Capital Structure and Innovation Riskiness∗

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Abstract

We document that since the 1970s, the leverage of innovative firms in the United States fell from 21.1% to 12.2%. This change was gradual and occurred at both the extensive and intensive margins of innovation. This shift was significantly larger than for non-innovative firms. We propose a model of equilibrium capital structure based on the risk of the project to explain this phenomenon. We demonstrate theoretically that equilibrium debt payoff functions are concave since debt-holders absorb the blow of bad income realizations through default and that equilibrium equity payoff functions are convex since they exclusively receive high income realizations. We use the model to parse apart the specific contributions of two possible explanations of this leverage phenomenon: Tax changes/financial deregulation in equity markets and increased project risk. Our calibrated model suggests that both forces are at work, but that equity issuance costs must have fallen by 31.2% while project risk only increased by 4.7%.

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1. Introduction

Since the 1970’s, US firms that engaged in innovative behavior displayed a marked decrease in their choice of leverage. This is seen clearly in Figure 1 and is quite robust to both the measure of leverage and the definition of ‘innovative’. The change was fairly gradual and observed at both margins, the extensive and the intensive i.e. new cohorts of firms entered with smaller levels of leverage and existing cohorts of firms found it optimal to delever over time\(^1\).

In Figure 1, innovative firms are distinguished from their counterparts by whether or not they engage in R&D in a given year, but we claim that the key difference between these two types of firms is the level of risk in the projects that they undertake. There are both theoretical and empirical reasons to believe that innovative projects are riskier, such as a longer time horizon, a greater asymmetry of information, or simply the fact that R&D investments are in general intangible (see Aghion et al. (2005) or Hall (2002)).

We will demonstrate in this paper that when risk is a distinguishing characteristic of innovation projects, we can expect this divergence in capital structures over time. Equity finance is preferred to debt finance for risky projects because of the dividend structures of the two assets i.e. equity has a convex payoff structure and debt has a concave payoff structure. This notion is not new in the finance literature (See Dewatripont and Tirole (1994) or Boyd and Smith (1999)), but to the authors’ knowledge, the literature has yet to explore the implications of this dichotomy for specific, economically relevant project types e.g. innovation.

Given that risk is the relevant characteristic of innovation, there are two potential explanations for the leverage phenomenon we observe: One on the supply-side and one on the demand-side.

On the supply-side there were numerous tax changes and deregulations that could have increased the supply of equity. In 1980, the corporate tax rate fell by 12%, from 46% to 34%. In addition, in 1982 an R&D tax credit of 20% was introduced, which for innovative firms is isomorphic to a corporate tax reduction. Lastly, the effective marginal dividend tax rate fell substantially during this time, from 43% to 17% (See McGrattan and Prescott (2003) for details). Since the interest on debt payments is tax-deductible, a reduction in the corporate tax rate would simultaneously make debt more expensive for the firm and equity cheaper since the supply of funds would increase. The decrease in the dividend tax would

\(^1\) Appendix A explores these trends in some detail and documents the robustness of these facts.
further increase the supply of equity and drive down the price of issuances. Since equity is used to fund riskier projects, such tax changes would allow for more risky projects to be undertaken using primarily equity finance.

Further, throughout this period there were manifold deregulations that effectively relaxed constraints on equity financing. For instance, in 1982 the SEC adopted a ‘safe harbor’ rule that protected firms from manipulation charges when they repurchased their stock, and in 1983 the SEC adopted a ‘shelf offering rule’ that allowed firms up to a two year window between the disclosure of the firm’s financial condition and the issuance of common stock\(^2\).

Certainly there were financial innovations that reduced the price of issuing debt as well, which would seem to have the opposite effect on leverage. However, Philippon (2012) argues that aggregate efficiency in the financial sector has actually decreased over the past century or so. His argument is not that technological innovations in the financial sector have not taken place, but that these innovations have not kept pace with the increasing difficulty of monitoring new types of projects. We take Phillipon’s stance

\(^2\)See Itenberg (2013) for a more complete list of deregulations and innovations.
here as well in arguing that stationarized monitoring costs likely did not change substantially over time, but that perhaps the composition of those costs did. Phillipon’s time-series analysis of financial sector inefficiencies does not account for these compositional changes.

The last effect that could have an impact from the supply side is the rise in institutional investors. Institutional investors are large entities, such as insurance companies or pension funds, that actively participate in the market for private equity. Aghion et al. (2013) document that in 1970, these institutions owned 10% of publicly traded equity and by 2006 they owned 60% of publicly traded equity. They argue that this rise is significant for innovative projects because institutional investors can more easily monitor manager activities because there is less difficulty in gathering a consensus vote from shareholders when the number of individual shareholders is smaller. We will interpret this rise in institutional investors in the same way that they do: As some sort of reduction in the costs of equity monitoring.

It is important to note that all of these supply-side mechanisms would not simply suggest that a reduced cost of equity implies lower leverage; this is trivially true. Rather, the significant nuance is that these changes would reduce leverage differentially across project risk. Risky, innovative firms would delever more quickly than their safer, more capital-intensive counterparts. The particular reasons why will be discussed shortly.

In addition to these supply-side changes in the availability of equity financing, there are possible demand-side changes that could cause the leverage trends as well. The leverage trends could simply be due to an exogenously (or endogenously) shifting ‘research frontier.’ It could be the case that the research frontier, which R&D was used to advance, became more complex over time. Thus, the risk associated with an R&D project grew over time. Lanjouw and Schankerman (2004) explore the increasing trends in the R&D to patent ratio, claiming that perhaps there are diminishing returns in the ‘knowledge production function,’ and that more human capital is thus required to produce the same quantity of patents. Jones (2009) argues that inventors face an increasingly difficult burden over time as knowledge accumulates, and thus it is more difficult and requires more specialized knowledge to advance the research frontier. In the context of finance, this would imply greater idiosyncratic project risk resulting from greater asymmetry of information.

We verify this empirically in Section 4 using both patent citation volatility and sales growth volatility as proxies for risk, and show that innovative firms have increased the degree of project risk undertaken.
throughout this time period. If this is the case, and these changes are indeed exogenous as the above authors have claimed, then innovation projects are simply becoming riskier and as such will exhibit a greater preference for equity finance over time.

In this paper we employ a new structural model to parse apart quantitatively the contributions of these two forces, the supply-side and the demand-side, to the leverage trends observed in the data. In addition, our model will present financial microfoundations for a large literature regarding technology adoption in economies (see Greenwood and Jovanovic (1990) or Greenwood and Smith (1997)). Many of these works focus on the project-level correlation of risk and return, which we will have as well, but don’t consider the endogenous optimal capital structure of the firm. They show that a greater capacity to undertake ‘high risk/return’ projects via financial development can have a significant impact on economic growth. We will show this to be true as well, but will also provide an explicit characterization of the firm’s problem of choosing an optimal capital structure.

Under either of the two theories mentioned, our model certainly suggests that the development of private equity markets and economic development are intimately related, especially in a framework in which innovation drives the endogenous growth of the economy, such as Romer (1986) or Aghion and Howitt (1990). However, understanding which of the theories above is the most relevant or at least most quantitatively important can have significant policy implications. For instance, if supply-side changes can cause the innovative sector to grow by orders of magnitude, then simple adjustments of the targeted tax rates or other deregulations aimed at increasing efficiency of this market can be used to attain a higher rate of growth\textsuperscript{3}. On the other hand, if the leverage trends are simply due to an shifting research frontier, then there is not much to be done from a policy perspective to assist this process save perhaps innovation tax credits and subsidies.

The intuition of our model is as follows: Risk-neutral debt-holders become risk-averse toward the project in which they invest because they absorb the downside of the risk when the firm defaults, but don’t see the upside of the risk when the firm does well since their returns are capped; similarly, risk-neutral equity-holders become risk-seeking toward the project because the debt-holders absorb all bad realizations with a

\textsuperscript{3}Empirical work has found that the efficiency and ‘intensity’ of private equity markets has lasting implications for economic growth, productivity growth, capital accumulation, and per capita income (See Levine and Zervos (1998) and Rousseau and Wachtel (2000) ). Our work provides some structural foundations for these results.
default, placing a floor on bad outcome realizations while realizing the full potential of good realizations. Given these forces, when the firm chooses its optimal capital structure subject to the zero-profit condition of its investors, riskier projects will imply lower leverage ratios.

It is important to note that in our model of mixed capital structure, risk enters in two ways: Through the risk-aversion of the debt-holders and the risk-seeking of the equity holders. Many authors have examined models of capital structure in which only one of these two channels is active. For instance, Covas and Haan (2012) consider an RBC model in the style of Bernanke et al. (1999), which suggests that leverage ratios are decreasing in risk; however, equity in that model is simply a costly ‘residual,’ and so the fact that leverage is decreasing in risk is due only to the risk-aversion of the debt-holders. There is no role for active risk-seeking on the part of the equity-holders, which would amplify this effect. In our model we allow for both effects to be at work.

In our model, a reduction in the costs of equity finance, via either deregulation, tax changes, or monitoring cost reductions, will disproportionately affect risky firms, since they optimally choose to use more equity finance. Safe, non-innovative firms, will exhibit a greater preference for debt finance and will be affected little, if at all, by a reduction in these costs. This will happen at the extensive margin as well: Some entirely debt financed-firms will find it optimal to mix their capital structure following a reduction in the costs of equity finance.

The framework of our model will be in the costly-state-verification spirit of Townsend (1979). Unlike Townsend, we will not solve an optimal contracting problem, but instead will take the dividend structure of the securities as fundamentals and find the equilibrium of a dynamic signaling game, much like Hvide and Leite (2008). There will be an equilibrium of this game for every possible capital structure, each with an implied payoff to the firm, and the firm will choose the capital structure that maximizes its expected payoff.

We will demonstrate that, in the absence of tax considerations and asymmetric information, this economy will boil down to a Modigliani-Miller (1958) world in which the optimal capital structure of the firm is indeterminate. We will also show that when financial frictions matter, this framework will induce some firms to choose only debt finance while others will prefer a mixed capital structure based on the investment requirements and associated risk.
The model’s quantitative solution lends insight into the potential causes of the leverage divergence. In the model, both explanations will decrease leverage ratios and interest rates while increasing project risk at the intensive margin; however, the demand-side effect drives down the extensive margin i.e. how many firms find it optimal to innovate in the first place. A higher project risk raises the expected costs of intervention under a debt financing scheme. Since a non-trivial fraction of innovative firms choose to be entirely debt-financed\footnote{We will discuss why this is when characterizing the model, but the intuition is simple: Townsend (1979) demonstrated that debt contracts minimize monitoring costs. Thus, equity finance is sub-optimal. For low-risk projects, firms will gain little from the increased willingness to pay of risk-seeking equity holders and will find it optimal to instead choose to minimize monitoring costs with a debt-type contract.}, those firms will find it optimal to not to innovate and instead to choose the safe project. Increases in the mass of mixed-capital structure firms will not be large enough to offset this fall. With supply-side increases this effect is reversed: Since equity financing effectively becomes cheaper, more firms choose to undertake these risky, equity-financed projects.

Since, in the data, the trends we see are increased innovation at both the intensive and the extensive margin, our analysis suggests that if indeed the risk frontier is changing, which in the context of most endogenous growth models is certainly occurring, then this effect must be complemented by supply-side changes in the financial market as well in order to match the patterns in the data. Our calibrated results indeed demonstrate this to be true. We find that equity issuance costs must have fallen by 31.2% while idiosyncratic project risk only increased by 4.7%.

