Firm Investment and the State-Dependent Transmission of Monetary Policy*

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Abstract

This paper explores how the distribution of default risk impacts the transmission of monetary policy to aggregate investment. In contractions, the distribution of firm default risk shifts, as firms become more likely to default on their debt obligations. I show both empirically and in a model that this shift in the distribution creates a state dependence in the transmission of monetary policy to aggregate investment: aggregate investment is less responsive to changes in interest rates in contractions. In both the data and my model, firms that are at high risk of default are responsible for driving this state dependent transmission because a decrease in interest rates does not pass through to the interest rates they face on issuing new debt. Thus, high default risk firms can't afford to issue new debt to finance additional investment at favorable enough interest rates. Quantitatively, I estimate that the decreased transmission of monetary policy to aggregate investment is large due to the fact that more firms become risky in contractions. In contractions, aggregate investment is between 1 - 2 percent less responsive to a 25 bps expansionary monetary policy shock.

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1 Introduction

There is a large literature in macroeconomics and corporate finance that focuses on the role that financial frictions play in determining firm investment. This paper looks to understand the role that one specific financial friction plays in determining firm investment and its response to monetary policy: default risk. More specifically, I look to understand how the overall distribution of default risk impacts monetary policy's transmission to aggregate investment over the business cycle. This question is motivated by the fact that in the data high default risk firms are less responsive to monetary policy shocks[1]. A priori, there are two possible answers. On one hand, aggregate investment may be less responsive to monetary policy in contractions because there is a larger mass of high default risk firms. Since high default risk firms are least responsive to monetary policy shocks, this leads to a lower aggregate response. On the other hand, the distribution of default risk may not vary much over the business cycle because high default risk firms exit in contractions. Thus, any differences in aggregate investment responses to changes in interest rates is independent of the distribution of default risk.

I address this question using micro-level firm data as well as a heterogeneous firm investment model with default. My empirical work integrates monetary policy shocks, using a high frequency identification strategy, into a rich data set on micro-level firm characteristics from Compustat. I show that high default risk firms are least responsive to monetary policy shocks in and out of contractions. My baseline empirical specification estimates how the semi-elasticity of aggregate investment to an expansionary monetary policy shock varies as the distribution of firm default risk shifts. I proxy firm default risk at the micro-level using distance to default, which estimates a probability of default. Panel regressions suggest that high default risk firms are driving the result: I find that across the business cycle, high default risk firms are less responsive to monetary policy shocks than their low-default counterparts. Motivated by this, I show that the distribution of firm default risk looks qualitatively different between expansions and contractions and construct a new aggregate measure of financial distress to explore how changes in the distribution of default risk interacts impacts the transmission of monetary policy to aggregate investment. My baseline measure of aggregate default risk counts the fraction of distressed firms, which I define to be a firm with a 50 percent or higher likelihood of defaulting next period. I find that when the fraction of distressed firms increases by one standard deviation, the semi-elasticity of aggregate investment to an expansionary monetary policy shock is lower. From there, I estimate that aggregate investment is between 1 - 2 percent less responsive to a 25 bps expansionary monetary policy shock in contractions compared to expansions.

In order to interpret these empirical results, I embed firm default risk into a workhorse corporate finance model of firm investment. Firms invest in capital using internal funds or external funds, which are debt or equity. External funds come at a cost to the firm. If the firm deems it optimal, they can choose to default on their debt, which leads to an interest rate spread on the debt that

[1]This data fact was first pointed out by Ottonello and Winberry (2020).

they issue. To keep the model tractable in order to build intuition about how default risk drives my results, I solve for a series of long-run steady states and do a comparative static exercise. I consider four different steady states: two different interest rate regimes and two different aggregate productivity regimes. More specifically, I consider (i) a high and low interest rate regime (that differ by 25 bps) and (ii) an expansion and contraction regime. I find that decreases in interest rates change aggregate investment by less in contractions, which is driven by changes in the default risk distribution. When the economy moves from an expansion to a contraction, default risk increases, primarily among firms that are at the highest risk of default. When the economy transitions from a high interest rate regime to a low interest rate regime, the probability of default among firms falls, primarily for firms that are at the lowest risk. As in the data, I find that high default risk firms are less sensitive to decreases in interest rates because they cannot secure external financing at favorable enough interest rates to warrant the additional investment. To be clear, these firms would like to increase investment if they could borrow at low enough interest rates. However, their default risk prohibits them from doing so. This is because cuts in the interest rate do not fully pass through to the interest rates firms at risk of default face on the debt they issue.

Literature Review

My paper contributes to four strands of the literature. The first is on financial frictions and heterogeneity in determining aggregate investment. In relation to financial frictions, Bernanke, Gertler, and Gilchrist (1999) embed a financial accelerator into the representative agent New Keynesian model. I build on their results by allowing for rich heterogeneity on the firm side. In addition Bernanke, Gertler, and Gilchrist (1999) assume firms face a constant returns to scale production function whereas I assume firms face decreasing returns to scale. This implies an optimal scale for firms. Khan, Senga, and Thomas (2017) build a model with firm default risk and aggregate shocks to study the effects of credit shocks. My paper introduces monetary policy shocks and more richly models firm's production. Other models that present models of investment under financial constraints are Khan and Thomas (2013) and Corbae and D'Erasmo (2021).

Second, my paper contributes to the literature on credit conditions and the impacts it has on real variables. Gilchrist and Zakrajšek (2012), Chodorow-Reich (2013), Giglio, Kelly, and Pruitt (2016), Adrian, Boyarchenko, and Giannone (2019) show that measures of distress in the financial sector predict economic contractions. My paper contributes to this literature by defining a new measure of financial distress. I also explore how monetary policy interacts with financial distress.

Third, my paper relates to how the transmission of monetary policy is impacted my micro-level heterogeneity. Most of this literature has focused on the household side (see McKay, Nakamura, and Steinsson (2016) and Kaplan, Moll, and Violante (2018)). My paper focuses on heterogeneity at the firm level like in Ottonello and Winberry (2020). In contrast to Ottonello and Winberry (2020), whose focus was on documenting the difference in investment response to monetary policy shocks by firms with different level of default risk, I consider the aggregate implications of movements in the distribution of default risk and how it impacts the transmission of monetary policy to investment.

Finally, my paper relates to a literature that argues that monetary policy is less effective in contractions. Tenreyro and Thwaites (2016) estimate a non-linear time series model and find that monetary policy shocks have a smaller impact on real economic activity in contractions compared to expansions. I extend their results by building a model that reproduce this empirical fact and show that default risk is important for explaining this result. Vavra (2013) and McKay and Wieland (2019) build models which support the claim that monetary policy is less responsive in contractions. Vavra (2013) argues that it is due to changes in the distribution of price adjustments; McKay and Wieland (2019) argue that it is due to changes in the distribution of durable expenditures.

Road Map

The rest of this paper is organized as follows. Section 2 provides empirical motivation and evidence that the transmission of monetary policy to aggregate investment is state dependent due to the distribution of firm default risk. Section 3 proposes a general equilibrium environment with firm dynamics where firms can endogenously choose to default on their debt obligations. Section 4 defines an equilibrium. Section 5 explores properties of the benchmark model and uses it to study the state-dependence of the transmission of monetary policy. Finally, Section 6 concludes.

2 Empirical Motivation & Results

In this section, I document that the transmission of monetary policy to aggregate investment is dependent on the distribution of firm default risk, as proxied by distance to default. First, I describe the details of the data employed in this paper. Additional details beyond what is contained in the main text can be found in Appendix A. Next, I explore the interaction between firm investment response to expansionary monetary policy shocks, taking into account firm specific default risk. In addition, these differences in how firms with different default risk change their investment behavior to changes in monetary policy persists over expansions and contractions. These results provide a foundation for the final subsection where I explore the state-dependence transmission of monetary policy to aggregate investment.

2.1 Data Description

Firm Level Data

Firm level data comes from Compustat. Data on all firm variables is at the quarterly level. Compustat has a few notable advantages. First, it provides a long sample of data for firms at a high enough frequency to study monetary policy shocks. Second, the data is easily available. The main downside is that Compustat only considers large publicly traded firms, which is not representative of the whole universe of firms [2].

[2] Crouzet and Mehrotra (2020) use US Census Bureau's Quarterly Financial Report survey to compare the difference in sensitivity to aggregate shocks of small firms to large firms. While they find a difference – small firms are more sensitive to aggregate events – they are too small, in terms of overall mass, to have any meaningful effect on

My main measure for firm investment is $\Delta log(k_{i,t+1})$. $k_{i,t}$ is measured as the book value of tangible capital stock at the end of period t for firm i. As stated above, I proxy for a firm's level of financial constraint by considering a firm's distance to default, following Gilchrist and Zakrajšek (2012) and Merton (1974)[3]. Given a firm's distance to default, one can compute the implied probability of default by $\Phi(-dd)$[4]. Table 1 provides summary statistics on firm investment and distance to default.

Table 1: Summary Statistics: Firm Level Variables[a]

	Mean	Median	St. Dev	95th Percentile	N
$\Delta log(k_{t+1})$	0.003	-0.003	0.113	0.127	316,032
dd	5.584	4.532	5.086	14.999	316,032

[a] Summary statistics of firm-level variables for the period 1983q3 to 2019q4. $\Delta log(k_{i,t+1})$ is the change in the capital stock and $dd_{i,t}$ is the firm's distance to default.

Monetary Policy Shocks

I measure monetary policy shocks using a high-frequency event study approach. Following Gürkaynak, Sack, and Swanson (2005), monetary policy shocks are constructed by considering the difference in Fed Funds futures around a 30 minute window on FOMC announcement dates. The sample of monetary policy shocks runs from 1990, when the Fed Funds futures market opened, through 2016. During that time there were 323 FOMC announcements. Data comes from Jarociński and Karadi (2020), which work with an updated version of the original Gürkaynak, Sack, and Swanson (2005) dataset. My my measure of interest rate surprises is the change in the 3-month ahead Fed Funds future rate. Changes in the 3-month ahead futures has the advantage of capturing both short-term surprises and near-term forward guidance surprises[5]. As noted by Jarociński and Karadi (2020), the 3-month ahead futures are invariant to timing surprise. These timing surprises can have little effects on real variables, but large impacts on future contracts traded at a duration shorter than three months. Table 2 provides summary statistics for the HFI shocks, as well as the quarterly aggregated monetary policy shock. I aggregate monetary policy shocks to the quarterly level by summing across the quarter. Table 2 shows that the moments of the summed shock are similar to the original data.

aggregate variables.

[3]Distance to default is being used here as a proxy for a firm's true default risk. It is unlikely that this data constructed measure of a firm's default risk is perfectly accurate. Regardless, I choose it because it is likely to correlate well with a firm's true default risk since a measure of distance to default is employed by ratings agencies to asses firm default risk. In addition, distance to default has been shown by Schaefer and Strebulaev (2008) to account well for variation in corporate bond prices due to default risk

[4]$\Phi(\cdot)$ is the CDF of a standard normal distribution. For example, if a firm's distance to default is 0, this firm's probability of default next quarter is 50%.

[5]While forward guidance is not the main focus of this paper, it is important to capture – at least in a simple way – given that the Fed relied heavily on forward guidance to conduct monetary policy in the Zero Lower Bound era.

Table 2: Summary Statistics: HFI Shocks[a]

	Mean	Median	St. Dev	Min	Max	N
HFI Shock	-0.011	0.000	0.054	-0.370	0.190	323
Summed HFI Shock	-0.011	-0.003	0.032	-0.145	0.057	108

[a] Summary statistics of monetary policy shocks for the period 1/1/1990 to 12/31/2016. "HFI Shock" are estimated using the event study strategy in Jarociński and Karadi (2020). "Summed HFI Shock" refers to time aggregating by simply summing all shocks within a quarter.

