Industry Competition, Winner's Advantage, and Cash Holdings

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Abstract

We examine firms' cash holding policies in industries with significant R&D. In our model firms compete to innovate but must also finance to bring innovations to the market. The model captures two important features of these industries: (1) the first successful launcher of a new product enjoys an advantage over the followers; (2) outside financing for the implementation of a product innovation takes time. Cash holdings, R&D intensity, and the number of firms are endogenously determined in equilibrium. Both cash holdings and R&D intensity increase with the winner's advantage and decrease with entry costs. Their relations with industry concentration depend on the source of exogenous variation. Empirical patterns of industry cash holdings and R&D intensity provide strong support to the key predictions of the model.

JEL codes: G32, G30

Key Words: Cash holdings, R&D, Competition, Winner's Advantage

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Over the last decades, cash has become a major item on the balance sheets of U.S. companies. Bates, Kahle, and Stulz (2009) estimate that the average ratio of cash to assets of listed U.S. industrial firms increased from 10.5% in 1980 to 23.2% in 2006. No other corporate asset has grown so much and so quickly. Such a large increase has attracted the attention of the press and the curiosity of analysts. Studies show, however, that there exists a large variation in cash holdings across industries. In particular, the high-tech and high R&D sectors concentrate a disproportionate amount of cash. Stulz and Williamson (2012) examine an international sample of firms, and find that the highest abnormal cash balances are held by high R&D multinationals.[1] Lyandres and Palazzo (2012) claim that the persistent increase in cash holdings in the last decades has been driven almost solely by innovating firms. These findings appear to suggest that industry characteristics are a key determinant in corporate cash holdings.

The literature has emphasized two main motives for cash holdings: to avoid costly financial distress, and to avoid foregoing valuable investment opportunities due to insufficient financial slack.[2] Although clearly important, these reasons do not apply to firms such as Microsoft, Apple, Cisco, and Merck, among others, which have a low probability of financial distress and face low costs of outside financing (in terms of monetary expenses). In an attempt to explain the large cash holdings of such companies, Foley, Hartzell, Titman, and Twite (2007) suggest that U.S. multinationals have a strong incentive to retain cash in foreign subsidiaries because of the tax costs associated with repatriating foreign income. Stulz and Williamson (2012), however, present findings that challenge this explanation. They show that multinationals with no R&D expenditures do not increase their cash holdings compared to domestic firms that have no R&D expenditures, and also that firms do not start to hold more cash when they become multinationals.

[1] In 2010, the top five companies holding the largest dollar amount of cash (including short-term investments) in their sample are Apple ($51 billion), Microsoft ($46 billion), Cisco ($40 billion), Google ($35 billion), and Oracle ($29 billion).

[2] See, for example, Kim, Mauer, and Sherman (1998), Almeida, Campello, and Weisbach (2004), Acharya, Almeida, and Campello (2007), Gamba and Triantis (2008), Denis and Sibilkov (2010), Riddick and Whited (2009), Asvanunt, Broadie, and Sundaresan (2010), Bolton, Chen, and Wang (2011), and Bolton, Chen, and Wang (2013). These studies do not explicitly consider product market competition.

This paper aims to shed light on the cash policy of innovating firms. It considers the strategic role of cash in the competition for product innovation. We develop a model of corporate cash holding and R&D policies that captures two typical features of innovating industries: (1) the first successful launcher of a new product enjoys an advantage over the followers; (2) outside financing needed for the introduction of a product innovation takes time.

A common trait of innovating industries is the winner's advantage. The market leader, for example the developer of a new drug or a new communication device, has a great advantage over the followers. It enjoys large profit margins and a monopolist-like status, either from regulation (such as patent laws), or from strong network effects among users. Many new technology products, such as Facebook, eBay, Skype, and Dropbox, share the common feature that an individual user's utility increases in the number of other users also using the same product. Such network effects create a natural barrier to new entrants. At the extreme, first movers are able to preempt subsequent entries for a long period of time, resulting in a situation where the winner takes all. The large winner's advantage creates strong incentives to engage in R&D competition. It also makes the speed of investment after a successful R&D breakthrough critically important.