The rest of the paper is organized as follows. Section 2 places our work in the context of the literature; Section 3 presents and characterizes the theoretical model; Section 4 documents empirically the relationship between capital structure and risk, especially as it pertains to innovation, and also demonstrates that the risky activity of innovative firms has actually increased as well; Section 5 uses the model to investigate the plausibility of the theories put forth and discusses the quantitative implications of the model; and Section 6 concludes.

2. Relation to Literature

Our work is primarily motivated by strong, currently undocumented trends in the data. There have been several papers that have explored the global rise in corporate saving, such as Armenter and Hnatkovska (2012) and Karabarbounis and Neiman (2012), but to our knowledge our work is the first to consider the
difference in these trends across firm types e.g. innovative versus non-innovative firms. Our approach in understanding these trends is in the tradition of at least three distinct literatures.

Our model is grounded in the finance literature originating with Townsend (1979), Gale and Hellwig (1985), and Williamson (1986) among others that emphasizes the role of asymmetric information as the key financial friction in otherwise smoothly operating competitive markets. The asymmetry of information can be dissipated, but at a cost. We do not, however, adopt an optimal contracting approach with an incentive constraint, as is commonly done in this literature. Instead, we consider a signaling game. This approach was first taken by Leland and Pyle (1977) and followed by others such as Grinblatt and Hwang (1989) and Bajaj et al. (1998) in their exploration of equity finance, though we will consider a vastly different game from theirs.

We will explore in some depth the significance of mixed capital structures, which has been done before in this finance literature. For instance, Aghion and Bolton (1992) and Dewatripont and Tirole (1994) develop models of incomplete contracts in which the firm’s choice of leverage can be used as an additional mechanism to implement the optimal contract. Boyd and Smith (1999) also argue that a mixed capital structure can implement an optimal contract when the firm has access to multiple technologies, the returns to only some of which are unobservable. Our model will abstract from the contracting problem considered by these authors and instead focus on an equilibrium outcome, since we are not interested in justifying the coexistence of debt and equity, as these authors were, but rather exploring their implications for risky projects in response to several proposed exogenous changes. For our purposes, we are willing to take their joint coexistence, and indeed their joint optimality, as given.

Our model will differ from the models of both Dewatripont and Tirole (1994) and Boyd and Smith (1998) not only in methodology, but also in implication. For instance, in the Dewatripont-Tirole paradigm, increased project risk will imply higher choice of leverage, since leverage is a disciplinary tool used to incentivize managers and this incentive problem becomes more pronounced as the project risk increases. In our model, increased project risk will imply lower leverage ratios, since more equity issuance is a less costly method of financing for these risky firms. In the Boyd-Smith model, equity financing is used primarily to finance projects whose returns are low and publicly observable, and is thus used more as high-returns from unobservable debt projects are driven down from increased project demand. Thus this model
suggests that equity financing is more frequently employed for projects with less asymmetric information. On the contrary, in our model, equity finance will be more frequently employed for projects with greater risk, which translates in our model to greater adverse selection problems.

We follow most closely a literature that seeks to remedy the incentive problems associated with Townsend’s basic model. The problem is that ex post intervention costs may be sufficiently high that the creditor may wish to accept a haircut instead of intervening, even though ex ante incentive constraints are satisfied. Boyd and Smith (1994) lift the assumption of the contractibility of intervention and allow for randomized interventions and find that contracts in this scenario are more plausible. Gale and Hellwig (1989) do this as well, but also seek randomized intervention that is stable in a strategical sense, noting that in some frameworks there may be a trade-off between stability and efficiency.

The model we propose is most closely related to Hvide and Leite (2008), who set up a dynamic finance game with both debt and equity securities and find assumptions under which a mixed capital structure is stable and optimal. Our finance game is essentially the same as theirs, but the equilibria that we find and analyze are different. They analyze the Perfect Bayesian Equilibrium of the game and are most interested in its stability and relationship to the literature; on the other hand, we weaken our equilibrium notion to a Weak Perfect Bayesian Equilibrium and in exchange get more empirically relevant shareholder behavior in the case of absolute priority violations as well as a demonstrable preference for risk on the part of the shareholders.

Besides the finance literature, our work is related to a large body of work on endogenous growth. This literature, which started with Romer (1986) and Aghion and Howitt (1990), seeks to understand the precise mechanisms by which economies grow and the factors that influence their growth rates. It emphasizes the role of innovation as the driver of growth. Our work, at least empirically, is quite concerned with the dynamics of innovation as well, and indeed many of our empirical results are derived from the NBER patent database. However, this literature is concerned mostly with the positive externalities and strategic dynamics associated with innovation itself and places little emphasis on the relevance of its finance. Some key exceptions are King and Levine (1993b) and Itenberg (2013).

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5 An Absolute Priority (AP) Violation occurs when a firm defaults on its debt obligations, which should suggest that the creditors seize ownership of the firm and yet the shareholders still retain some ownership or control rights.
Lastly, our work is related to a large literature on the joint dynamics of economic and financial development. This literature documents empirically strong correlations between measures of financial development and economic growth and posits theoretical models to explain this phenomenon. Classic examples of this literature are Greenwood and Jovanovic (1990), King and Levine (1993a), Levine and Zervos (1998), and Rajan and Zingales (1998). This literature often employs optimal contracting techniques in their treatment of financial markets.

There has been work in this literature similar to ours in that it tries to explain the distinct properties of equity and debt that lead to financial development. Boyd and Smith (1998) develop a model with two different technologies, one of which is optimally financed with debt and another optimally financed with equity, and show that there is a threshold level of income below which debt is the only method of finance employed and above which an equity market grows. Blackburn et al. (2005) show that a debt-equity mixture can be optimal if the optimal contracting problem faces enforcement constraints along multiple dimensions. To our knowledge, however, our work is the first to explore in a macrofinancial context the intimate relationship between risk and equity finance and its implications for optimal project choice and growth.

3. Model

In this section we present a theoretical model that will allow us to explore in depth the financial market changes proposed in the introduction.

We consider a unit mass of overlapping, heterogeneous firms, each of which has access to two distinct projects, a safe one and a risky one. Each incur the same investment cost, $I^6$. The firm must decide which project to pursue and can only pursue one. Firms are heterogeneous along the level of risk and the absolute return of the safe project. For firm $ij \in [0, 1] \times [0, 1]$, the risky project has a mean given by $\bar{x}$ and a variance $\sigma_i^2$, while the safe project yields a certain return of $\gamma_j \bar{x}$, where $\gamma_j < 1 \ \forall j \in [0, 1]$. Suppose that the outcome of the risky project is continuously distributed and bounded in $[x_L, x_H]$, with positive density on the entire domain.

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6This assumption can be relaxed. We can assume that the firms enter with some net worth, $n$, and that the project costs some $K > n$. We then simply take $I = K - n$ i.e. the portion of the project that requires external finance.
3.1. Financing Game

Firm \(ij\) has only the technology, and requires external finance to cover the cost of investment, \(I\). Upon choosing the project, the firm must make use of either or both of two financing technologies, debt and equity, to undertake its project. Investors of both types know the type of the firm, \(ij\), but not the realization of the risky project, \(x\), which only the firm observes. We assume a risk-free interest rate of 0 and that investors are competitive and thus pushed to zero net returns.

We assume for now that safe projects are financed with debt. Since there is no risk, there is no meaningful distinction between debt and equity finance, but we will show later that the optimal capital structure in the limit as we take the variance of a project to zero involves no outside equity. To model the financing of the risky project, we consider the CSV debt-equity game of Hvide and Leite (2008), henceforth H&L.

In this game, a capital structure consists of \((D, \beta)\), where \(D\) is the promised repayment to the debtors and where the shareholders are entitled to a fraction \(\beta\) of the firm’s residual earnings. Because of the asymmetry of information, investors must pay a cost to learn of the project realization. For debt-holders, this cost is \(c_D\) and for equity-holders this cost is \(c_E\). The monitoring cost is assumed to be paid by the firm\(^7\). From now on, the action of monitoring will be referred to as an ‘intervention.’

Given any capital structure \((D, \beta)\), the financing game proceeds as follows\(^8\):

1. The firm learns of the realization of the project, \(x\)
2. The firm decides how much to repay its debtors
   (a) If the firm decides to pay back all of its debt, \(D\), then
      i. The firm decides how much of the residual earnings to issue as dividends
      ii. The shareholders decide whether or not to intervene
   (b) If the firm decides to default partially or wholly, then
      i. The debt-holder decides whether to intervene or accept the haircut
         A. If the debt-holder accepts the haircut, then the firm decides how much of the residual earnings to issue as dividends (absolute priority violation)

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\(^7\)This assumption is tautological for debt, and for equity the propositions can be generalized. See Hvide and Leite (2008) for further discussion.

\(^8\)Note that an intervention always ends the game since the asymmetry disappears.
B. The shareholders decide whether or not to intervene

The game is described visually in Figure 2. The firm’s, debt-holders’, and shareholders’ strategies are black, red, and blue respectively.

One nice property of this model is its behavior in the absence of financial constraints, as we will see in Proposition 3.1.

**Proposition 3.1.** (Modigliani-Miller Equivalence) *If \( c_D = c_E = 0 \), then the optimal capital structure of the firm is indeterminate.*

The proof it given in Appendix C. The intuition for Proposition 3.1 is simple. If the firm is entirely financed with debt, then its repayment will be \( D = I \) and its payoff will be \( Ex – I \). If the firm wishes to start issuing equity to reduce its debt, then the amount be which it reduces its debt obligations will be exactly offset by the requisite dividends it must issue, since shareholders are compensated exactly as the firm is.

### 3.2. Equilibrium in the Financial Game

We use backward induction to characterize the equilibrium.
3.2.1. Equity Holders (No AP Violation)

Suppose that the debt obligations have been repaid in full. This implies that the firm has a value given by \( x - D \) and that outside equity holders hold a claim to a fraction \( \beta \) of these cash flows. We consider an equilibrium in which the firm’s strategy is to issue a dividend of size \( \tilde{E} = \beta(x - D - c_E) \). The benefit of this strategy is that it always renders the shareholder indifferent between monitoring and not. And so the equity holder’s problem does not change from the original H&L model i.e. the monitoring strategy that induces truth-telling on the part of the firm is characterized by a differential equation whose solution takes the form:

\[
P_E(\tilde{E}) = e^{\frac{\tilde{E}}{\gamma_E} + \kappa}
\]

To choose the constant of integration, we set \( \kappa \) such that the acceptance probability is 1 at \( E_H = \beta(x_H - D - c_E) \). This is important for the firm’s incentives. To see why, suppose that \( P_E(E_H) = \xi < 1 \). Then a firm of type \( x_H \) could always offer a small \( \tilde{E} = E_H + \epsilon \) for some small \( \epsilon \). Doing so would guarantee acceptance for an arbitrarily small \( \epsilon \) since the shareholder would have no incentive to intervene, since the largest claim it can attain by doing so is \( E_H \). Thus, an arbitrarily small \( \epsilon \) ‘bribe’ can induce a discrete change in the probability of acceptance given by \( 1 - \xi > 0 \). We prevent this by choosing \( \kappa \) such that a type \( E_H \) firm already faces a probability 1 of acceptance. Doing so yields

\[
P_E(\tilde{E}) = e^{\frac{\tilde{E} - E_H}{\gamma_E}}
\]

For reasons that will be apparent later, it is convenient to write this expression as

\[
P_E(\tilde{E}) = \eta(D, \beta) e^{\frac{\tilde{E} - E_L}{\gamma_E}}
\]

(1)

where \( E_L = \beta(c_D - c_E) \) and so

\[
\eta(D, \beta) = e^{-\beta(x_H - D - c_D)} < 1
\]

(2)

The function \( \eta(D, \beta) \) will play an important role in guaranteeing the continuity and convexity of the shareholder’s payoff.
3.2.2. The AP Violation Subgame and Weak Perfect Bayesian Equilibrium

The key difference between our equilibrium and H&L lies in the treatment of the subgame in which an absolute priority violation occurs i.e. the firm defaults wholly or partially but nevertheless the creditors accept the payment and shareholders still have some control over the firm.

