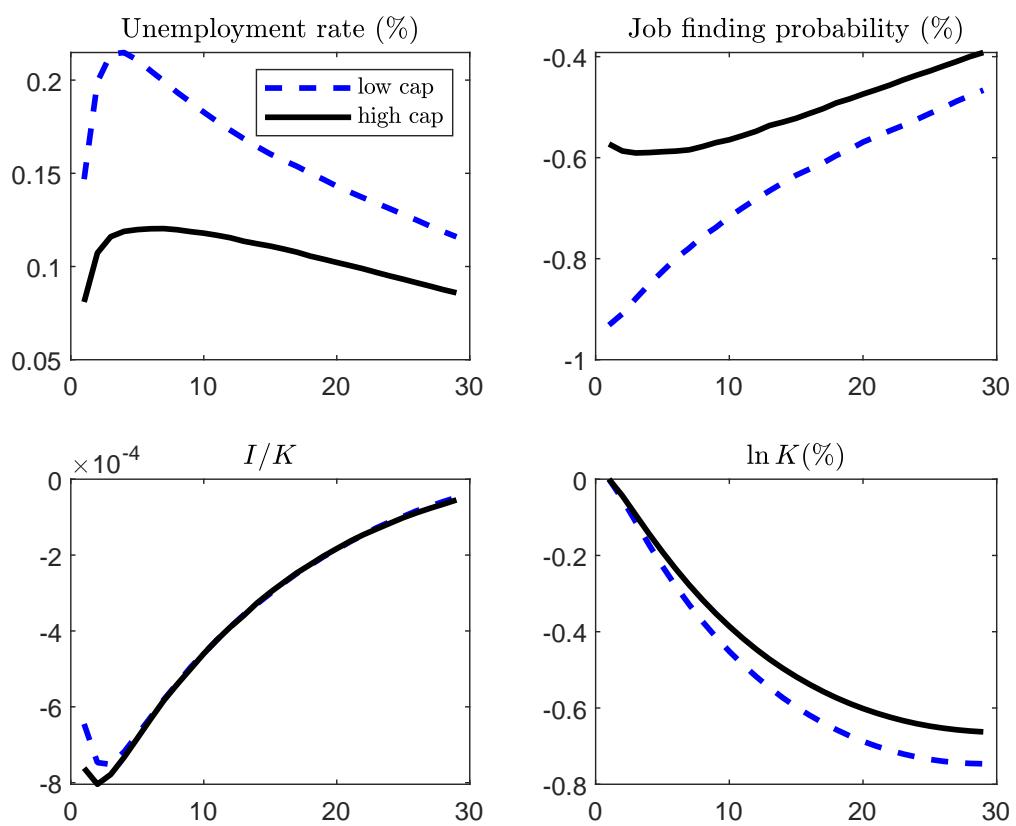


Figure 3.2: Responses to a -1 standard deviation productivity shock: labor market and physical capital.

on impact. μ_t is more than 10 times as large in the low capital ratio state as in the high capital ratio state in response to a negative one standard deviation productivity shock. Another measure of the financial distress is the marginal value of the financial intermediary wealth, Ω_t . It increases when a negative productivity shock decreases the stock price. Like μ_t , Ω_t increases much more in the low capital ratio state, where the magnitude is twice as large as in the high capital ratio state. In contrast, the impulse responses of the marginal product of labor and wage are nearly indistinguishable throughout the entire horizon in the two states. This implies that the expected paths of matching surpluses are similar in the high capital ratio state and the low capital ratio state. It is the discount rate that makes the present values of matching surpluses very different, and thus amplifies unemployment in a financial crisis.

Comparing with the back-of-the-envelope calculation in the empirical section, the amplifications of the theoretical impulse responses at $h = 4$ are the following:

$$\Delta d \ln L = 0.1\%, \Delta d \ln K = 0.03\%, \Delta d \ln w = 0.09\%.$$

Plugging in equation (2.3), the implied amplification of employment is -0.24% . That is, the impulse response of $\ln L$ should have a *smaller* magnitude in the low capital ratio state. This is mostly due to the large amplification of the wage. The model implied excess impulse response of the physical capital is 30% of the excess fall in the employment rate ($0.03\% / 0.1\%$), while it is 38% in the data ($0.14\% / 0.37\%$). The model excess fall in the wage is 90% of the excess fall in the employment rate ($0.09\% / 0.1\%$), but the same ratio is only 5% in the data ($0.02\% / 0.37\%$). Nevertheless, the exaggerated state dependence of the real wage helps strengthen the point that the contemporaneous marginal product of labor does not explain the amplification of unemployment in the low capital ratio state. Intuitively, a lower real wage should stimulate labor demand and reduce unemployment. The key point of the model and the empirical calculation is that the amplification of the physical capital is much smaller in magnitude than the amplification of unemployment. As long as this is true, equation (2.3) would suggest that the contemporaneous MPL channel fails to account for the high unemployment.

Simulations with different capital ratios To illustrate that different capital ratios can lead to large differences in the labor market outcomes, Figure 3.4 compares results of two sets of simula-

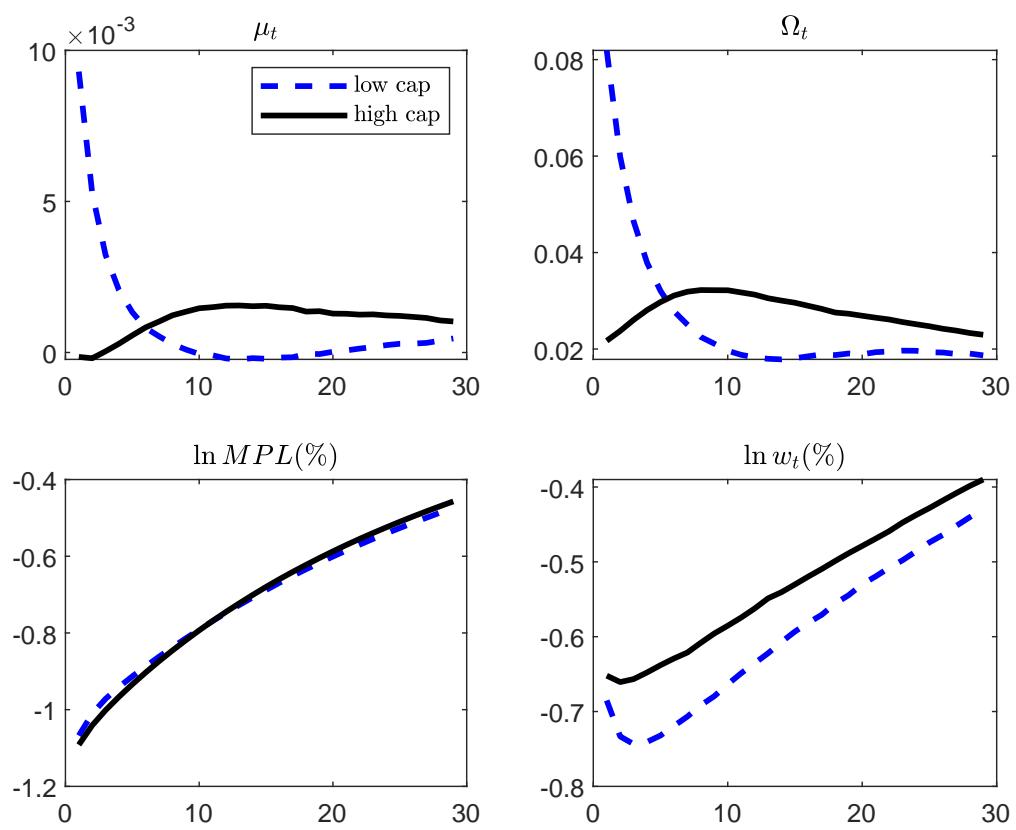


Figure 3.3: Responses to a -1 standard deviation productivity shock: determinants of matching surpluses.

