The Collateralizability Premium

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Abstract

This paper studies the implications of credit market frictions for the cross-section of expected stock returns. A common prediction of macroeconomic theories of credit market frictions is that the tightness of financial constraints is countercyclical. As a result, capital that can be used as collateral to relax such constraints provides insurance against aggregate shocks and should command a lower risk compensation compared non-collateralizable assets. Based on a novel measure of asset collateralizability, we provide empirical evidence that supports the above prediction. A long-short portfolio constructed from firms with low and high asset collateralizability generates an average excess return of around 7.96% per year. We develop a general equilibrium model with heterogeneous firms and financial constraints to quantitatively account for the effect of collateralizability on the cross-section of expected returns.

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1 Introduction

A large literature in economics and finance emphasizes the importance of credit market frictions in affecting macroeconomic fluctuations.[1] Although models differ in details, a common prediction is that financial constraints exacerbate economic downturns because they are more binding in recessions. As a result, theories of financial frictions predict that assets that relax financial constraints should provide insurance against aggregate shocks. We evaluate the implication of this mechanism for the cross-section of equity returns.

From the asset pricing perspective, when financial constraints are binding, the value of collateralizable capital includes not only the dividends it generates, but also the present value of the Lagrangian multipliers of the collateral constraints it relaxes. If financial constraints are tighter in recessions, then a firm that holds more collateralizable capital should require a lower expected return in equilibrium, since the collateralizability of its assets provides a hedge against the risk of being financially constrained, making the firm less risky.

To examine the relationship between asset collateralizability and expected returns, we first construct a measure of firms' asset collateralizability. Guided by the corporate finance theory that links firms' capital structure decisions to collateral constraints, for example, Rampini and Viswanathan (2013), we measure asset collateralizability as the value-weighted average of the collateralizability of the different types of assets owned by the firm. Our measure can be interpreted as the fraction of firm value that can be attributed to the collateralizability of its assets.

We sort stocks into portfolios according to this collateralizability measure and document that the spread between the low collateralizability portfolio and the high-collateralizability portfolio is on average about 7.96% per year among the financially constrained firms. In Appendix A, we provide more empirical evidence to show the robustness on the collateralizability premium. The difference in returns remains significant after controlling for conventional factors such as the market, size, value, momentum, and profitability.

To quantify the effect of asset collateralizability on the cross-section of expected returns, we develop a general equilibrium model with heterogeneous firms and financial constraints. In our model, firms are operated by entrepreneurs who experience idiosyncratic productivity shocks. As in Kiyotaki and Moore (1997, 2012), lending contracts can not be fully enforced and therefore requires collateral. Firms with high productivity and low net worth have higher financing needs and in equilibrium, acquires more collateralizable assets in order to borrow. In the constrained efficient allocation in our model, heterogeneity in productivity and net

[1] Quadrini (2011) and Brunnermeier et al. (2012) provide comprehensive reviews of this literature.

worth translates into heterogeneity in the collateralizability of firm assets. In this setup, we show that, at the aggregate level, collateralizable capital requires lower expected returns in equilibrium, and in the cross-section, firms with high asset collateralizability earn low risk premiums.

We calibrate our model by allowing for the negatively correlated productivity and financial shocks. It quantitatively matches the conventional macroeconomic quantity dynamics and asset pricing moments, and is able to quantitatively account for the empirical relationship between asset collateralizability, leverage, and expected returns.

Related Literature This paper builds on the large macroeconomics literature studying the role of credit market frictions in generating fluctuations across the business cycle (see Quadrini (2011) and Brunnermeier et al. (2012) for recent reviews). The papers that are most related to ours are those emphasizing the importance of borrowing constraints and contract enforcements, such as Kiyotaki and Moore (1997, 2012), Gertler and Kiyotaki (2010), He and Krishnamurthy (2013), and Brunnermeier and Sannikov (2014). Gomes et al. (2015) studies the asset pricing implications of credit market frictions in a production economy. A common prediction of the papers in this literature is that the tightness of borrowing constraints is counter-cyclical. We study the implications of this prediction on the cross-section of expected returns.

Our paper is also related to the corporate finance literature that emphasize the importance of asset collateralizability for the capital structure decisions of firms. Albuquerque and Hopenhayn (2004) study dynamic financing with limited commitment, Rampini and Viswanathan (2010, 2013) develop a joint theory of capital structure and risk management based on asset collateralizability, and Schmid (2008) considers the quantitative implications of dynamic financing with collateral constraints. Falato et al. (2013) provide empirical evidence for the link between asset collateralizability and leverage in aggregate time series and in the cross section.

Our paper belongs to the literature on production-based asset pricing, for which Kogan and Papanikolaou (2012) provide an excellent survey. From the methodological point of view, our general equilibrium model allows for a cross section of firms with heterogeneous productivity and is related to previous work including Gomes et al. (2003), Gârleanu et al. (2012), Ai and Kiku (2013), and Kogan et al. (2017). Compared to the above papers, our model incorporates financial frictions. In addition, our aggregation result is novel: despite the heterogeneity in productivity and the presence of aggregate shocks, the equilibrium in our model can be solved without using distribution as a state variable.

Our paper is also connected to the broader literature that links investment to the cross section of expected returns. Zhang (2005) provides an investment-based explanation for the value premium. Li (2011) and Lin (2012) focus on the relationship between R&D investment and expected stock returns. Eisfeldt and Papanikolaou (2013) develop a model of organizational capital and expected returns. Belo et al. (2017) study implications of equity financing frictions on cross-section of stock returns.

The rest of the paper is organized as follows. We summarize our empirical results on the relationship between asset collateralizability in Section 2. We describe a general equilibrium model with collateral constraints in Section 3 and analyze its asset pricing implications in 4. In Section 5, we provide a quantitative analysis of our model. Section 6 concludes.

2 Empirical facts

2.1 Measuring collateralizability

To examine the link between asset collateralizability and expected returns, we first construct a measure of collateralizability at the firm level. Models with collateral constraints typically feature financing constraints that take the following general form:

$$B_i \leq \sum_{j=1}^{J} \zeta_j q_j K_{i,j}, \tag{1}$$

where we assume that there are J types of capital that differ in their collateralizability. We use q_j for the price of type j capital, and $K_{i,j}$ for the amount of type j capital used by firm i. In equation (1), B_i for the total amount of borrowing for firm i, and $\zeta_j \in [0, 1]$ is the collateralizability parameter for capital of type j. A value of $\zeta_j = 1$ implies that type-j capital can be fully collateralized, and $\zeta_j = 0$ means that this type of capital cannot be collateralized at all.

Our collateralizability measure is the value-weighted average of the collateralizability for a firm's asset. Specifically, the collateralizability of fim i's asset, $\bar{\zeta}_i$ is defined as:

$$\bar{\zeta}_i \equiv \sum_{j=1}^{J} \zeta_j \frac{q_j K'_{i,j}}{V_i}, \tag{2}$$

where V_i denotes the total value of firm i's assets. In models of financing constraints, the value of collateralizable capital typically includes both the present value of the dividends it generates and that of the Lagrangian multipliers on the collateral constraints it relaxes. In Section 4 of the paper, we show that, in our model, the measure $\bar{\zeta}_i$ can be intuitively interpreted as weight of present value of the Lagrangian multiplier in firms' asset valuation. As a result, it summarizes the heterogeneity in firms' risk exposure due to asset collateralizability.

To construct the collateralizability measure, $\bar{\zeta}_i$ for each firm, we follow a two-step procedure. First, we use a regression-based approach to estimate the structural callateralizability parameters ζ_j for each type of capital. Motivated by the previous work, for example, Rampini and Viswanathan (2013, 2017), we broadly classify assets into three categories base on their collateralizability: structures, equipment, and intangible capital. Dividing both sides of inequality (1) by the total value of assets at time t, $V_{i,t}$, and focusing on the subset of firms whose collateral constraints are binding, we obtain

$$\frac{B_{i,t}}{V_{i,t}} = \sum_{j=1}^{J} \zeta_j \frac{q_{j,t} K_{i,j,t+1}}{V_{i,t}}.$$

The above equation links firms' leverage ratio, $\frac{B_{i,t}}{V_{i,t}}$ to the value-weighted collateralizability parameters. Empirically, we run a panel regression of firm leverage, $\frac{B_{i,t}}{V_{i,t}}$, on the relative weights of the different types of capital to estimate the collateralizability parameter ζ_j for structures and equipment, respectively.[2]

Second, the firm i specific "collateralizability score", denoted as $\bar{\zeta}_{i,t}$, is defined as a weighted average of collateralizability by

$$\bar{\zeta}_{i,t} = \sum_{j=1}^{J} \widehat{\zeta}_j \frac{q_{j,t} K_{i,j,t+1}}{V_{i,t}},$$

where $\widehat{\zeta}_j$ denotes the coefficient estimate from the panel regression described above. We provide further details concerning the construction of the collateralizability measure in Appendix B.1. .

2.2 Collateralizability and expected returns

In this section, we provide empirical evidence on the relationship between asset collateralizability and expected returns. Consistent with theoretical models of financial constraints, we focus on the subset of financially constrained firms. We sort financially constrained firms

[2] We impose the restriction that $\zeta_j = 0$ for intangible capital both because previous work typically argue that intangible capital cannot be used as collateral, and because its empirical estimate is slightly negative in unrestricted regressions.

into portfolios according to our asset collateralizability measure developed in our previous section. Table 1 reports the average annualized excess returns and the Sharpe ratio of the five collateralizability sorted portfolios, where we use three alternative measures of financial constraints, the WW index (Whited and Wu (2006), Hennessy and Whited (2007)), the SA index (Hadlock and Pierce (2010)) and dividend payment. We classify a firm as being financially constrained if it has a WW index higher than the median (top panel), or a SA index higher than the median (middle panel), or if it does not pay any dividend during that year (bottom panel). In the top panel, among the financially constrained firms, the low collateralizability portfolio (Quintile 1) and high collateralizability portfolio (Quintile 5) deliver a 7.96% annual return spread. The return difference is both statistically and economically significant with a t-statistic of 2.76. Other measures of financial constraints produce similar results: the magnitude and the statistical significance of the return differences of collateralizability sorted portfolios have a similar pattern in the middle and the bottom panel of Table 1.

Table 1: Univariate Portfolio Sorting on Collateralizability, Value Weighted

This table reports average excess returns in annual percentages and their statistics for portfolios sorted on collateralizability. The sample starts from 1979 July and ends in 2016 December. At the end of June of each year t, we sort the constrained firms into five quintiles based on collateralizability measure at the end of year $t-1$. Firms are classified as constrained at the end of year $t-1$, if their WW and SA index are higher than the corresponding median in year $t-1$, or if the firms do not pay dividend in year $t-1$. WW and SA index are constructed according to Whited and Wu (2006) and Hadlock and Pierce (2010). The table reports average excess returns $E[R]-r^f$, standard errors σ, t-statistics (t), and Sharpe ratio SR. We annualize returns by mutiplying by 12. All portfolio returns are value-weighted by firm market capitalization.

	1	2	3	4	5	1-5
	Financially constrained firms - WW index					
$E[R]-R_f(\%)$	13.33	11.59	9.43	9.37	5.36	7.96
t-stat	(2.82)	(2.71)	(2.32)	(2.33)	(1.44)	(2.76)
SR	0.46	0.44	0.38	0.38	0.24	0.45
	Financially constrained firms - SA index					
$E[R]-R_f(\%)$	10.42	11.40	11.42	8.47	4.47	5.95
t-stat	(2.16)	(2.55)	(2.61)	(2.14)	(1.12)	(2.11)
SR	0.35	0.42	0.43	0.35	0.18	0.34
	Financially constrained firms - Non-Dividend					
$E[R]-R_f(\%)$	14.98	9.91	12.10	6.34	7.97	7.00
t-stat	(3.30)	(2.33)	(2.78)	(1.48)	(2.08)	(2.50)
SR	0.54	0.38	0.45	0.24	0.34	0.41

In sum, the collateralizability spread in the group of financially constrained firms is consistent with theoretical models of financial constraints. In the next section, we develop a general equilibrium model to formalize the above intuition and to quantitatively account for the (negative) collateralizability premium.