We assume at this point that the value of the firm in this subgame is $c_D$, and will verify this with equilibrium behavior in the debt subgame. H&L find a Perfect Bayesian Equilibrium of the game by assuming that shareholders accept a payment of $E_L = \beta(c_D - c_E)$ with probability 1 and any other payment with probability 0. An unfortunate result of doing this is that the debt-holder behavior supporting this behavior generates a discontinuity in the equity payoff function. This results from the necessity of the firm’s payoff being continuous at the point $D + c_D$, which requires the debt-holder’s monitoring strategy to be discontinuous at this point.

In our equilibrium, we assume that in this subgame shareholders accept a payment $E_L$ not with probability 1 but with probability $\eta(D, \beta) < 1$, where $\eta(D, \beta)$ was derived in the subgame with no AP violation. The shareholder will receive a payment of $E_L$ whether it monitors or not, so it is indifferent between monitoring strategies, and the firm will always be better off having some chance of not being monitored, even if $\eta(D, \beta)$ is arbitrarily small.

The beliefs that support this behavior are not sequentially rational, and so the equilibrium is not Perfect Bayesian, but Weak Perfect Bayesian. We will later discuss this issue in more detail and also elaborate on the manifold benefits that come from our specification relative to H&L.

3.2.3. Debt-Holders

Having characterized the equilibrium in the latter two subgames, we now consider the debt subgame. We assert that the strategy of the firm is to either repay or offer $\tilde{D} = x - c_D$. The advantage of this strategy is that, as in the equity subgames, the incentives of the bank to monitor are trivial. In the case of full repayment, $D$, the bank will never monitor since it can claim at most $D$ by doing so. In the case of default, the bank is rendered indifferent between monitoring and not monitoring, since if it monitors it will get $x - c_D$, which is exactly the payment it receives.

We now simply need to find a strategy on the part of the bank that gives the firm the appropriate incentives. Let $P_D(\tilde{D})$ be the probability that the bank accepts a default offer $\tilde{D}$. Then this function must
induce the firm to reveal truthfully, i.e. the problem

$$\max_{\tilde{D}} P_D(\tilde{D})[\eta(x - \tilde{D} - \beta(c_D - c_E)) + (1 - \eta)(1 - \beta)(x - \tilde{D} - c_E)] + (1 - P_D(\tilde{D})) \times 0$$

must yield as it’s unique solution $\tilde{D} = x - c_D$. A FOC($\tilde{D}$) along with this substitution yields a differential equation with a solution characterized by

$$\rightarrow P_D(\tilde{D}) = e^{\frac{1-\beta+\eta\beta}{\eta c_F + (1-\beta)(c_D-c_E)}(\tilde{D} - D)}$$

We choose the constant of integration such that if the firm repays the full debt, $D$, the debtholder accepts with probability 1 to prevent the sort of ‘bribing’ behavior described in the equity subgame. Thus the bank’s monitoring strategy is

$$P_D(\tilde{D}) = e^{\frac{1-\beta+\eta\beta}{\eta c_F + (1-\beta)(c_D-c_E)}(\tilde{D} - D)}$$

(3)

At the left-tail of the cash flow distribution, $x_L$, we specify that $P_D(\tilde{D}) = 0 \ \forall \tilde{D} < x_L - c_D$. Thus, if a firm plays the equilibrium strategy at $x_L$, its payoff will be $c_D P_D(x_L - c_D) > 0$, which is the payoff from deviation to no payment.

3.2.4. Results

Having described the equilibrium of interest, we now provide some interesting results.

**Theorem 3.2**. For any mixed capital package $(D, \beta)$, there exists an $\hat{x}$ such that if $x_H > \hat{x}$, then a unique, weak perfect Bayesian equilibrium (WPBE) exists of the following type.

$\eta$ is a constant given by

$$\eta = e^{-\frac{\beta(x_H-D-c_D)}{c_E}}$$

In the debt subgame, the strategies are:

$$\tilde{D}(x) = \begin{cases} x - c_D, & x \leq D + c_D \\ D, & x > D + c_D \end{cases}$$

$$P_D(\tilde{D}) = \begin{cases} 0, & \tilde{D} < x_L - c_D \\ e^{\frac{1-\beta+\eta\beta}{\eta c_F + (1-\beta)(c_D-c_E)}(\tilde{D} - D)}, & x_L - c_D \leq \tilde{D} < D \\ 1, & D \leq \tilde{D} \end{cases}$$

In the equity (no AP violation) subgame, the strategies are:

$$\tilde{E}(x) = \beta(x - D - c_E)$$
\[ P_E(\tilde{E}) = \begin{cases} 
0, & \tilde{E} < E_L \\
\eta \frac{\tilde{E} - E_L}{c_E}, & E_L \leq \tilde{E} < E_H \\
1, & E_H \leq \tilde{E} 
\end{cases} \]

In the equity (AP violation) subgame, the strategies are:

\[ \tilde{E} = \beta(c_D - c_E) \]

\[ H_E(\tilde{E}) = \begin{cases} 
\eta, & \tilde{E} = \beta(c_D - c_E) \\
0, & o/w 
\end{cases} \]

Again, the proof is given in Appendix C. Before we discuss this theorem, we can infer a trivial corollary demonstrating the risk-aversion of the debt-holders.

**Corollary 3.3.** The debt payoff function is concave in the cash flows.

Notice that, unlike H&L, our equilibrium is not sequentially rational (thus, the equilibrium found in H&L is unique in its class, as they claim). This is because of the assumption made on the off-the-equilibrium-path beliefs in the AP violation subgame. If the firm deviates from paying the dividend specified by the equilibrium during an AP violation and instead tries to offer \( \epsilon \) more to guarantee acceptance, the shareholder interprets this as an enormously successful firm and slams it with an intervention.

The equilibrium described in Theorem 3.2 thus requires the existence of potentially large realizations, but fortunately there is no requirement on their relative likelihood. Since the beliefs are off the equilibrium path, they could even have probability 0 provided they are in the domain since they need not be reinforced by Bayes’ rule.

This belief system, however, is not consistent with a sequence of ‘nearby’ mixed strategies. If, from time to time, the firm in this subgame randomly payed a dividend slightly higher than the one specified in the equilibrium, then the share-holder would accept for certain, knowing that the firm’s type hasn’t changed and thus he’s getting a slightly higher payoff by not monitoring.

There are significant benefits to weakening our equilibrium concept relative to H&L. Though in a theoretical sense the shareholder’s strategy is myopic but unstable, the practical implication is that the shareholder intervenes in times of financial distress. In a more intricate theoretical model with an explicit contracting problem between the owner and the firm manager, we would certainly expect this and our equilibrium can proxy for this sort of behavior. Further, there is empirical support for shareholder
intervention during financial distress. Gilson (1989) demonstrates that, during this time period, 52% of financially distressed firms experienced senior-level management change\(^9\), and only direct intervention by bank lenders only accounts for 21% of these changes. Wruck (1990) demonstrates that financial distress provides a mechanism to initiate top-management changes.

Further, in our equilibrium, unlike H&L, we can demonstrate the following proposition using a fairly benign assumption.

**Proposition 3.4.** If \( c_E \in [c_D/2, c_D) \), then the equity payoff function is continuous and convex.

Once again, the proof is provided in the Appendix C. The reason why the lower bound on the equity monitoring costs are needed is to ensure that the marginal returns to equity in the AP Violation subgame are not excessively high at the point of repayment. High marginal returns here would induce a kink with a ‘tent’ shape in the equity payoff function, which would clearly not be convex. Figure 3 shows graphically the payoff to equity under the assumptions given in Proposition 3.4. From this figure it is also trivial that the debt payoff function is concave, since it is linear (and upsloping) in the region of default and fixed in the region of repayment. The curvature of these payoff functions has significant implications for capital structure choice as a function of risk.

Notice further that our separating equilibrium satisfies the single-crossing condition Spence (1973) put forth as necessary for a separating equilibrium to exist. It can be shown that

\[
\frac{\partial^2 \hat{x}}{\partial E \partial x} \propto -\frac{\beta}{c_E + \beta(x - D - c_E) - \hat{E}} < 0
\]

which is a sufficient condition for single-crossing i.e. the indifference curves in Dividend \( \times \) Perceived Type space intersect only once and grow flatter as types increase. Intuitively this means that it is less costly for high-type firms to issue larger dividends to make their types known than it is for low-type firms. The indifference curves in the debt subgame look similar, since the beliefs are also linear.

---

\(^9\)This can be compared to only 19% when the firm is not financially distressed.
Figure 3: Payoff Functions
3.3. Firm’s Optimal Capital Structure Choice

Having characterized the financing game, we now explore the firm’s problem. The risk-neutral firm maximizes its expected payoff, which are cash flows net of debt and dividend payments, subject to the constraint that the expected payoff of the investors is zero. Thus, in the absence of taxation, the firm’s problem is given by the following program:

$$\max_{\beta \in [0,1], D \geq 0} \int_{x_1}^{D+cD} \left[ \eta(D, \beta) c_E + (1-\beta)(c_D-c_E) \right] e^{\frac{1-\beta(1-\eta(D, \beta))}{1-\beta(1-\eta(D, \beta))}(x-c_D-D)} f(x) dx$$

$$+ \int_{D+cD}^{x_H} \left[ (1-\beta)(x-D-c_E) + \eta(D, \beta) e^{\frac{\beta(x-D-c_E)}{c_E}} c_E \right] f(x) dx$$

s.t.

$$\int_{x_L}^{D+cD} \beta(c_D-c_E) e^{\frac{1-\beta(1-\eta(D, \beta))}{1-\beta(1-\eta(D, \beta))}(x-c_D-D)} f(x) dx + \int_{D+cD}^{x_H} \beta(x-D-c_E) f(x) dx \geq I$$

$$\eta(D, \beta) = e^{\frac{\beta(x_H-D-c_D)}{c_E}}$$

It is important to note that we are not technically guaranteed a solution to this problem. Theorem 3.2 demonstrated that for any capital structure, there was a sufficiently high cash flow realization such that the equilibrium of the finance game existed. If we take $x_H$ as a non-changing fundamental though, then there may be very small levels of $\beta$ for which the shareholders’ beliefs in the subgame with an AP violation can never be justified i.e. the shareholders have a claim to such small fraction of the cash flows that even if the cash flows were enormous it is not worth it to intervene when a high dividend ‘bribe’ is offered to guarantee acceptance.

In the quantitative work, as we will show, this is never a problem. It is never optimal for the firm
to issue such minute quantities of external equity. We will show that this model tends to generate IPOs quite naturally. Firms prefer debt finance for safer projects since they can avoid paying the dilution costs associated with equity, but at a certain point the risk-seeking equity investors become so willing to invest in this project that they pay a large premium and the firm issues a massive amount of external equity all at once while simultaneously deleveraging.