tions. Both sets of simulations start from 2008Q3 with the same level of initial unemployment rate and the productivity sequence from San Francisco Fed. The simulations differ by the initial capital ratio. Similar with the GIRF exercise, the low capital ratio simulations start with capital ratios below the 10th percentile of a simulated sample of 1000 periods, and the high capital ratio simulations start with capital ratios above the 90th percentile. The figure plots the average paths of each group. Probably due to missing other important shocks, the model is unable to generate the extremely low capital ratio during the 2008 Great Recession. Consequently, the simulated unemployment rate is lower than the data. However, the contrast between the two sets of simulations suffices to illustrate the importance of the capital ratio to the labor market. Starting with a high capital ratio, the unemployment rate stays close to 5% throughout the simulation. In sharp contrast, the low capital ratio unemployment rate rapidly climbs to 7% and remains there throughout the simulation. The difference is 2%, which is approximately equal to one standard deviation of the unemployment rate in the 1970-2017 sample. The low initial capital ratio tightens the financial constraint and increases the marginal value of intermediary wealth, Ω_t , and the Lagrange multiplier, μ_t , on the financial constraint. As previously noted, the primary dealer capital ratio was above the 90th percentile at the beginning of the 2001 recession and below the 10th percentile at the beginning of the 2008 Great Recession. The simulation suggests that if the financial intermediary sector in 2008Q4 had been as “healthy” as in early 2001, the reduction in the discount rate would have lowered the unemployment rate by one standard deviation during the Great Recession.

4 Extensions

In this section, I consider three exercises. The first exercise removes the labor search and matching friction. The model becomes the Gertler and Karadi (2011) model with flexible prices. Importantly, the stock price becomes $P_t = q_t K_{t+1}$. The exercise shows that the risk premium falls substantially in the absence of labor as an asset pricing factor. The second exercise replaces the endogenous SDF in the baseline model by an exogenous SDF estimated from the S&P 500 returns. The firm’s problem and the search and matching problem are the same as the baseline model. The goal of this exercise is to show that the endogenous response of the SDF to unemployment is crucial for the dynamics of the labor market. The third exercise studies the effects of government purchasing the risky asset when the financial intermediary sector has low wealth. By reducing the financial intermediary exposure to risky asset returns in down turns, the policy stabilizes the SDF and thus

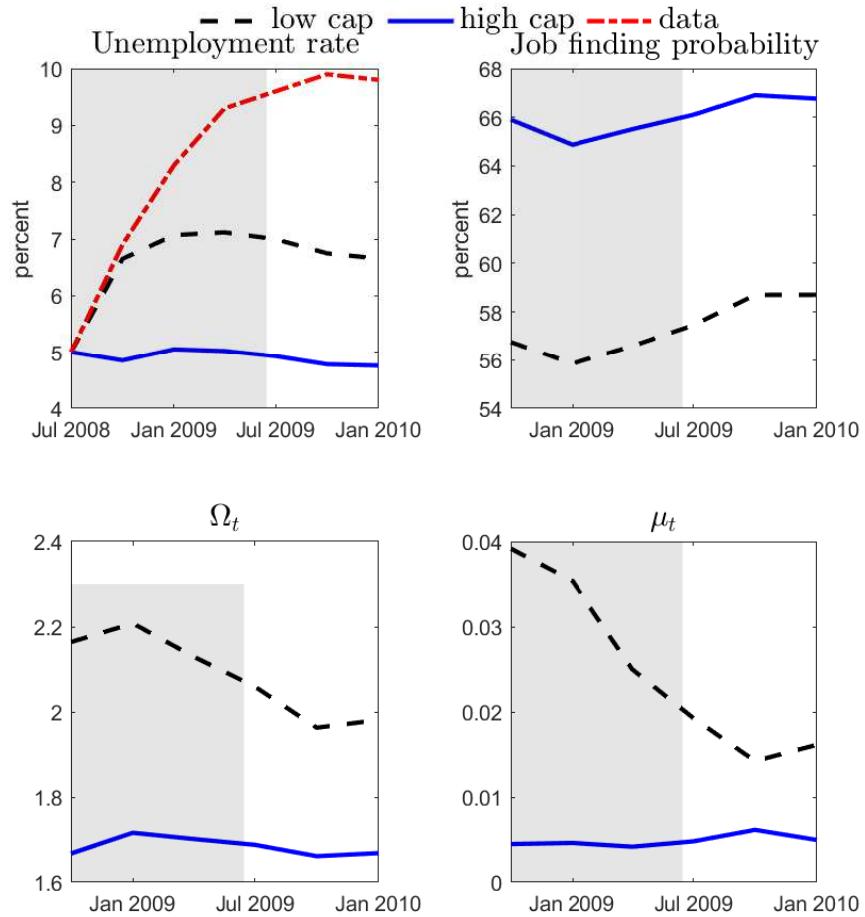


Figure 3.4: Simulated time series with different initial capital ratios. The simulations start from 2008Q4 with the same unemployment level but different capital ratios. The low capital ratio (“low cap”) series start with capital ratios below the 10th percentile of a simulated sample of 1000 periods, and the high capital ratio (“high cap”) series start with capital ratios above the 90th percentile. The figure plots the averages within each group.

reduces the volatility of unemployment.

4.1 Frictionless labor market

This subsection shows the importance of the feedback from the labor market to the financial market. Recall that the ex-dividend stock price in the baseline model is $P_t = (\alpha - 1)Y_t + w_t L_t + q_t K_{t+1} + J_t L_t$. The last term in the expression implies that low employment in a financial crisis directly depresses the stock price and increases the risk premium. This is an important channel in my model to generate the high risk premium and high unemployment in a financial crisis.

In order to assess the importance of this channel, I remove the search and matching friction in the labor market. Equilibrium wage is always equal to the contemporaneous marginal product of labor. The constraint (3.7) is removed from the firm optimization problem and the problem is identical to Hayashi (1982). Therefore, the ex-dividend stock price is $P_t = q_t K_{t+1}$. In order to have fluctuations in employment, I augment the household preference with disutility of labor:

$$u(C_t, L_t) = \frac{C_t^{1-\gamma}}{1-\gamma} - \frac{L_t^{1+\psi}}{1+\psi}.$$

I set $\psi = 0.5$, which is a standard value in the literature. Other settings and parameters are identical to the baseline model.

Figure 4.1 shows the simulated time series from the baseline model and the frictionless labor market model. Again, I start from the steady state in 1947Q2 and feed in the SF Fed productivity series, then take the snapshot from 2000Q1 to 2009Q2. The volatility of the I/K ratio and the intermediary capital ratio are almost identical. Unemployment, broadly interpreted as the complement of hours worked, and the risk premium in the frictionless model are substantially lower than those in the baseline model in a financial crisis. The reason for the difference is that the marginal value of intermediary wealth and the shadow value of the financial constraint are significantly smaller and less volatile in the frictionless labor market model. Without the fluctuations of employment as a driver of asset price movements, the stochastic discount factor becomes less volatile. Therefore, the risk premium only increases moderately in a financial crisis. This example shows that the dynamic labor demand not only generates high unemployment, but also contributes to the high risk premium in a financial crisis.