2.2 Firm Investment Sensitivity to Monetary Policy over Business Cycles

Next, I explore the heterogeneous response of investment to expansionary monetary policy shocks by firms with different levels of default risk. The empirical approach and results are largely in line with work first done by Ottonello and Winberry (2020) with two extensions. First, I extend the sample through the Great Recession. Second, I explore whether the heterogeneous investment responses of firms with different default risk to monetary policy shocks persists over the business cycle.

Regression Specification

The first regression specification I consider is:

$$\Delta log(k_{i,t+1}) = \alpha_i + \alpha_{s,t} + \beta(dd_{i,t-1} - \bar{d}d_i)\varepsilon_t^m + \Gamma' Z_{i,t} + e_{j,t} \tag{1}$$

where α_i is a firm specific fixed effect, $\alpha_{s,t}$ is a sector time fixed effect, ε_t^m is a quarterly aggregated monetary policy shock, and $(dd_{i,t-1} - \bar{d}d_i)$ is a demeaned measure of a firm's distance to default[6]. Equation 1 considers interactions between a demeaned measure of a firm's financial position with a monetary policy shock; the coefficient β captures how the semi-elasticity of firm investment varies with their distance to default. Table 3 reports the results for three different samples: (1) the full sample, (2) expansion periods, and (3), contraction periods. Contraction periods are a dummy variable that takes a value of one if the economy is in a recession as measured by NBER Business Cycle Dating Committee.

I control for a number of factors that are likely to affect firm investment at a firm specific or aggregate level. The vector of firm specific controls includes the firm's financial position (dd), an interaction between distance to default and one quarter lagged GDP growth, total assets, sales growth, and current assets as a share of total assets. The vector of aggregate controls includes four quarter lags of GDP growth, inflation, and the unemployment rate.

[6] I consider demeaned distance to default to control for permanent heterogeneity in firm characteristics. This is motivated in part by my modeling approach where firms are ex-ante identical. In the data, however, firms my be ex-ante different in certain characteristics like default risk, as pointed out by Lemmon, Roberts, and Zender (2008). By demeaning firms distance to default, my estimates are driven by how a firm responds to a monetary policy shock when it has a higher/lower default risk than than usual.

Finally, following Ottonello and Winberry (2020), I have normalized the sign of the monetary policy shock so that positive signed shocks correspond to expansionary monetary policy shocks. In addition, I standardize all variables of interest to provide an easy interpretation.

Results

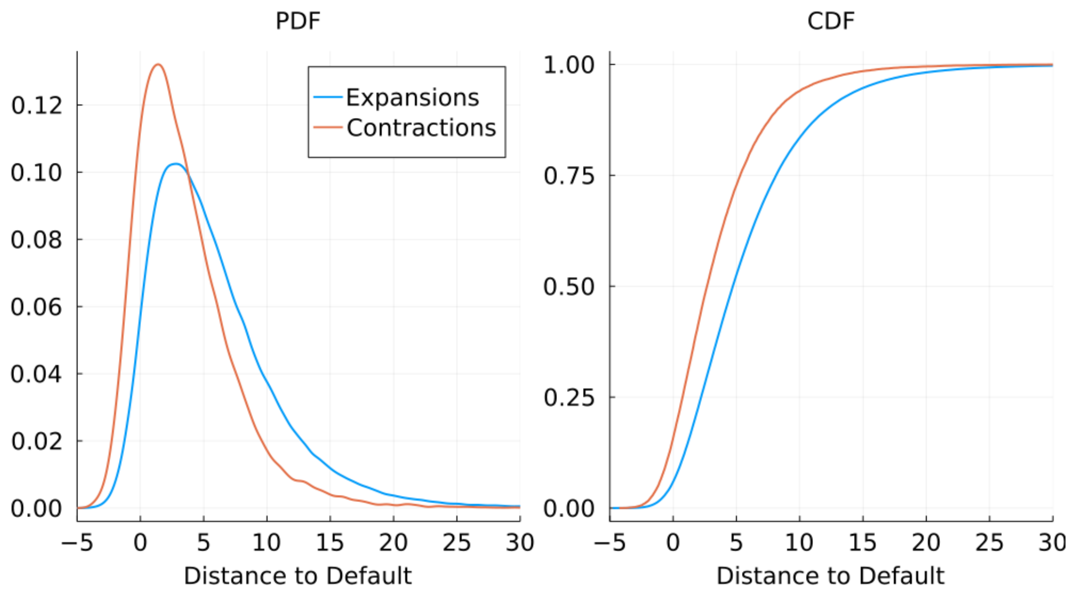
The estimated regression results are shown in Table 3. The table shows that firms that are further away from their default threshold – that is, have a high distance to default measure – are more responsive to monetary policy shocks over the business cycle. The first column replicates the findings of Ottonello and Winberry (2020). The next two columns explore how monetary policy interacts with a firm's default risk at different points in the business cycle. The results show that low default risk firms are most responsive to monetary policy shocks in expansions. While the relationship is not statistically significant in the contraction sample – likely due to the small number of contraction observations in my sample – the estimated sign is in line with the other estimates. The results suggest that the relationship first pointed out in Ottonello and Winberry (2020) – that low default risk firms are most responsive to expansionary monetary policy shocks – persists over the business cycle. In addition, the point estimates of the semi-elasticity of investment with respect to a monetary policy shock in Table 3 is lower in contractions than expansions.

Table 3: Heterogeneous Responses Of Monetary Policy[a]

	Full Sample	Expansions	Contractions
	(1)	(2)	(3)
	$\Delta log(k_{t+1})$	$\Delta log(k_{t+1})$	$\Delta log(k_{t+1})$
dd × ffr shock	1.22**	1.27**	0.44
	(0.47)	(0.63)	(0.62)
Observations	233773	207066	25969
R^2	0.136	0.139	0.357
Time sector FE	yes	yes	yes
Time clustering	yes	yes	yes

[a] *, **, and *** denotes significance at 10%, 5%, and 1% levels respectively. Results are from estimating $\Delta log(k_{i,t+1}) = \alpha_i + \alpha_{s,t} + \beta(dd_{i,t-1} - \bar{d}d_i)\varepsilon_t^m + \Gamma' Z_{i,t} + e_{j,t}$, where α_i is a firm fixed effect, $\alpha_{s,t}$ is a sector-by-quarter fixed effect, $dd_{i,t-1} - \bar{d}d_i$ is demeaned distance to default, ε_t^m is a monetary policy shock (with the sign normalized so expansionary shocks are positive numbers), $Z_{i,t}$ is a vector of firm-level controls containing demeaned distance to default, sales growth, size, current assets as a share of total assets, an indicator for fiscal quarter, and the interaction of demeaned financial position with lagged GDP growth. Standard errors are two-way clustered by firms and quarter.

Figure 1: Distribution of Firms



2.3 Aggregate Investment Response to Monetary Policy over Business Cycles

The results above suggest that a firm's default risk is important in characterizing their investment response to monetary policy shocks. The actions of individual firms taken together add up to an aggregate response. Thus, the *distribution* of firm default risk likely matters for the aggregate response of investment to changes in monetary policy. Two natural questions follows: (i) how does the distribution of firm default risk vary over the business cycle; (ii) does this alter the sensitivity of how aggregate investment responds to changes in monetary policy?

In Figure 1, I plot a kernel density estimation of the density and distribution of firms default risk. In doing so, I impose an upper bound of 30 on the distance to default a firm can take[7]. Figure 1 shows a sharp contrast between the distribution of firm default risk in expansions (blue line) and contractions (orange line). In contractions, the distribution of firms shifts to the left. In other words, firms are, on average, more likely to default on their debt obligations.

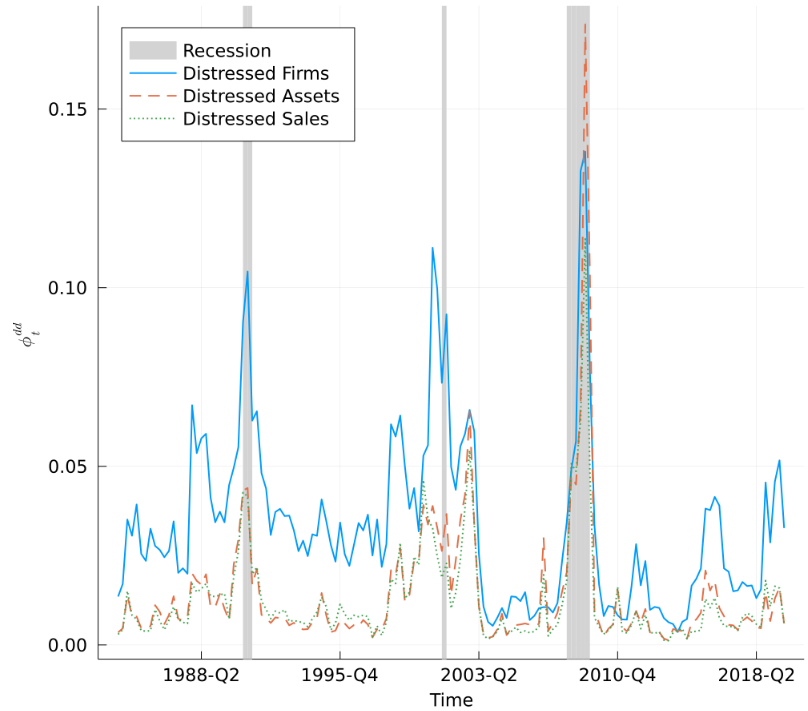
Recall the interpretation of coefficient estimate in regression (1) of Table 3: firms with a larger distance to default are more responsive to monetary policy shocks. Given that firms are more risky a contraction, this suggests that the transmission of monetary policy to aggregate investment is state-dependent and depends on the distribution of firms default risk. In what follows, I lay out an empirical strategy to test this hypothesis and assess the statistical and economic significance of it.

Regression Specification

A notable restriction on the analysis done above is that I consider two extreme cases of the business cycle: expansion periods and contraction periods. Given the relatively small number of

[7]An distance to default measure of 30 and above corresponds to a probability of default less than 4.9×10^{-198} in the Merton (1974) Model. In addition, there is a negligible mass of firms greater than 30.

Figure 2: Fraction of Distressed Firms



contraction observations over the sample period – just three contractions – it leads to imprecise estimates of the overall effect that changes in the aggregate state has on aggregate investment response to monetary policy shocks. To alleviate this problem, I define a new measure of aggregate default risk that more finely captures movements in the distribution of default risk. Let ϕ_t^{dd} be a measure of the fraction of distressed firms. More formally, I call a firm distressed if it has a distance to default measure of 0 or smaller. This translates into an expected probability of default next year of 50 percent or higher. I consider three measures of the fraction of financially distressed firms in a given time period:

1. Fraction of distressed firms in quarter t.

2. Fraction assets held by distressed firms in quarter t.

3. Fraction of sales attributed to distressed firms in quarter t[8].

Figure 2 plots how the three different measures move over the sample period: they rise in contractions and fall in expansions. I choose this measure to capture continuous changes to the distribution of default risk over time, while still capturing movements in the business cycle.

[8]Note that measuring the fraction of assets and sales attributed to distressed firms has an intensive and extensive margin at play that move in opposite directions. Along the intensive margin, distressed firms are likely to hold fewer assets and make less sales. Along the extensive margin, as the aggregate state worsens, there are more firms that are likely to be distressed. In Figure 2, I see that both the fraction of assets and sales attributed to distressed firms increases from expansions to contractions, implying that the extensive margin is dominating the intensive margin.

To explore the aggregate movements in the distribution of firm default, I estimate the following regression:

$$\Delta log(K_{t+1}) = \beta\phi_t^{dd}\varepsilon_t^m + \Gamma' Z_t + e_t \tag{2}$$

where Z_t is a vector of aggregate controls including ϕ_t^{dd}, the effective federal funds rate, and aggregate GDP. Aggregate capital is constructed using the Compustat data. To make the results easy to interpret, I standardize ϕ_t^{dd}. The main coefficient of interest is β; it captures aggregate investment response to monetary policy shocks as the different distributions of firm default risk changes over the business cycle.