Note also that we abstract from explicitly incorporating tax policy into the firm’s problem. During the period of interest there were three main tax changes: The corporate tax rate fell, the effective marginal dividend tax rate fell, and, substantially later, the capital gains tax fell. We will interpret tax changes over this time as simply a reduction in the cost of equity issuance, \( c_E \), since they will all work to simply increase the supply of private equity since they increase the post-tax returns to equity investment. This interpretation only grows more complicated if we allow for a tax advantage to debt, since we would need to account for this policy explicitly in the firm’s incentives and this becomes difficult quickly. Thus, we ignore for simplicity this possibility, since it would only strengthen our results anyway by increasing the relative cost of debt to equity.

### 3.3.1. Characterizing the Optimal Solution

Though this problem is quite complicated, there is some simple intuition regarding its solution. The solution as a function of the risk of the project, \( \sigma \) will be of the form

\[
V(\sigma) = \max\{V_c(\sigma), V_i(\sigma)\}
\]

where \( V_c(\sigma) \) is the level of utility when no external equity is issued i.e. the corner solution and \( V_i(\sigma) \) is the level of utility when the marginal benefit of external equity issuance is equated to its marginal cost i.e. the interior solution. We can rest assured that there will not be a corner solution when \( \beta = 1 \) since debt contracts minimize monitoring costs (See Townsend (1979)) and so at least some debt will be used in any optimal solution.

The corner problem is quite easy to characterize, since it simply becomes

\[
\max_{D \geq 0} \int_{x_L}^{D+c_D} c_D e^{\frac{x-D-c_D}{c_D}} f(x)dx + \int_{D+c_D}^{x_H} (x - D) f(x)dx
\]
The left-hand side of the budget constraint is strictly increasing in \( D \), and so if a solution to this problem exists i.e. if \( I \) is not too large, then it is unique and given by solving the participation constraint. Let the solution to this problem be \( D^*(\sigma) \) for a given level of risk, \( \sigma \). We can establish a simple proposition by starting with the following lemma:

**Lemma 3.5.** Suppose a solution to the corner problem exists. Then \( D^*(\sigma) \) is strictly increasing in \( \sigma \).

**Proof** The bank’s payoff is both strictly increasing in \( D \) and strictly concave in \( x \). Increasing the risk thus strictly decreases the bank’s payoff, and so \( D \) must strictly increase to meet the participation constraint. 

Before we consider how the value function responds to risk changes, we must establish one more lemma. First, we will define carefully how we will explore risk. Let \( F \) be a distribution over the cash flows with a mean, \( \bar{x} \). We say that the distribution \( G \) is **symmetrically riskier** than \( F \) if and only if

\[
\begin{align*}
F(x) &< G(x), \quad x < \bar{x} \\
F(x) &> G(x), \quad x > \bar{x}
\end{align*}
\]

where \( \bar{x} \) is the mean of both distributions. Note that this is the same definition of risk that is used in Dewatripont and Tirole (1994). Now, let us define

\[
\hat{F}(x) = e^{\frac{x - D - cD}{\epsilon D}} F(x)
\]

where \( D \) is some arbitrary positive number. The following is trivial:

**Lemma 3.6.** \( G(x) \) is symmetrically riskier than \( F(x) \) if and only if \( \hat{G}(x) \) is symmetrically riskier than \( \hat{F}(x) \).

And the following follows from the definition of second-order stochastic dominance\(^{10}\).

**Lemma 3.7.** If \( \hat{G}(x) \) is symmetrically riskier than \( \hat{F}(x) \), then \( \hat{F}(x) \) second-order stochastic dominates \( \hat{G}(x) \).

---

\(^{10}\)In particular, it follows from the fact that if the mean is preserved between the two distributions, a risk-averse agent will strictly prefer the distribution with less risk.
With these lemmas in hand, we now consider how the value function will respond to risk changes. We can now establish the following proposition:

**Theorem 3.8.** Suppose that $G$ is symmetrically riskier than $F$. Then $V_c(\sigma_G) < V_c(\sigma_F)$.

**Proof** First, we note that we can substitute in the participation constraint to derive the following expression for the value function.

$$V_c(F) = Ex - I - \int_{x_L}^{DF+cD} cD \left(1 - e^{\frac{x-DF-cD}{cD}}\right) f(x)dx$$

In words, since the bank receives a payoff of zero in expectation, the firm essentially pays the investment plus any monitoring costs incurred by the bank. Now we can consider the difference in value functions below:

$$V_c(F) - V_c(G) = -\int_{x_L}^{DF+cD} cD \left(1 - e^{\frac{x-DF-cD}{cD}}\right) f(x)dx + \int_{x_L}^{DG+cD} cD \left(1 - e^{\frac{x-DG-cD}{cD}}\right) g(x)dx$$

$$= cD \left[\int_{x_L}^{DF+cD} \left(1 - e^{\frac{x-DG-cD}{cD}}\right) g(x)dx + \int_{x_L}^{DG+cD} \left(1 - e^{\frac{x-DG-cD}{cD}}\right) g(x) - \left(1 - e^{\frac{x-DF-cD}{cD}}\right) f(x)\right] dx$$

$$> cD \left[\int_{x_L}^{DF+cD} \left(1 - e^{\frac{x-DF-cD}{cD}}\right) g(x) - \left(1 - e^{\frac{x-DF-cD}{cD}}\right) f(x)\right] dx$$

$$= \int_{x_L}^{DF+cD} \left(\hat{G}(x) - \hat{F}(x)\right) dx \geq 0$$

The second to last line follows because $DF < DG$. The last line follows from integration by parts and the last inequality follows from second-order stochastic dominance.

Theorem 3.8 is significant but not a new notion in the finance literature. It says that the debt-only value function is strictly decreasing in risk. This is because riskier projects will place more weight on the tail realizations where monitoring is necessary, and since monitoring costs drive the real interest rate that comes out of these debt contracts, riskier projects will imply higher interest rates and ultimately lower payoffs.

This stands in sharp contrast to the case of a mixed capital structure. Although we have not been able to formulate a theoretical proof, quantitative results suggest that risk has the opposite effect on firm
payoff in the case of mixed capital structure. That is, as the risk increases, the firm’s payoff increases. This is because the equity holders are willing to pay a premium for the risk and so, for any given fraction of external equity issued, the firm does not need to issue as much debt to cover the costs of investment. This effect is strong enough to counteract the reduced payoff of the debt-holders that both comes from a lower \( D \) and from greater risk.

Given these trends, we can begin to characterize finance behavior as a function of risk. For very low levels of risk, the firm gains little from the risk premium coming from the equity holders; as such it is better off by choosing the debt-only solution, which minimizes monitoring costs. As the risk increases, however, the payoff from using only debt falls and the payoff from mixing rises. Thus, at some point the firm IPOs and issues away, all at once, a substantial fraction of its equity. This can be seen in the quantitative results that we will see in Section 5, particularly in Figures 7 and 8.

These theoretical results support a ‘pecking-order’ theory of finance as a function of risk. Firms will first exhaust any retained earnings or net worth when they require funds for investment, since there is no costly informational friction associated with this. If the project is only modestly risky, then the firm will fund the project using debt alone, since this minimizes expected monitoring costs. It is only for riskier projects that equity begins to be used, and even when it is, debt is used as well.

4. Empirics

In this section, we investigate the trends in the data that will be of relevance in analyzing the implications of the theoretical model just described.

To conduct the empirical analysis, we construct a dataset consisting of an unbalanced panel of public manufacturing firms between the years 1976-2005, drawing information from two sources: Standard and Poors Compustat and the NBER Patent Database. Table A.9 in Appendix A provides some of the summary statistics for the dataset. All nominal variables are adjusted by the GDP deflator in the corresponding year and expressed in millions of 2005 US dollars. Definitions of the data items used in the empirical analysis are outlined in Appendix A. What follows is a description of these data sources.

**Standard and Poor’s Compustat Database:** The S&P Compustat North America files contain
financial statements for publicly traded firms from the 1950’s until the present day. We restrict the analysis to domestic\textsuperscript{11} manufacturing firms\textsuperscript{12} in the dataset between 1976-2005\textsuperscript{13}. From this database, we use firms’ annual income statements, balance sheet, and cash flow statements to gather information on industry, firm size, R&D and capital expenditures, and capital structure. We drop observations for which sales are nonpositive or total stockholders’ equity is negative.

One point that is worth discussing is that the sample of Compustat firms is one subject to selection bias and thus has changed significantly over the period in focus. Figure A.11 in Appendix A illustrates this point. The first graph shows that the number of firms has varied throughout the sample period. Of particular interest is the surge in IPO activity in the early 1990’s and its subsequent drop\textsuperscript{14}. The second graph in this figure illustrates how the composition of firms have changed over time across a subset of the most prominent sectors in the sample. An example of such a shift is the sharp increase in the share of firms in the Chemicals industry, mostly driven by the rise of Drugs (SIC 283) firms. The last panel shows how the distribution of size changed over time. The distribution of sales seems to have gotten more dispersed, with a higher fraction of small firms in the sample. Throughout the empirical analysis section, we will explore how these compositional changes affect the capital structure and innovation trends.

**NBER Patent Database**: The NBER Patent Database contains information on all utility patents granted by the United States Patent and Trademark Office (USPTO) in the period 1976-2006. A patent is a type of intellectual property which gives its owner monopoly rights to commercialize an invention in exchange for public disclosure. A patent in the database includes information about characteristics of the inventor, the technology class of the innovation, and the legal claims which are covered by the patent. In addition, it is possible to link patents through citations and for each patent to compute statistics regarding forward citations, which can be used to proxy for patent quality. A detailed description of this dataset can be found in Hall et al. (2001). We use the application year as the relevant date for the patent as it

\textsuperscript{11}Domestic is defined as having headquarters in the United States.
\textsuperscript{12}Manufacturing firms are defined as those with 2-digit industry SIC codes between 20 and 39.
\textsuperscript{13}We start the sample in 1976 because that is the starting year for the NBER patent data. In addition, we ensure consistency in the accounting reporting of R&D as the Financial Accounting Standards Board issued a uniform standard for reporting R&D expenditures in June 1974. We end our analysis in 2005 as we would like to abstract from effects of the financial crisis in 2008.
\textsuperscript{14}[Reference something here with regard to this].
corresponds more closely to when the innovation was actually created and developed. Since there is usually a time lag between when the patent is applied for and when it is granted, there is a truncation issue in the sample of granted patents. An example of this could a patent which was applied for in 2004 but not granted until 2007. Although this patent should be included when in the empirical analysis, it is missing from the patent data. In addition, forward citations of patents granted later on in the period are subject to the truncation bias described in Hall et al. (2001). To mitigate these issues, we restrict the data to the period 1976-1997 when looking at patent statistics.

A crucial feature of this database is the ability to match to the Compustat firms, which allows us to construct patent portfolios for those public manufacturing firms that were granted a patent in this period. We use the subset of observations from this database which are matched to the sample of Compustat firms.

In the rest of the empirical section, we will isolate trends in the data that will be useful when we return to quantitatively characterize the theoretical model.