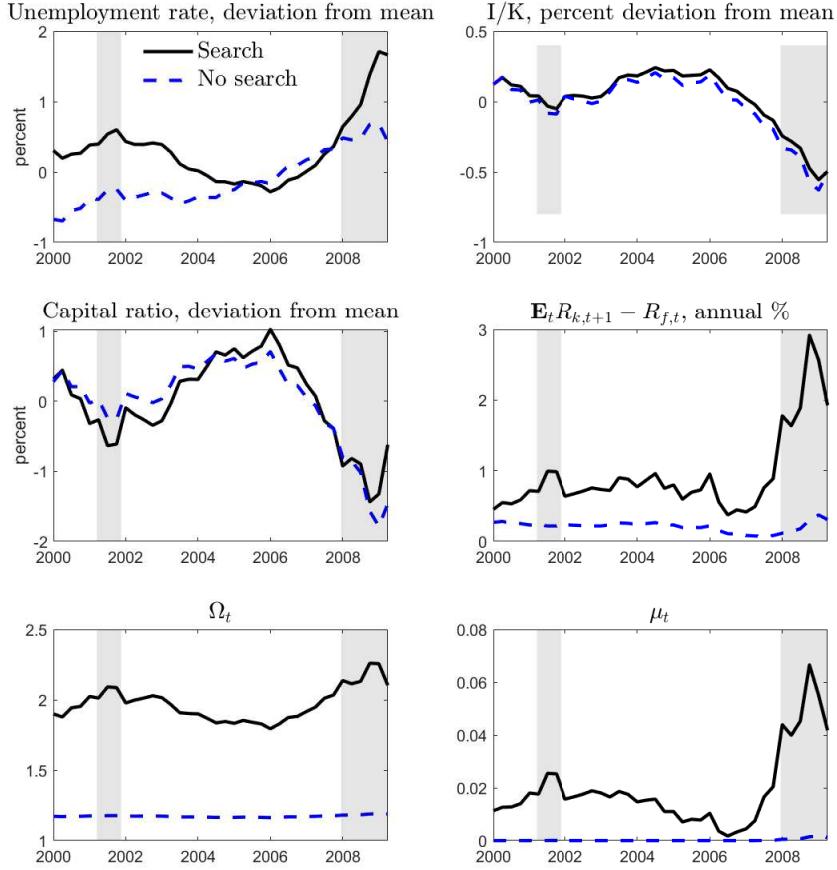


Figure 4.1: Comparing the frictionless labor market model with the baseline model. The solid line denotes the baseline model. The dashed line denotes the frictionless labor market model. The “unemployment rate” for the frictionless labor market model is $1 - L_t$, though there is no involuntary unemployment in the model. The simulation starts in 1947Q2 from the steady state, and feeds in the SF Fed productivity series since then. The figure takes the snapshot from 2000Q1 to 2009Q2.

4.2 Exogenous SDF

Hall (2017) argues that an exogenous SDF estimated from the S&P 500 returns can explain the large fluctuations in the unemployment rate in U.S. data. Apart from the obvious difference in the determinants of the SDF, this paper also differs from Hall (2017) by having physical capital accumulation and using Nash bargaining to determine the wage. However, this subsection shows that the endogenously determined SDF is the key difference between the two papers. Keeping other parts identical to the baseline model, I fit in an exogenous SDF estimated from the S&P 500 returns. Since the endogenous SDF in the baseline model is related to the financial intermediary capital ratio, it is reasonable to believe that the SDF in either model relates the labor market dynamics to fluctuations in the financial market. The crucial difference is that the SDF in the baseline model responds to employment thanks to equation (3.17), but this channel is absent in the exogenous SDF model.

The procedures for estimating the exogenous SDF follow Hall (2017). Assuming the stock market follows a 5-state Markov chain, the states are identified from the joint distribution of $\theta \equiv U/V$ and the P/D ratio. Specifically, define an index as a sum of the labor market tightness, θ , and the PD ratio of the S&P 500 : $index = \theta/sd(\theta) + PD/sd(PD)$. Sort the index into 5 equal sized bins, and define each bin as a state. Productivity is also averaged into 5 bins according to the identified states of each date. The SDF is obtained by solving for $m(1), \dots, m(5)$ and β from

$$1 = \sum_{s'=1}^5 \beta \frac{m(s')}{m(s)} \frac{P(s') + D(s')}{P(s)}, \forall s = 1, 2, \dots, 5,$$

where s denotes the current state and s' denotes one of the next-period states. Normalize $m(1) = 1$ such that there are equal number of equations and unknowns. The stochastic discount factor is

$$M_{s,s'} = \beta \frac{m(s')}{m(s)}.$$

I substitute $M_{s,s'}$ for $M_{t,t+1}^I$ in equations (3.14), (3.16), (3.19), and (3.20) to solve the capital accumulation and labor search and matching problems.

Figure 4.2 compares the unemployment rate series simulated by the exogenous SDF model and the baseline model. The simulated time series are generated by feeding the SF Fed productivity data into the respective models. The simulated series are contrasted with the civilian unemploy-

ment time series from the FRED. Surprisingly, the exogenous SDF model generates almost no fluctuations in the unemployment rate. The simulated unemployment rate is much less volatile than in Hall (2017) because of the smoothing effect of capital accumulation. The I/K ratio in the exogenous SDF model is way more volatile than the data and the baseline model, indicating stronger smoothing effect of capital accumulation. However, the baseline model significantly increases the volatility of unemployment even though the capital accumulation channel is still in force. This is because the SDF in the baseline model is more related to unemployment. Equation (3.17) suggests that labor is a pricing factor for the firm's stock price. Since the SDF is closely related to the financial intermediary capital ratio, which consists of the firm's stock price, unemployment has feedback effects on the SDF in the baseline model. The feedback effects are absent in the exogenous SDF model. Moreover, as Hall (2017) documented, the productivity and the *P/D* ratio of the S&P 500 index are not closely related. This further decreases the correlation between the SDF and the matching surpluses in the exogenous SDF model.

4.3 Government purchasing the risky asset

The previous sections suggest that under the financial constraint, a low intermediary capital ratio aggravates unemployment. Government policies can reduce unemployment by reducing the intermediary exposure to negative asset returns. Suppose the government intervenes in the financial market by purchasing shares of the risky asset when the financial intermediary capital ratio is below some target. The purchase is financed by lump sum taxes so there are no distortions in relative prices. From September 2008 to March 2010, the Federal Reserve and the treasury purchased \$1.5 trillion worth of mortgage backed securities¹⁰, which is roughly 10 percent of the total stock of \$15 trillion of intermediated assets. Motivated by this fact, suppose that the public sector purchases 10% of outstanding shares of the risky asset in 2008Q4 and continues until March 2010. For simplicity, the policy intervention is unexpected by the economy before it is exercised. The balance sheet of the intermediary sector is

$$S_{p,t}P_t = N_t + B_t,$$

¹⁰Source: Federal Housing Finance Agency <https://www.fhfa.gov/DataTools/Downloads/Pages/Treasury-and-Federal-Reserve-Purchase-Programs-for-GSE-and-Mortgage-Related-Securities.aspx>.