3 A general equilibrium model

This section describes the ingredients of our quantitative theory of the collateralizability spread. The aggregate aspect of the model is intended to follow standard macro models with collateral constraints such as Kiyotaki and Moore (1997) and Gertler and Kiyotaki (2010). We allow for heterogeneity in the collateralizability of assets as in Rampini and Viswanathan (2013). The key additional elements in the construction of our theory are idiosyncratic productivity shocks and firm entry and exit. These features allow us to generate quantitatively plausible firm dynamics in order to study the implication of financial constraints for the cross section of equity returns.

3.1 Households

Time is infinite and discrete. The representative household consists of a continuum of workers and a continuum of entrepreneurs. Workers and entrepreneurs receive their incomes every period and submit them to the planner of the household, who makes decisions for consumption for all members of the household. Entrepreneurs and workers make their financial decisions separately.[3]

The household ranks her utility according to the following recursive preference as in Epstein and Zin (1989):

$$U_t = \left\{ (1-\beta) C_t^{1-\frac{1}{\psi}} + \beta \left(E_t[U_{t+1}^{1-\gamma}] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}},$$

where β is the time discount rate, ψ is the intertemporal elasticity of substitution, and γ is the relative risk aversion. As we will show later in the paper, together with the endogenous equilibrium long run risk, the recursive preferences in our model generate a volatile pricing kernel and a significant equity premium as in Bansal and Yaron (2004).

In every period t, the household purchases the amount $B_t(i)$ of risk-free bonds from entrepreneur i, from which she will receive $B_t(i)R_{t+1}^f$ next period, where R_{t+1}^f denotes the risk-free interest rate from period t to $t+1$. In addition, she receives capital income $\Pi_t(i)$

[3] Like Gertler and Kiyotaki (2010) we make the assumption that household members make joint decisions on their consumption to avoid the need to keep the distribution of entrepreneur income as the state variable.

from entrepreneur i and labor income $W_t L_t(j)$ from worker j. Without loss of generality, we assume that all workers are endowed with the same number of hours per period, and suppress the dependence of $L_t(j)$ on j. The household budget constraint at time t can therefore be written as:

$$C_t + \int B_t(i)\, di = W_t L_t + R_t^f \int B_{t-1}(i)\, di + \int \Pi_t(i)\, di.$$

Let M_{t+1} denote the the stochastic discount factor implied by household consumption. Under recursive utility, $M_{t+1} = \beta \left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\psi}} \left(\frac{U_{t+1}}{E_t[U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}$, and the optimality of the intertemporal saving decisions implies that the risk-free interest rate must satisfy

$$E_t[M_{t+1}] R_{t+1}^f = 1.$$

3.2 Entrepreneurs

Entrepreneurs are agents operating a productive idea. An entrepreneur who starts at time 0 draws an idea with initial productivity $\bar{z}$ and begins operation with initial net worth N_0. Under our convention, N_0 is also the total net worth of all entrepreneurs at time 0 because the total measure of all entrepreneurs is normalized to one.

Let $N_{i,t}$ denote the net worth of an entrepreneur i at time t, and let $B_{i,t}$ denote the total amount of risk-free bonds the entrepreneur issues to the household. Then the time-t budget constraint for the entrepreneur is given as

$$q_{K,t} K_{i,t+1} + q_{H,t} H_{i,t+1} = N_{i,t} + B_{i,t}. \tag{3}$$

In (3) we assume that there are two types of capital, K and H, that differ in their collateralizability and use $q_{K,t}$ and $q_{H,t}$ for their prices at time t. $K_{i,t+1}$ and $H_{i,t+1}$ is the amount of capital that entrepreneur i purchases at time t, which can be used for production in period from t to $t+1$. We assume that at time t, the entrepreneur has an opportunity to default on his lending contract and abscond with all of the type-H capital and a fraction of $1-\zeta$ of the type-K capital. Because lenders can retrieve a fraction ζ fraction of the type-K capital upon default, borrowing is limited by

$$B_{i,t} \leq \zeta q_{K,t} K_{i,t+1}. \tag{4}$$

Type-K capital can therefore be interpreted as collateralizable, while type-H capital cannot be used as collateral.

From time t to $t+1$, the productivity of entrepreneur i evolves according to the law of motion

$$z_{i,t+1} = z_{i,t} e^{\mu + \sigma \varepsilon_{i,t+1}}, \tag{5}$$

where $\varepsilon_{i,t+1}$ is a Gaussian shock assumed to be i.i.d. across agents i and over time. We use $\pi\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right)$ to denote the entrepreneur i's equilibrium profit at time $t+1$, where $\bar{A}_{t+1}$ is aggregate productivity in period $t+1$.

In each period, after production, the entrepreneur experiences a liquidation shock with probability λ, upon which he loses his idea and needs to liquidate his net worth to return it back to the household.[4] If the liquidation shock happens, the entrepreneur restarts with a draw of a new idea with initial productivity $\bar{z}$ and an initial net worth χN_t in period $t+1$, where N_t is the total (average) net worth of the economy in period t, and χ is a parameter that determines the ratio of the initial net worth of entrepreneurs relative to that of the economy-wide average. Conditioning on not receiving a liquidation shock, the net worth $N_{i,t+1}$ of entrepreneur i at time $t+1$ is determined as

$$\begin{aligned} N_{i,t+1} &= \pi\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right) + (1-\delta)\, q_{K,t+1} K_{i,t+1} \\ &\quad + (1-\delta)\, q_{H,t+1} H_{i,t+1} - R_{f,t+1} B_{i,t}. \end{aligned} \tag{6}$$

The interpretation is that the entrepreneur receives $\pi\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right)$ from production. His capital holdings depreciate at rate δ, and he needs to pay back the debt borrowed last period plus interest, amounting to $R_{f,t+1} B_{i,t}$.

Because whenever liquidity shock happens, entrepreneurs submit their net worth to the household who chooses consumption collectively for all members, they value their net worth using the same pricing kernel as the household. Let $V_t^i\left(N_{i,t}\right)$ denote the value function of entrepreneur i. It must satisfy the following Bellman equation

$$V_t^i\left(N_{i,t}\right) = \max_{K_{i,t+1}, H_{i,t+1}, N_{i,t+1}} E_t\left[M_{t+1}\{\lambda N_{i,t+1} + (1-\lambda)\, V_{t+1}^i\left(N_{i,t+1}\right)\}\right], \tag{7}$$

where the law of motion of $N_{i,t+1}$ is given by (6).

We use variables without an i subscript to denote economy-wide aggregate quantities, the

[4] This assumption effectively makes entrepreneurs less patient than the household and prevents them from saving their way out of the financial constraint.

aggregate net worth in the entrepreneurial sector satisfies

$$N_{t+1} = (1-\lambda)\left[\begin{array}{c} \pi\left(\bar{A}_{t+1}, K_{t+1}, H_{t+1}\right) + (1-\delta)\, q_{K,t+1} K_{t+1} \\ + (1-\delta)\, q_{H,t+1} H_{t+1} - R_{f,t+1} B_t \end{array}\right] + \lambda \chi N_t, \tag{8}$$

where $\pi\left(\bar{A}_{t+1}, K_{t+1}, H_{t+1}\right)$ denotes the aggregate profit of all entrepreneurs.

3.3 Production

3.3.1 Final output

With $z_{i,t}$ denoting the idiosyncratic productivity for firm i at time t, output $y_{i,t}$ of firm i at time t is assumed to be generated through the following production technology:

$$y_{i,t} = \bar{A}_t \left[z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu}\right]^{\alpha} L_{i,t}^{1-\alpha} \tag{9}$$

In our formulation, α is capital share, and ν is the span of control parameter as in Atkeson and Kehoe (2005). Note that collateralizable and non-collateralizable capitals are perfect substitutes in production. This assumption is made for tractability.

Firm i's profit at time t, $\pi\left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t}\right)$ is given as

$$\begin{aligned} \pi\left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t}\right) &= \max_{L_{i,t}} y_{i,t} - W_t L_{i,t} \\ &= \max_{L_{i,t}} \bar{A}_t \left[z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu}\right]^{\alpha} L_{i,t}^{1-\alpha} - W_t L_{i,t}, \end{aligned} \tag{10}$$

where W_t is the equilibrium wage rate, and $L_{i,t}$ is the amount of labor hired by entrepreneur i at time t.

It is convenient to write the profit function explicitly by maximizing out labor in equation (10) and using the labor market clearing condition $\int L_{i,t} di = 1$ to get

$$L_{i,t} = \frac{z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu}}{\int z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu} di}, \tag{11}$$

and

$$\pi\left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t}\right) = \alpha \bar{A}_t z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu}\left[\int z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu} di\right]^{\alpha-1}. \tag{12}$$

Given the output of firm i, $y_{i,t} = \bar{A}_t \left[z_{i,t}^{1-\nu}\left(K_{i,t} + H_{i,t}\right)^{\nu}\right]^{\alpha} L_{i,t}^{1-\alpha}$, the total output of the economy is given as

$$Y_t = \int y_{i,t} di,$$
$$= \bar{A}_t \left[\int z_{i,t}^{1-\nu} (K_{i,t} + H_{i,t})^{\nu} di \right]^{\alpha}. \quad (13)$$

3.3.2 Capital goods

We assume that capital goods are produced from a constant-return-to-scale and convex adjustment cost function $G(I, K + H)$, that is, one unit of the investment good costs $G(I, K + H)$ units of consumption goods. Therefore, the aggregate resource constraint is

$$C_t + I_t + G(I_t, K_t + H_t) = Y_t. \quad (14)$$

Without loss of generality, we assume that $G(I_t, K_t + H_t) = g\left(\frac{I_t}{K_t+H_t}\right)(K_t + H_t)$ for some convex function g.

We further assume that fractions ϕ and $1-\phi$ of the new investment goods can be used for type-K and type-H capital, respectively. This is another simplifying assumption. Because at the aggregate level, the ratio of type-K to type-H capital is always equal to $\frac{\phi}{(1-\phi)}$, and the total capital stock of the economy can be summarized by a single state variable. The aggregate capital stocks of the economy will satisfy:

$$K_{t+1} = (1-\delta) K_t + \phi I_t, \quad (15)$$
$$H_{t+1} = (1-\delta) H_t + (1-\phi) I_t.$$

3.4 Exogenous shocks

In this section, we formalize the specification of the exogenous shocks in this economy. We make an additional assumption that the aggregate productivity is given by $\bar{A}_t = A_t K_t^{1-\nu\alpha}$, where $\{A_t\}_{t=0}^{\infty}$ is an exogenous productivity process. This assumption generates an endogenous growth on one hand. On the other hand, combining with the recursive preferences, this assumption enhances the volatility of the pricing kernel, as in the stream of long-run risk model (e.g. Bansal and Yaron (2004) and Kung and Schmid (2015)).