4.1. R&D Trends

In the introduction, we showed that trends in firm capital structure diverge by innovative behavior. In this section, we outline the facts associated with the rise in the undertaking of innovative activity over the period among the firms in our sample. The first panel of Figure 4 shows the intensive margin of these trends. In particular, the mean and median R&D composition of investment among all of the firms who reported positive R&D in this sample undoubtedly rose. The second panel of Figure 4 demonstrates that there has also been an increase in the share of firms reporting positive R&D expenditures in a particular year i.e. the extensive margin, rising from 55 percent to almost 75 percent. This is a key empirical fact that will be quite important when we analyze the model’s predictions.

In the third panel of Figure 4, we show further evidence that the changes in innovation investment occurred at both margins. This panel shows that the upward trend in R&D composition of investment has been prevalent in each cohort within our sample, even for those firms which had already become public by 1976. Notice, though, that younger cohorts invest relatively more in innovation than their older counterparts.

Thus, the data suggest that whatever structural changes took place in the innovative (or financial) sector
increased innovative behavior at both the intensive and extensive margins. This is the relevant take-away for the analysis of the model’s implications.

**Figure 4: R&D Trends**

![R&D Trends](image)

### 4.2. Innovation Risk Trends

In this section, we demonstrate that the kind of innovation that these firms undertook has also changed. In particular, we document an increase in the risk associated with investing in innovation.

We first note that there has been an increase in the dispersion of sales growth among innovative firms. In the second panel of Figure 5, we plot the median standard deviation of sales growth within the firm. In order to construct this metric, we follow Comin and Philippon (2005) and define within firm volatility as:

\[
\hat{\sigma}_{i,t} = \left[ \frac{1}{5} \sum_{\tau=-2}^{\tau=2} \left( \gamma_{i,t+\tau} - \bar{\gamma}_{i,t} \right)^2 \right]^{\frac{1}{2}}
\]

where \( \gamma_{i,t+\tau} \) is firm \( i \)'s sales growth in period \( t \) and \( \bar{\gamma}_{i,t} \) is the 5-year rolling average of sales growth for this firm. The resulting trends illustrate a steep increase in the idiosyncratic volatility of innovative firms over their counterparts. We also verify in Appendix A that these trends are present when we look at the growth in labor productivity as opposed to sales.

The first panel of Figure 5 displays the dispersion of sales growth in the cross-section. We compute the standard deviation of sales growth for each year among innovative and non-innovative firms separately\(^\text{15}\).

\(^{15}\)In the first panel of Figure 5, we exclude top and bottom 5 percent of sales growth observations in each year.
Although there seems to be a rise in volatility for all firms, the increase is much sharper if we restrict the sample to only innovative firms. Even though this trend is not as strong as the within-firm measure, it is useful for our purposes because it is a measure we will be able to map into our theoretical model directly.\textsuperscript{16}

**Figure 5:** Sales Growth Volatility Trends

Next, we look at the patents granted to the firms in the sample to verify that there has been an increase in dispersion associated with the value of these patents. We employ two metrics of quality: The first is the number of forward citations that each patent receives and the second is the number of patent claims. Hall et al. (2001) and Lanjouw and Schankerman (2004) show that patent citations and claims act as good proxies for innovative quality and economic importance. The first and last panels in Figure 6 show that the standard deviation of both measures of patent quality has increased over the from 1976-1997. The middle panel shows that the share of patents receiving no citations has also increased. In order to verify that the increase in the standard deviation in patent citations is not driven by the surge in patenting activity in the 80’s and 90’s, we adjust the standard deviation in patent citations by the average patent citations in each year and report the results in Appendix A. These facts suggest public manufacturing firms have been investing in progressively riskier innovation projects over this time period.

At this point, we do not take a stance on causality. Seeing this increase in the risk could be explained by either of our two stories: We could take it as an indication that the degree of idiosyncratic risk at the

\textsuperscript{16}Since firms in our model are short-lived, we have no way of computing a similar measure of within-firm volatility, although we will certainly show that the volatility of projects undertaken increases on average.
research frontier is increasing as the frontier grows more ‘complex.’ In this paradigm, the data are evidence of the demand-side story we told in the introduction. However, it could also be the case that a greater capacity for financing risky projects allowed for riskier projects to be financed. According to this story, the research frontier did not change in any fundamental way, but its riskier parts were simply unreachable before. The data alone would not be able to distinguish between these two theories.

Figure 6: Patent Forward Citations and Claims

5. Quantitative Results and Theory Tests

Having identified some key patterns of the data, we now turn to our model’s implications and how they line up with these patterns.

The firm’s problem described at the end of Section 3 is quite complicated, but it is not difficult to solve numerical examples, which is sufficient for our purposes. We have solved the model for a simple parameterization described here: $I = 1.75, x_L = 1.2, x_H = 4.8, c_D = x_L, c_E = .7c_D$. We assume the cash flow is a symmetric truncated normal in the region of the cash flows and explore the optimal capital structure in response to different levels of project risk, as measured by the standard deviation of the cash flow distribution.

5.1. Policy Functions and Payoffs

We examine how capital structure differs across project risk, and how this optimal choice is affected by a decrease in $c_E$ i.e. we can explore implications from both the supply-side changes and demand-side
changes. The results are plotted in Figure 7.

![Figure 7: Optimal Capital Structure Across Risk and Equity Efficiency](image)

Our numerical work shows that indeed an interior capital structure choices exist for this reasonable parameterization\textsuperscript{17}. Figure 7 shows us quite clearly that, as we predicted, an exogenous reduction in equity monitoring costs has a differential impact on capital structure based on project risk. Further, just as was predicted in our theoretical section, there exists some threshold level of risk below which projects are entirely funded by debt and above which projects are funded with a mixed capital structure.

\textsuperscript{17}Refer to Appendix B for details describing our solution method.
This is readily apparent in the policy functions given by Figure 8. For low equity costs, some equity issuance is optimal even at low levels of risk, but there is a level of risk above which the firm’s optimal choice dictates a discrete drop in leverage, which entails both a significant fall in debt levels and a significant rise in external equity issuance. For higher equity costs, this low-risk state simply implies that the firm remains debt-financed; once the risk becomes large enough, the firm issues away a significant fraction of its ownership while cutting back substantially on its debt levels.

![Figure 8: Policy Functions Across Risk](image)

5.2. Quantitative Analysis

With an understanding of both the data and the basic quantitative properties of our model, we now turn to analyze how our proposed theories impact this economy. Recall that the firms are heterogenous along two dimensions: They have varying relative productivities of the safe project, $\gamma_i$, and they have varying risk levels, $\sigma_j$. Their expected payoff from the safe project is simply $\gamma_iEx - I$ because there are no intervention costs since there is no asymmetry of information.

Since there is no risk involved in the safe project, the debt and equity contract are really the same thing.
Each specifies a non-state-contingent payment of $I$ once the project is realized. We will assume, however that the safe project is financed with entirely debt because Figure 7 shows that this is the clear optimal choice of risky projects as we take the risk to zero in the limit. We define firms that undertake the risky projects as innovative.

5.2.1. Supply-Side Changes

We begin our analysis of the quantitative results by examining how the economy responds to a reduction in the cost of the equity intervention from $0.7c_D$ to $0.6c_D$. At the present moment we will interpret historical tax changes in this way as well (though the next step in our project is to solve for them explicitly), as these tax changes had essentially the same effect: They reduced the effective cost of equity finance relative to debt. Figure 9 shows how both optimal project choice and capital structure respond to this change.

**Figure 9:** Economy’s Response to a Reduction in $c_E$

*For project choice, safe projects are in blue and risky (innovative) projects are in red. For capital structure, red is entirely debt-funded and blue is a mixed capital structure; deeper shades of blue signify lower leverage.*

From Figure 9 a few trends are clear. First, the decision to undertake the risky project is non-monotonic because of the optimal financial instruments. For low levels of risk, risky projects are only undertaken when the safe project performs poorly i.e. the risky project has a very low opportunity cost. These projects are funded with debt alone, which minimizes monitoring costs and avoids dilution costs as in the CSV
However, once the project becomes sufficiently risky, then the risk preference of potential equity-holders kicks in; this preference is strong enough to overcome the larger monitoring costs associated with a contractually sub-optimal equity scheme. As the risk grows, leverage ratios fall as we would expect. Further, we see that as the project risk increases, some firms begin to undertake risky projects *given the same opportunity cost*. The risk ‘discount’ taken by shareholders increases with the project risk and so the risky project becomes more appealing as risk increases.

We can see that the changes in the effective cost of equity does not affect most debt-funded firms i.e. firms on the far left of the graph are essentially unchanged. However, the marginal degree of risk for which a mixed capital structure becomes optimal shrinks. Further, in the region of risk where a mixed capital structure can be optimal, more firms choose the risky project. Lastly, the non-monotonicity that results from these two distinct financing schemes becomes more pronounced as the risk ‘discount’ taken by the shareholders increases as $c_E$ falls.

The first set of results from this exercise is given in Table 1. We see that as equity finance becomes more accessible we see a large increase in the measure of innovative firms. This is the *extensive margin* discussed in the introduction i.e. more firms now find it optimal to undertake innovation projects. The measure more than doubles, in fact. At the same time, we can explain another historical fact of this period, which is falling interest rates. This framework suggests one reason why post-war interest rates fell from the 1970’s until the recent financial crisis is that outside equity became a more preferred means of finance. This drove down the demand for debt finance and its concomitant price, the interest rate.

**Table 1: Supply-Side Change: Extensive Margin and Interest Rate**

<table>
<thead>
<tr>
<th></th>
<th>$c_E = 0.70c_D$</th>
<th>$c_E = 0.65c_D$</th>
<th>$c_E = 0.60c_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure of Innovative Firms</td>
<td>0.199</td>
<td>0.355</td>
<td>0.552</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>0.079</td>
<td>0.058</td>
<td>0.038</td>
</tr>
</tbody>
</table>

In the next set of results, given by Table 2, we see that the capital structure of innovative firms falls as we reduce equity monitoring costs. In fact, it falls quite substantially, by a factor of less than one-third. Even though this does not happen with non-innovative firms by assumption, since they are entirely debt-financed, the innovative firms pull down the aggregate leverage figures in this economy, which occurred in
Table 2: Supply-Side Change: Capital Structures

<table>
<thead>
<tr>
<th>Mean $\alpha$</th>
<th>$c_E = 0.70c_D$</th>
<th>$c_E = 0.65c_D$</th>
<th>$c_E = 0.60c_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe Project Firms</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Risky Project Firms</td>
<td>0.723</td>
<td>0.350</td>
<td>0.200</td>
</tr>
<tr>
<td>All Firms</td>
<td>0.945</td>
<td>0.769</td>
<td>0.558</td>
</tr>
</tbody>
</table>

Table 3: Supply-Side Change: Intensive Margin

<table>
<thead>
<tr>
<th>S.D. Project Realization</th>
<th>$c_E = 0.70c_D$</th>
<th>$c_E = 0.65c_D$</th>
<th>$c_E = 0.60c_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe Project Firms</td>
<td>0.038</td>
<td>0.030</td>
<td>0.020</td>
</tr>
<tr>
<td>Risky Project Firms</td>
<td>0.875</td>
<td>0.919</td>
<td>0.934</td>
</tr>
<tr>
<td>All Firms</td>
<td>0.449</td>
<td>0.604</td>
<td>0.741</td>
</tr>
</tbody>
</table>

the data as well.

The final set of results explains the intensive margin. Table 3 shows how the cross-sectional dispersion of project outcomes increases for innovative firms and decreases for safe project firms i.e. firms that were undertaking risky projects will now take on even riskier projects as a result of these financial innovations. The opposite effect is true for the safe project firms; since more firms are undertaking risky projects, only safe projects of high relative productivity are being undertaken instead of a larger range of such projects, and so their cross-sectional dispersion falls.