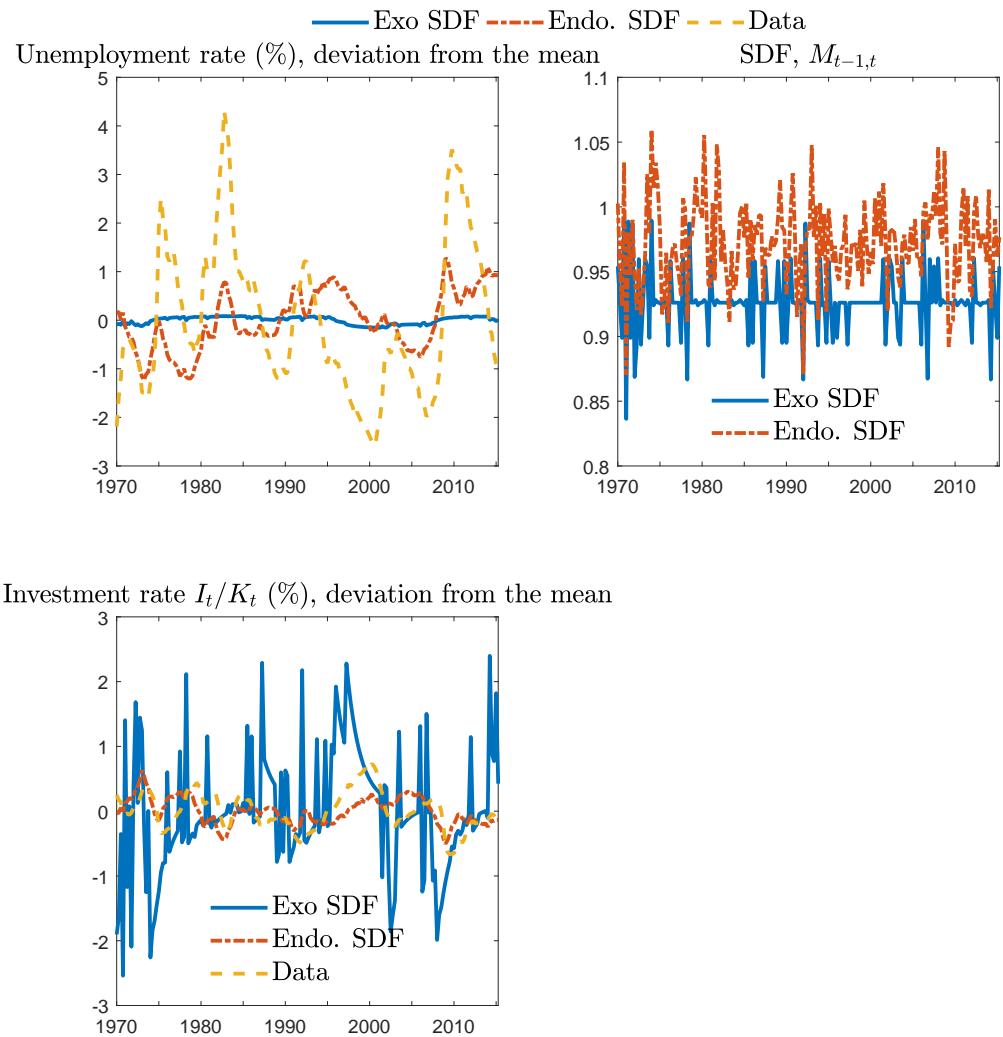


Figure 4.2: Unemployment rate. The “Endo SDF” model refers to the baseline model. The “Exo SDF” model replaces the financial intermediary SDF by an exogenous SDF estimated from the S&P 500 returns. “Data” is the civilian unemployment rate from FRED.

where $S_{p,t} = 1 - S_{g,t} = 0.9$. The law of motion for the net wealth of the financial intermediary sector is

$$N_{t+1} = \mathbb{E} [(R_{K,t+1} - R_{f,t}) P_t S_{p,t} + R_{f,t} N_t] + \chi P_{t+1} S_{p,t+1}.$$

The policy reduces the financial intermediary exposure to the negative realized excess return $R_{K,t+1} - R_{f,t}$. Consequently, the net wealth N_{t+1} is stabilized in financial crisis. Since a low capital ratio is risky to the financial intermediary, the stochastic discount factor puts high weights on low capital ratio states. Stabilizing the capital ratio alleviates the risk of having a low capital ratio, so the crisis state stochastic discount factor in this experiment is lower than it would be in the baseline model.

Figure 4.3 plots the simulated time series from the baseline model and a policy experiment with $S_g = 10\%$. The policy starts from 2008Q4 and ends in 2010Q1. The start and end of the public intervention are unexpected. To generate the time series, I feed into the model a sequence of productivity shocks estimated from the San Francisco Fed productivity data. The figure shows simulations in the period 2008Q3-2010Q3. Let the simulation with $S_g = 10\%$ represent the Great Recession with quantitative easing. The unemployment rate peaked at 6.5%. It is lower than the real world data because the model does not include other important mechanisms characterizing the financial crisis, such as the capital quality shock (Gertler et al. (2019), Brunnermeier and Sannikov (2014)), bank run (Gertler et al. (2019)), irrational beliefs, etc. The policy experiment is highly stylized and the productivity shock is obviously not the only exogenous process in the real world. so there is little hope that the simulation matches the real data. The purpose of this exercise is to illustrate that the public authority could reduce the unemployment rate through the capital ratio channel. The dash line shows the simulation results of the baseline model, which does not have the policy intervention. Without the public purchasing of risky assets, the unemployment would have been 1% higher at the trough of the Great Recession. There is no efficiency loss (in the sense of Gertler and Karadi (2011)) associated with the government stock purchasing, the effects of the intervention solely result from reducing the financial intermediary exposure to negative stock returns. In an exogenous SDF model or a standard RBC model without the intermediary financial constraint, the government stock purchasing would have no effects on real activities. In this paper, the policy increases the financial intermediary capital ratio in the financial crisis and reduces the Lagrange multiplier on the financial constraint. The marginal value of intermediary wealth is also reduced by the policy intervention. Notice that when the Lagrange multiplier reaches zero, the marginal value of wealth is still larger than one. This is because the financial intermediary antic-

ipates the constraint to be binding in some future states. The policy relaxes the current financial constraint, but also relaxes the anticipated future constraints.

5 Conclusion

This paper studies why aggregate unemployment in a financial crisis is more severe than in a non-financial recession. The central argument is that a low financial intermediary capital ratio amplifies the response of unemployment to a negative shock. The reduction in the quantity of credit or physical capital is insufficient for generating the amplification of unemployment. The discount rate channel is important for understanding the state-dependent dynamics of unemployment.

I incorporate financial intermediary friction in a Diamond-Mortensen-Pissarides labor search and matching model to rationalize the empirical facts. A sequence of negative productivity shocks decrease the capital ratio and the financial intermediaries face a tighter financial constraint. The constraint prevents the financial intermediaries from exploiting arbitrage opportunities and optimize their portfolios, so the marginal value of the capital ratio increases. The stochastic discount factor increases with the marginal value of capital ratio to reflect the fact that the financial intermediaries can't optimize their portfolios in the low capital ratio states. Meanwhile, the negative productivity shocks decrease the matching surpluses in the labor market, and thus the surge in the SDF amplifies the negative relationship between the stochastic discount factor and the matching surplus. The present value of a match is smaller in a financial crisis, so the firms are less willing to post vacancies. The endogenous response of the stochastic discount factor to unemployment is important for the amplification of unemployment. The endogenous response is due to the fact that labor is a pricing factor of the firm stock price and that the stock price affects the intermediary capital ratio. If the 2008 Great Recession had started with the 2001 intermediary capital ratio, the unemployment rate would have been 1 standard deviation lower. In an exogenous SDF model lacking such feedback, unemployment is almost flat due to the smoothing effect of capital accumulation. Finally, a government policy that reduces the financial intermediary exposure to negative asset returns in a financial crisis can reduce unemployment by alleviating the financial constraint.