Results

Table 4: Monetary Policy Over the Distribution[a]

	(1) $\Delta log(K_{t+1})$	(2) $\Delta log(K_{t+1})$	(3) $\Delta log(K_{t+1})$
% distressed firms × ffr shock	-2.04***		
	(0.62)		
% distressed assets × ffr shock		-3.48***	
		(1.09)	
% distressed sales × ffr shock			-2.50**
			(0.98)
Observations	108	108	108

[a] *, **, and *** denotes significance at 10%, 5%, and 1% levels respectively. Results are from estimating $\Delta log(K_{t+1}) = \beta\phi_t^{dd}\varepsilon_t^m + \Gamma' Z_t + e_t$, where ϕ^{dd} is a measure of the fraction of distressed firm, ε_t^m is a monetary policy shock (with the sign normalized so expansionary shocks are positive numbers), Z_t is a vector of aggregate-level controls containing ϕ_t^{dd}, the effective federal funds rate, and GDP growth. Newey-West standard errors are reported.

Table 4 reports the estimates for the three different measures of fractions of distressed firms. The estimates are negative and statistically significant with the following interpretation: a one standard deviation increase in the fraction of distressed firms leads to a lower semi-elasticity of aggregate investment to a monetary policy shock. In other words, when there are more distressed firms – that is, firms with high default risk – aggregate investment is less responsive to changes interest rates.

In Table 5, I quantify the economic significance of these results. I do so by measuring the number of standard deviations the distribution of firm default risk shifts from expansions to contractions. Framing things in terms of number of standard distributions moved by the distribution makes it easy to quantify the economic significant in light of the results in Table 4. I begin with calculating the mean of ϕ^{dd} in expansions and contractions and the number of standard deviations above or below it is from the unconditional mean $\bar{\phi}^{dd}$: $\bar{\phi}_E^{dd}$ and $\bar{\phi}_R^{dd}$, respectively. Note that the standardized

Table 5: Economic Significance of Changes in Default Risk Distribution[a]

	$\bar{\phi}_E^{dd}$	$\bar{\phi}_R^{dd}$	$0.25\beta(\bar{\phi}_R^{dd} - \bar{\phi}_E^{dd})$
% distressed firms	-0.23	1.89	-1.08%
% distressed assets	-0.21	2.00	-1.92%
% distressed sales	-0.22	1.97	-1.37%

[a] Results are from calculating $0.25\beta(\bar{\phi}_R^{dd} - \bar{\phi}_E^{dd})$, where β is the coefficient of interest from Equation 25, $\bar{\phi}_E^{dd}$ is the standardized value of the average fraction of distressed firms in an expansion relative to the unconditional average fraction of distressed firms, and $\bar{\phi}_R^{dd}$ is the standardized value of the average fraction of distressed firms in a contraction relative to the unconditional average fraction of distressed firms.

values for $\bar{\phi}_E^{dd}$ are negative meaning there are a fewer number of distressed firms in the economy or, firms are, on average, *less* likely to default on their debt obligations compared to the unconditional average; similarly the standardized values for $\bar{\phi}_R^{dd}$ are positive meaning firms are, on average, *more* likely to default on their debt obligations compared to the unconditional average. From here, I construct the overall economic impact as:

$$0.25\beta(\bar{\phi}_R^{dd} - \bar{\phi}_E^{dd}).$$

$(\bar{\phi}_R^{dd} - \bar{\phi}_E^{dd})$ quantifies how many standard deviations the fraction of distressed firms changes by moving from expansions to contractions and β captures how much aggregate investment changes in response to monetary policy shocks as for a change in the standard deviation of the fraction of distressed firms. I find that aggregate investment is between 1% - 2% less responsive to a 25 bps expansionary shock when the fraction of distressed firms in the economy increases. The results further suggest that firm investment is statistically and economically significant and suggests that the transmission of monetary policy to aggregate investment is significantly impacted by the distribution of firm default risk.

2.4 Additional Empirical Results

Appendix B contains a number of robustness exercises. The cutoff choice of distance for default to define a distressed firm was somewhat arbitrary. I conduct a number of robustness exercises using different cutoff values to ensure my results, and their magnitudes, are not dependent on my baseline cutoff choice. Additionally, I consider the GZ-Spread of Gilchrist and Zakrajšek (2012) as an independent measure of aggregate credit conditions. I also consider aggregate investment data from the NIPA. Finally, I consider leverage as a possible proxy for firm default risk.

3 Environment

In this section, I build a model that can qualitatively replicate features of my empirical exercise. To do so, I consider a discrete time general equilibrium model. There are three main actors in my model: firms, lenders, and households. To keep the model simple, I consider a model with real variables and prices. I take the real interest rate to be a policy parameter as in a small open economy framework. To gain intuition from my model I focus on a long-run comparative static analysis, whereby the real interest rate changes[9] – to proxy for high and low interest rate regimes – and aggregate TFP changes – to proxy for expansions and contractions. This allows me to understand the mechanism delivered in my model that likely would carry through in a richer quantitative model. A future version of this paper would incorporate aggregate uncertainty into my model.

In my model, heterogeneous firms, receiving idiosyncratic productivity shocks, produce an identical good. Firms undertake investment and dividend choices through issuing short-term defaultable debt and costly equity. There is a representative lender who lends to firms. Given firms can renege on their promised debt payment, the lender forecasts if a firm is likely to default on their debt to set the price on debt borrowed by the firm. Households supply labor to the firms and save through the lenders.

3.1 Firms and Technology

Firms, indexed by j, produce an identical good that can be sold or used as capital. Firm j wishes to maximize the expected present discounted value of dividends. Formally:

$$\max_{\{l_{j,t},k_{j,t+1},b_{j,t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t d_{j,t}, \tag{3}$$

where $d_{j,t}$ is the per-period dividend payout of firm j and $\frac{1}{1+r}$ is the firm's discount rate. This environment can be thought of as a small open economy where the real interest rate is taken to be exogenously given. Firm j produces an output good $y_{j,t}$ and has access to a decreasing returns to scale production technology:

$$y_{j,t} = Az_{j,t}k_{j,t}^{\alpha_k}l_{j,t}^{\alpha_l}, \tag{4}$$

where A is aggregate productivity common to all firms and $z_{j,t} \in Z \equiv \{z_1, z_2, \dots, z_{n_z}\}$ is an idiosyncratic productivity shock which is iid across all firms. The idiosyncratic productivity shock follows a first-order Markov process with transition matrix $G_z(z_{j,t+1}|z_{j,t})$. $k_{j,t}$ is the current capital stock of firm j in period t and $l_{j,t}$ is labor the firm hires in period t. Note, the production technology is decreasing returns to scale, so $\alpha_k + \alpha_l < 1$. Firms hire labor on a spot market at wage rate w_t. In order to produce, firms must pay a fixed cost c_f. Firms own their own capital and decide how

[9] In my setup, movements in the real interest rate are going to be exogenous. Mechanically, they will come through changes in the Household's discount factor.

much capital they should invest in for future production:

$$i_{j,t} = k_{j,t+1} - (1-\delta)k_{j,t} \tag{5}$$

where δ is the depreciation rate on capital. Additionally, firms are subject to an adjustment cost on capital:

$$\Psi_{j,t} = \frac{c_a}{2}\left(\frac{i_{j,t+1}}{k_{j,t}} - \delta\right)^2 k_{j,t}. \tag{6}$$

Firms finance production and investment decisions through the use of internal or external funds. In any given period, firm j's profits – or internal funds – are defined to be revenue less costs:

$$\pi_{j,t} = y_{j,t} - w_t l_{j,t} - c_f, \tag{7}$$

where w_t is the cost of labor, common across all firms. External financing comes from two sources: (i) one-period non-contingent discount bonds $b_{j,t+1}$ at price $Q_{j,t}$ and (ii) external equity injections ($e_{j,t} < 0$) at a cost $\lambda(e_{j,t})$.

Each period a mass of firms m_t enters the economy. After entering, firms observe their initial idiosyncratic productivity level $z_{j,0} \sim \bar{G}_z(z)$ which is drawn from the stationary distribution of the Markov process. Entering firms must pay an entry cost, the fixed cost to produce, and make capital and bond choices financed by a costly equity injection.

3.2 Financial Markets

Lenders

There is a risk neutral representative financial intermediary who has access to one-period risk free discount bonds at a price $\frac{1}{1+r}$ and lends discount bonds to firms at a firm-specific loan price $Q_{j,t}(k_{j,t+1}, b_{j,t+1}, z_{j,t})$. The price of bonds is a function of: (i) the amount of capital the firm plans to invest in – as this impacts the recovery value the lender can get in the event of default – (ii) the amount of bonds the firm wishes to borrow, and (iii) firm specific productivity level. The bond price is firm specific because it encompasses the likelihood that a firm will default on their debt obligations next period.

Equity Issuance

If firms choose to finance through equity, they must pay a cost $\lambda(e_{j,t})$, which is increasing in the amount of equity needed to be injected.

3.3 Households

At each point in time, households choose consumption C_t, labor L_t, risk free bonds B_{t+1}, and shares in incumbent and entering firms $S_{j,t+1}$ to maximize the present discounted value of utility given by:

$$\max_{\{C_t, L_t, B_{t+1}, \{S_{j,t+1}\}\}} \sum_{t=0}^{\infty} \beta^t U(C_t, L_t), \tag{8}$$

subject to:

$$C_t + \int_j S_{j,t+1} p_{j,t} dj + \frac{1}{1+r} B_{t+1} = \int_j S_{j,t}(p_{j,t} + d_{j,t}) dj + B_t, \tag{9}$$

where $p_{j,t}$ is the after-dividend stock price of firm j.

3.4 Timing

At each period t:

1. Idiosyncratic productivity $z_{j,t}$ is realized by firms. The state space for an incumbent firm is $(k_{j,t}, b_{j,t}, z_{j,t})$.

2. Exit and default decisions are made by firms. If a firm chooses to default on their debt, the firm is liquidated and the lender recovers a fraction of the firm's capital stock. If a firm does not choose to default, they repay their debt in full and decide whether or not to exit. If a firm exits or defaults, they avoid paying the fixed cost of production.

3. If a firm stays, it pays the fixed cost of production, hires labor, and makes capital and debt choices for next period.

4. Potential entrants decide whether to enter the market or not. A mass of firms m_t enters the economy. After entering, firms observe the aggregate productivity level and their initial idiosyncratic productivity level $z_{j,0} \sim \bar{G}_z(z)$ which is drawn from the stationary distribution of the Markov process. Entering firms must pay the fixed cost to produce and make capital and bond choices financed by equity.

5. Households choose labor supply, shares, and bonds, which determines their consumption.

4 Equilibrium

To save on notation, I drop the firm specific j subscript. Additionally, date t variables have dropped the time subscript and date $t+1$ variables are denoted by primes.