Aggregate shocks In our economy, we assume there are two types of exogenous shocks. First, the productivity process in logrithem term, i.e. $a_t \equiv \log(A_t)$, follows

$$a_{t+1} = a_{ss}(1-\rho_A) + \rho_A a_t + \sigma_A \varepsilon_{A,t+1}.$$

Second, there is an financial shock that is directly originated from the financial sector, in the same spirit of Jermann and Quadrini (2012). In this paper, we model the financial shock as the shock to the exit probability, λ. As in Ai, Li, and Yang (2017), this shock can be considered as a shock to the agency frictions which directly affects entrepreneur's discount rate. To maintain $\lambda \in (0,1)$ in a parsimony way, we set

$$\lambda_t = \frac{\exp(x_t)}{\exp(x_t) + \exp(-x_t)},$$

where x_t follows an autocorrelated process:

$$x_t = x_{ss}(1-\rho_x) + \rho_x x_{t-1} + \sigma_x \varepsilon_{x,t+1}.$$

We assume the innovations have the following structure:

$$\begin{bmatrix} \varepsilon_{A,t+1} \\ \varepsilon_{x,t+1} \end{bmatrix} \sim Normal\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho_{A,x} \\ \rho_{A,x} & 1 \end{bmatrix} \right),$$

in which the parameter $\rho_{A,x}$ captures the correlation between these two shocks. In the benchmark calibration, we assume the correlation coefficient $\rho_{A,x} = -1$. First, a negative correlation indicates that a negative productivity shock is associated with a positive discount rate shock. This assumption is necessary to quantitatively generate a positive correlation between consumption and investment growth that is consistent with the data. If only the financial shock innovations, $\varepsilon_{x,t+1}$, are present, such innovations will affect the contemporaneous consumption and investment but not the output. The resource constraint in equation (14) implies a counterfactually negative correlation between consumption and investment growth. Second, the assumption of a perfectly negative correlation is for simplicity and it effectively implies there is only one aggregate shock in this economy.

Idiosyncratic shocks In order to generate firm heterogeneity, we introduce idiosyncratic productivity shocks. From time t to $t+1$, the productivity of entrepreneur i evolves according to the law of motion

$$z_{i,t+1} = z_{i,t} e^{\mu + \sigma \varepsilon_{i,t+1}}, \tag{16}$$

where $\varepsilon_{i,t+1}$ is a Gaussian shock assumed to be i.i.d. across agents i and over time.

Distribution of idiosyncratic productivity In our model, the law of motion of idiosyncratic productivity shocks, $z_{i,t+1} = z_{i,t}e^{\mu+\sigma\varepsilon_{i,t+1}}$, is time invariant, implying that the cross-sectional distribution of the $z_{i,t}$ will eventually converge to a stationary distribution.[5] At the macro level, the heterogeneity of idiosyncratic productivity can be conveniently summarized by a simple statistic: $Z_t = \int z_{i,t}di$. It is useful to compute this integral explicitly.

Given the law of motion of $z_{i,t}$, we have:

$$Z_{t+1} = (1-\lambda_t)\int z_{i,t}e^{\varepsilon_{i,t+1}}di + \lambda_t \bar{z}_t.$$

The interpretation is that only a fraction $(1-\lambda_t)$ of entrepreneurs will survive until the next period, while a fraction λ_t of entrepreneurs will restart with productivity of $\bar{z}_t$. Note that based on the assumption that $\varepsilon_{i,t+1}$ is independent of $z_{i,t}$, therefore, we can integrate out $\varepsilon_{i,t+1}$ firstly and write the above equation as

$$\begin{aligned} Z_{t+1} &= (1-\lambda_t)\int z_{i,t}E\left[e^{\varepsilon_{i,t+1}}\right]di \ + \lambda_t \bar{z}_t, \\ &= (1-\lambda_t) Z_t e^{\mu+\frac{1}{2}\sigma^2} + \lambda_t \bar{z}_t, \end{aligned}$$

where the last line exploits the property of the log-normal distribution. It is straightforward to see that if we choose the normalization $\bar{z}_t = \frac{1}{\lambda_t}\left[1-(1-\lambda_t)e^{\mu+\frac{1}{2}\sigma^2}\right]$ and initialize the economy from $Z_0 = 1$, then $Z_t = 1$ for all t. This assumption is hold for the rest of the paper.

4 Equilibrium asset pricing

4.1 Aggregation

Our economy is one with both aggregate productivity and financial shocks, as well as idiosyncratic productivity shocks. In general, we need to use the joint distribution of capital and net worth as an infinite-dimensional state variable in order to characterize the equilibrium recursively. In this section, we present an aggregation result and show that the aggregate quantities and prices of our model can be characterized without any reference to distribu-

[5] In fact, the stationary distribution of $z_{i,t}$ is a double-sided Pareto distribution. Our model is therefore consistent with the empirical evidence of the power law distribution of firm size.

tions. Given aggregate quantities and prices, quantities and shadow prices at the individual firm level can be constructed using equilibrium conditions.

Firm profit We assume that $\varepsilon_{i,t+1}$ is observed at the end of period t when the entrepreneurs plan for the next period capital. As we show in the appendix, this implies that entrepreneur will choose $K_{i,t+t} + H_{i,t+1}$ to be proportional to $z_{i,t+1}$. Additionally, because the idiosyncratic nature of $z_{i,t}$, thus $\int z_{i,t+1} di = 1$. We must have

$$K_{i,t+t} + H_{i,t+1} = z_{i,t+1} \left(K_{t+1} + H_{t+1} \right),$$

where K_{t+1} and H_{t+1} are aggregate quantities.

The assumption that capital is chosen after $z_{i,t+1}$ is observed implies that the total output does not depend on the joint distribution of idiosyncratic productivity and capital. This is because given idiosyncratic shock, all entrepreneurs choose optimal level of capital such that the marginal productivity of capital is the same across all the entrepreneurs. It allows us to write $\mathbf{Y}_t = \bar{\mathbf{A}}_t \left(K_{t+1} + H_{t+1} \right)^{\alpha\nu} \int \mathbf{z}_{i,t} \mathbf{di} = \bar{\mathbf{A}}_t \left(K_{t+1} + H_{t+1} \right)^{\alpha\nu}$. It also implies that the profit at the firm level is proportional to productivity, i.e.,

$$\pi \left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t} \right) = \alpha \bar{A}_t z_{i,t} \left(K_t + H_t \right)^{\alpha\nu},$$

and the marginal products of capital are equalized across firms for the two types of capital:

$$\frac{\partial}{\partial K_{i,t}} \Pi \left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t} \right) = \frac{\partial}{\partial H_{i,t}} \Pi \left(\bar{A}_t, z_{i,t}, K_{i,t}, H_{i,t} \right) = \alpha \bar{A}_t \left(K_t + H_t \right)^{\alpha\nu - 1}. \tag{17}$$

Intertemporal optimality Having simplified the profit functions, we can derive the optimality conditions for the entrepreneur's maximization problem (7). Note that given equilibrium prices, the objective function and the constraints are linear in net worth. Therefore, the value function V_t^i must be linear as well. We write $V_t^i \left(N_{i,t} \right) = \mu_t^i N_{i,t}$, where μ_t^i can be interpreted as the marginal value of net worth for entrepreneur i. Furthermore, let η_t^i be the Lagrangian multiplier associated with the collateral constraint (4). The first order condition with respect to $B_{i,t}$ implies

$$\mu_t^i = E_t \left[\widetilde{M}_{t+1}^i \right] R_{t+1}^f + \eta_t^i, \tag{18}$$

where we use the notation:

$$\widetilde{M}_{t+1}^i = M_{t+1} [\left(1 - \lambda_{t+1} \right) \mu_{t+1}^i + \lambda_{t+1}]. \tag{19}$$

The interpretation is that one unit of net worth allows the entrepreneur to reduce one unit of borrowing, the present value of which is $E_t\left[\widetilde{M}^i_{t+1}\right] R^f_{t+1}$. Additionally, and relaxes the collateral constraint, the benefit of which is measured by η^i_t.

Similarly, the first order condition for $K_{i,t+1}$ is

$$\mu^i_t = E_t\left[\widetilde{M}^i_{t+1}\frac{\Pi_K\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right)+\left(1-\delta_K\right)q_{K,t+1}}{q_{K,t}}\right]+\zeta\eta^i_t. \tag{20}$$

An additional unit of type-K capital allows the entrepreneur to purchase $\frac{1}{q_{K,t}}$ units of capital, which pays a profit of $\frac{\partial\pi}{\partial K}\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right)$ over the next period before it depreciates at rate δ. In addition, a fraction ζ of type-K capital can be used as collateral to relax the borrowing constraint.

Finally, optimality with respect to the choice of type-H capital implies

$$\mu^i_t = E_t\left[\tilde{M}^i_{t+1}\frac{\Pi_H\left(\bar{A}_{t+1}, z_{i,t+1}, K_{i,t+1}, H_{i,t+1}\right)+\left(1-\delta_H\right)q_{H,t+1}}{q_{H,t}}\right]. \tag{21}$$

Recursive construction of the equilibrium Note that in our model, firms differ in their net worth. Firstly, the net worth depends on the entire history of idiosyncratic productivity shocks, as can be seen in equation (6). Secondly, the net worth also depends on the need for capital which is relies on the realization of next period's productivity shock. Therefore in general, the marginal benefit of net worth, μ^i_t, and the tightness of the collateral constraint, η^i_t, depend on the individual firm's entire history. Below we show that despite the heterogeneity in net worth and capital holdings across firms, our model allows an equilibrium in which μ^i_t and η^i_t are equalized across firms, and aggregate quantities can be determined independent of the distribution of net worth and capital.

Note that the assumptions that type-K and type-H capital are perfect substitutes and that the idiosyncratic shock $z_{i,t+1}$ is observed before the decisions on $K_{i,t+1}$ and $H_{i,t+1}$ are made. These two assumption imply that the marginal product of both types of capital are equalized within and across firms, as shown in equation (17). As a result, equations (18) to (21) permit solutions where μ^i_t and η^i_t are not firm-specific. Intuitively, because the marginal product of capital depends only on the sum of $K_{i,t+1}+H_{i,t+1}$ itself and not on its composition, entrepreneurs will choose the total amount of capital to equalize its marginal product across firms. This is also because that $z_{i,t+1}$ is observed in period t. Depending on her borrowing need, an entrepreneur can then determine the amount of $K_{i,t+1}$ to satisfy the collateral constraint. Because capital can be purchased from a competitive market, entrepreneurs will choose $K_{i,t+1}$ to equalize its price and its marginal benefit, which includes the marginal product of capital and the Lagrangian multiplier η_t^i. Because both the prices and the marginal product of capital are equalized across firms, so is the tightness of the collateral constraint.

We formalize the above observation by providing a recursive characterization of the equilibrium. Let lower case variables denote aggregate quantities normalized by current-period capital stock, so that n denotes aggregate net worth N_t normalized by the total capital stock $K_t + H_t$. Let $s \equiv (A, \lambda)$ be a vector of exogenous state variables. The equilibrium objects are consumption, $c(s,n)$, investment, $i(s,n)$, the marginal value of net worth, $\mu(s,n)$, the Lagrangian multiplier on the collateral constraint, $\eta(s,n)$, the price of type-K capital, $q_K(s,n)$, the price of type-H capital, $q_H(s,n)$, and the risk-free interest rate, $R_f(s,n)$ as functions of the state variables s and n.

To introduce the recursive formulation, we denote variable in period t as X and variable in period $t+1$ as X'. Given these equilibrium functionals, we can define

$$\Gamma(s,n) = \frac{K' + H'}{K + H} = (1-\delta) + i(s,n)$$

as the growth rate of the capital stock and construct the law of motion of the endogenous state variable n from equation (8)[6]:

$$n' = (1-\lambda)\left[\alpha A' + \phi(1-\delta) q_K(s',n') + (1-\phi)(1-\delta) q_H(s',n') - \zeta \phi q_K(s,n) \frac{R_f(s,n)}{\Gamma(s,n)}\right] + \lambda \chi \frac{n}{\Gamma(s,n)}.$$

With the law of motion of the state variables, we can construct the normalized utility of the household as the fixed point of:

$$u(s,n) = \left\{(1-\beta) c(s,n)^{1-\frac{1}{\psi}} + \beta \Gamma(s,n)^{1-\frac{1}{\psi}} \left(E[u(s',n')^{1-\gamma}]\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right\}^{\frac{1}{1-\frac{1}{\psi}}}.$$

The stochastic discount factors can then be written as:

$$\begin{aligned} M' &= \beta \left[\frac{c(s',n')\Gamma(s,n)}{c(s,n)}\right]^{-\frac{1}{\psi}} \left[\frac{u(s',n')}{E\left[u(s',n')^{1-\gamma}\right]^{\frac{1}{1-\gamma}}}\right]^{\frac{1}{\psi}-\gamma}, \\ \widetilde{M}' &= M'[(1-\lambda')\mu(s',n') + \lambda']. \end{aligned}$$

[6] We make use of the property that the K/H ratio is always equal to $\phi/(1-\phi)$, as implied by the law of motion of capital stock (15).