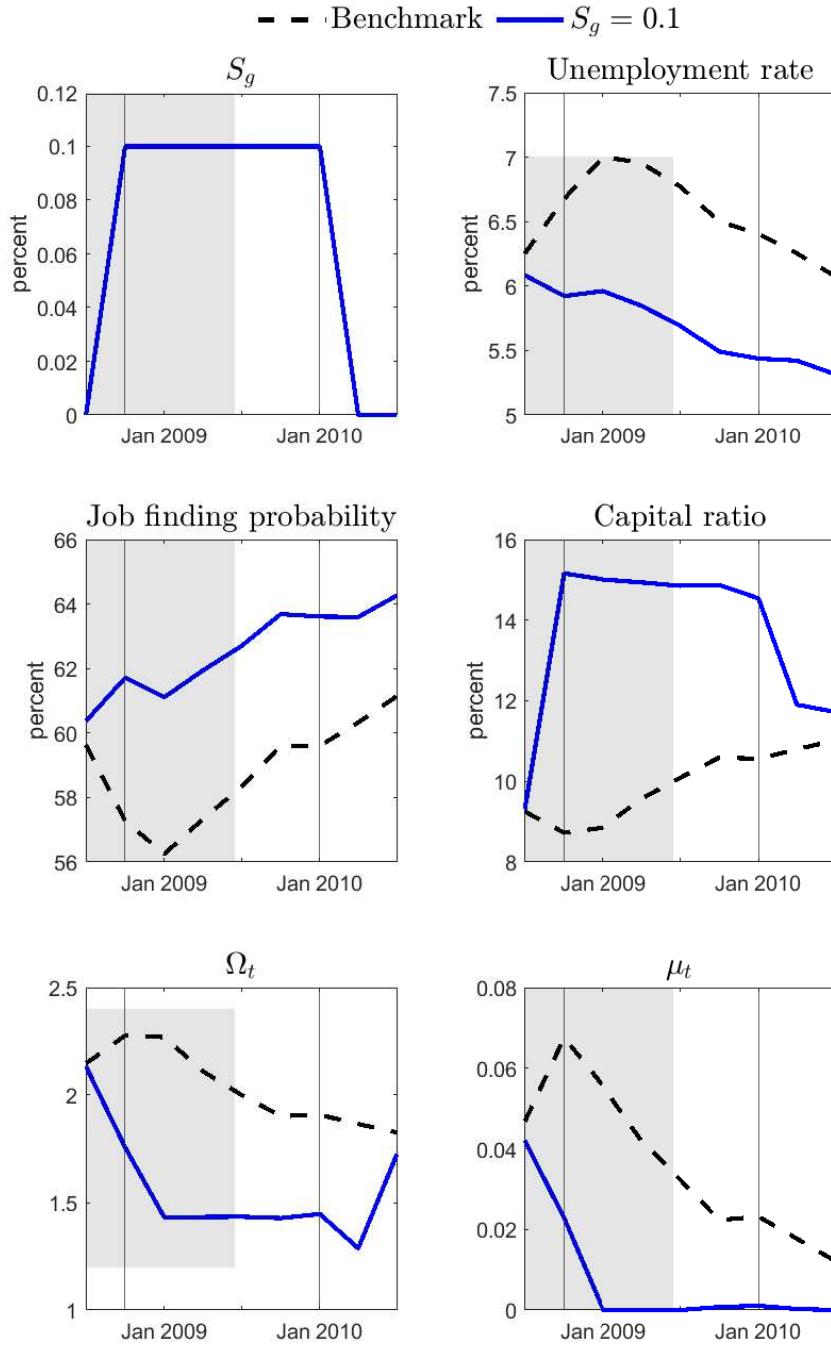


Figure 4.3: Public purchasing risky assets in the crisis. The public sector starts purchasing the risky asset in 2007Q3 and stops in 2010Q31. The economic agents don't expect the start or the end of the public purchasing. The dashed line is the baseline model, which does not have the policy intervention. The solid line is the model with the public sector purchasing 10% of the risky assets.

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A Proofs

Proof of Proposition 1. Suppose the value function of the intermediary is $W_{i,t} = \Omega_t N_{i,t}$. The value function is

$$\Omega_t (P_t S_{i,t} - B_t) = \max_{S_{i,t}, B_{i,t}} \mathbf{E}_t [\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) (R_{K,t+1} P_t S_{i,t} - R_{f,t} B_{i,t})] + \mu_t [\Omega_t (P_t S_{i,t} - B_t) - \lambda P_t S_{i,t}].$$

The first-order conditions are

$$\begin{aligned}\Omega_t &= \mathbf{E}_t [\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) R_{K,t+1}] + \mu_t (\Omega_t - \lambda) \\ \Omega_t &= \mathbf{E}_t [\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) R_{f,t}] + \mu_t \Omega_t.\end{aligned}$$

These are the Euler equations (3.3) and (3.4) for $R_{K,t+1}$ and $R_{f,t}$. Equation (3.5) follows from the household's intertemporal first-order condition for deposit.

Now we prove that Ω_t does not depend on $N_{i,t}$ as long as $\Lambda_{t,t+1}$, $R_{K,t+1}$, and $R_{f,t}$ don't depend on $N_{i,t}$. The value function of the intermediary can be written as

$$\begin{aligned}\Omega_t &= \mathbf{E}_t \left[\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) \frac{N_{i,t+1}}{N_{i,t}} \right] + \mu_t \left(\Omega_t - \lambda \frac{P_t S_{i,t}}{N_{i,t}} \right) \\ &= \mathbf{E}_t \left[\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) \left(R_{f,t} + (R_{K,t+1} - R_{f,t}) \frac{P_t S_{i,t}}{N_{i,t}} \right) \right] + \mu_t \left(\Omega_t - \lambda \frac{P_t S_{i,t}}{N_{i,t}} \right).\end{aligned}$$

The terms that depend on $N_{i,t}$ are

$$(\mathbf{E}_t [\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) (R_{K,t+1} - R_{f,t})] - \mu_t \lambda) \frac{P_t S_{i,t}}{N_{i,t}}.$$

The Euler equations for $R_{K,t+1}$ and $R_{f,t}$ imply

$$\mathbf{E}_t [\Lambda_{t,t+1} (1 - \Xi + \Xi \Omega_{t+1}) (R_{K,t+1} - R_{f,t})] - \mu_t \lambda = 0,$$

so Ω_t only depends on $\Lambda_{t,t+1}$, $R_{K,t+1}$, and $R_{f,t}$. $\Lambda_{t,t+1}$ is derived from the representative household's optimization problem, which is independent of $N_{i,t}$. Intermediaries take the asset prices as given, so asset prices only depend on aggregate variables. This completes the proof.