5.2.2. Demand-Side Changes

We now consider the effects of a demand-side change i.e. an exogenous increase in the risk-frontier for innovative projects. Here, we simply increase the risk of every type of project uniformly while keeping the return structure otherwise identical. We leave the monitoring structure the same.

We interpret this change not simply as an increase in idiosyncratic risk that one might expect from a growing economy as in a quality-ladder growth model such as Aghion and Howitt (1990) or Klette and Kortum (2004). In these models, the returns to innovation are constant, but the resources required to innovate grow over time, implying an increasing idiosyncratic risk. Since innovating firms are risk-neutral, or innovating households are perfectly diversified, this is never an issue in those models. But this natural increase is not what we have in mind in our demand-side theory, since it would follow nearly trivially that financial markets need to grow in efficiency at the same rate to finance these projects and sustain a
balanced growth path.

Rather, we are interested in the notion that the research frontier itself may be fundamentally changing, perhaps as a result of the ‘knowledge production function’ described in Lanjouw and Schankerman (2004) or Jones (2009). One could think of all of the ‘low-hanging fruit,’ on the research frontier as disappearing over time, leaving only projects requiring increasingly intensive expenditures on human capital. Greater levels of human capital will imply greater adverse selection problems and, from the investor’s point of view, greater risk.

**Figure 10:** Economy’s Response to an Increase in the Risk Frontier

*For project choice, safe projects are in blue and risky (innovative) projects are in red. For capital structure, red is entirely debt-funded and blue is a mixed capital structure; deeper shades of blue signify lower leverage.*

Figure 10 shows the economy’s response to such a change. The two graphs on the far left are identical to their counterparts in Figure 9. As the risk of the projects increases overall, we see that the marginal degree of risk required for a mixed capital structure falls, as with the supply-side changes, but it does not seem that, contingent on sufficient risk for a mixed capital structure project, more firms are choosing the risky project as the project risk increases.

Instead the major effects seem to be coming from those risky projects financed entirely with debt. In particular, fewer and fewer such projects are being undertaken. Why is this? In the Townsend CSV
Table 4: Demand-Side Change: Extensive Margin and Interest Rate

<table>
<thead>
<tr>
<th>Measure of Innovative Firms</th>
<th>Base Risk</th>
<th>$1.25 \times \text{Base Risk}$</th>
<th>$1.5 \times \text{Base Risk}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.199</td>
<td>0.1516</td>
<td>0.1406</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>0.079</td>
<td>0.0382</td>
<td>0.0190</td>
</tr>
</tbody>
</table>

Table 5: Demand-Side Change: Capital Structures

<table>
<thead>
<tr>
<th>Safe Project Firms</th>
<th>Base Risk</th>
<th>$1.25 \times \text{Base Risk}$</th>
<th>$1.5 \times \text{Base Risk}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Risky Project Firms</td>
<td>0.723</td>
<td>0.4457</td>
<td>0.2504</td>
</tr>
<tr>
<td>All Firms</td>
<td>0.945</td>
<td>0.9160</td>
<td>0.8946</td>
</tr>
</tbody>
</table>

paradigm, expected monitoring costs are increasing in the degree of risk. Since there is no monitoring associated with the safe project and because the expected monitoring costs are increasing as the risk-frontier increases, the mass of risky projects chosen falls substantially in this region.

Table 4 gives the first set of results, which is again the extensive margin and the interest rate. In this table we see that, as with the supply-side changes, the interest rate falls. Unlike the supply-side changes, though, the extensive margin actually falls i.e. as the risk-frontier increases, less firms begin to innovate. The intuition for this is simple: As the projects become riskier, the expected intervention/monitoring costs increase as in the typical Townsend (1979) paradigm, driving down the value of the project. If there is no fundamental change in the monitoring technology or supply of finance, then we would expect less firms to undertake these risky projects due to the high monitoring costs.

The next set of results is given in Table 5 and gives the capital structures under the changes. These results are isomorphic to their supply-side counterparts but they are not as drastic. Safe projects remain debt-financed by assumption and risky projects decrease their leverage as the level of risk increases. This tends to drive down aggregate leverage ratios, but by not nearly as much as the supply-side changes since the measure of innovative firms is also decreasing.

The last set of results regards the intensive margin and is given in Table 6. The results from the demand-side change are essentially the same as the supply-side change. Safe project dispersion falls only slightly while risky project dispersion increases substantially, which causes overall project risk to increase even though their mass is falling.
### Table 6: Demand-Side Change: Intensive Margin

<table>
<thead>
<tr>
<th></th>
<th>Base Risk</th>
<th>$1.25 \times \text{Base Risk}$</th>
<th>$1.5 \times \text{Base Risk}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe Project Firms</td>
<td>0.0127</td>
<td>0.0126</td>
<td>0.0126</td>
</tr>
<tr>
<td>Risky Project Firms</td>
<td>1.3256</td>
<td>1.9220</td>
<td>2.4096</td>
</tr>
<tr>
<td>All Firms</td>
<td>0.2739</td>
<td>0.3021</td>
<td>0.3609</td>
</tr>
</tbody>
</table>

### 5.3. Estimation Strategy

In the previous section we derived intuition regarding how our model reacts to supply-side and demand-side changes quantitatively. In this section, we attempt to take our model to the data in a serious way to discover by how much each of these changes must have occurred to produce the observed leverage trends. For a detailed description of our solution method, refer to Appendix B.

In a preliminary calibration, we begin by assuming that the cash flows follow a symmetric, truncated normal distribution. This is convenient since it will imply that our model is scale-invariant, and thus we only need to target relevant ratios. We normalize the required investment, $I$, to one. Table 7 describes the rest of the parameterization.

### Table 7: Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Target</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I$</td>
<td>1</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>$\bar{x}/I$</td>
<td>1.182</td>
<td>1.182</td>
<td>Innovative Firm Average Return on Assets</td>
</tr>
<tr>
<td>[$\gamma_L, \gamma_H$]</td>
<td>[.95, 1]</td>
<td>1.129</td>
<td>Non-Innovative Firm Average Return on Assets</td>
</tr>
<tr>
<td>$c_D$</td>
<td>.05</td>
<td>5% Assets</td>
<td>Boyd and Smith (1994)</td>
</tr>
<tr>
<td>$x_L$</td>
<td>.05</td>
<td>$c_D$</td>
<td>Lowest Possible</td>
</tr>
<tr>
<td>$x_H$</td>
<td>2.314</td>
<td>$2x - c_D$</td>
<td>Symmetry of Truncated Normal</td>
</tr>
</tbody>
</table>

Note that the values in Table 7 are computed using COMPUSTAT data from 1975-1986. As is made clear in Table 7, much of the calibration can be done without simulation. Only two parameters need to be estimated: The effective cost of equity, $c_E$, which captures supply-side changes, and the degree of risk, $\sigma_{max}$, which captures the demand-side changes. It is assumed that $\sigma_{min} = 0$ i.e. there exist ‘risky’ projects that have effectively no risk. How risky they become will be a target for estimation.

Table 8 describes the identification strategy used in simulated method of moments. In particular, we use the median leverage of innovative firms to identify the effective cost of equity issuance and we use
the fraction of innovative firms over total firms to identify the degree of risk. Both parameters will have
the same substantial effect on leverage, but they will tend to have the opposite effects on the measure of
innovative firms. We exploit this orthogonality to identify these parameters.

Lastly, it should be noted that we relax the assumption that $c_E \in [c_D/2, c_D)$. While we lose explicit
convexity of the equity payoff function outside of these bounds, the relationship with risk is still there
quantitatively, and it can fit the data better. This will likely change in a more nuanced calibration that
we plan to pursue later.

Table 8: Estimation (SMOM)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Target (Data)</th>
<th>Target (Model)</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_E$ (Before)</td>
<td>0.562</td>
<td>0.211</td>
<td>0.211</td>
<td>Median Leverage</td>
</tr>
<tr>
<td>$\sigma_{max}$ (Before)</td>
<td>3.113</td>
<td>0.570</td>
<td>0.570</td>
<td>Measure of Innovative Firms</td>
</tr>
<tr>
<td>$c_E$ (After)</td>
<td>0.387</td>
<td>0.122</td>
<td>0.122</td>
<td>Median Leverage</td>
</tr>
<tr>
<td>$\sigma_{max}$ (After)</td>
<td>3.259</td>
<td>0.693</td>
<td>0.693</td>
<td>Measure of Innovative Firms</td>
</tr>
</tbody>
</table>

It should be noted before we proceed with the discussion of the results how we interpret our model
empirically. In our present calibration, we take a firm of type $ij$ to be a ‘firm’ as we see it in the data. This
is a bit problematic, given that our analysis in Section 3 suggests that a mass of firms will have interior
leverage choices and a mass will be entirely debt-financed. This implies that our model will generate some
firms that are entirely debt-financed, which is not consistent with our sample of COMPUSTAT firms, all
of which have issued an IPO.

A more detailed calibration is indeed in order, and likely one that interprets a firm as a ‘project’ and not
as a firm in an empirical sense. Thus, a publicly traded firm will consist of a portfolio of projects, some of
which as financed with a mixed capital structure and others which are financed with debt alone. The end
result will be some more plausible capital structure. However, this will require us to change our definition
of ‘innovative,’ to one in which, for example, a firm is innovative if its innovation intensity is greater than
one half. The empirical trends still hold for this definition, and it is simply a matter of re-working the
empirical and quantitative exercise to derive a more precise estimate.

It should also be noted that our measure of ‘return on assets’ may be on the small side. This is because
we assume that the firm finances its projects entirely with external funds i.e. it has no net worth or retained
earnings. In reality, firms, especially large firms, often finance many projects with retained earnings. We
can also account for this by explicitly allowing for some net worth, which we plan to do in future work.

With these qualifications in mind, we now turn to the key results. We can see that under the assumption that only the two theories discussed in this paper are responsible for changing the leverage ratios, that equity issuance costs must have fallen by 31.2% while the exogenous level of risk must have risen by only 4.7%. The intuition for these changes comes largely from the external margin of entry into innovation, as was discussed before. Both effects will reduce leverage and interest rates, but equity issuance costs will increase the mass of firms engaging in innovation by making it optimal more often to mix capital structures and thus pursue the risky project, while raising the level of risk will increase the cost of debt-only projects, which remain a substantive fraction of overall projects, since the debt contract does minimize monitoring costs.

In a more nuanced and careful calibration we expect that these key results will change slightly in magnitude, but certainly not in direction. The intuition will still remain even if the identification strategy changes. Our results suggest that the most relevant change for innovative firms over the past 40 years or so is not in the type of projects that they undertake, but rather their capacity to raise funds for those projects by issuing outside equity. Thus, our results support Greenwood and Jovanovic (1990) and suggest that the ‘research frontier’ and the level of financial development in any country may be much more endogenous and interconnected than they at first appear.