Proposition 4.1. *(Recursive equilibrium)*

The equilibrium functionals, $c(s,n)$, $i(s,n)$, $\mu(s,n)$, $\eta(s,n)$, $q_K(s,n)$, $q_H(s,n)$, and $R_f(s,n)$ are the solution to the following set of functional equations:

$$E\left[M'\middle|\, s\right] R_f(s,n) = 1,$$

$$\mu(s,n) = E\left[\widetilde{M}'\middle|\, s\right] R_f(s,n) + \eta(\theta,n), \tag{22}$$

$$\mu(s,n) = E\left[\widetilde{M}' \frac{\alpha A' + (1-\delta)\, q_K(s',n')}{q_K(s,n)}\middle|\, s\right] + \zeta\eta(s,n), \tag{23}$$

$$\mu(s,n) = E\left[\widetilde{M}' \frac{\alpha A' + (1-\delta)\, q_H(s',n')}{q_H(s,n)}\middle|\, s\right], \tag{24}$$

$$n = (1-\zeta)\, q_K(s,n) + q_H(s,n),$$

$$G'(i(s,n)) = \phi q_K(s,n) + (1-\phi)\, q_H(s,n),$$

$$c(s,n) + i(s,n) + g(i(s,n)) = A$$

The above proposition allows us to solve for the aggregate quantities of the economy first, and then use the firm-level budget constraint and the law of motion of idiosyncratic productivity in (3) and (4) to construct the cross-section of net worth and capital holdings.

4.2 The collateralizability spread

Our model allows for two types of capital, where type-K capital is collateralizable, while type-H capital is not. Note that one unit of type j capital costs $q_{j,t}$ in period t and it pays off $\Pi_{j,t+1} + (1-\delta)\, q_{j,t+1}$ in the next period, for $j \in \{K, H\}$. Therefore, the un-levered returns on the claims to the two types of capital are given by:

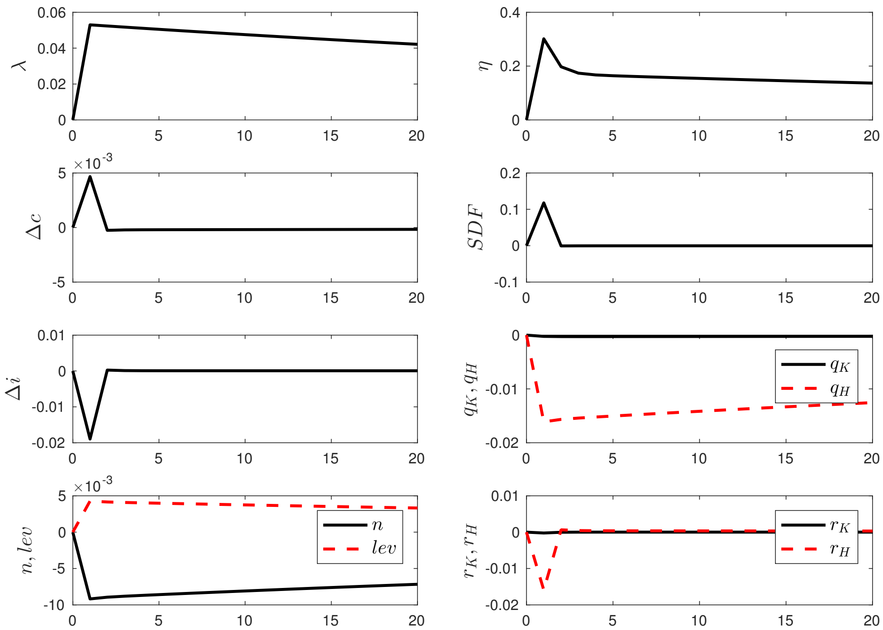
$$R_{j,t+1} = \frac{\alpha A_{t+1} + (1-\delta)\, q_{j,t+1}}{q_{j,t}}, \quad j = K, H.$$

Undoubtedly, risk premiums are determined by the covariances of the payoffs with respect to the stochastic discount factor. Given that the components representing the marginal products of capital are identical for the two types of capital, the key to understand the the collateralizability premium, as shown in the expression (26), is the cyclical properties of the price of capital, $q_{j,t+1}$.

We can iterate equations (20) and (21) forward to obtain expression for $q_{K,t}$ and $q_{H,t}$ as present value of future cash flows. Clearly, the present value of $q_{K,t}$ contains the Lagrangain multipliers $\{\eta^i_{t+j}\}_{j=0}^{\infty}$, while the present value of $q_{H,t}$ does not. Because the Lagrangian multipliers are counter-cyclical and act as a hedge, $q_{K,t}$ will be less sensitive to aggregate shocks and less cyclical. These asset pricing implications of our model are best illustrated with impulse response functions.

Figure 1: Impulse Responses to the Financial shock

This figure plots the log-deviations from the steady state for quantities and prices with respect to a one-standard deviation shock to the λ. One period is a year. All parameters are calibrated as in Table 2.



In Figure 1, we plot the percentage deviations of quantities and prices from the steady state in response to a one-standard deviation financial shock, i.e. the shock to λ. The parameters are corresponding to Table 2. The only exception in the above figure is that the financial shock, ε_x, is imposed to be orthogonal to the productivity shock, ε_A, in order to highlight the effect of a financial shock. In the other words, $\rho_{A,x} = 0$. Our motivation to shut down the correlation is to highlight the separate effect from a pure financial shock, and we also want to point out the major departure of the model with an orthogonal financial shock from the benchmark model with correlated shocks.

Three observations are summarized as follows. First, a positive shock to λ (first panel in the left column) works as a positive discount rate shock to entrepreneurs, and it leads to a tightening of the collateral constraint as reflected by a spike in the Lagrangian multiplier, η (the first panel in the right column).

Second, a tightening of the collateral constraint translates into a lower investment (the third panel in the left column). However, a financial shock does not affect contemporaneous period output; according to the resource constraint equation (14), consumption responds oppositely to investment (the second panel in the left column). This outcome presents a counterfactually negative correlation between consumption and investment, as the main departure of a single orthogonal financial shock from the standard RBC model. To resolve the negative correlation problem, in our benchmark calibration, we assume a perfectly negative correlation between the productivity shock and financial shock, i.e. $\rho_{A,x} = -1$. A positive financial shock is perfectly associated with a negative productivity shock, which directly affect the current period output on impact. In the end, the negative correlation between two shocks delivers a positive correlation between consumption and investment.

Third and most importantly, as the collateral constraint gets tightened, the entrepreneur's net worth drops sharply and the leverage rises immediately (the last panel in the left column). Moreover, upon a positive financial shock, because the entrepreneur net worth drops sharply, so does the price of type-H capital. However, the decrease in the price of the type-K capital is almost neglectable by comparison. This is because the Lagrangian multiplier on the collateral constraint (η) increases on impact and offsets the negative effect of a positive discount rate shock on the price of type-K capital. As a result, the return of type-H capital responds much less to negative productivity shocks than that of the type-H capital. Collateralizable capital is less risky than non-collateralizable capital in our model.

5 Quantitative model predictions

In this section, we examine whether our model can quantitatively account for the collateralizability premium in the data. We calibrate the model parameters, report moments of macroeconomic quantities and asset prices at the aggregate level, and then study its implications on the cross-section of expected returns. We show that our model can quantitatively replicate the main features of firm characteristics, and produce a collateralizability premium at the cross-section comparable to that in the data.

5.1 Calibration

We calibrate our model at the monthly frequency, and list the parameters in Table 2. We group our parameters into four blocks. In the first block, we list the parameters which can be determined by the previous literature. In particular, we set the relative risk aversion (γ)

to be 10 and the intertemporal elasticity of substitution (ψ) to 1.25. These parameter values in line with the long-run risks literature, e.g., Bansal and Yaron (2004). The capital share parameter (α) is set to be 0.33, as in the standard RBC literature. The span of control parameter (ν) is set to be 0.85, consistent with Atkeson and Kehoe (2005).

Table 2: **Calibrated Parameter Values**

Parameter	Symbol	Value
Relative risk aversion	γ	10
IES	ψ	1.25
Capital share in production	α	0.33
Span of contral parameter	ν	0.85
Mean productivity growth rate	a_{ss}	-3.15
Time discount rate	β	0.999
Share of type-K investment	ϕ	0.667
Capital depreciation rate	δ	0.08/12
Average death rate of entrepreneurs	$\bar{\lambda}$	0.01
Collateralizability parameter	ζ	0.702
Transfer to entering entrepreneurs	χ	0.915
Persistence of TFP shocks	ρ_A	0.988
Vol. of TFP shock	σ_A	0.007
Persistence of financial shocks	ρ_x	0.988
Vol. of financial shock	σ_x	0.053
Corr. Between TFP and financial shocks	$\rho_{A,x}$	-1
Invest. adj. cost paramter	τ	30
Mean idio. Productivity growth	μ_Z	0.003
Vol. of idio. Productivity growth	σ_Z	0.029

The parameters in the second block are determined by matching a set of first moments of quantities and prices to their empirical counterparts. We set the average economy-wide productivity growth rate (a_{ss}) to match a mean growth rate of U.S. economy of 2% per year. The time discount factor (β) is set to match the average real risk free rate of 1% per year. The share of type-K capital investment (ϕ) is set to be 0.67 to maintain the average intangible to tangible asset ratio 60% to be consistent with an average US Compustat firm [7]. The capital depreciation rate is set to be 8% per year. For parsimony, we assume the same depreciation rate for both types of capital. The parameter x_{ss} is set to match an average exit probability ($\overline{\lambda}$) of 0.01, targeting an average corporate duration of 10 years of US Compustat firms. We calibrate the remaining two parameters related to financial frictions, namely, the collateralizability parameter (ζ) and the transfer to entering entrepreneurs (χ) by jointly matching two moments, including the non-financial corporate sector leverage ratio, defined as the debt to asset ratio, of 0.50, and an average consumption to investment ratio $E(C/I)$ of 4.5. This targeted leverage ratio is broadly in line with the median lease capital adjusted leverage ratio of US non-financial firms in COMPUSTAT.

The parameters in the third block are not directly related to the first moments of the economy, but they are determined by the second moments in the data. The persistence parameters ρ_A and ρ_x are calibrated to be the same at 0.988, to roughly match the auto-correlations of consumption and output growth. As explained before, we impose a perfectly negative correlation, $\rho_{x,A} = -1$. The standard deviation of the λ shock, σ_x, and that of the productivity shock, σ_A, are jointly calibrated to match the volatilities of consumption growth and the correlation between consumption and investment growth. The elasticity parameter of the investment adjustment cost functions, ζ, is set to allow our model to achieve a reasonable high volatility of investment, in line with the data.

The last block contains the parameters related to idiosyncratic productivity shocks, μ_Z and σ_Z. We calibrate them to match the mean (2.5%) and the volatility (10%) of the idiosyncratic productivity growth of the cross-section of U.S. non-financial firms in the Compustat database.

5.2 Aggregate moments

We solve and simulate our model at the monthly frequency and aggregate the model-generated data to compute annual quantities.[8] We now turn to the quantitative implications of the model.

In this section, we report the quantitative moments of our model for quantities and asset prices at the aggregate level. We show that our model is broadly consistent with the

[7] The construction of intangible capital is detailed in Appendix .