Proof of Proposition 2. The first order conditions with respect to V_t, L_t, i_t, K_{t+1} are

$$-\kappa_t + J_t Q_t = 0 \quad (\text{A.1})$$

$$J_t = (1 - \alpha) \frac{Y_t}{L_t} - w_t + \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I \rho J_{t+1}] \quad (\text{A.2})$$

$$\Phi'(i_t) = \frac{1}{q_t} \quad (\text{A.3})$$

$$q_t = \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t \left[M_{t,t+1}^I \left(\alpha \frac{Y_{t+1}}{K_{t+1}} - i_{t+1} + q_{t+1} (1 - \delta + \Phi(i_{t+1})) \right) \right]. \quad (\text{A.4})$$

Multiplying equation (A.2) by L_t and equation (A.4) by K_{t+1} , summing up:

$$\begin{aligned} J_t L_t + q_t K_{t+1} &= (1 - \alpha) Y_t - w_t L_t + \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I \rho J_{t+1} L_t] \\ &\quad + \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I (\alpha Y_{t+1} - i_{t+1} K_{t+1} + q_{t+1} K_{t+2})]. \end{aligned} \quad (\text{A.5})$$

Equation (A.1) implies

$$\begin{aligned} \rho J_{t+1} L_t &= J_{t+1} (L_{t+1} - Q_t V_t) \\ &= J_{t+1} L_{t+1} - \kappa_t V_t. \end{aligned}$$

Substituting for $\rho J_{t+1} L_t$ in equation (A.5):

$$\begin{aligned} P_t &\equiv (\alpha - 1) Y_t + w_t L_t + J_t L_t + q_t K_{t+1} \\ &= \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I (\alpha Y_{t+1} - i_{t+1} K_{t+1} - \kappa_t V_t + J_{t+1} L_{t+1} + q_{t+1} K_{t+2})] \\ &= \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I (((\alpha - 1) Y_{t+1} + w_{t+1} L_{t+1} + J_{t+1} L_{t+1} + q_{t+1} K_{t+2}) + P_{t+1})] \\ &= \frac{1}{1 - \mu_t \left(1 - \frac{\lambda_t}{\Omega_t}\right)} \mathbf{E}_t [M_{t,t+1}^I (D_{t+1} + P_{t+1})]. \end{aligned}$$

This is the expression for ex-dividend price, so we have

$$P_t = (\alpha - 1)Y_t + w_t L_t + q_t K_{t+1} + J_t L_t.$$

The cum-dividend price is

$$\begin{aligned}\tilde{P}_t &= P_t + (Y_t - w_t L_t - i_t K_t - \kappa_t V_t) \\ &= \alpha Y_t - i_t K_t - \kappa_t V_t + q_t K_{t+1} + J_t L_t.\end{aligned}$$

The stock return follows by definition

$$R_{K,t+1} = \frac{P_{t+1} + D_{t+1}}{P_t} = \frac{\alpha Y_{t+1} - i_{t+1} K_{t+1} - \kappa_{t+1} V_{t+1} + q_{t+1} K_{t+2} + \mu_{L,t+1} L_{t+1}}{(\alpha - 1) Y_t + w_t L_t + q_t K_{t+1} + \mu_{L,t} L_t}.$$

This completes the proof.

B Data

B.1 Business cycle variables

- Data from FRED
 - Real Gross Domestic Product (GDPC1), Real Personal Consumption Expenditures (PCECC96), Civilian Unemployment Rate (UNRATE), Employment Level (CE16OV), 3-Month Treasury Bill: Secondary Market Rate (TB3MS), 10-Year Treasury Constant Maturity Rate (DGS10).
- Capital stock and I/K ratio
 - Investment is the NIPA Investment in Private Nonresidential Fixed Assets, adjusted by the NIPA implicit deflator for nonresidential fixed assets.
 - Following Hall (2001), the capital stock is imputed by iterating on the law of motion of capital.

B.2 Financial variables

- Data from Flow of Funds Z1 tables <https://www.federalreserve.gov/datadownload/Choose.aspx?rel=Z.1>:
 - Domestic Nonfinancial Corporate Business: L103(Q).
 - Households and Nonprofit Organizations: L101(Q).

B.3 The primary dealer capital ratio

The primary dealer capital ratio is taken from Asaf Manela's website: <http://apps.olin.wustl.edu/faculty/manela/data.html>. A list of historical primary dealers can be found in He et al. (2017).

C Numerical Solution

C.1 Equilibrium characterization

I solve for a Markov equilibrium. The state variables are $\bar{S} = (K, n, L_{-1}, \zeta)$. The equilibrium of the baseline model is characterized by the following conditions.

Households

$$\Lambda(\bar{S}, \bar{S}') = \beta \left(\frac{C(\bar{S}')}{C(\bar{S})} \right)^{-\gamma}$$

$$1 = \mathbf{E} \left[\Lambda(\bar{S}, \bar{S}') R_f(\bar{S}) | \bar{S} \right].$$

Financial intermediary

$$1 - \mu(\bar{S}) \left(1 - \frac{\lambda}{\Omega(\bar{S})} \right) = \mathbf{E} \left[\Lambda(\bar{S}, \bar{S}') \frac{1 - \Xi + \Xi \Omega(\bar{S}')}{\Omega(\bar{S})} R_K(\bar{S}') | \bar{S} \right],$$

$$1 - \mu(\bar{S}) = \mathbf{E} \left[\Lambda(\bar{S}, \bar{S}') \frac{1 - \Xi + \Xi \Omega(\bar{S}')}{\Omega(\bar{S})} R_f(\bar{S}) | \bar{S} \right],$$

$$\Omega(S) n(S) \geq \lambda,$$

$$\begin{aligned} n'(\bar{S}) &= \Xi \left[\left(R_K(\bar{S}') - R_f(\bar{S}) \right) + R_f(\bar{S}) n \right] \frac{P(\bar{S})}{P(\bar{S}')} + \chi \\ n(\bar{S}') &= n'(\bar{S}) \\ \mu(\bar{S}) &\geq 0, \\ \mu(\bar{S})(\Omega(\bar{S})n(\bar{S}) - \lambda) &= 0. \end{aligned}$$

Firm and labor search

$$\begin{aligned} \kappa(\bar{S}) &= \kappa_0 + \kappa_1 Q(\bar{S}) \\ \Phi'(i(\bar{S})) &= \frac{1}{q(\bar{S})} \\ J(\bar{S}) &= \frac{\kappa(\bar{S})}{Q(\bar{S})} \\ R_K(\bar{S}') &= \frac{\alpha Y(\bar{S}') - i(\bar{S}') K(\bar{S}') - \kappa(\bar{S}') V(\bar{S}') + q(\bar{S}') K'(\bar{S}') + J(\bar{S}') L(\bar{S}')}{(\alpha - 1)Y(\bar{S}) + w(\bar{S})L(\bar{S}) + q(\bar{S})K'(\bar{S}) + J(\bar{S})L(\bar{S})}. \\ P(\bar{S}) &= (\alpha - 1)Y(\bar{S}) + w(\bar{S})L(\bar{S}) + q(\bar{S})K'(\bar{S}) + J(\bar{S})L(\bar{S}) \\ Y(\bar{S}) &= K^\alpha(\bar{S}) \left(e^{\zeta(\bar{S})} L(\bar{S}) \right)^{1-\alpha} \\ K'(\bar{S}) &= (1 - \delta + \Phi(i(\bar{S}))) K(\bar{S}) \\ K(\bar{S}') &= K'(\bar{S}) \\ L(\bar{S}) &= \rho L_{-1}(\bar{S}) + Q(\bar{S})V(\bar{S}) \\ L_{-1}(\bar{S}') &= L(\bar{S}) \\ Q(\bar{S}) &= \frac{1}{(1 + \theta(\bar{S})^\sigma)^{\frac{1}{\sigma}}} \end{aligned}$$