4.1 Recursive Representation of the Firm's Problem

I begin with the problem faced by an incumbent firm. An incumbent firm enters the period with capital k, debt b, and idiosyncratic productivity z. The firm chooses between three discrete actions: (i) to stay in the economy and produce, (ii) to exit the economy and pay back its debt, or

(iii) to default on its debt payment and exit the economy. In other words, the firm maximizes its value over these three distinct choices:

$$V(k,b,z) = \max\{V^{stay}(k,b,z), V^{exit}(k,b,z), V^{default}(k,b,z)\}, \tag{10}$$

where $\{V^{stay}, V^{exit}, V^{default}\}$ denote the value of the firm if it chooses to stay in the economy, if it chooses to repay its debt and exit the economy, and if it chooses to default on its debt. If the firm chooses to repay its debt and exit, the firm obtains a value of:

$$V^{exit}(k,b,z) = \xi_e k - b. \tag{11}$$

Here, $\xi_e < 1$ is the exit price of capital[10]. In the event that a firm chooses to exit, the firm sells off its capital but it can only do so at a price less than its full value. Note that the firm chooses to exit – and not default – if and only if $\xi_e k > b$, since the firm's value is bounded below by limited liability. In the event that its debt obligation is larger than the liquidated value of its capital stock, the firm chooses to default and obtains a value $V^{exit}(k,b,z) = 0$. Define $g^{exit}(k,b,z)$ and $g^{default}(k,b,z)$ to be the exit and default decision rules made by the firm, respectively. In the event of exit, $g^{exit}(k,b,z) = 1$; similarly in the event of default, $g^{default}(k,b,z) = 1$.

If the firm does not choose to exit or default on their debt obligation, we can express the firm's problem of staying as follows:

$$V^{stay}(k,b,z) = \max_{\{l,k',b'\}} \left\{ d + \frac{1}{1+r} \sum_{z'} V(k',b',z') G_z(z'|z) \right\} \tag{12}$$

subject to

$$d = \begin{cases} e + \lambda(e) & e < 0 \\ e & e \geq 0 \end{cases}$$

where $e = \pi - i - \Psi(i,k) - b + Q(k',b',z)b'$ is the firm's cash flow. The optimal decision rules for labor, capital, debt, and dividends are denoted by $l = g_l^{stay}(k,b,z)$, $k' = g_k^{stay}(k,b,z)$, $b' = g_b^{stay}(k,b,z)$, $d = g_d^{stay}(k,b,z)$ respectively.

4.2 Entrants Problem

If a new firm chooses to enter the economy, it must pay an entrance cost c_e; then it chooses its next period capital and debt. I assume here that the entering firms come in with zero capital and zero debt. Thus, to finance an initial investment, entering firms must issue costly equity and debt.

[10] In this version of the model, the exit price of capital is a parameter that is exogenously calibrated. It is possible that ξ_e could be endogenized and vary based on how many firms are defaulting, which varies with the aggregate state. I abstract from that possibility in this version of the paper to keep the model simple.

The value of a potential entrant is given by:

$$V^{ent} = \max_{\{k',b'\}} \left\{ d^{ent} + \frac{1}{1+r} \sum_{z'} V(k',b',z') \bar{G}_z(z) \right\}. \tag{13}$$

At the beginning of the next period, the firm draws its idiosyncratic productivity from the stationary Markov distribution of G_z.

4.3 Lender's Problem

To price debt for firms, the representative lender must forecast the likelihood of default given the firm's capital choice, debt choice, and current idiosyncratic productivity level. On a given loan to a firm with idiosyncratic productivity z who chooses capital k' and debt level b', the lender makes expected profits:

$$\begin{aligned} \Omega(k',b',z) = -Q(k',b',z)b' + \frac{1}{1+r}(1-\Lambda(k',b',z))b' + \\ \frac{1}{1+r}\Lambda(k',b',z)\min\{b', \xi_r(1-\delta)k'\} \end{aligned} \tag{14}$$

where $D(k,b) = \{z \in Z | g^{default}(k,b,z) = 1\}$ is the set of states of the world where the firm defaults and $\Lambda(k',b',z) = \sum_{z \in D(k',b')} G_z(z'|z)$ is the lender's forecast of the probability that a firm will default next period.

Lender's profits for a given loan can be decomposed into the cost to the lender today and the expected revenue she gets tomorrow. The cost to the lender is the first summand of Equation 14, which is the total amount of debt lent to the firm. The the second and third summands are the expected revenue to the lender, which incorporate the forecasting done by the lender. The second summand can be interpreted as the discounted expected repayment value the lender will receive, since $1-\Lambda(k',b',z)$ is the forecasted probability a firm will not default. Finally, the third summand of lender's profits is the expected recovery value in the event of default. Here, $\xi_r < 1$ is the recovery rate the lender can get in the event of default.

In my model, I assume default risk is priced competitively, meaning that the profits made by the lender on a given loan to a firm is equal to zero. This allows for a closed form expression for the price of a given loan made to the firm:

$$\begin{aligned} Q(k',b',z) = \frac{1}{1+r}(1-\Lambda(k',b',z)) + \\ \frac{1}{1+r}\Lambda(k',b',z)\min\left\{1, \frac{\xi_r(1-\delta)k'}{b'}\right\} \end{aligned} \tag{15}$$

As will be confirmed in the numerical results, debt prices are increasing in the amount of capital the firm wishes to invest in (since recovery values are higher), decreasing in the amount of debt issued due to default risk, and increasing in both idiosyncratic and aggregate productivity level because high productive firms are at lower default risk and in good aggregate states, aggregate default risk is lower.

4.4 Household's Problem

I paramatarize the utility function to be $U(C,L) = C + L^{1+\gamma}/(1+\gamma)$. The first order conditions for the household's problem are given by:

$$[L]: \quad L^{\gamma} = w \tag{16}$$

$$[B']: \quad \frac{1}{1+r} = \beta \tag{17}$$

$$[S'_j]: \quad p_j = \beta \mathbb{E}_z(p'_j + d'_j) \tag{18}$$

In order to characterize stock prices, let $p_j = V_j - d_j$. From here, it is straightforward to see that Equation 18 is equivalent to Equation 12 by substituting p_j into Equation 17. Note that the stock price of a firm that exits the economy is 0.

4.5 Cross-Sectional Distribution

Let $k \in K \subset \bar{K}$, $b \in B \subset \bar{B}$, and $z \in Z \subset \bar{Z}$. We can define the law of motion for the cross-sectional distribution of firms as the following:

$$\begin{aligned} \mu'(k,b,z;m) = &\int_{K,B,Z} (1 - g^{exit}(k,b,z)) \mathbb{1}_{\{k'=g_k^{stay}(k,b,z), b'=g_b^{stay}(k,b,z)\}} \\ &\times G_z(z'|z) d\mu(k,b,z) + m \int_Z \mathbb{1}_{\{k'=k_0, b'=b_0\}} \bar{G}(dz) \end{aligned} \tag{19}$$

where m is the mass of new entrants.

4.6 Definition of Equilibrium

A stationary equilibrium is a collection of allocations and prices $\{V^*, \Lambda^*, \mu'^*, m^*, Q^*, r^*, w^*, p^*\}$ such that:

1. Given r^*, Q^*, w^*, firms optimize yielding V^* and is consistent with Equation 10 - 12.
2. The probability of default (Λ^*) in Equation 14 is consistent with firm decision rules.
3. Loan prices Q^* are such that lenders expect to earn zero profits consistent with in Equation 15.
4. The expected value for an entering firm, consistent with Equation 13, is zero.
5. The cross-sectional distribution μ'^* is given by Equation 19 and is consistent with firm decision rules.

6. Goods, Labor, Bond, and Stock markets clear at w^*, r^* and p^*:

$$
\begin{aligned}
(w^*)^\gamma &= \int_{K,B,Z} (1 - g^{exit}(k,b,z)) g_l^{stay}(k,b,z) d\mu(k,b,z) \\
B'^* &= \int_{K,B,Z} (1 - g^{exit}(k,b,z)) g_b^{stay}(k,b,z) d\mu(k,b,z) \\
S'^* &= 1
\end{aligned}
$$

5 Results

For the remainder of my paper, I consider a simplified version of my model where I do not consider aggregate uncertainty. However, a future version of this paper would look to include aggregate uncertainty to better match features of the data. Abstracting from aggregate uncertainty is to keep the model tractable and builds intuition about mechanism driving the results. In the results that follow, I take A and r to be a parameter. In Section 5.3, I consider alternative parameterizations of A – to proxy for expansions and contractions – and r – to proxy for high and low interest rate regimes – to understand how aggregate investment varies across these steady states and how changes in the distribution of default risk across these steady states drives these results.

5.1 Parameterization

Table 6: Calibrated Parameters

Parameter	Description	Parameter Value	Target/Reference
r	Real Interest Rate (Annualized)	3.000	3 Month T-Bill Rate
A	Aggregate Productivity	1.000	Normalization
α_k	Capital Share	0.220	Standard
α_l	Labor Share	0.640	Standard
δ	Capital Depreciation	0.025	Standard
ξ_r	Lenders Recovery Rate	0.900	Default Rate
ξ_e	Exit Price of Capital	0.700	Corbae & D'Erasmo
γ	Labor Supply Elasticity	2.000	Clementi & Palazzo
c_a	Capital Adjustment Cost	0.297	Corbae & D'Erasmo
c_f	Fixed Cost of Production	0.148	Exit Rate
c_e	Entry Cost	0.052	-
λ	Equity issuance cost	0.010	Corbae & D'Erasmo
ρ_z	Persistence: Productivity Shock	0.900	Ottonello & Winberry
σ_z	St. Dev: Productivity Shock	0.030	Ottonello & Winberry

To derive some numerical results from my model, I make a parametric assumption on the shock process. I assume that idiosyncratic productivity follows an AR(1) process:

$$log(z_{t+1}) = \rho_z log(z_t) + \epsilon_{z,t+1}, \quad \epsilon_z \sim \mathcal{N}(0, \sigma_z),$$

where $\rho_z < 1$ is the persistence parameter on the shock. To break up the shock into a discrete grid of points, I follow the method proposed in Tauchen (1986).

The parameters of my model are calibrated to qualitatively capture important features I observe in the data. The full calibration is reported in Table 6. In my model, one period corresponds to one quarter.

I set the real interest rate to be 3.0% annualized, which roughly targets the long-run 3-month Treasury bill rate over my sample period. Aggregate productivity is normalized to 1. In the following section, I will consider a changes to these parameters to quantity how aggregate investment changes across these steady states. I set the returns to scale parameter on capital and labor to be 0.22 and 0.64 respectively, implying a total returns to scale of 86%. Capital depreciates at a quarterly rate of 2.5%. γ is calibrated to 2, consistent with Clementi and Palazzo (2016). I calibrate the recovery value obtained by lenders in the event of default to be 90% and the exit price of capital to be 60%, which are chosen to roughly target average default and exit rates calculated by Ottonello and Winberry (2020). Additionally, I calibrate the capital adjustment cost, fixed cost of production, fixed equity issuance cost, and variable equity issuance cost to be consistent with Corbae and D'Erasmo (2021)[11]. Finally, I calibrate the persistence and shock size parameters to match Ottonello and Winberry (2020).

5.2 Model Properties

Given that the firm's exit/default decision is important to my model, I begin with looking at the exit/default decisions made by firms. I plot firm's exit/default decision conditional on firm's idiosyncratic productivity level in Figure 3a. The top panel displays low productivity firm's decisions and the bottom panel displays high productivity firm's decisions. Recall that a firm can choose between three discrete choices: (i) to stay in the economy and continue producing, denoted by the yellow color; (ii) to exit the economy, but in the process, repay all debts, denoted by the light green color; or (iii) to default on their debt and exit the economy, denoted by the dark green color.