[8] Because the limited commitment constraint is binding in the steady-state, we solve the model using a second-order local approximation around the steady state using the `Dynare` package. We have also solved version solved versions of our model using the global method developed in Ai, Li, and Yang (2016) and verified the accuracy of the local approximation.

key empirical features of macroeconomic quantities and asset prices. More importantly, it produces a sizable negative collateralizability spread at the aggregate level.

Table 3 reports the key moments of macroeconomic quantities (top panel) and those of asset returns (bottom panel) respectively, and compares them to their counterparts in the data where available.

In terms of aggregate moments on macro quantities (top panel), our calibration features a low volatility of consumption growth (2.62%) and a relatively high volatility of investment (8.48%). Thanks to the negative correlation between the productivity and financial shocks, our model can reproduce a positive consumption-investment correlation (33%), consistent with the data. The model also reproduces a reasonable persistence of output growth (65%) in line with the aggregate data, and a consistent average intangible-tangible capital ratio (50%), broadly consistent with the average ratio among US Compustat firms.

Table 3: Model Simulations and Aggregate Moments

This table presents the annualized moments from the model simulation. We simulate the economy at monthly frequency based on the monthly calibration as in Table 2, then aggregate the monthly observations to annual frequency. The model moments are obtained from repetitions of small simulation samples. Data counterparts refer to the US and span the sample period 1930-2016. The market return R_M corresponds to the return on entrepreneurs' net worth at the aggregate level and embodies an endogenous financial leverage. R_K^{Lev} and R_H denote the levered return on the type-K capital and the un-levered return on type-H capital respectively. Numbers in parenthesis are GMM Newey-West adjusted standard errors.

Moments	Data	Benchmark
$\sigma(\Delta c)$	2.53 (0.56)	2.62
$\sigma(\Delta i)$	10.30 (2.36)	8.48
$corr(\Delta c, \Delta i)$	0.40 (0.28)	0.33
$AC1(\Delta y)$	0.49 (0.15)	0.65
$E[H/K]$	0.60	0.50
$E[R_M - R_f]$	6.51 (2.25)	8.21
$E[R_f]$	1.10 (0.16)	1.24
$E[R_H - R_f]$		12.28
$E[R_K - R_f]$		0.84
$E[R_K^{Lev} - R_H]$		-9.45

Turn the attention to the asset pricing moments (bottom panel), our model produces a low risk free rate (1.24%) and a high equity premium (8.21%), comparable to the data. Second, in our model the risk premium on type-K capital (0.84%) is much lower than that on type-H capital (12.28%).

In the last row of Table 3, we also report a sizable negative average return spread of

-9.45% between a levered claim on type-K capital and non-collateralizable capital ($E[R_K^{Lev} - R_H]$). The type-K capital is collateralizable, and allows firm to borrow more and raise the leverage and therefore tends to increase the expected return on equity. If we assume a binding constraint so as to replace $B_{i,t}$ by $\zeta q_{j,t} K_{j,t+1}$, buying type-K capital effectively delivers a levered return,

$$
\begin{aligned}
R_{K,t+1}^{Lev} &= \frac{\alpha A_{t+1} + (1-\delta)\, q_{K,t+1} - R_{f,t+1}\zeta q_{K,t}}{q_{K,t}\,(1-\zeta)}, \\
&= \frac{1}{1-\zeta}(R_{K,t+1} - R_{f,t+1}) + R_{f,t+1}. \qquad (25)
\end{aligned}
$$

The denominator $q_{K,t}\,(1-\zeta)$ denotes the minimum down payment per unit of capital (initial investment). The numerator $\alpha A_{t+1} + (1-\delta)\, q_{K,t+1} - R_{f,t+1}\zeta q_{K,t}$ is the after-debt repayment payment per unit of capital. Because type-H capital is non-collateralizable and has to be purchased 100% with equity, therefore, it cannot be levered up. In sum, the (negative) collateralizability premium at the aggregate level can be interpreted as the difference between the average return of a levered claim on the type-K capital and an un-levered claim on the type-H capital.

Combine the two Euler equations, (18) and (20), and eliminate η_t, we have

$$
E_t\left[\widetilde{M}_{t+1} R_{K,t+1}^{Lev}\right] = \mu_t,
$$

and the rearrangement in the equation (21) gives

$$
E_t\left[\widetilde{M}_{t+1} R_{H,t+1}\right] = \mu_t.
$$

Therefore, the expected return spread is equal to

$$
\begin{aligned}
E_t\left(R_{K,t+1}^{Lev} - R_{H,t+1}\right) &= \frac{1}{E_t\left(\widetilde{M}_{t+1}\right)}\left(Cov_t\left[\widetilde{M}_{t+1}, R_{K,t+1}^{Lev}\right] - Cov_t\left[\widetilde{M}_{t+1}, R_{H,t+1}\right]\right), \\
&= \frac{1}{E_t\left(\widetilde{M}_{t+1}\right)}\left(\frac{1}{1-\zeta} Cov_t\left[\widetilde{M}_{t+1}, R_{K,t+1}\right] - Cov_t\left[\widetilde{M}_{t+1}, R_{H,t+1}\right]\right) \qquad (26)
\end{aligned}
$$

However, the leverage $\frac{1}{1-\zeta}$ may offset this effect by amplifying the cyclical fluctuations of a levered claim on the type-K capital. The relative riskiness of the type-K versus type-H capital thus depends on the relative contributions of the countercyclical Lagrangian multiplier effect versus the offsetting leverage effect. Our quantitative analysis shows that the first effect dominates, and there is a negative collateralizability premium.

In our calibration, this countercyclical Lagrangian multiplier effect dominates the leverage effect on the type-K capital. The collateralizable capital, despite of its leverage nature, is quantitatively less risky than the non-collateralizable capital.

5.3 The cross section of collateralizability and equity returns

We now turn to the collaterlizability-based portfolio sorting from the firm simulation, the sizable collateralizability premium generated at the aggregate level as shown in the previous section promises a quantitatively significant return spread among collateralizability sorted portfolios.

Equity claims to firms in our model can be freely traded among entrepreneurs. The return on an entrepreneur's net worth is $\frac{N_{i,t+1}}{N_{i,t}}$. Using (3) and (6), we can write this return as

$$\begin{aligned} & \frac{\alpha A_{t+1}\left(K_{i,t+1}+H_{i,t+1}\right)+(1-\delta)\,q_{K,t+1}K_{i,t+1}+(1-\delta)\,q_{H,t+1}H_{i,t+1}-R_{f,t+1}B_{i,t}}{q_{K,t}K_{i,t+1}+q_{H,t}H_{i,t+1}-B_{i,t}}, \\ = \; & \frac{(1-\zeta)q_{K,t}K_{i,t+1}}{N_{i,t}}R^{Lev}_{K,t+1}+\frac{q_{H,t}H_{i,t+1}}{N_{i,t}}R_{H,t+1}, \end{aligned}$$

where $R^{Lev}_{K,t+1}$ is a levered return on the type-K capital, as defined in equation 25. The above expression has intuitive interpretations. The return on equity is the weighted average of the levered return on the type-K capital and the un-levered return on the type-H capital. The weights $\frac{(1-\zeta)q_{K,t}K_{i,t+1}}{N_{i,t}}$ and $\frac{q_{H,t}H_{i,t+1}}{N_{i,t}}$ are the proportions the down payment of type-K capital and the expense on type-H capital with respect to entrepreneur's total net worth, respectively. The weights sum up to one, as restricted by the budget constraint and the binding collateral constraint. In our model, $R^{Lev}_{K,t+1}$ and $R_{H,t+1}$ are common across all firms. As a result, firm level expected returns differ only because of the composition of expenditures on two different types of capital. The compositions of expenditure are equivalently summarized by the collateralizability of firm assets.

To further understand the collateralizability premium at the firm level, note that the return on a firm's asset is the value-weighted return of different types of capital owned by the firm. Because type-H capital provides a higher expected return than type-K capital, firms with more collateralizable capital earns lower risk premium. In our model, the above relationship between asset collateralizability and expected return can be summarized by the collateralizability measure we constructed in Section 2 of the paper. To see this, let j index the type of capital, and using the fact that μ^i_t and η^i_t are identical across firms, equations

(20) and (21) can be summarized as:

$$\mu_t q_{j,t} K_{j,t+1} = E_t \left[\tilde{M}^i_{t+1} \left\{ \Pi_{j,t+1} + (1-\delta) q_{j,t+1} \right\} K_{j,t+1} \right] + \zeta_j \eta_t q_{j,t} K_{j,t+1}. \tag{27}$$

Let $V_t = \sum_{j=1}^{J} q_{j,t} K_{j,t+1}$ be the total value of the firm's assets. Dividing the above equation by V_t and summing over all j, we have:

$$\mu_t = \frac{\sum_{j=1}^{J} E_t \left[\tilde{M}^i_{t+1} \left\{ \Pi_{j,t+1} + (1-\delta) q_{j,t+1} \right\} K_{j,t+1} \right]}{V_t} + \eta_t \sum_{j=1}^{J} \zeta_j \frac{q_{j,t} K_{j,t+1}}{V_t}. \tag{28}$$

Note that μ_t is the shadow value of entrepreneur's net worth. Equation (28) decomposes μ_t into two parts. Because the term $E_t \left[\tilde{M}^i_{t+1} \left\{ \Pi_{j,t+1} + (1-\delta) q_{j,t+1} \right\} K_{j,t+1} \right]$ can be interpreted as the present value of the cash flows generated by type-j capital, the first component is the fraction of firm value that comes from cash flow. The second component is the Lagrangian multiplier on the collateral constraint multiplied by our measure of asset collateralizability.

In our model, μ_t and η_t are common across all firms. All types of capital generate the same marginal product in the future. As a result, expected returns differ only because of the composition of asset collateralizability, which is completely summarized by the asset collateralizability measure, $\sum_{j=1}^{J} \zeta_j \frac{q_{j,t} K_{j,t+1}}{V_t}$. As we will show in Table 4, this parallel between our model and our empirical procedure allows our model to match very well the quantitative features of the collateralizability spread in the data.

In Table 4, we report our model's implication for the cross-section of asset collateralizability, leverage ratio, and expected returns and compare them with the data. In the data, we focus on financially constrained firms, which are defined according to the WW index, and report our results in the top panel in Table 4. As we show in Section 2, other measures of financial constraints yields quantitatively similar results on the collateralizability premium. We follow the same procedure with the simulated data in our model and sort stocks into five portfolios based on the collateralizability measure and the corresponding moments are report in the bottom panel of Table 4.

First, the collateralibility scores in our model are similar in magnitudes as those in the data across different portfolios. Despite its simplicity, this indicates that our model endogenously generates a plausible distribution of asset collateralizability in the cross-section.

Second, firms with high asset collateralizability, despite their high leverage, have a significantly lower expected return than those with low asset collateralizability. Quantitatively, our model produces a collateralizability spread (5.30%), comparable to the return spread

Table 4: Cross-Section Firm Characteristics and Expected Returns

This table compares the model simulated moments and the corresponding data counterparts at the portfolio level. The sample starts from 1979 July and ends in 2016 December. At the end of June of each year t, we sort the constrained firms into five quintiles based on collateralizability measure at the end of year $t-1$. The table reports the mean of firm collateralizability and the average excess returns $E[R] - R^f(\%)$ (annualized), value weighted within the five quintile portfolios sorted on collateralizability. Panel A reports the statistics computed from the financially constrained data sample (proxied by Whited-Wu index). In each year, a firm is classified as financially constrained if the firm's Whited-Wu index is higher than the cross-section median of all firms' Whited-Wu index in that year. Whited-Wu index is defined as in Whited and Wu (2006). Panel B reports the statistics computed from simulated data. In particular, we firm simulate the firm level characteristics and returns at the monthly level, and then conduct the same portfolio sorting as in the data.