$$\begin{aligned}
f(\bar{S}) &= \frac{1}{\left(1 + \theta(\bar{S})^{-\sigma}\right)^{\frac{1}{\sigma}}} \\
V(\bar{S}) &= \theta(\bar{S})(1 - \rho L_{-1}) \\
J(\bar{S}) &= (1 - \alpha) \frac{Y(\bar{S})}{L(\bar{S})} - w(\bar{S}) + \rho \frac{1}{1 - \mu(\bar{S}) \left(1 - \frac{\lambda}{\Omega(\bar{S})}\right)} \mathbf{E} \left[\Lambda(\bar{S}, \bar{S}') \frac{1 - \Xi + \Xi \Omega(\bar{S}')}{\Omega(\bar{S})} J(\bar{S}') | \bar{S} \right] \\
E(\bar{S}) - F(\bar{S}) &= w(\bar{S}) - b + \rho \mathbf{E} \left[\Lambda(\bar{S}, \bar{S}') \frac{1 - \Xi + \Xi \Omega(\bar{S}')}{\Omega(\bar{S})} \left(1 - f(\bar{S}')\right) \left(E(\bar{S}') - F(\bar{S}')\right) | \bar{S} \right]. \\
(1 - \eta)(E(\bar{S}) - F(\bar{S})) &= \eta J(\bar{S}) \\
\Phi(i(\bar{S})) &= \frac{1}{\phi} \left(\sqrt{1 + 2\phi i(\bar{S})} - 1 \right) \\
\zeta(\bar{S}') &= \rho_\zeta \zeta(\bar{S}) + \sigma_\zeta \varepsilon^{TFP}.
\end{aligned}$$

Resource constraint

$$C(\bar{S}) + i(\bar{S}) K(\bar{S}) + \kappa(\bar{S}) V(\bar{S}) = Y(\bar{S}).$$

C.2 Numerical algorithm

I approximate the policy functions and state transition functions by piecewise smooth functions parameterized by γ^x . Let $S = (K, B, L, \zeta)$ be the vector of state variables and $T(S)$ be a vector collecting Chebyshev polynomials of the state variables¹¹. A function $x(S)$ is approximated by the Chebyshev polynomials as

$$\hat{x}(S) = \gamma^x T(S).$$

The numerical solution looks for γ^x such that first-order conditions are satisfied for $\hat{x}(S)$ on a set of collocation points.

¹¹The state variable n is replaced by deposit, B , to facilitate computation. (K, B, L) and (K, n, L) contain the same information. Intuitively, the stock price is determined by (K, L) and the intermediary portfolio consists of stocks and deposit. Therefore, n and B can be transformed to each other using the intermediary balance sheet once the stock price is controlled for.

In order to avoid the curse of dimensionality, the choice of collocation points and Chebyshev polynomials follows Smolyak method. Conditional expectations are calculated following the approach of Judd et al. (2017). Furthermore, the conditional expectation can be computed accurately. In the case of normally distributed shocks, it can be computed in closed form. The intuition is that when the policy functions are approximated by polynomials, the conditional expectations are linear combinations of conditional expectations of future state variables raised to certain powers. Furthermore, when the endogenous state variables predetermined, the conditional expectations reduce to predetermined state variables times conditional expectations of exogenous state variables. See Judd et al. (2017) for details. This method avoids a Markov chain approximation to the AR(1) process and computes conditional expectations only once in the entire solution process.

The algorithm uses backward induction solution as an initial guess, then solve the set of equilibrium conditions jointly. The algorithm is as follows.

Step 0.A: Defining the grid and polynomials. Set upper and lower bounds on the state variables $S = (K, B, L, \zeta)$. The bounds for K and B are obtained by simulating the model with a third-order perturbation. The bounds are adjusted to account for the fact that the perturbation solution assumes that the intermediary's financial constraint is always binding. Furthermore, the grid is constructed on a rotation of K and B to account for the tight correlation between the two variables. The rotation matrix is generated by singular value decomposition of the simulated joint series of K and B with a third-order perturbation.

Step 0.B: Precomputing conditional expectations. Computing conditional expectations of the exogenous state variable using the formula in Judd et al. (2017).

Step 1: Solving the period T problem. Assume there are no future periods. Then $i_t = 0$ and the search problems have no continuation values. Solve for the policy functions.

Step 2: Solving the period $T - 1$ problem. Taking the policy functions from the previous step as the next-period policy functions, solve for period $T - 1$ policy functions. Specifically, the variables in the conditional expectations are taken as given by the results of the period T problem, solve for the control variables outside the conditional expectations.

Step 3: Iterating backwards. In each iteration, take the policy functions in the conditional expectations as given by the policy functions from the previous iteration and solve for the policy functions for the current period. Iterate until convergence.

Step 4: Jointly solving the equilibrium conditions. Use the results from Step 3 as an initial guess, jointly solve the equilibrium conditions using the MATLAB equation solver `fsove`.

D Additional Results

D.1 State-dependent impulse responses

This subsection presents additional results on the state-dependent impulse responses. The primary dealer capital ratio, cap_t , in equation (2.2) is replaced one-at-a-time by the physical capital ($\ln K_t$), real GDP ($\ln GDP_t$), the effective bond premium (EBP) in Gilchrist and Zakrajšek (2012), the GZ spread (GZ) in Gilchrist and Zakrajšek (2012), and the CBOE S&P 100 volatility index (VXO). $\ln K_t$ and $\ln GDP_t$ are detrended using the method of Hamilton (2017). The GZ spread measures the spread between corporate bond returns and the risk-free rate. The EBP takes out the default premium from the GZ spread, serving as a measure of the risk premium. The goal of the exercise is to examine whether the capital ratio is more likely to reflect real activities, as captured by the physical stock and GDP, or financial conditions, as captured by the rest of the variables.

Table 7 presents the linear response β_1^h and the state-dependent response β_2^h using $\ln K_t$ as the state variable. Unlike the case for the primary dealer capital ratio, the linear response and the state-dependent response have the same sign, indicating that a higher level of physical capital amplifies the responses to a productivity shock. Table 8 presents the results with $\ln GDP_t$ as the state variable. Despite the noisy estimations at some horizons, the UE transition probability, the unemployment rate, and the I/K ratio are amplified when GDP is below average. The relative magnitudes of the state-dependent response, $|\beta_2^h|/|\beta_1^h|$, are small for the UE transition probability and the I/K ratio. In general, the results with the real activities being the state variable seem to be qualitatively different from the results with the primary dealer capital ratio being the state variable.

Table 9 presents the results with EBP serving as the state variable. All impulse responses are amplified when EBP is above average. Since risk premia increase when the financial sector is under distress, the results are consistent with the findings with the primary dealer capital ratio. The

Table 7: State-Dependent Impulse Responses, $\ln K_t$ as the State Variable.

	UE	Unemployment rate	I/K	$\ln K$	$\ln L$
$h = 1$					
ε_t^{TFP}	1.06*** (0.34)	-0.22*** (0.05)	0.08*** (0.01)	0.14 (0.09)	0.38*** (0.10)
$\varepsilon_t^{TFP} \times \ln K_{t-1}$	0.34 (0.24)	-0.05 (0.05)	0.01 (0.01)	0.21*** (0.08)	0.12 (0.10)
$h = 4$					
ε_t^{TFP}	2.32*** (0.48)	-0.50*** (0.11)	0.13*** (0.02)	0.52*** (0.12)	0.85*** (0.21)
$\varepsilon_t^{TFP} \times \ln K_{t-1}$	1.02*** (0.37)	-0.29*** (0.09)	0.04** (0.02)	0.32*** (0.11)	0.19 (0.18)
$h = 8$					
ε_t^{TFP}	1.60*** (0.59)	-0.36** (0.16)	0.05* (0.03)	0.38*** (0.14)	0.42* (0.25)
$\varepsilon_t^{TFP} \times \ln K_{t-1}$	0.92 (0.58)	-0.28** (0.14)	0.03 (0.02)	0.28*** (0.11)	0.06 (0.22)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h x_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_{t-1} : cyclical component of the log of the physical capital by Hamilton (2017) filter, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

magnitudes of the impulse responses are comparable to those with the primary dealer capital ratio, though the relative magnitudes of the state-dependent responses are smaller in this case. Table 10 presents the results with the GZ spread serving as the state variable. The results are similar with EBP, except that the linear responses are slightly stronger and the state-dependent effects are weaker. Table 11 presents the results with VXO as the state variable. VXO measures the implied volatility of the S&P 100, which is countercyclical. A high VXO amplifies the impulse responses. Results with all of the three financial market variables are consistent with the finding that the impulse responses are amplified in a recession. Furthermore, the unemployment rate has significantly stronger state dependence than the investment rate, as measured by $|\beta_2^h|/|\beta_1^h|$.