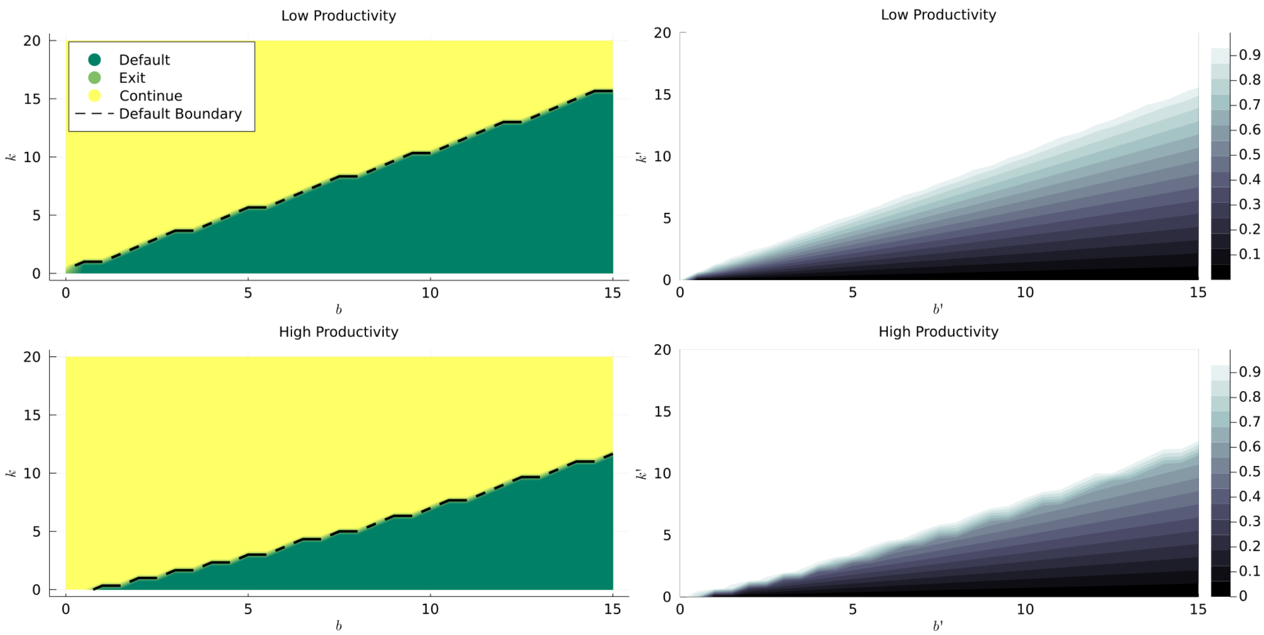
Observe that the choice for the firm to repay all its debt and exit is only optimal for small firms with low productivity. However, the decision to default on ones debt is present across all productivity levels. A firm finds it optimal to default on their debt if it become too highly levered – that is, if the ratio between their debt level and capital stock grows too large. It is important to note, however, that a firm that has higher productivity can sustain a higher leverage ratio. This is due to the persistence in the idiosyncratic productivity shock, reflecting the fact that if a firm is

[11]Corbae and D'Erasmo (2021) build and estimate a structural model of corporate bankruptcy that is similar in a number of ways to my model. While their focus is not monetary policy, their model estimation provides an initial calibration for my model.

Figure 3

(a) Exit Decisions
— Conditional on Productivity —

(b) Bond Prices
— Conditional on Productivity —



highly productive today, it is also likely to be highly productive tomorrow.

Tightly linked to the firm's default decision is the price the firm faces on external debt, plotted in Figure 3b. The bond price the firm faces reflects their default risk next period for a given choice of capital and debt. Firms that face face a lower price (a higher interest rate) on debt are more likely to default next period.

Similar to Figure 3a, we see that conditional on productivity, bond prices are increasing in productivity, due to the persistence in the firm's productivity shock. Additionally, the price of debt faced by the firm is decreasing in their debt choice and increasing in their capital choice. Intuitively, the price of debt is falling in the amount of debt the firm wishes to take out because the greater debt taken out by the firm, the more likely they are to default. To understand why the price of debt is increasing in the capital choice of the firm, recall that the in the event of default, the lender is entitled to recover a fraction of the capital stock held by the firm. Thus, if the firm is willing to make a large investment in capital, they are more likely to receive a favorable price on debt, all else equal.

A firm may find itself in a position that for any realization of future productivity, the firm will never choose to default. In this case, the firm is "risk free" and can borrow at the risk free rate. Firms that typically that find themselves in this position have sufficiently low leverage ratios or currently have high productivity levels.

Finally, I plot the stationary distribution for firms over their capital stock and debt level in Figure 4. The left subplot looks at the distribution of firms over their capital stock conditional on

Figure 4: Model Distribution of Firms
— Conditional on Productivity —

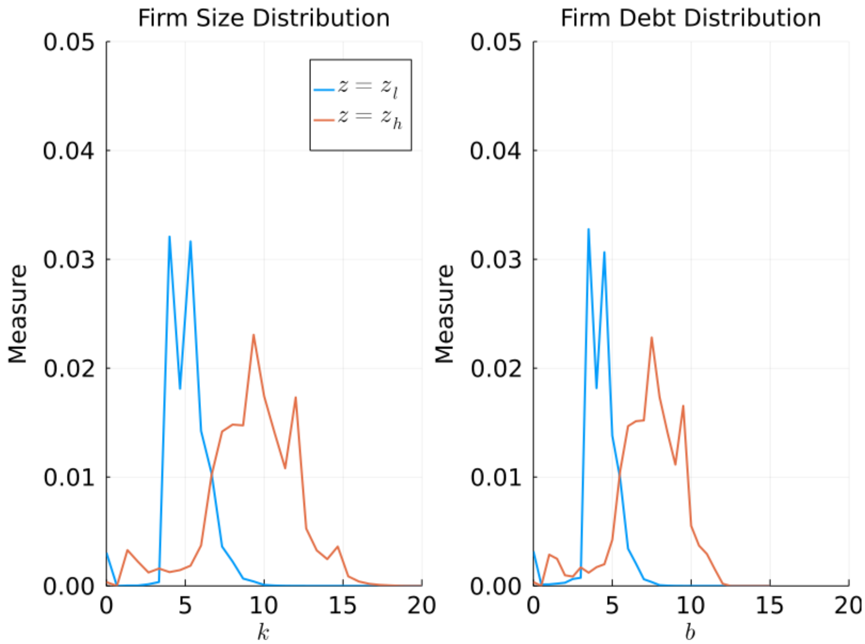


Table 7: Aggregate Model Moments

Moments	Description	Model
I	Investment	0.553
I/K	Investment Rate	0.028
B/K	Leverage	0.807
Π/K	Profitability	0.034
Frac $(d > 0)$	Fraction of Firms Issuing Dividends	0.417
$\mathbb{E}$[exit rate]	Annualized Exit Rate	6.15%
$\mathbb{E}$[default rate]	Annualized Default Rate	2.03%

their productivity level and the right subplot looks at the distribution of firms over their debt level conditional on their productivity level. It is evident from looking at the stationary distribution that the average size of firms is increasing in their productivity level. The cause for this is importantly related to the exit/default decisions made by firms and the debt prices firms of various productivity levels face. Low productivity firms are very likely to exit/default, so they face a low price (high interest rate) on taking out debt restricting how much they can grow. On the other hand, highly productive firms are less likely to default and are able to sustain high leverage ratios, This allows them to grow large and are amassed near the upper end of the capital and debt distribution. Table 7 presents some simulated moments derived from my model.

5.3 Analysis of Investment Sensitivity to Monetary Policy Shocks in and out of Contractions

I now qualitatively analyze the effect of a long run change to real interest rates on aggregate investment. In addition, I explore how the sensitivity of aggregate investment in response to a decrease in the real interest rate differs in and out of contractions, as proxied by a long-run change in aggregate TFP. All in all, there are four steady states I solve for:

i. Expansions - High Real Rate: $r = 3.0\%$ and $A = 1.0$.

ii. Expansions - Low Real Rate: $r = 2.75\%$ and $A = 1.0$.

iii. Contractions - High Real Rate: $r = 3.0\%$ and $A = 0.975$.

iv. Contractions - Low Real Rate: $r = 2.75\%$ and $A = 0.975$.

The goal of the comparative static exercise is to characterize how changes to interest rates affects changes in aggregate investment in and out of contractions.

As suggested in the data, heterogeneity among firm's risk of default is an important component for understanding the aggregate investment response to changes in monetary policy. To decompose the aggregate investment response seen in my model, I sort firms into three groups based on the probability that a given firm defaults on their debt:

i. High Risk Firms: Probability of Default $\geq 16\%$[12].

ii. Low Risk Firms: Probability of Default $\in (0\%, 16\%)$.

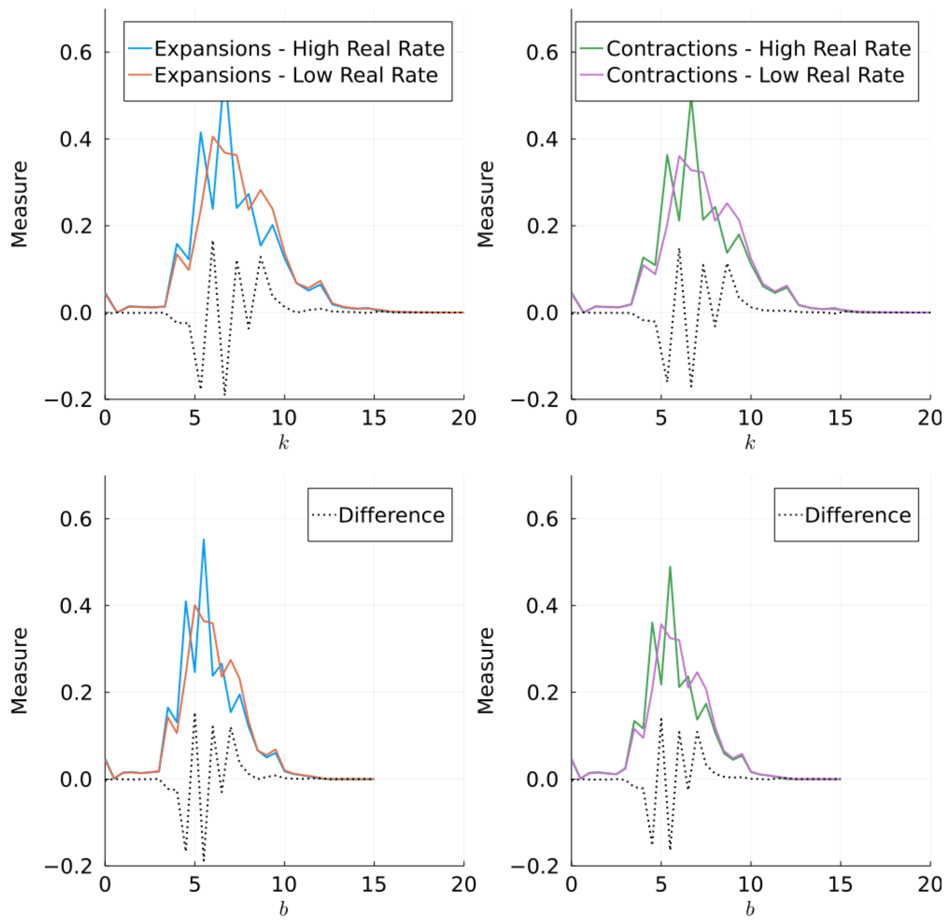
iii. Risk Free Firms: Probability of Default $= 0\%$.

By sorting firms based on their probability of default, I can characterize which firms are driving the aggregate investment response. In addition, I can also characterize how the bond prices faced by these firms impacts their ability to change their investment decision.

[12] I choose 16% as my cutoff for high risk firms because a 16% *quarterly* probability of default corresponds to an approximately 50% *annual* probability of default, which is my definition for a distressed firm in the data. If p is the quarterly probability that a firm defaults, then the annualized probability that a firm defaults is given by $p \sum_{q=1}^{4} (1-p)^{q-1}$.

While this modeling experiment is not setup is not identical with the empirical results from Section 2, the setup is tractable enough that I can cleanly decompose aggregate responses to changes in interest rates and TFP to understand how heterogeneous default risk drives my results. Future work would consider a richer modeling environment where one would include unexpected temporary shocks to both interest rates and aggregate TFP, which would lead to more realistic experiements.