Panel A: Data

	1	2	3	4	5	5-1
Collateralizability	0.051	0.098	0.144	0.220	0.788	
$E[R] - R^f(\%)$	13.33	11.59	9.43	9.37	5.36	7.96

Panel B: Model

	1	2	3	4	5	5-1
Collateralizability	0.282	0.507	0.587	0.635	0.678	
$E[R] - R^f(\%)$	11.68	9.59	8.18	7.24	6.37	5.30

(7.96%) in the data.

In our model, increases in the holdings of type-K capital raises firms' asset collateralizability and have two effect on the expected return of its equity. On one hand, because collateralizable capital has a lower expected return than non-collateralizable capital, higher asset collateralizability tend to lower the expected return on firms' equity. On the other hand, because higher asset collateralizability allows firm to borrow more, it raises firms' leverage and tend to increase the expected return on equity. Our quantitative analysis shows that, despite the high leverage nature of holding collateralizable capital, the levered position on it still generates a significantly lower expected return than that of the non-collateralizable capital.

6 Conclusion

In this study, we present a general equilibrium asset pricing model with collateral constraints and two types of assets differing in their collateralizability. Our model predicts that the collateralizable asset provides insurance against aggregate shocks and should therefore earn a lower expected return, since it relaxes the countercyclical collateral constraint in bad times.

We propose an empirical measure for the degree to which a firm's assets are collateralizabile, and document empirical evidence consistent with the predictions of our model. In particular, we find in the data that the stocks of financially constrained firms with a smaller share of collateralizable capital earns an average return, which is on average around 7.96% higher than the return on the stock of a firm with a higher share. When we calibrate our model to the dynamics of macroeconomic quantities, we show that the credit market friction channel is a quantitatively important determinant for the cross-section of asset returns.

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Appendix A: Additional empirical evidence

In this section, we provide additional empirical evidence on the collateralizability premium, including the standard multi-factor asset pricing test and cross-sectional regressions (Fama and MacBeth (1973)). We also provide robustness evidence by sorting portfolios within Fama-French 17 industries and double-sorting portfolios with the collateralizability and the financial leverage.

A.1. Asset pricing test

In this section, we investigate to what extent the variation in the average returns of the collateralizability-sorted portfolios can be explained by exposures to standard risk factors, as captured by Carhart (1997) model and the Fama and French (2015) five-factor model. In particular, we run monthly time-series regressions of the annualized excess returns of each portfolio on a constant and the standard risk factors as suggested by the above-mentioned risk factor models. Table A.1 reports the intercepts and exposures (i.e. betas) with respect to standard risk factors. The intercepts from these regressions can be interpreted as pricing errors (abnormal returns) which are still unexplained by the controlled risk factors.

We make several observations. First, the pricing errors (intercepts) of the collateralizablity sorted portfolio remain large and significant, ranging from 10 % for Carhart (1997) model to 11.47% from the Fama and French (2015) five-factor models, and these intercepts are 3.81 and 5.63 standard errors away from zero, as reported in the t-statistic. Second, the pricing errors implied by both factor models are are larger than the collateralizability spread in the univariate sorting as in Table 1. This result follows from the fact that the exposures to HML factor (in both panels) and the exposures to profitability factor, CMA, (in Panel B) of high versus low collateralizability portfolios go into the wrong direction. In particular, the low collateralizablity portfolio (Quintile 1) has more negative exposures to both the HML and CMA factors, which both suggest such portfolios should have lower returns (risk) according to the interpretation of value premium and profitability premium, and therefore is inconsistent with the empirical fact that it low collateralizablity portfolio enjoys higher average returns (risk). Third, the exposures of collateralizability sorted portfolios to the size factor, SMB, display an increasing pattern (in panel A). This indicates that low collateralizability portfolio is more exposed to SMB factor. But the significant and sizable alpha even after controlling for the size factor implies that size premium itself would not be sufficient to explain the observed collateralizability spread.

Table A.1: Asset Pricing Test

This table shows asset pricing tests for five value-weighted portfolios sorted on collateralizability. In Panel A, we regress the five portfolios on Carhart (1997) four-factor model. In Panel B we regress the five portfolios on Fama and French (2015) five-factor model. The t-statistics (t) are computed using Newey-West estimator. We annualize alphas by multiplying with 12. The analysis is performed for constrained firms, which are classified by WW index as in Whited and Wu (2006). For Panel C, the sample ends in December 2008.

Panel A: Carhart Four-Factor Model

	1	2	3	4	5	1-5
α	5.69	3.59	0.92	0.32	-4.35	10.04
t-stat	(2.88)	(2.30)	(0.59)	(0.23)	(-2.79)	(3.81)
β_{MKT}	1.08	1.08	1.06	1.09	1.13	-0.05
t-stat	(28.01)	(29.04)	(29.57)	(35.25)	(28.00)	(-0.91)
β_{HML}	-0.63	-0.46	-0.32	-0.14	-0.01	-0.63
t-stat	(-9.71)	(-8.80)	(-6.26)	(-3.01)	(-0.09)	(-6.60)
β_{SMB}	1.30	1.12	1.09	1.12	0.76	0.54
t-stat	(19.06)	(16.45)	(18.92)	(24.89)	(9.23)	(4.62)
β_{MOM}	-0.06	-0.06	-0.04	-0.08	-0.02	-0.04
t-stat	(-1.17)	(-1.72)	(-1.22)	(-2.43)	(-0.50)	(-0.48)
R^2	0.85	0.87	0.89	0.89	0.84	0.28

Panel B: Fama-French Five-Factor Model

	1	2	3	4	5	1-5
α	7.18	5.38	2.06	1.00	-4.29	11.47
t-stat	(4.83)	(4.65)	(1.77)	(0.86)	(-3.38)	(5.63)
β_{MKT}	1.02	1.01	1.03	1.07	1.13	-0.11
t-stat	(26.70)	(32.58)	(33.92)	(39.15)	(28.95)	(-2.11)
β_{SMB}	1.11	0.96	0.98	1.03	0.90	0.21
t-stat	(16.58)	(16.79)	(19.79)	(21.94)	(15.55)	(2.37)
β_{HML}	-0.77	-0.50	-0.49	-0.29	-0.05	-0.71
t-stat	(-8.83)	(-7.84)	(-7.47)	(-4.97)	(-0.73)	(-6.03)
β_{RMW}	-0.65	-0.56	-0.39	-0.33	0.22	-0.88
t-stat	(-6.37)	(-7.02)	(-5.94)	(-4.52)	(2.89)	(-6.75)
β_{CMA}	0.13	-0.05	0.19	0.15	-0.15	0.28
t-stat	(0.97)	(-0.48)	(2.16)	(1.58)	(-1.86)	(1.76)
R^2	0.88	0.89	0.90	0.90	0.86	0.40

Panel C: Control for Organizational Capital Factor

	1	2	3	4	5	1-5
α	6.07	3.82	0.89	0.97	-3.65	9.72
t-stat	(2.61)	(2.00)	(0.43)	(0.51)	(-1.67)	(2.99)
β_{MKT}	1.12	1.08	1.08	1.09	1.10	0.02
t-stat	(21.33)	(24.32)	(23.13)	(25.25)	(26.57)	(0.40)
β_{HML}	-0.57	-0.45	-0.35	-0.11	-0.04	-0.53
t-stat	(-7.06)	(-7.22)	(-5.59)	(-1.59)	(-0.34)	(-3.97)
β_{SMB}	1.36	1.13	1.08	1.14	0.73	0.63
t-stat	(17.77)	(17.17)	(19.59)	(27.50)	(6.59)	(4.56)
β_{OMK}	-0.04	0.00	0.04	-0.04	-0.16	0.12
t-stat	(-0.58)	(0.02)	(1.03)	(-0.84)	(-2.44)	(1.20)
R^2	0.86	0.87	0.89	0.88	0.83	0.31

Additionally, in order to distinguish our collateralizability measure from organizational capital, we also control for organizational capital factor as in Eisfeldt and Papanikolaou (2013),[9] together with the Fama-French three-factor model. The results are shown in Table A.1. As we can see that the pricing errors are still significant with the presence of organizational capital factor, with magnitude 9.7% per year and t-stat of 3. In particularly, the five portfolios sorted on collateralizability are not strongly exposed to this organizational capital, because the coefficients are small and insignificant.

Taken together, the cross-sectional return spread across collateralizability sorted portfolios cannot be explained by either the Carhart (1997) four-factor, the Fama and French (2015) five-factor model or the organizational capital factor. In the next section, we go beyond the portfolio sorting and control for multiple firm characteristics simultanenously by running cross-sectional regressions.

A.2. Firm-level return predictability regression

In this section, we extend the previous analysis to investigate the joint link between collateralizability and the future stock return in the cross-section using firm level multivariate regressions that include the firm's collateralizability and other controls as return predictors.

We run standard firm-level cross-sectional regressions (Fama and MacBeth (1973)) to predict future firm-level stock returns as follows:

$$R_{i,t+1} = \alpha^i + \beta Collateralizability_{i,t} + \gamma Controls_{i,t} + \varepsilon_{it}, \tag{A1}$$

where $R_{i,t+1}$ is stock i' cumulative return from July of year t to June of each year $t+1$. And the control variables include the lagged firm collateralizability, size, book-to-market (BM), profitability (ROA) and book leverage. To avoid using future information, all the balance sheet variables are based on the values available in year t. Table A.2 reports the results for Fama-MacBeth regressions. The regressions exhibit a significantly negative slope coefficient on collateralizability, which supports our theory.

In our empirical measure, only structure and equipment capital contribute to firm's collateralizability, not the intangible capital. Therefore, by construction, potentially our measure is weakly negatively correlated with measures of intangible capital. In order to empirically distinguish our theoretical channel with the organizational capital (Eisfeldt and Papanikolaou (2013)) and the R&D capital (Chan, Lakonishok, and Sougiannis (2001), Croce et al.

[9]We would like to thank Dimitris Papanikolaou for sharing the time series of the organizational factor.

(2017)). Following literature, we also control for OG/AT (Specification 4-6) or XRD/AT (Specifications 7-9) one each time. As shown in Table A.2 , the negative slope coefficients of collateralizability remain significant, though become smaller in magnitude, after controlling for these two firm characteristics. Instead of using R&D expenditure to asset ratio as the control variable as in the literature, we also tried R&D capital to asset ratio, the results remain similar.

A.3. Robustness on portfolio sorting

As an attempt for robustness check, we sort portfolios within 17 Fama-French industries. By doing so, we essentially control for the industry fixed effect, and compare firms with different collateralizability with each industry. Table A.3 reports the portfolio sorting results. The results are virtually unchanged as compared with the benchmark table 1.

A.4. Double sorting on collateralizability and leverage

Firms with higher asset collateralizablility have higher debt capacity and financial leverage. As we know from finance theory, if a firm is highly levered, then the equity is more exposed to aggregate risks. These two effects offset each other in determining the overall riskiness and the average returns of firm equity. In order to further differentiate the two effects, we conduct a double sort on firms' collateralizability and book leverage. The average returns for the sorted portfolios are reported in Table A.4. We make three observations. First, within each tercile on book leverage, the collateralizability spread is always significantly positive. Second, controlling for the collateralizability within each quintile, the correlation between leverage ratio and average returns (riskiness) is not robust. Additionally, the t-statistics of return spread of high minus low portfolios, based on the leverage within each collateralizability quintile, implie that they are statistically insignificant difference from zero. Third, we could potentially construct a profitable long-short trading strategy that long high leverage but low collateralizability portfolio (the top right in the 5 times 3 portfolios) and short low leverage but high collateralizability portfolio (the bottom left of the 5 times 3 portfolios), to obtain an annualized excess returns of 13.44 % for value-weighted scheme.