The results in this subsection seem to confirm that the amplification effects of the primary dealer capital ratio are related to the financial market distress instead of real activities.

Table 8: State-Dependent Impulse Responses, $\ln GDP$ as the State Variable.

	UE	Unemployment rate	I/K	$\ln K$	$\ln L$
$h = 1$					
ε_t^{TFP}	0.86** (0.26)	-0.15*** (0.03)	0.07*** (0.01)	0.22** (0.10)	0.34*** (0.09)
$\varepsilon_t^{TFP} \times \ln GDP_{t-1}$	-0.31 (0.32)	0.15*** (0.05)	-0.00 (0.01)	0.25** (0.10)	-0.05 (0.09)
$h = 4$					
ε_t^{TFP}	2.03*** (0.53)	-0.38*** (0.10)	0.12*** (0.02)	0.58*** (0.14)	0.71*** (0.16)
$\varepsilon_t^{TFP} \times \ln GDP_{t-1}$	-0.24 (0.35)	0.17** (0.08)	-0.01 (0.02)	0.22** (0.11)	-0.22 (0.16)
$h = 8$					
ε_t^{TFP}	1.35** (0.61)	-0.27* (0.14)	0.05* (0.03)	0.39** (0.16)	0.31 (0.21)
$\varepsilon_t^{TFP} \times \ln GDP_{t-1}$	-0.20 (0.40)	0.11 (0.10)	0.01 (0.02)	0.10 (0.10)	-0.22 (0.16)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h x_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_{t-1} : cyclical component of the log of the physical capital by Hamilton (2017) filter, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

Table 9: State-Dependent Impulse Responses, EBP as the State Variable.

	UE	Unemployment rate	I/K	$\ln K$	$\ln L$
$h = 1$					
ε_t^{TFP}	0.77*** (0.23)	-0.17*** (0.04)	0.07*** (0.01)	0.13 (0.10)	0.31*** (0.09)
$\varepsilon_t^{TFP} \times \text{EBP}_{t-1}$	0.61*** (0.18)	-0.12*** (0.02)	-0.01*** (0.01)	-0.03 (0.04)	0.14*** (0.04)
$h = 4$					
ε_t^{TFP}	1.98*** (0.49)	-0.37*** (0.09)	0.11*** (0.02)	0.42*** (0.13)	0.66*** (0.16)
$\varepsilon_t^{TFP} \times \text{EBP}_{t-1}$	0.42* (0.21)	-0.22*** (0.05)	0.03*** (0.01)	0.12*** (0.04)	0.36*** (0.07)
$h = 8$					
ε_t^{TFP}	1.31** (0.57)	-0.25* (0.13)	0.04 (0.03)	0.30* (0.15)	0.31 (0.19)
$\varepsilon_t^{TFP} \times \text{EBP}_{t-1}$	0.32* (0.16)	-0.17*** (0.04)	0.01 (0.01)	0.11 (0.08)	0.23*** (0.07)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h x_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_{t-1} : cyclical component of the log of the physical capital by Hamilton (2017) filter, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

Table 10: State-Dependent Impulse Responses, GZ Spread as the State Variable.

	UE	Unemployment rate	I/K	$\ln K$	$\ln L$
$h = 1$					
ε_t^{TFP}	0.90*** (0.22)	-0.20*** (0.05)	0.07*** (0.01)	0.11 (0.10)	0.35*** (0.09)
$\varepsilon_t^{TFP} \times GZ_{t-1}$	0.56*** (0.14)	-0.07*** (0.01)	0.01*** (0.01)	-0.02 (0.04)	0.06 (0.06)
$h = 4$					
ε_t^{TFP}	2.08*** (0.48)	-0.42*** (0.09)	0.12*** (0.02)	0.46*** (0.13)	0.77*** (0.18)
$\varepsilon_t^{TFP} \times GZ_{t-1}$	0.32 (0.19)	-0.15*** (0.03)	0.02** (0.01)	0.07 (0.05)	0.20** (0.09)
$h = 8$					
ε_t^{TFP}	1.38** (0.53)	-0.29** (0.12)	0.04 (0.03)	0.34** (0.15)	0.37** (0.19)
$\varepsilon_t^{TFP} \times GZ_{t-1}$	0.33* (0.20)	-0.18*** (0.05)	0.00 (0.01)	0.06 (0.06)	0.23*** (0.08)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h x_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_{t-1} : cyclical component of the log of the physical capital by Hamilton (2017) filter, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.

Table 11: State-Dependent Impulse Responses, VXO as the State Variable.

	UE	Unemployment rate	I/K	$\ln K$	$\ln L$
$h = 1$					
ε_t^{TFP}	0.67*** (0.26)	-0.11*** (0.04)	0.06*** (0.01)	0.17* (0.10)	0.17 (0.11)
$\varepsilon_t^{TFP} \times \text{VXO}_{t-1}$	0.77*** (0.13)	-0.11*** (0.02)	0.02*** (0.00)	0.00 (0.03)	0.19*** (0.03)
$h = 4$					
ε_t^{TFP}	1.73*** (0.65)	-0.34*** (0.13)	0.10*** (0.03)	0.36*** (0.11)	0.49** (0.20)
$\varepsilon_t^{TFP} \times \text{VXO}_{t-1}$	0.33 (0.38)	-0.16*** (0.05)	0.03** (0.01)	0.19*** (0.07)	0.34*** (0.08)
$h = 8$					
ε_t^{TFP}	1.51* (0.83)	-0.46** (0.21)	0.07* (0.04)	0.41* (0.21)	0.49 (0.31)
$\varepsilon_t^{TFP} \times \text{VXO}_{t-1}$	0.28 (0.29)	-0.11 (0.07)	0.00 (0.01)	0.07 (0.09)	0.23** (0.10)

Notes. Newey-West standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, shocks and capital ratio are standardized. The table presents the estimates of β_1^h and β_2^h in the local projection equation $y_{t+h} = \alpha + \beta_1^h \varepsilon_t^{TFP} + \beta_2^h x_{t-1} \times \varepsilon_t^{TFP} + \beta_3 r_{f,t} + \beta_4 TS_t + \sum_{l=1}^p \gamma_l^h y_{t-l} + \varepsilon_{t,t+h}$ at horizons $h = 1, 4, 8$. UE: U-E transition probability. x_{t-1} : cyclical component of the log of the physical capital by Hamilton (2017) filter, normalized to mean 0 and s.d. 1. ε_t^{TFP} : the productivity shock, normalized to mean 0 and s.d. 1. $r_{f,t}$: 3-month treasury yield. TS_t : 10-year treasury yield minus 3-month treasury yield.