Figure 5: Stationary Distribution Changes Across Equilibria



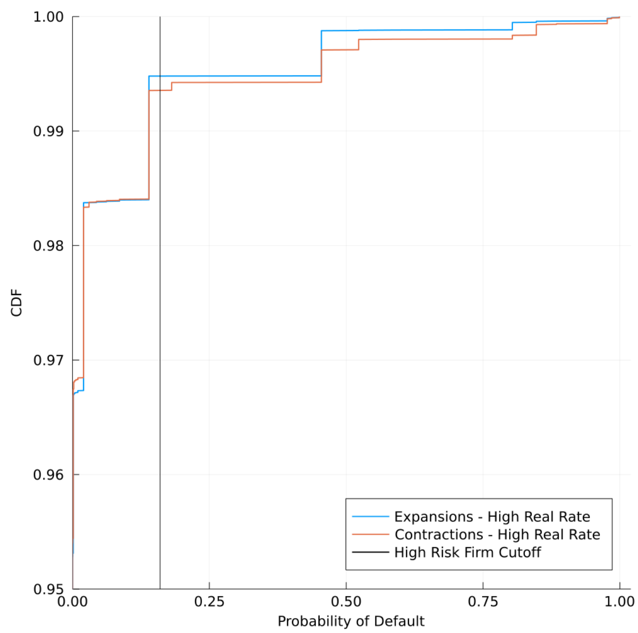
Before getting to the main results of the paper – characterizing how aggregate investment changes in response to decreases in interest rates in and out of recessions – it is important to detail how changes in the real interest rate and aggregate TFP impact the stationary distribution of firms, which is considered in Figure 5. Understanding how decreases in the interest rate shift the stationary distribution yields some intuition about how decreases in interest rates impact aggregate investment. The panels on the left (right) detail how a decrease of the real interest rate changes capital and debt holdings by firms in an expansion (contraction). Notice that in both expansions and contractions the stationary distribution shifts slightly to the left, which is consistent with the interpretation that aggregate capital and holdings increase. This is driven by two margins: (i) on average, firms hold higher levels of capital and debt – the intensive margin – and (ii) there are more firms in the economy when there is a lower interest rate – an extensive margin.

Along the intensive margin, incumbent firms are, on *average*, holding higher levels of capital and debt under a low interest rate regime[13]. For example, in expansions, average capital stock increases from 7.06 to 7.34 in the low interest rate regime and average debt stock increases from 5.69 to 5.90 in the low interest rate regime. Along the extensive margin, a decrease in the real interest rate induces more entry by firms. This is reflected by the fact that the total mass of firms in the economy increases in a low interest rate regime in both expansions and contractions. For example, in expansions, the mass of firms in a high interest rate regime is 2.83 and the mass of firms in a low interest rate regime is 2.85.

In addition to changes in the interest rate, aggregate capital and debt holdings decrease when the economy moves from an expansion to a contraction; however, this is primarily driven through the extensive margin as there is a smaller mass of firms in the economy in a contraction, due to firms defaulting or exiting.

Default Risk Distribution

Figure 6: Change in Default Risk Distribution
— Expansions v. Contractions —



Next I turn to characterizing how the distribution of default risk varies across the steady states. Figure 6 characterizes how the default risk distribution changes as the economy moves from an expansions to a contractions in the model. I find that the distribution of firm default risk, as measured by the probability of default, shifts to the left. In other words, firms become more risky. This is consistent with the interpretation of Figure 1 that firms become more risky when the

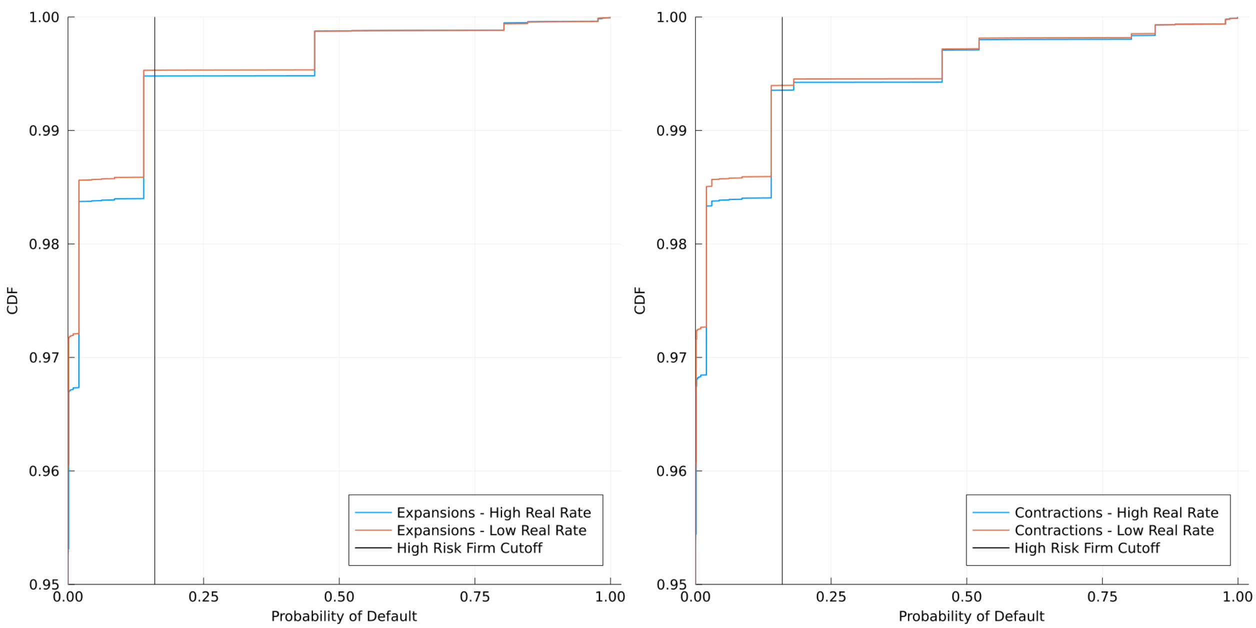
[13]Looking at average capital/debt stocks, as opposed to aggregate capital/debt stocks controls for the fact the mass of firms varies across the different steady states.

economy finds itself in a contraction. I find that the average probability of default across all firms is 1.874% in expansions and 2.070% in contractions.

In the model, there is a large fraction of risk-free firms in both expansions (blue line) and contractions (orange line), which is consistent with the data. Additionally, my model suggests that when the economy transitions from expansions to contractions, high risk firms (firms that have a quarterly probability of default of 16% or higher) become more risky, while low risk firms don't become much more risky.

Figure 7: Change in Default Risk Distribution
— Decrease in Interest Rates —

(a) Expansions (b) Contractions



Next I show how the distribution of default risk changes as the economy moves from a high interest rate regime to a low interest rate regime. Figure 7 plots how the model generated default risk distribution changes as the economy moves from a high interest rate regime to a low interest rate regime in expansions (Figure 7a) and in contractions (Figure 7b).

In response to a decrease in the interest rates, I find that the probability of default shifts to the right, which is consistent with the interpretation that firms become less risky. I find that the average probability of default across all firms falls from 1.874% to 1.681% in expansions and falls from 2.070% to 1.887% in contractions. In both expansions and contractions, I find that the mass of risk-free and low risk firms increases in response to a decrease in the real interest rate. In contrast, high risk firms only become slightly less likely to default. Thus, the model suggests that a decrease in the real interest rate makes makes low-risk firms less risky. This has implications for the bond prices firms face when issuing new debt, which will be explored later in this section.

Finally, I explore how aggregate investment differs in response to a decrease in the real interest

Table 8: Change in Investment

	Total Effect		Effect from Intensive Margin Only	
Group	Expansions	Contractions	Expansions	Contractions
Aggregate	3.869	3.845	2.882	2.733
High Risk Firms	0.754	1.271	0.203	0.187
Low Risk Firms	3.807	4.417	2.821	3.289
Risk Free Firms	4.541	4.615	3.548	3.495

rate in expansions and contractions. Table 8 reports the change in investment in response to a decrease in the real interest rate in the aggregate and across the different risk groups. This is reported in the "Total Effect" column Recall that the total effect incorporates an intensive margin — the fact that firms change their investment decisions — and an extensive margin — the fact that the mass of firms changes in response to a decrease in interest rates. The column "Effect from Intensive Margin Only" controls for the fact that the mass of firms is changing and reports how much average investment behavior is changing. The "Expansion" ("Contraction") column is measuring the percent change in investment as the economy transitions from a high-interest rate regime to a low-interest rate while the economy stays in an expansion (contraction).

In response to a decrease in the real interest rate, I find that investment increases in the aggregate and among firms of all risk groups across expansions and recessions. This result is consistent with the intuition that a decrease in interest rates incentives firms to increase investment, which will be made more explicit in the discussion of the model mechanism in the next section. Note that in both expansions and recessions, the investment response is decreasing in the riskiness of the firm. In other words, high default risk firms are less responsive to a decrease in the interest rate in both expansions and recessions, which is qualitatively consistent with the results from Table 3. In addition, I find that aggregate investment is less responsive to a decrease in the real interest rate in contractions, which is consistent with the results from Table 4. In my model, I find that aggregate investment increases by 3.89% in expansions while it only increases by 3.85% in contractions. I find that between 70% - 75% of the Total Effect is driven by the intensive margin – that is, incumbent firms are changing their investment behavior. Between 25% - 30% is driven by the extensive margin, or the fact that the mass of firms is changing across steady states. In Appendix D, I argue that the intensive margin is mainly driven by a composition effect. In other words, changes in aggregate investment are driven mainly by firms moving around within the stationary distribution and are not caused by firms changing their investment behavior.

Mechanism Explaining Result

In order to better understand the results that aggregate investment is less responsive to decreases in interest rates in contractions, it is instructive to understand what is constraining investment decisions at the firm level as these decisions ultimately aggregate up to the overall investment response to changes in monetary policy. Recall that a firm's investment decision can be financed in two different ways: internal funds and external funds. As is consistent with the Myers and Majluf (1984) pecking order theory, firms opt to finance investment first with internal funds and then with external funds. Firms opt to finance investment first with internal funds since it is costless to utilize those funds[14]. After using up internal funds, firms finance investment with external funds – debt and equity; however there is a cost associated with doing so, be it the debt price firms face Q or an equity injection cost $\lambda(e)$. How much they externally finance depends on how firms trade off the future benefits of a higher capital stock tomorrow with the risk of defaulting on their liabilities. In equilibrium, firms are relying on external debt to finance investment as evidence of the positive leverage ratio simulated from the model, presented in Table 7.

If the economy moves from a high interest rate regime to a low interest rate regime, how do firm's investment decisions respond? All firms want to increase their capital stock, since a decrease in the interest rate increases expected benefit of investment; this can be seen in Table 8. In addition, a decrease in interest rates also decreases the cost of investing by increasing the recovery value that lenders get in the event of default. However, if additional investment must be financed by firms levering up, firms may find themselves constrained in their ability to invest in additional capital because of the increase in default risk they face from borrowing more.

To highlight the mechanism clearly, I consider a special case of my model where there are no investment adjustment and equity issuance costs. Then, an incumbent firm's problem – that is, a firm that is continuing to the next period – is:

$$V^{stay}(k,b,z) = \underset{\{k',b'\}}{max} \left\{ \pi - i - b + Q(k',b',z)b' + \frac{1}{1+r} \sum_{z'} V(k',b',z')G_z(z'|z) \right\}, \tag{20}$$

Taking FOCs, we have:

$$[k']: \;\; 1 - \frac{\partial Q'}{\partial k'}b' = \frac{1}{1+r} \sum_{z'} \left[\frac{\partial \pi'}{\partial k'} + (1-\delta) \right] G_z(z'|z) \tag{21}$$

$$[b']: \;\; \frac{\partial Q'}{\partial b'}b' + Q' = \frac{1}{1+r}. \tag{22}$$

Equation 21 and 22 jointly determine the firm's optimal capital and debt choice for next period.