Table A.2: Fama Macbeth Regression

This table reports the Fama-MacBeth regression results by regressing annual cumulative individual firm stock returns on firm's lagged characteristics. The reported coefficients are the average slope from year-by-year regression. The reported R-squared is the time-series average of the cross-section R-squared. The columns labeled with SA (WW) refers to the sample where firms are classified as constrained using SA (WW) index in year t. The column labeled with Non-Dividend refers to the firms do not pay dividend in year t. ROA is Compustat item IB divided by book assets. OG/AT is organizational capital to book asset ratio. XRD/AT is R&D expenditure to book asset ratio. We adjust t-statistics by using Newey-West estimator. The sample period is from 1979 to 2016.

	(1) SA	(2) WW	(3) Non-Dividend	(4) SA	(5) WW	(6) Non-Dividend	(7) SA	(8) WW	(9) Non-Dividend
Collateralizability	-0.170***	-0.169***	-0.152***	-0.105*	-0.132**	-0.126***	-0.0892***	-0.0669**	-0.0694**
	(-3.68)	(-3.73)	(-3.84)	(-1.92)	(-2.49)	(-2.82)	(-2.75)	(-2.22)	(-2.25)
log(ME)	-0.108***	-0.108***	-0.0496***	-0.104***	-0.105***	-0.0466***	-0.113***	-0.116***	-0.0539***
	(-4.72)	(-6.23)	(-4.61)	(-4.58)	(-6.21)	(-4.53)	(-4.88)	(-6.46)	(-4.90)
BM	0.0626***	0.0429***	0.0538***	0.0663***	0.0442***	0.0555***	0.0679***	0.0510***	0.0598***
	(3.28)	(3.50)	(4.90)	(3.37)	(3.41)	(4.77)	(3.56)	(4.11)	(5.21)
Lagged return	0.0144	0.00527	0.0175	0.0123	0.00354	0.0156	0.0147	0.00694	0.0180
	(0.92)	(0.33)	(0.92)	(0.81)	(0.23)	(0.83)	(0.94)	(0.43)	(0.93)
ROA	0.0804	0.0729	0.0888*	0.0873	0.0814	0.0962*	0.202***	0.223***	0.225***
	(1.18)	(1.21)	(1.70)	(1.23)	(1.30)	(1.74)	(3.42)	(4.25)	(4.90)
Book Leverage	-0.0854	-0.0364	-0.00990	-0.0653	-0.0242	0.000523	-0.0378	0.0169	0.0475
	(-1.68)	(-0.78)	(-0.20)	(-1.29)	(-0.50)	(0.01)	(-0.85)	(0.44)	(1.07)
OG/AT				0.0662***	0.0392**	0.0374**			
				(3.73)	(2.26)	(2.05)			
XRD/AT							0.529***	0.690***	0.570***
							(3.27)	(3.87)	(3.21)
Constant	0.580***	0.593***	0.389***	0.513***	0.551***	0.352***	0.537***	0.542***	0.335***
	(5.72)	(7.88)	(5.94)	(5.28)	(7.64)	(5.45)	(5.42)	(7.81)	(5.11)
Observations	32258	37378	43907	32258	37378	43907	32258	37378	43907
R^2	0.0799	0.0753	0.0603	0.0836	0.0780	0.0637	0.0862	0.0816	0.0675

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Portfolios Sorted on Collateralizability within FF 17 Industries

This table reports asset pricing tests for portfolios sorted on collateralizability. The sample starts from 1979 July and ends in 2016 December. At the end of June each year t, we sort the constrained firms in the same Fama-French 17 industry into five quintiles based on collateralizability measure at the end of year $t-1$. Firms are classified as constrained at the end of year $t-1$, if their WW and SA index are higher than the corresponding median in year $t-1$, or if the firms do not pay dividend in year $t-1$. WW and SA index are constructed according to Whited and Wu (2006) and Hadlock and Pierce (2010). Additionally, we consider a subsample where the firms are classified as constrained by all three measures. The table reports average excess returns $E[R]-r^f$ and t-statistics (t), and the alphas. The t-statistics are estimated using Newey-West estimator. We annualize returns and by multiplying by 12. All portfolio returns are value-weighted by firm market capitalization. α^{FF+MOM} and α^{FF5} are the alphas with respect to Carhart four-factor model and Fama-French five-factor model, respectively.

	1	2	3	4	5	1-5
	Financially constrained firms - All measures					
$E[R]-r^f(\%)$	12.56	12.26	12.21	8.22	5.32	7.24
t-stat	(2.63)	(2.60)	(2.89)	(1.92)	(1.24)	(3.19)
$\alpha^{FF3+MOM}$	4.03	3.50	3.34	-1.75	-3.47	7.50
t-stat	(2.05)	(1.75)	(1.69)	(-0.89)	(-1.90)	(3.13)
α^{FF5}	5.64	5.42	3.97	0.04	-1.78	7.42
t-stat	(3.51)	(3.54)	(2.56)	(0.02)	(-1.22)	(3.67)
	Financially constrained firms - WW index					
$E[R]-r^f(\%)$	12.20	13.17	10.05	8.56	5.75	6.44
t-stat	(2.77)	(2.99)	(2.49)	(2.18)	(1.43)	(3.46)
$\alpha^{FF3+MOM}$	3.30	5.10	1.92	-0.60	-3.25	6.56
t-stat	(2.05)	(2.97)	(1.30)	(-0.41)	(-2.23)	(3.31)
α^{FF5}	5.03	6.08	2.73	0.14	-1.34	6.37
t-stat	(4.06)	(4.71)	(2.28)	(0.13)	(-1.14)	(4.03)
	Financially constrained firms, SA index					
$E[R]-r^f(\%)$	10.94	10.99	9.70	9.07	6.18	4.76
t-stat	(2.38)	(2.42)	(2.28)	(2.26)	(1.45)	(2.25)
$\alpha^{FF3+MOM}$	3.00	3.88	2.65	0.46	-2.17	5.17
t-stat	(1.53)	(2.23)	(1.32)	(0.28)	(-1.20)	(2.40)
α^{FF5}	5.72	6.30	4.91	2.00	-0.57	6.30
t-stat	(4.38)	(4.48)	(2.54)	(1.31)	(-0.44)	(3.80)
	Financially constrained firms, Non-Dividend					
$E[R]-r^f(\%)$	12.42	13.83	8.58	7.75	7.42	5.00
t-stat	(2.92)	(3.11)	(2.09)	(1.93)	(1.76)	(2.08)
$\alpha^{FF3+MOM}$	4.66	6.61	0.76	0.53	0.08	4.58
t-stat	(2.26)	(3.12)	(0.42)	(0.31)	(0.04)	(1.86)
α^{FF5}	5.20	7.01	1.35	0.60	1.55	3.65
t-stat	(2.70)	(4.30)	(0.97)	(0.40)	(0.94)	(1.65)

Table A.4: Independent Double Sort on Collateralizability and Leverage

This table reports annualized average excess returns of independent double sorted portfolios. The sample starts from 1979 July and ends in 2016 December. Among the financially constrained firms, at the end of June each year t, we independently sort firms into five quintiles based on collateralizability (vertical direction) and into tertiles based on book financial leverage (horizontal direction), which are available at the end of year $t-1$. WW index is constructed according to Whited and Wu (2006). The table reports average excess returns and the t-statistics of the return spreads. We annualize returns by multiplying by 12. All portfolio returns are value-weighted by firms' market capitalization.

	L Lev	2	H Lev	H-L	t-stat
L Col	16.56	17.51	22.14	5.58	(1.67)
2	13.77	16.69	18.67	4.89	(1.70)
3	14.50	13.52	13.01	-1.49	(-0.53)
4	13.61	16.59	10.46	-3.15	(-1.14)
H Col	8.70	8.75	10.16	1.46	(0.52)
L-H	7.86	8.76	11.98	4.12	(1.15)
t-stat	(2.34)	(2.48)	(3.21)		

Appendix B: Data and Measurement

In the Appendix, we provide details on the data sources, and the empirical constructions of the collateralizability measure of firm assets, as well as the measurement of intangible capital.

B.1. Data Sources

Our major sources of data are (1) firm level balance sheet data in the CRSP/Compustat Merged Fundmentals Annual Files, (2) monthly stock returns from CRSP, and (3) industry level non-residential capital stock data from the BEA table "Fixed Assets by Industry". We adopt the standard screening process for the CRSP/Compustat Merged Database. We exclude utilities and financial firms (SIC codes between 4900 and 4999 and between 6000 and 6999, respectively). Additionally, we keep common stocks that are traded on NYSE, AMEX and NASDAQ. The accounting treatment of R&D expense reporting was standardized in 1975, we allow three years for firms to adjust to the new accounting rule, therefore the sample starts in 1978. Following Campello and Giambona (2013), we exclude firm-year for which the value of total assets or sales is less than $1 million. We focus on the impact of asset collateralizability on debt capacity of firms, therefore we drop small firms, which do not have much debt. In practice we drop firm-year observations with market value of equity below $8 million, this roughly corresponds to firms at bottom 5%. All firm characteristics are winsorized at 1% level. The potential delisting bias of stock returns is corrected following Shumway (1997) and Shumway and Warther (1999).

In order to obtain a long sample with broader coverage[10], we use the narrowly defined industry level non-residential fixed asset (structure, equipment and intellectual) from the BEA tables to back out industry level structure and equipment capital shares.

In Table B.7, we document the definitions of the variables used in this paper.

B.2. Measurement of collateralizability

This section provides details on the construction of the firm specific collateralizability measure, and it complements the description of the methodology provided in Section 2.

In the empirical implementation, we firstly construct proxies for the share of each type of capital, *StructShare* and *EquipShare*. Then we run the leverage regression as in equation

[10]COMPUSTAT shows the components of physical capital (PPEGT) only for the period from 1969 to 1997. However, even for the years between 1969 and 1997, only 40% of the observations have a non-missing record for PPENB, PPENME and PPENLI.

(2), which allows us to calculate the firm specific collateralizability score latter.

The BEA classification features 63 industries. We match the BEA data to COMPUSTAT firm level data using NAICS codes, assuming that, for a given year, firms in the same industry have the same structure and equipment capital shares. We construct measures of structure and equipment shares for industry j in year t as

$$\begin{aligned} StructShare_{j,t} &= \frac{\text{Structure}_{j,t}}{AT_{j,t}}, \\ EquipShare_{j,t} &= \frac{\text{Equipment}_{j,t}}{AT_{j,t}}, \end{aligned}$$

In order to make the empirical collateralizability measure comparable to the theoretically motivated measure (2), we run the following regression,

$$\begin{aligned} \frac{B_{i,t}}{Asset_{i,t}} &= c + \zeta_S StructShare_{j,t} + \zeta_E EquipShare_{j,t} \\ &\quad + \gamma X_{i,t} + \sum_t Year_t + \varepsilon_{i,t}, \end{aligned} \tag{B2}$$

where i and j index are for firm and industry, respectively. Firm i belongs to indsutry j. $X_{i,t}$ represents a vector of controls typically used in capital structure regressions, including size, book-to-market ratio, profitability, marginal tax rate, earnings volatility and bond ratings. B_{it} is the total debt defined as long term debt (DLTT) plus short term debt (DLC). Additionally in order to capture non-financial debt, following Rampini and Viswanathan (2013), we adjust debt by adding capitalized rental expenses.

The results are shown in Table B.5. We run the leverage regression on constrained firms classified using SA and WW index. Additionally we also regard the firms which do not pay divided as financially constrained in a given year. As we can see in both of the regressions, among the financial constrained firms, there is significant asymmetry in term of collateralizability of structure and equipment capital. In particular, structure capital enjoys higher collateralizability and it can support more debt. The evidence here is in line with the findings of Campello and Giambona (2013).

We interpret $\zeta_S StructShare_{j,t} + \zeta_E EquipShare_{j,t}$ as the contribution of structure and equipment capital to financial leverage, we interpret the product of this term with book value of assets as the measure of collateralizable capital.[11] The collateralizability score for

[11] We also use market value of asset as an alternative. If we construct collateralizability in that way, the empirical collteralizability spread based on this sorting measure is even stronger.