One last comment regarding the calibration is in order. It should be noted that we have assumed that $c_D$, the stationary monitoring cost of debt, has remained constant over time. We justify this by referring to work by Philippon (2012), which demonstrates that by value added measures, the financial sector has not become more efficient over time. We plan to make this more explicit by perhaps constructing a measure of financial efficiency that is some function $f(c_D, c_E)$, which is decreasing in both arguments. We could then calibrate the model such that this measure remains constant. Our results would almost surely suggest that $c_D$ has increased over time while $c_E$ has fallen\textsuperscript{18}, which would flesh out in more detail the story of financial development over the last forty years or so. Even though there have been innovations to debt funding, such as the acceptance of Asset-Backed Securities and the collateralizability of intangibles, these innovations have not been able to keep pace with the more complicated nature projects they are used to

\textsuperscript{18}Remember that both are interpreted as stationarized.
fund. On the other hand, deregulations and development of private equity markets have more than kept pace with the advancement of these projects.

6. Conclusion

In this paper, we demonstrated empirically that leverage ratios diverged for innovative and non-innovative firms over the latter half of the post-war era in the US and presented a tractable model for parsing apart potential theories to explain this. In particular, we demonstrated a strong negative relationship between innovation and leverage both at the intensive and extensive margins and demonstrated that this trend grew over time.

Conditional on risk being the finance-relevant aspect of innovative projects, we developed a model in the spirit of Townsend (1979) following most closely Hvide and Leite (2008) to parse apart potential explanations for this leverage phenomenon. The model generated a ‘pecking-order’ hierarchy for finance as a function of risk, in which retained earnings are employed first, then debt, then equity as the project grows riskier. The calibrated model suggested that equity issuance costs must have fallen by 31.2% while idiosyncratic project risk must have risen by only 4.7%.

Our results underscore the importance supply-side changes in the financial markets. Both supply-side and demand-side effects work to decrease leverage ratios, lower real interest rates, and increase innovation at the intensive margin, but supply-side changes also increased innovation at the extensive margin whereas demand-side changes decreased innovation at this margin. The intuition was that a large mass of innovative projects are optimally financed entirely with debt, and as risk increases the expected monitoring costs increase, rendering these projects inferior to their safer counterparts with no associated monitoring costs.

Our work supports claims by Rajan and Zingales (1998), Brown et al. (2009), and others who claim that financial considerations are relevant for investment decisions in contrast to the result of Modigliani and Miller (1958). Further, our work demonstrates that either tax policy, deregulation, or substantial development of private equity markets must be present to justify patterns seen in the data, and thus complements Itenberg (2013).

This paper could serve as a launchpad for several potential avenues of future research. First, the model predicts an intimate relationship between the undertaking of innovative projects and equity financing.
One could test these predictions using cross-country data on economic development and the efficiency of private equity markets. In fact, one could potentially calibrate our model more appropriately using this cross-country data and perhaps use it to construct a new measure of the efficiency of equity markets.

On the other hand, one could explore in more theoretical depth the implications of the discrete jumps in our model. In our model, as projects become riskier, there exists some risk threshold beyond which firms discretely delever and issue away a large fraction of their firm to outside investors. This may be one potential explanation for the ‘leverage collapse’ observed in the recent financial crisis, which was commonly associated with an increase in risk.

7. References


**Appendix A. Empirics**

**Appendix A.1. Summary Statistics**

Summary statistics for the sample of public manufacturing firms are in Table A.9.

**Appendix A.2. Definition of Data Items**

- \( \text{Assets}_t \) : Book assets (item 6) in period \( t \).
- \( \text{ROA}_t \) : Return on assets in period \( t \) is defined as operating income before depreciation (item 13) divided by book assets in period \( t \) (item 6).
- \( \text{Levg}_t \) : Leverage is defined as debt in current liabilities (item 34) plus long-term debt (item 9) divided by book assets (item 6) in period \( t \). Alternative definitions of leverage are as follows: a) long-term debt (item 9) divided by book assets (item 6) in period \( t \); b) long-term debt (item 9) divided by total stockholders’ equity (item 216) in period \( t \); c) debt in current liabilities (item 34) plus long-term debt (item 9) divided by the sum of debt in current liabilities (item 34), long-term debt (item 9) and total stockholders’ equity (item 216) in period \( t \).
- \( \text{R&DT}_t \) : Research and development expenditures (item 46) in period \( t \).
- \( \text{Capx}_t \) : Capital expenditures (item 128) in period \( t \).
- \( \text{Cash Flows}_t \) : Gross cash flows in period \( t \) are defined as (after-tax) income before extraordinary items (item 18) in period \( t \) plus depreciation and amortization (item 14) in period \( t \) plus research and development expenses (item 46) in period \( t \).
Table A.9: Summary Statistics

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>S&amp;P Compustat</td>
<td>Firm Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Log(Assets)</td>
<td>94,972</td>
<td>4.687</td>
<td>2.317</td>
</tr>
<tr>
<td></td>
<td>Log(Sales)</td>
<td>95,027</td>
<td>4.643</td>
<td>2.565</td>
</tr>
<tr>
<td></td>
<td>Log(Employment)</td>
<td>86,418</td>
<td>-0.306</td>
<td>2.207</td>
</tr>
<tr>
<td></td>
<td>Investment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R&amp;D</td>
<td>60,505</td>
<td>77.072</td>
<td>403.028</td>
</tr>
<tr>
<td></td>
<td>Capx</td>
<td>92,689</td>
<td>116.501</td>
<td>761.145</td>
</tr>
<tr>
<td></td>
<td>R&amp;D Share of Inv</td>
<td>94,055</td>
<td>0.331</td>
<td>0.340</td>
</tr>
<tr>
<td></td>
<td>Financing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leverage</td>
<td>94,747</td>
<td>0.241</td>
<td>0.206</td>
</tr>
<tr>
<td></td>
<td>Cash Flows</td>
<td>94,709</td>
<td>204.947</td>
<td>1223.079</td>
</tr>
<tr>
<td></td>
<td>Equity Financing</td>
<td>93,905</td>
<td>-1.883</td>
<td>217.182</td>
</tr>
<tr>
<td></td>
<td>Debt Financing</td>
<td>93,667</td>
<td>19.996</td>
<td>460.257</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Firm Age</td>
<td>95,027</td>
<td>14.266</td>
<td>12.206</td>
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<tr>
<td></td>
<td>Unique Firms</td>
<td>9,154</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>NBER Patent Database</td>
<td>Citations</td>
<td>445,351</td>
<td>17.229</td>
<td>25.486</td>
</tr>
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<td></td>
<td>(matched)</td>
<td></td>
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<td></td>
<td>Claims</td>
<td>445,351</td>
<td>15.528</td>
<td>12.828</td>
</tr>
<tr>
<td></td>
<td>Unique Firms</td>
<td>3,843</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: All nominal variables are adjusted by the GDP deflator in the corresponding year and expressed in millions of 2005 U.S. dollars.
• **Equity Fin**\textsubscript{t} : Equity financing in period \( t \) is defined as the sale of common and preferred stock (item 108) in period \( t \) minus the purchase of common and preferred stock (item 115) in period \( t \). Alternative definition of equity financing used is the change in the book value of equity (item 216) between period \( t \) and \( t - 1 \) minus change in the balance-sheet item for (accumulated) retained earnings (item 36) between period \( t \) and \( t - 1 \).

• **Debt Fin**\textsubscript{t} : Debt financing in period \( t \) is defined as the long-term debt issuance (item 111) in period \( t \) minus long-term debt reduction (item 115) in period \( t \). Alternative definition of debt financing used is the change in total liabilities (item 181) between period \( t \) and \( t - 1 \).

• **Sales Gr**\textsubscript{t} : Sales growth in period \( t \) is defined as sales (item 12) in period \( t \) minus sales in period \( t - 1 \) divided by sales in period \( t - 1 \).

• **LP Gr**\textsubscript{t} : Labor productivity growth is defined as labor productivity in period \( t \) minus labor productivity in period \( t - 1 \) divided by labor productivity in period \( t - 1 \). Labor productivity in period \( t \) defined as sales (item 12) in period \( t \) divided by employment (item 29) in period \( t \).

• **Firm Age**\textsubscript{t} : Firm age in period \( t \) is defined as the number of years from when the firm first appeared in the Compustat to period \( t \).

• **Cite**\textsubscript{t} : Forward citation for a particular patent are defined as the number of future patents citing it. The citation count is adjusted by a weight to correct for truncation as derived in Hall, et al (2001).

• **Claim**\textsubscript{t} : The claims in the patent specification outline the property rights protected by the patent and define the novel features of the invention.

• **Innovative** : A firm is defined as innovative in period \( t \) if they report positive R&D expenditures in period \( t \). Alternative definitions used rely on the cutoff for R&D share of investment and average reporting of R&D throughout the firm history.

### Appendix A.3. Composition of Firms in the Compustat

Figure A.11 shows the trends in the number of firms in the sample, share accounted for by the most prominent industries, and the size distribution change over time.
Appendix A.4. Additional Capital Structure Trends

In this section, we present additional facts regarding capital structure and firm financing.

**Cohort Analysis:** Although median and mean leverage decreased over the period of 1976-2005, it is not yet clear whether this change was due to differences in the financing behavior of incumbent firms or differences in the characteristics of firms that made an IPO within that period. To shed light on this, we break our sample into 6 cohorts depending on when the firms first show up in the sample and look at their respective leverage trends separately. The results of this experiment are demonstrated in Figure A.12. The leverage trends for innovative firms appear to be a combination of two factors: a decrease in leverage over time for older cohorts and a lower initial level of leverage for each entering cohort. The decrease of leverage within the cohort is more pronounced for the firms which entered the sample between 1976-1980 and 1981-1985. The observation of lower leverage of entering cohorts is prevalent for each innovative cohort throughout this period. We do not observe similar trends for the sample of those firms which do not innovate. More specifically, although there does seem to be a slight decrease in leverage in the last decade for the older cohorts, some entrants appeared in the sample with higher levels of leverage than the incumbent firms.

**Alternative Definitions of Leverage:** The observed leverage trends are robust to different definitions of leverage. Using three alternative definitions, we demonstrate that there has been a decrease in leverage
among innovative firms, but not their counterparts. For more details regarding alternative definitions of leverage as well as the advantages and disadvantages of each specification, we refer the readers to Rajan and Zingales (1995) and Frank and Goyal (2009).

**Firm Internal and External Financing:** In Figure A.14, we demonstrate how the availability of internal financing and external equity financing scaled by sales has evolved over the period for innovative and non-innovative firms. There do not seem to be pronounced trends in the availability of internal financing (cash-flows) for either type of firm. On the other hand, there is a striking increase in the use of external equity financing among innovative firms beginning in the 1990’s. This result further confirms our interpretation of leverage trends among innovative firms resulting from greater use of equity as opposed to debt to finance investment. This observation is also is consistent with the finding in Brown et al. (2009) of increased equity financing for high-tech public firms over the period since a significant fraction of innovation activity is concentrated among these firms.

**Leverage Regressions:** In order to explore the relationship between capital structure and innovation controlling for other firm observables, we run the following regression for firm-year observations:

\[
Levg_{i,t} = \beta_0 + \beta_1 \left( \frac{R&D_{i,t}}{Inv_{i,t}} \right) + \beta_3 X_{i,t-1} + \delta_j + \delta_t + \varepsilon_{i,t}
\]
Figure A.13: Leverage (Alternative Definitions) Trends

(A) \( \text{LT Debt} \) / \( \text{Assets} \)  
(B) \( \text{LT Debt} \) / \( \text{Stockholder Equity} \)  
(C) \( \text{Total Debt} \) / \( \text{Total Debt + Stockholder Equity} \)

Figure A.14: Internal and External Financing
where \( X_{i,t-1} \) contains a measure of firm size, \( \log(\text{Assets}) \), and profitability, \( \text{ROA} \). Industry and year fixed effects are denoted by \( \delta_j \) and \( \delta_t \) respectively. The results of this regression are presented in Table A.10. The negative relationship between leverage and firm profitability and the positive relationship between leverage and firm size is consistent with findings by Fama and French (2002) and Frank and Goyal (2009). In addition to these observations, we find that leverage is negatively related to a measure of firm-level innovation intensity, R&D share of investment. This holds true even when firm fixed effects are included in the regression.