In Equation 21, we can interpret the left hand side as the marginal cost of investing in an additional unit of capital, while the right hand side is the discounted marginal benefit of investing in an additional unit of capital today. Recall from Figure 3b that $\partial Q/\partial k' > 0$. From this equation, it is easy to see that in response to a decrease in the interest rate, firm's want to increase investment. Additionally, investing in more capital lowers the bond price that firms pay on the debt that they take out. In other words, a higher capital choice (financed by a fixed level of debt b') reduces the marginal cost of investing. Intuitively, the firm now has more skin in the game – that is, the lender can recover more in the event of default – so they can get a more favorable rate on debt. In short, in

[14] The original paper by Myers and Majluf (1984) provides an information theoretic explanation as to why there exists a pecking order of funds. However, it is still analogous to this example.

response to a expansionary monetary policy shock, firms want to increase investment, conditional on the debt they currently hold.

How does a firm's debt choice respond if a firm wants to increase investment? We can similarly decompose Equation 22. We can interpret the left hand side as the marginal benefit of investing in an additional unit of debt, while the right hand side is the marginal cost of investing in an additional unit of debt today. Recall from Figure 3b that $\partial Q/\partial b' < 0$. Note that a higher debt choice reduces the marginal benefit of holding debt because the firm faces a lower price (higher interest rate) on their debt. If a firm wants to increase their capital stock and need to finance it by taking out additional debt, firms may find themselves constrained in doing so because for high enough values of additional debt and low enough prices (high enough interest rates) on that additional debt, the marginal benefit of holding an additional unit of debt may be close to zero or negative. In other words, firms with high default risk may find themselves in the position where they would like to increase their investment in response to a decrease in interest rates, but cannot do so because the default risk on borrowing more debt outweighs the benefits of the recovery value to the lender.

Table 9: Change in Debt Interest Rates and Debt Holdings

	Debt Interest Rates		Debt Holdings	
Group	Expansions	Contractions	Expansions	Contractions
Aggregate	-0.250	-0.250	4.610	4.888
High Risk Firms	-0.144	0.035	1.622	0.697
Low Risk Firms	-0.248	-0.248	1.410	1.279
Risk Free Firms	-0.250	-0.250	4.323	4.642

Table 9 highlights this point. In my model, a decrease in the real interest rate does not fully pass through to the interest rates faced on debt for all firms in the economy, which limits the ability of risky firms to increase their debt holdings: the pass-through of real rates is monotonically decreasing in firms riskiness. This result is consistent with the fact that a decrease in interest rates does not decrease the overall riskiness of high risk firms, as shown by Figure 7. Here, default risk of the firm is a driving factor in the firm's responsiveness to a decrease in interest rates, and provides a model consistent explanation to the empirical results provided in Table 3. What implications does this have for the transmission of monetary policy to aggregate investment over the business cycle? The distribution of firm default risk fluctuates over the business cycle, as confirmed in Figure 1. As more firms become constrained, there are more firms whose investment decision is insensitive to changes in monetary policy.

6 Conclusion

In this paper I have argued that the distribution of firm default risk leads to a state-dependence in the transmission of monetary policy. My analysis build off of the results in Ottonello and

Winberry (2020). There are two main components to my argument. First, I showed that in the micro-data, high default risk firms are less responsive to monetary policy shocks, independent of whether the economy is in an expansion or a contraction. With results in hand about the micro-level behavior of firms, I explored what are the aggregate implications of this? I estimate that investment is between 1.0 - 2.0 percent less responsive to expansionary monetary policy shocks in contractions due to changes in the distribution of firm default risk. I built a heterogeneous firm model with endogenous default. I explored qualitatively how a change in monetary policy impacts high default risk and low default risk firms differently. My model qualitatively replicates my results from the data that investment is less sensitive to expansionary monetary policy shocks in contractions due to increases in aggregate firm default risk.

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Technical Appendix

This technical appendix is organized as follows:

- Section A describes the details of the data construction in Section 2.1.
- Section B describes additional empirical results noted at the end of Section 2.
- Section C describes the computational algorithm used to solve the model in Section 4.
- Section D describes a way to decompose changes in aggregate variables into changes in the extensive margin and intensive margin described in Section 5.

A Data Construction

In this subsection, I describe the firm level variables used in the empirical exercises of the paper. All data comes from Compustat. Definitions of variables and sample selection follow relatively standard practices in the literature. For example, see Whited (1992) and Clementi and Palazzo (2016).

A.1 Variables

1. Investment: Investment is defined at $\Delta log(k_{j,t+1})$, where $k_{j,t+1}$ is the firm's capital stock at the end of period t. For each firm, I set the first value of $k_{j,t+1}$ to be the level of gross plant, property, and equipment (`ppegt`) in the first period for which it is reported in Compustat. Going forward, I compute the evolution of $k_{j,t+1}$as the change in net plant, property, and equipment (`ppent`). I do this because net investment has significantly more observations. If a firm is missing a single observation between periods, I impute the missing value with linear interpolation techniques. If there is more than a single observation missing between periods, I do not impute the value.

2. Leverage: Leverage is defined as the ratio of total debt (sum of short term debt (`dlcq`) and long term debt (`dlttq`)) to total assets (`atq`).

3. Distance to Default: Distance to default (dd) is calculated following Merton (1974) and Gilchrist and Zakrajšek (2012) and is defined as follows:

$$dd = \frac{log(V/D) + (\mu_V - 0.5\sigma_V^2)}{\sigma_V},$$

   where V denotes the total value of the firm, D denotes firm's debt, μ_V, is the annual expected return on V, and σ_V is the annual volatility of the firm's value. I estimate V following an iterative procedure based on Gilchrist and Zakrajšek (2012).

   i. Guess an initial value of the firm, where firm value is equal to the sum of debt and equity. I measure equity is measured as the firm's stock price times the number of shares outstanding. Stock price data and data on shares outstanding comes from CRSP.

   ii. Estimate the mean and variance of return on firm's value over a 250 day moving window. The return on firm's value is defined as the daily log return on assets.

iii. Obtain a new estimate of V for every day of the 250 day rolling window via the Black-Scholes-Merton option pricing framework:

$$E = V\Phi(\delta_1) - e^{-rT} D\Phi(\delta_2)$$
$$\delta_1 = \frac{log(V/D) + (r + 0.5\sigma_V^2)T}{\sigma_V^2 \sqrt{T}}$$
$$\delta_2 = \delta_1 - \sigma_V \sqrt{T}$$

where r is the daily one-year constant maturity Treasury-yield. Data comes from the Federal Reserve Board of Governors H.15 Selected Interest Rates Release.

iv. Iterate on [ii] and [iii] until convergence.

5. Real Sales Growth: Real sales growth is defined as the log difference in sales (`saleq`). Sales are deflated using the BLS implicit price deflator.

6. Size: Size is measured as the log of total real assets deflated using the BLS implicit price deflator.

7. Cash Flow: Cash flow is measured as earnings before interest and tax (EBIT) divided by the firm's capital stock.

8. Dividend Payer: Dividend payer is defined as a dummy taking the value of 1 if the firm paid dividends to preferred stock in a given quarter.

9. Sectoral Dummies: I consider the following sectors:

   i. Agriculture, forestry and fishing (SIC $<$ 999)
   ii. Mining (1000 $<$ SIC $<$ 1499)
   iii. Construction (1500 $<$ SIC $<$ 1799)
   iv. Manufacturing (2000 $<$ SIC $<$ 3999)
   v. Transportation, Communications, Electric, Gas, ad Sanitary Services (4000 $<$ SIC $<$ 4999)
   vi. Wholesale Trade (5000 $<$ SIC $<$ 5199)
   vii. Retail Trade (5200 $<$ SIC $<$ 5999)
   viii. Services (7000 $<$ SIC $<$ 8999)

A.2 Sample Selection

As is common in the empirical literature, I exclude firms in my sample that satisfy the following criteria.

1. Firms that are in:

   i. Finance, Insurance and Real Estate sectors (6000 $<$ SIC $<$ 6799).
   ii. Utilities (4900 $<$ SIC $<$ 4999).
   iii. Non-Operating Establishments (SIC = 9995),.
   iv. Industrial Conglomerates (SIC = 9997).

2. Firms that do not operate in the US.

3. Firm observations that meet the following conditions:

    i. Negative capital or assets.
    ii. Acquisitions larger than 5% of assets.
    iii. Investment rates in the top and bottom 0.5% of the distribution.
    iv. Net current assets as a share of total liabilities outside of $(-10, 10)$.
    v. Leverage higher than 10 or negative.
    vi. Quarterly real sales growth outside of $(-1, 1)$.
    vii. Negative sales.

After applying these exclusions, I winsorize observations of leverage and distance to default at the top and bottom 0.5% of the distribution.

B Additional Empirical Results

B.1 Alternate Cutoffs

In the main text, I define a distressed firm by a cutoff rule: if a firm has a measure of distance to default less than or equal to zero in a given quarter, that firm is distressed. A distance to default less than or equal to zero corresponds to the firm having a greater than 50% chance of defeating within the next year. To make sure my results are not dependent on the cutoff choice which defines a distressed firm, I consider alternative cutoff choices:

- $dd \leq -1$: this corresponds to a 84 percent chance of defaulting next year.
- $dd \leq -0.5$: this corresponds to a 69 percent chance of defaulting next year.
- $dd \leq 0.5$: this corresponds to a 30 percent chance of defaulting next year.
- $dd \leq 1$: this corresponds to a 15 percent chance of defaulting next year.

From here, I rerun the regression specified in Equation 25. The results are displayed in Table 10. The regression results show that the qualitative results from the main text are robust to different cutoff values. Note that the coefficients are increasing in the size of the cutoff: as a larger fraction of firms is considered "distressed", the decrease in investment response to an expansionary monetary policy shock grows. This is expected, since we are taking into account the investment response of a larger number of firms by definition.

Table 10: Alternate Cutoff Rules

	(1) $\Delta log(K_{t+1})$	(2) $\Delta log(K_{t+1})$	(3) $\Delta log(K_{t+1})$	(4) $\Delta log(K_{t+1})$	(5) $\Delta log(K_{t+1})$	(6) $\Delta log(K_{t+1})$	(7) $\Delta log(K_{t+1})$	(8) $\Delta log(K_{t+1})$	(9) $\Delta log(K_{t+1})$	(10) $\Delta log(K_{t+1})$	(11) $\Delta log(K_{t+1})$	(12) $\Delta log(K_{t+1})$
ffr	0.05	0.24	0.22	-0.00	0.22	0.20	-0.05	0.26*	0.25	-0.07	0.20	0.22
	(0.20)	(0.18)	(0.19)	(0.22)	(0.17)	(0.18)	(0.22)	(0.16)	(0.16)	(0.23)	(0.14)	(0.15)
% distressed firms × ffr shock: cutoff = -1	-2.78***											
	(0.52)											
% distressed assets × ffr shock: cutoff = -1		-7.59***										
		(1.52)										
% distressed sales × ffr shock: cutoff = -1			-4.13***									
			(1.17)									
% distressed firms × ffr shock: cutoff = -0.5				-2.91***								
				(0.57)								
% distressed assets × ffr shock: cutoff = -0.5					-6.32***							
					(1.32)							
% distressed sales × ffr shock: cutoff = -0.5						-4.18***						
						(0.98)						
% distressed firms × ffr shock: cutoff = 0.5							-3.30***					
							(0.60)					
% distressed assets × ffr shock: cutoff = 0.5								-2.92***				
								(0.71)				
% distressed sales × ffr shock: cutoff = 0.5									-3.05***			
									(0.73)			
% distressed firms × ffr shock: cutoff = 1										-3.52***		
										(0.67)		
% distressed assets × ffr shock: cutoff = 1											-3.37***	
											(0.98)	
% distressed sales × ffr shock: cutoff = 1												-3.58***
												(0.97)
Observations	108	108	108	108	108	108	108	108	108	108	108	108
R^2	0.122	0.166	0.115	0.123	0.164	0.125	0.124	0.117	0.116	0.122	0.137	0.130

Table 11: Gilchrist and Zakrajšek (2012) Spread

	(1) $\Delta log(K_{t+1})$
ffr	0.32**
	(0.15)
GZ Spread × ffr shock	-3.16***
	(0.70)
Observations	107
R^2	0.117

B.2 Gilchrist and Zakrajšek (2012) Spread

Gilchrist and Zakrajšek (2012) develop a measure aggregate credit conditions known as the GZ-Spread. To ensure that my aggregate measure of firm default risk – defined by the measure of distressed firms in the economy – are sensible, I run the following regression:

$$\Delta log(K_{t+1}) = \beta GZ_t \varepsilon_t^m + \Gamma' Z_t + e_t. \tag{23}$$

This regression specification is identical to Equation 25 except that I substitute the GZ-Spread in for my measure of firm default risk. The results are in Table 11. The estimated coefficients appear to be in line with the estimated coefficients from the regression in Equation 25.