Table B.5: Capital Structure Regressions (Book Leverage)

This table reports the results for regression (B2) using book leverage as the left-hand side variable. *Struct Share* and *Equip Share* are constructed using BEA and Compustat data, as defined in Section B.1. . *Book Size* is the log of *PPEGT* plus intangible capital of the firm, *BM* is the book-to-market ratio. *Profitability* is defined as Compustat item *OIBDP/AT*. *Marginal Tax Rate* is following Graham (2000), from John Graham's website. *Sales Grth Volatility* is computed using 4-year windows of consecutive firm observations of sales growth. *Rating Dummy* is a dummy variable that takes a value of 1 if the firm has either a bond rating (*splticrm*) or a commercial paper rating (*spsticrm*), and 0 otherwise. Standard errors are clustered at firm year level. The column labeled with 'Full' corresponds to the regression performed on all firms. The columns labeled with 'Non-Dividend', 'SA', 'WW' corresponds to the firms classified as constrained using no dividend paying, SA and index. The column 'All Cons.' refers the firms which are classified as constrained using all three measures.

	(1) Full	(2) Non-Dividend	(3) SA	(4) WW	(5) All cons.
Struct Share	0.434***	0.622***	0.559***	0.558***	0.626***
	(10.95)	(9.03)	(6.31)	(7.19)	(13.79)
Equip Share	0.00553	0.155**	0.172	0.0924	0.223***
	(0.13)	(2.16)	(1.53)	(1.16)	(3.06)
Book Size	-0.0113***	0.00829*	0.0467***	0.0546***	0.0639***
	(-3.96)	(1.71)	(5.78)	(7.93)	(13.04)
BM	0.0207***	0.0264***	-0.00688	0.00325	0.00657
	(3.59)	(3.31)	(-0.53)	(0.33)	(0.72)
Profitability	-0.0480	-0.0414	-0.0168	-0.0322	-0.00835
	(-1.54)	(-1.15)	(-0.45)	(-0.88)	(-0.26)
Marginal Tax Rate	-0.180***	-0.108***	-0.251***	-0.209***	-0.153***
	(-8.08)	(-3.09)	(-5.59)	(-5.69)	(-4.46)
Sales Grth Volatility	-0.00175**	-0.00218**	-0.00184**	-0.00196**	-0.00180***
	(-2.35)	(-2.18)	(-2.34)	(-2.11)	(-2.84)
Rating Dummy	0.0592***	0.0457**	-0.0139	0.0806***	0.0787**
	(4.78)	(2.14)	(-0.32)	(2.60)	(2.40)
Constant	0.429***	0.262***	0.198***	0.171***	0.0907**
	(20.93)	(7.26)	(4.14)	(4.44)	(2.38)
Observations	58903	27849	17496	23976	12709
R^2	0.0495	0.0727	0.0580	0.0773	0.0721

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

firm i in year t is then computed as

$$\zeta_{i,t} = \frac{(\zeta_S \cdot StructShare_{j,t} + \zeta_S \cdot EquipShare_{j,t}) \cdot AT_{i,t}}{PPEGT_{i,t} + Intangible_{i,t}}$$

where the numerator is collateralizable capital, and $Intangible_{i,t}$ is the intangible capital of firm i in year t. The importance of taking intangible capital into account has been emphasized in the recent literature, e.g., by Eisfeldt and Papanikolaou (2013) and Peters and Taylor (2017). The $\zeta_{i,t}$ coefficients we adopt in this paper are the ones from the last column of Table B.5, where the firms are classified as constrained using all three financial constraint measures, WW and SA index, and non-dividend paying.

In the above collateralizability measure we implicitly assume the collateralizability parameter for intangible capital to be equal to zero. There is empirical evidence that intangible capital can hardly be used as collateral, since only 3% of total loan value is written on intangibles like patents or brands (Falato et al. (2013)). Our results remain qualitatively very similar when we exclude intangible capital from the collateralizability measure and only exploit the asymmetric collateralizability between structure and equipment capital within tangible assets. Details concerning the measurement of firm specific intangible capital are provided below in Appendix B.3. .

B.3. Measuring intangible capital

In this section, we provide details on the construction of firm specific intangible capital, used in our empirical measure of collateralizability, as in Appendix B.1. .

The total amount of intangible capital of a firm is given by the sum of externally acquired intangible capital, R&D capital, and organizational capital. Externally acquired intangible capital is given by item *INTAN* from Compustat. Firms typically capitalize this type of asset on the balance sheet as part of intangible assets. For an average firm, *INTAN* is about 19% of total intangible capital with a median of 3%, consistent with Peters and Taylor (2017). We set INTAN to zero when missing.

Internally created intangible capital has two components, R&D and organizational capital. R&D capital does not appear on the firm's balance sheet, but it can be estimated by accumulating past expenditures. Following Falato et al. (2013) and Peters and Taylor (2017), we capitalize past R&D expenditures (Compustat item *XRD*) using perpetual inventory method, i.e.,[12]

$$RD_{t+1} = (1 - \delta_{RD})RD_t + XRD_t$$

where δ_{RD} is the depreciation rate of R&D capital. As in Peters and Taylor (2017), the depreciation rates for different industries are following Li and Hall (2016). For unclassified industries, the depreciation rate is set to 15%.[13]

However, this is not enough to identify the stock of R&D capital, the initial value RD_0 for R&D capital is still undefined. We use the first non-missing R&D expenditure, XRD_1, as the first R&D investment, and specify initial value of R&D capital, RD_0, as

$$RD_0 = \frac{XRD_1}{g_{RD} + \delta_{RD}} \tag{B3}$$

where g_{RD} is the average annual growth rate of firm level R&D expenditure. In our sample, g_{RD} is around 29%.

Following Eisfeldt and Papanikolaou (2013) and Peters and Taylor (2017), our organizational capital is constructed in a similar fashion by accumulating a fraction of Compustat item $XSGA$, "Selling, General and Administrative Expense", which indirectly reflects the reputational or human capital of a firm. However, as documented by Peters and Taylor (2017), $XSGA$ also includes R&D expenses, unless they are included in the cost of goods sold (Compustat item $COGS$). Additionally, $XSGA$ sometimes also incorporate the in process R&D expense (Compustat item $RDIP$). So following Peters and Taylor (2017), to exclude R&D capital from organizational capital, we define SGA as $XSGA - XRD - RDIP$.[14] Additionally, also following Peters and Taylor (2017), we add a filter: when XRD exceeds XSGA but is less than COGS, or when XSGA is missing, we keep XSGA with no further adjustment. we replace missing XSGA with zero.

As in Hulten and Hao (2008), Eisfeldt and Papanikolaou (2014), and Peters and Taylor (2017), we count only 30% of SGA expenses as investment in organizational capital, the rest is treated as operating costs.

Using the same procedure as described above for internally created R&D capital, organizational capital is constructed as,

$$OG_{t+1} = (1 - \delta_{OG})OG_t + SGA_t,$$

where $SGA_t = 0.3(XSGA_t - XRD_t - RDIP_t)$ and δ_{OG} is set to 20%, consistent with Falato,

[12]This method is also used by the BEA R&D satellite account.

[13]Our results are not sensitive to the choice of depreciation rates.

[14]$RDIP$ is quoted as a negative number in Compustat.

Kadyrzhanova, Sim, Falato, and Sim (2013) and Peters and Taylor (2017). The average annual growth rate of firm level $XSGA$, g_{OG}, is 18.9% in our sample. We set the initial level of organizational capital as

$$OG_0 = \frac{SGA_1}{g_{OG} + \delta_{OG}}.$$

B.4. Firm Characteristics

In Table B.6 we present the firm characteristics of portfolios sorted on collateralizability.

Table B.6: Firm Characteristics Mean

This table reports the mean of firm characteristics of the five quintile portfolios sorted on collateralizability. The sample covers the firms classified as constrained by WW index. In each year, if a firm's WW index is higher than the median, then it is financially constrained. BM is the book-to-market equity ratio. FD/AT is financial debt ($DLTT$+DLC) over total asset ratio. Tangibility is Compustat item $PPEGT$ divided by the sum of $PPEGT$ and intangible capital. Book leverage is adjusted for capital rent. BM is book-to-market ratio. log(ME) is nature log of market equity. I/K is investment ($CAPX$) over physical capital ($PPEGT$) ratio. ROA is income before extraordinary items (IB) divided by total assets (AT). SA and WW are financial constraint measures following Hadlock and Pierce (2010) and Whited and Wu (2006), respectively. Dividend dummy takes value zero if a firm does not pay dividend during that fiscal year, and one otherwise.

	1	2	3	4	5
Collateralizability	0.051	0.098	0.144	0.220	0.788
Tangibility	0.256	0.346	0.404	0.494	0.620
FD/AT	0.127	0.157	0.173	0.210	0.235
Book leverage	0.494	0.408	0.448	0.594	0.529
BM	0.635	0.762	0.829	0.925	0.927
log(ME)	4.203	4.415	4.495	4.601	4.573
I/K	0.458	0.538	0.416	0.430	0.544
ROA	-0.038	0.064	0.086	0.098	0.090
SA	-2.391	-2.620	-2.681	-2.714	-2.670
WW	-0.146	-0.174	-0.183	-0.187	-0.184
Dividend dummy	0.143	0.159	0.174	0.174	0.159

Table B.7: Definition of variables

Variables	Definition	Sources
Structure share	Firstly we construct the structure shares from BEA industry capital stock data, defined as structure capital over total fixed asset ratio. Then we rescale the structure shares by the corresponding industry average of physical asset (PPEGT) to book asset ratio (AT).	BEA + Compustat
Equipment share	Firstly we construct the equipment shares from BEA industry capital stock data, defined as equipment capital over total fixed asset ratio. Then we rescale the equipment shares by the corresponding industry average of physical asset (PPEGT) to book asset ratio (AT).	BEA + Compustat
Intangible capital	Intangible capital is defined following Peters and Taylor (2017). We capitalize R&D and SG&A expenditures using perpetual inventory method.	Compustat
Collateralizability	Collateralizability capital divide by PPEGT + Intangible. Collateralizability capital and intangible capital defined in Section B.1. .	BEA + Compustat
BE	Book value of equity is the book value of stockholders equity, plus balance sheet deferred taxes and investment tax credit (if available), minus the book value of preferred stock. Depending on availability, we use the redemption, liquidation, or par value (in that order) as the book value of preferred stock.	Compustat
ME	Market value of equity is price times shares outstanding. Price is from CRSP, shares outstandings are from Compustat or CRSP, depending on availability.	CRSP+Compustat
log(ME)	The nature log of market value of equity.	CRSP+Compustat
BM	Book to market value of equity ratio.	Compustat
Tangibility	Physical capital (PPEGT) to the sum of physical (PPEGT) and intangible capital ratio.	Compustat
Book size	The nature log of the sum of PPEGT and intangible capital.	Compustat
Profitability	Compustat item OIBDP divided by AT.	Compustat
OG/AT	Organizational capital divided by total assets (AT).	Compustat
XRD/AT	R&D expenditure to book asset ratio, XRD/AT.	Compustat
Book leverage	Lease adjusted book leverage is defined as financial debt (DLTT+DLC) plus XRENT*10, denominated by AT.	Compustat
Dividend Dummy	A dummy variable takes value of one if the firm's dividend payment (DVT, DVC or DVP) is positive.	Compustat
Saless Grth Volatility	Sale growth volatility is defined as the rolling window standard deviation of past 4 year's sales growth.	Compustat
Rating Dummy	A dummy variable takes value of one if the firm has either a bond rating (splticrm) or a commercial paper rating (spsticrm), and zero otherwise.	Compustat
Marginal Tax Rate	Following Graham (2000).	John Graham's website
WW index	Following Whited and Wu (2006).	Compustat
SA index	Following Hadlock and Pierce (2010).	Compustat
ROA	Return on asset, defined as income before extraordinary items (IB) divided by total assets (AT).	Compustat