<table>
<thead>
<tr>
<th>Table A.10: Leverage and Firm Size Regressions (Variables Winsorized)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>( \log(\text{Assets}_{i,t-1}) )</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>( \text{ROA}_{i,t-1} )</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>( \text{R&amp;D}<em>{i,t}/\text{Inv}</em>{i,t} )</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Year dum</td>
</tr>
<tr>
<td>Industry dum</td>
</tr>
<tr>
<td>Cohort dum</td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>( R^2 )</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses.
Source: COMPUSTAT 1976-2005
* \( p < 0.05 \), ** \( p < 0.01 \), *** \( p < 0.001 \)

Next, we explore how these relationships changed over time. We modify the specification above to include an indicator for the years 1996-2005 and run the following regression for the data containing only periods 1976-1985 and 1996-2005:

\[
\text{Lev}_{i,t} = \beta_0 + \beta_1 (\text{R&D}_{i,t}/\text{Inv}_{i,t}) + \beta_3 \text{Present} + \beta_4 \text{Present} \times (\text{R&D}_{i,t}/\text{Inv}_{i,t}) + \beta_5 X_{i,t-1} + \delta_j + \delta_t + \varepsilon_{i,t}
\]

The \text{Present} indicator captures the average trend in leverage controlling for the other observables and interacting this indicator with R&D share of investment captures the changes in the relationship between innovation and leverage over time. Therefore, \( \beta_1 < 0 \) and \( \beta_4 < 0 \) denotes that the negative relationship
between leverage and innovation has become even more so over time. Table A.11 shows that this is indeed the case even when fixed effects are included.

### Table A.11: Leverage and Firm Size Trend Regressions (Variables Winsorized)

<table>
<thead>
<tr>
<th></th>
<th>(1) OLS</th>
<th>(2) OLS</th>
<th>(3) OLS</th>
<th>(4) FE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Present</strong></td>
<td>-0.0415*** (0.00505)</td>
<td>0.00836 (0.00537)</td>
<td>0.00657 (0.00538)</td>
<td>-0.0238*** (0.00497)</td>
</tr>
<tr>
<td><strong>R&amp;D_{i,t}/Inv_{i,t}</strong></td>
<td>-0.0344*** (0.00523)</td>
<td>-0.0494*** (0.00554)</td>
<td>-0.0196** (0.00692)</td>
<td></td>
</tr>
<tr>
<td><strong>R&amp;D_{i,t}/Inv_{i,t} \times Present</strong></td>
<td>-0.111*** (0.00553)</td>
<td>-0.121*** (0.00583)</td>
<td>-0.0143* (0.00714)</td>
<td></td>
</tr>
<tr>
<td><strong>Log(Assets_{i,t-1})</strong></td>
<td>0.00651*** (0.000409)</td>
<td>0.0233*** (0.00133)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ROA_{i,t-1}</strong></td>
<td>-0.101*** (0.00458)</td>
<td>-0.116*** (0.00600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>0.296*** (0.00886)</td>
<td>0.288*** (0.00873)</td>
<td>0.245*** (0.00910)</td>
<td>0.140*** (0.00683)</td>
</tr>
<tr>
<td><strong>Year dum</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Industry dum</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>63083</td>
<td>62583</td>
<td>55550</td>
<td>55550</td>
</tr>
<tr>
<td><strong>R^2</strong></td>
<td>0.081</td>
<td>0.107</td>
<td>0.128</td>
<td>0.667</td>
</tr>
<tr>
<td><strong>Adjusted R^2</strong></td>
<td>0.079</td>
<td>0.105</td>
<td>0.126</td>
<td>0.612</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
* p < 0.05 , ** p < 0.01 , *** p < 0.001

### Appendix A.5. Additional Innovation Trends

In this section, we present additional facts regarding firm-level risk and innovation. Figure A.15 shows an increase in the cross-sectional and within firm dispersion in labor productivity growth. Figure A.16 instead shows the increase in patent citations scaled by the mean patent citations in each year.
Figure A.15: Sales Growth Volatility Trends

Figure A.16: Patent Citations Trends
Appendix B. Solution Method

We know that the firm’s optimal capital structure will either be debt-only or a mixture of the two. It will never use equity alone since equity-financing a sub-optimal contract and the firm has access to the optimal contract, so it will choose to finance at least a portion of the project with debt.

The debt-only solution is pinned down uniquely by the lender’s participation constraint:

\[
\int_{x_L}^{D+c_D} (x - c_D)f(x)dx + \int_{D+c_D}^{x_H} Df(x)dx = I
\]

It is easy to show that the LHS is concave and strictly increasing in \(D\), so long as there is positive mass on the entire domain of \(x\).

\[
FOC(D) = \int_{D+c_D}^{x_H} f(x)dx > 0
\]

\[
SOC(D) = -f(D + c_D) < 0
\]

Thus, if there is a feasible repayment scheme i.e. \(I\) is not too large, then that repayment scheme is unique and we can simply solve this lender’s participation constraint to obtain the debt-only solution.

The mixed capital solution will involve a trade-off of debt and equity at the margin, thus the FOC of the Lagrangian optimization problem will hold (it is not sufficient for an overall maximum, but it is necessary for an interior maximum). To estimate the model, we solve for both types of solutions (debt alone and mixed capital structure), and then determine which yields the higher payoff. After estimation, we verify that the interior solutions found are indeed optimal with a grid-search algorithm, since there can be multiple local maxima (and indeed, some local minima).

Appendix C. Theoretical Proofs

Proof of Proposition 3.1: Given \(c_D = c_E = 0\), the investors will choose to monitor with probability 1 and the asymmetry of information disappears. Thus, the firm solves the problem:

\[
\max_{D \geq 0, \beta \in [0,1]} (1 - \beta) \int_{D}^{x_H} (x - D)f(x)dx
\]

s.t. \(\int_{x_L}^{D} xf(x)dx + \int_{D}^{x_H} Df(x)dx + \int_{D}^{x_H} \beta(x - D)f(x)dx \geq I\)
We can substitute out for $\beta$ from the constraint and simplify the integrals, giving the following problem

$$\max_{D \geq 0} \left(1 - \frac{I - \int_{x_L}^{D} x f(x) dx - D[1 - F(D)]}{\int_{D}^{x_H} x f(x) dx - D[1 - F(D)]}\right) \left(\int_{D}^{x_H} x f(x) dx - D[1 - F(D)]\right)$$

Which simplifies to

$$\max_{D \geq 0} Ex - I$$

Regardless of the choice of $D$ (and concomitant $\beta$, via the lender participation constraint), the firm’s payoff is the same, $Ex - I$. Thus, the firm is completely indifferent to the choice of capital structure.

**Proof of Theorem 3.2:** In the debt subgame, supporting beliefs on the part of the lender are given by $\tilde{D}^{-1}(\tilde{D})$ in the region of partial default. When $\tilde{D} < x_L - c_D$, any beliefs will support the action of monitoring; the same is true of acceptance when $\tilde{D} \geq D$.

In the equity subgame with no absolute priority violation, supporting beliefs are given by $\tilde{E}^{-1}(\tilde{E})$ in the region of equilibrium repayment. If $\tilde{E} < E_L$, any beliefs support intervention; the same is true for $\tilde{E} \geq E_H$ to support acceptance.

In the equity subgame with absolute priority violation, supporting beliefs are the same as the debt subgame on the equilibrium path i.e. $\tilde{D}^{-1}(\tilde{D})$, since the equity holder observes the recovery rate by assumption. Off the equilibrium path, if $\tilde{E} > E_L$, then equity-holders believe the type to be $x_H$ with probability 1, implying that the expected payoff from intervention is $E_H$. Thus, so long as $E_H = \beta(x_H - D - c_E) > c_D$, which is the largest bribe the firm can offer, these beliefs can sustain an equilibrium. The threshold $\hat{x}$ is thus given by

$$\hat{x} = \frac{c_D}{\beta} + D + c_E$$

If $\tilde{E} < E_L$, then any beliefs will support intervention.

Lastly, the firm’s payoffs need to be continuous at the point $x = D + c_D$ i.e. this threshold firm needs to be indifferent between joining the default subgame and the repayment subgame. In the default subgame, a payment of $D$ would be accepted for certain by the creditor, and so the firm would immediately enter the AP violation subgame.
\[ \eta(c_D - \beta(c_D - c_E)) + (1 - \eta)((1 - \beta)(c_D - c_E)) = \\
PE(\beta(c_D - c_E))(c_D - \beta(c_D - c_E)) + (1 - PE(\beta(c_D - c_E)))(1 - \beta)(c_D - c_E) \]

Since \( P(\beta(c_D - c_E)) = \eta e^{\frac{\tilde{D}_{L} - \tilde{D}_{E}}{c_E}} = \eta \), the above expression always holds.

The equilibrium is unique because the value of \( \eta \) given in the theorem is the only value that simultaneously satisfies the firm’s indifference requirements at the threshold \( x = D + c_D \) and at the boundary point \( x = x_H \) in the equity subgame with full debt repayment.

**Proof of Proposition 3.4:** We know that in the region of default the equity-holders’ payoff function from a realization \( x \) will be \( E_L \) conditional on the debt-holders accepting a default. Thus, their unconditional payoff is given by \( P_D(\tilde{D}(x))E_L \), which is a continuous function of \( x \). At the point \( \hat{x} = D + c_D \), we will have \( \hat{D} = D \) and thus the left-hand side of the payoff function at \( \hat{x} \) converges to \( E_L \). Since the equity subgame to the right of \( \hat{x} \) simply provides a linear payoff from \( E_L \) to \( E_H \), we know that the right-hand side of the payoff function is continuous and converges to \( E_L \). Thus, the equity payoff function is continuous.

We know that the payoff function is exponential in the range of default, and therefore convex. It is linear in the range of repayment. We need only show that the slope at \( D + c_D \) is greater in the case of repayment than default.

\[
FOC(RHS) = \beta \ \forall x
\]

\[
FOC(LHS) = \beta(c_D - c_E) \frac{1 - \beta + \eta \beta}{[\eta c_E + (1 - \beta)(c_D - c_E)]} e^{\frac{1 - \beta + \eta \beta}{[\eta c_E + (1 - \beta)(c_D - c_E)]}(x - c_D - D)}
\]

\[
FOC(LHS)|_{x=D+c_D} = \beta(c_D - c_E) \frac{1 - \beta + \eta \beta}{[\eta c_E + (1 - \beta)(c_D - c_E)]} = \beta \left[ \frac{1 - \beta + \eta \beta}{1 - \beta + \eta \left( \frac{c_E}{c_D - c_E} \right)} \right]
\]

Therefore, the LHS will be smaller than the RHS iff

\[
\beta \leq \frac{c_E}{c_D - c_E}
\]

\[
1/\beta \geq \frac{c_D}{c_E} - 1
\]

We know that \( 1/\beta \geq 1 \) and under the assumption, the largest that \( c_D/c_E \) can get is 2. Therefore, this
inequality always holds in equilibrium and the function is convex.