B.3 NIPA Data

Table 12: NIPA Data

	(1) $\Delta log(K_{t+1})$	(2) $\Delta log(K_{t+1})$	(3) $\Delta log(K_{t+1})$
ffr	0.28	0.68***	0.68***
	(0.30)	(0.25)	(0.26)
% distressed firms × ffr shock	-4.88***		
	(0.77)		
% distressed assets × ffr shock		-8.89***	
		(1.32)	
% distressed sales × ffr shock			-6.29***
			(1.10)
Observations	108	108	108
R^2	0.163	0.182	0.159

I construct a series for aggregate investment from Compustat. To ensure that my aggregate investment series behaves similar to aggregate investment data as a whole, I rerun the regression in Equation 25 where my aggregate investment series comes from NIPA. The results are in Table 12. Compared to my baseline results, the estimated decrease in investment sensitivity from expansions to contractions is larger. This is likely because Compustat only considers large public firms in their sample while NIPA is much larger. However, the qualitative results still hold: As the distribution of firm default risk gets worse, firm investment's sensitivity to monetary policy shocks decline.

B.4 Leverage

In the main text, I focus on distance to default the main measure of firm default risk. In this section I consider a firm's leverage ratio as a proxy for a firm's default risk. I run the regression:

$$\Delta log(k_{i,t+1}) = \alpha_i + \alpha_{s,t} + \beta(lev_{i,t-1} - \bar{lev_i})\varepsilon_t^m + \Gamma' Z_{i,t} + e_{j,t} \tag{24}$$

where α_i is a firm specific fixed effect, $\alpha_{s,q}$ is a sector quarter fixed effect, ε_t^m is a quarterly aggregated monetary policy shock, and $\beta(lev_{i,t-1} - \bar{lev_i})$ is a demeaned leverage. Equation 24 considers interactions between a demeaned measure of a firm's financial position with a monetary policy shock; the coefficient β captures how the semi-elasticity of firm investment varies with their measure of distance to default. Table 13 reports the results for three different samples: (1) the full sample, (2) non-contraction periods, and (3), contraction periods. Recession periods are a dummy variable that takes a value of one if the economy is in a contraction as measured by NBER Business Cycle Dating Committee. The results are presented in Table 13 and the interpretation of the coefficients is analogous to that in the main text: Firms that have a higher leverage ratio are more less responsive to monetary policy shocks. This holds across the business cycle.

Table 13: Heterogeneous Responses Of Monetary Policy: Leverage[a]

	Full Sample	Expansions	Contractions
	(1)	(2)	(3)
	$\Delta log(k_{t+1})$	$\Delta log(k_{t+1})$	$\Delta log(k_{t+1})$
lev × ffr shock	-0.78**	-0.92**	-0.79
	(0.32)	(0.40)	(0.48)
Observations	370763	328887	41010
R^2	0.122	0.129	0.331
Time sector FE	yes	yes	yes
Time clustering	yes	yes	yes

[a] *, **, and *** denotes significance at 10%, 5%, and 1% levels respectively. Results are from estimating $\Delta log(k_{i,t+1}) = \alpha_i + \alpha_{s,t} + \beta(lev_{i,t-1} - \bar{lev_i})\varepsilon_t^m + \Gamma' Z_{i,t} + e_{j,t}$, where α_i is a firm fixed effect, $\alpha_{s,t}$ is a sector-by-quarter fixed effect, $lev_{i,t-1} - \bar{lev_i}$ is demeaned leverage, ε_t^m is a monetary policy shock (with the sign normalized so expansionary shocks are positive numbers), $Z_{i,t}$ is a vector of firm-level controls containing demeaned leverage, sales growth, size, current assets as a share of total assets, an indicator for fiscal quarter, and the interaction of demeaned financial position with lagged GDP growth. Standard errors are two-way clustered by firms and quarter.

Analogous to the main text, I define a distressed firm if it has a leverage ratio greater than 75% and run the following regression:

$$\Delta log(K_{t+1}) = \beta \phi_t^{lev} \varepsilon_t^m + \Gamma' Z_t + e_t \tag{25}$$

where Z_t is a vector of aggregate controls including ϕ_t^{dd}, the effective federal funds rate, and aggregate GDP. Aggregate capital is constructed using the Compustat data. The results, presented in Table 14, hold the opposite interpretation with those in the main body of the text: When the fraction of firms with a leverage ratio greater than 75% increases, aggregate investment is more responsive to monetary policy shocks.

Table 14: Monetary Policy Over the Distribution[a]

	(1) $\Delta log(K_{t+1})$	(2) $\Delta log(K_{t+1})$	(3) $\Delta log(K_{t+1})$
% distressed firms × ffr shock	2.53**		
	(1.16)		
% distressed assets × ffr shock		2.26*	
		(1.29)	
% distressed sales × ffr shock			2.00
			(1.42)
Observations	108	108	108

[a] *, **, and *** denotes significance at 10%, 5%, and 1% levels respectively. Results are from estimating $\Delta log(K_{t+1}) = \beta\phi_t^{lev}\varepsilon_t^m + \Gamma' Z_t + e_t$, where ϕ^{lev} is a measure of the fraction of distressed firm, ε_t^m is a monetary policy shock (with the sign normalized so expansionary shocks are positive numbers), Z_t is a vector of aggregate-level controls containing ϕ_t^{dd}, the effective federal funds rate, and GDP growth. Newey-West standard errors are reported.

C Computational Algorithm

In this section I describe the computational algorithm used to solve the model in the main text.

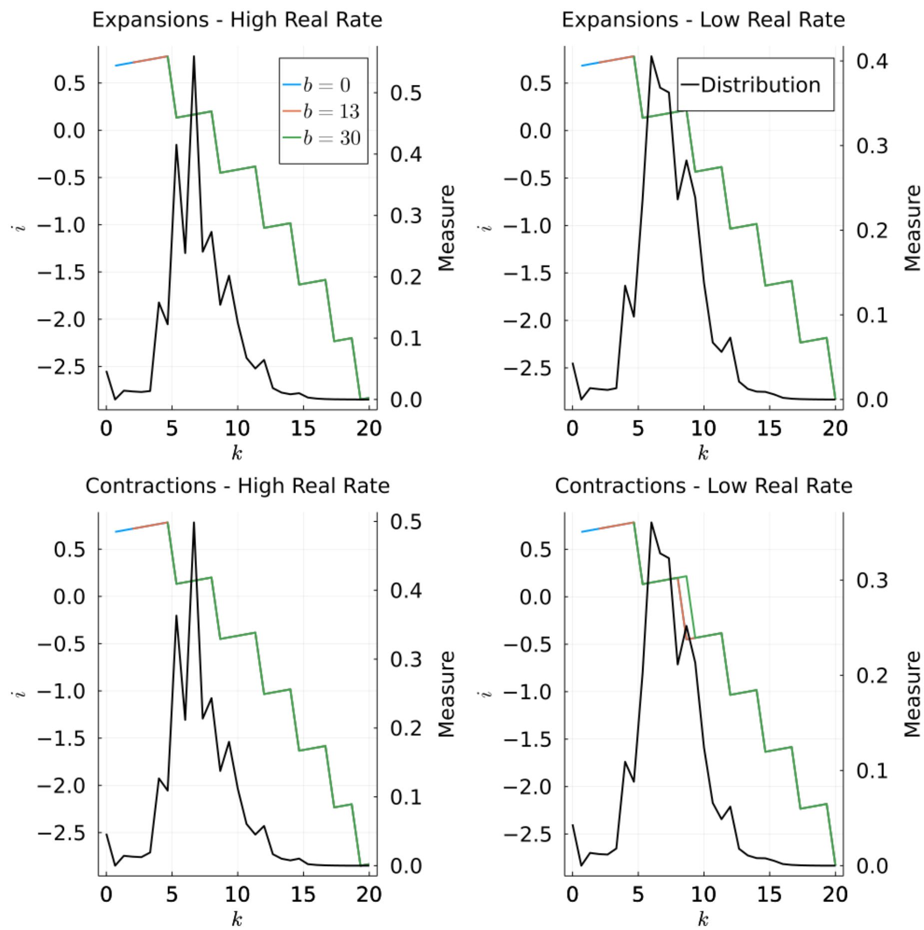
1. Set grids for $k \in K$ and $b \in B$ such that firm choices fall within the interior of the set.
2. Guess wage rate w_0 and menu of bond prices $Q_0(k', b', z)$.
3. Solve firm's problem to obtain $V(k, b, z)$.
4. Evaluate zero profit condition at $Q_0(k', b', z)$: if satisfied, continue; otherwise, return to step 2 and update bond prices following Equation 15.
5. Evaluate free entry condition at wage w_0: if satisfied, continue; otherwise return to step 2 and update wage as follows: if $V^E > 0$, set $w_1 > w_0$; otherwise, if $V^E < 0$, set $w_1 < w_0$.
6. Solve for the mass of firms from labor market clearing. Derive the stationary distribution when $m = 1$, defined to be $\mu * (k, b, z; m = 1)$. Calculate labor demand as

$$L_d(w^*; m = 1) = \int_{K,B,Z} (1 - g^{exit}(k, b, z)) g_l^{stay}(k, b, z) d\mu(k, b, z, A; m = 1) + m \int_Z g_l^{stay}(k_0, b_0, z)\bar{G}(dz)$$

Set m^* to satisfy $L_s(w^*) = m^* L_d(w^*; m = 1)$.

D Decomposition of Intensive Margin

Figure 8: Investment Change Intensive Margin Decomposition



Changes in aggregate investment across steady states change along two margins: an extensive and intensive margin. The extensive margin accounts for firm entry and exit into the economy across steady states. The intensive margin accounts for changes among incumbent firms. In the "Total Effect" column of Table 8, I report the effect that a decrease in interest rates has on aggregate investment. This change has accounts for both the extensive and intensive margin. The "Intensive Margin Only Effect" column controls for the extensive margin to understand how incumbent firms are changing their behavior.

The intensive margin can be further decomposed into an behavior effect and a composition effect. The behavior effect accounts for how firms change their optimal investment behavior in response to a decrease in the real interest rate. The composition effect accounts for how firms move around within the stationary distribution. In my model, I find that the composition effect is responsible for driving much of the change in aggregate investment attributed to the intensive margin.

Figure 8 looks to highlight this point. Each subplot is one of the four steady states I solve for. The blue, orange, and green line show the investment policy function, as a function of firm's capital stock, for a given debt level The black line plots the stationary capital distribution. Note that when the economy transitions from a high interest rate regime to a low interest rate regime, the policy functions do not change by much. However, as discussed in Section 5, there is a shift in the stationary distribution as firms on average become larger.