Innovating firms are by and large betting on the future, which represents high risks and that most of their assets are intangibles. At the initial stages of a product innovation, firms have imprecise ideas and preliminary prototypes, and most of their assets, being knowledge and human capital, are hard to collateralize. Innovation is, by definition, a trial-and-error process, with many set-backs. Obtaining outside financing in these circumstances is difficult and, especially, time consuming. Even if firms are able to obtain outside financing for investment, it can come with large delays. For firms engaging in high tech innovation, the cost in time needed to gather finance is much more important than the monetary costs of financing. Indeed, delays in getting finance can compromise success in contests where the winner's advantage is large.

These two characteristics of product innovation make cash holdings and R&D essential and firmly intertwined. We study the link between them in an industry equilibrium. Firms in our model engage in R&D to develop new products that are usually close substitutes. Each firm faces a random arrival of a R&D breakthrough, which is characterized by a Poisson process independent across firms. Upon a breakthrough firms can make a lump-sum investment to introduce and market the new product. The first firm that successfully brings a new product to market captures a large fraction of the profits. At the extreme, it takes all the profits. Raising funds for the product takes time if done with outside finance, causing delays in implementing the innovation. Due to the time needed to finance the investment project, the first firm to have a technical breakthrough from its R&D effort may not be the winner of the innovation. Firms have to pay a lump-sum cost to enter the competition, and also a per period cost for each dollar carried over time. Firms optimally decide whether to enter the competition, and choose both the R&D intensity and the amount of cash balances to hold. The number of firms in the competition, the intensity of R&D, and the cash holdings are all determined endogenously in equilibrium.

Our model shows explicitly how the industry equilibrium is shaped by a number of key factors. First, the winner's advantage increases both R&D intensity and cash holdings. At the same time, it reduces the number of firms entering the competition. A large winner's advantage increases firms' incentives to engage in costly R&D and to hold cash in order to be the winner. This increases the costs of participating in the competition and reduces the number of participants. Second, low entry costs increase R&D intensity, cash holdings, and the number of firms in the industry. Low entry costs induce more firms to enter the competition. In turn, this increases the importance of becoming the winner of the competition, because the market share of each non-winning firm declines in the number of participating firms. Third, a high expected market profitability increases R&D intensity, cash holdings, and the number of firms in the competition. High expected market profitability increases the expected payoff to all firms *ex ante*, and therefore attracts more firms and generates stronger incentives to engage in R&D and to hold cash. Fourth, higher R&D efficiency reduces the expected holding time of cash. It also increases the importance of the time to finance in determining the competition outcome, therefore increasing both R&D intensity and cash holdings. Finally, longer time delays in raising outside finance increase both R&D intensity and cash holdings.

These results suggest a strong positive correlation between R&D intensity and cash holdings. Both move in the same direction, independent of the source of exogenous variation. Our model thus provides an explanation for the strong connection between cash and R&D in industries driven by innovation. Interestingly, we find an ambiguous relation between the number of firms and cash holdings. If industry concentration is driven by high entry costs, then concentration indicates weak competition, resulting in low R&D and low cash holdings. However, in industries with a strong winner's advantage, a small number of firms is associated with intense rivalry, high R&D intensity, and large cash holdings. In such industries, instead of being an indicator of weak competition, fewer firms is the outcome of intense competition when the costs to succeed are high. This helps to explain why firms that seem to operate in highly concentrated and competitive sectors, such as Google, Microsoft, and Apple, still hold very large amounts of cash.

By incorporating the winner's advantage in the competition for product innovation together with the time needed to gather outside finance, our model provides an explanation for the high cash holdings puzzle in innovative sectors of the economy. A key insight of the model is that competition pushes all firms to hold large amounts of cash, allowing them to quickly react upon hitting a technological breakthrough. However, because of the winner's advantage, firms that do not win the competition find the market much less attractive after the leader makes a move. These firms end up investing much less and do not exhaust their cash to invest. In the extreme case of winner-takes-all, all firms hold cash but only one ends up investing it. This dramatically increases the cash holdings relative to the *realized* capital expenditures. As a result, even though individual firms do not hold more cash than the amount needed for future investment, the time-series and cross-sectional averages of cash holdings are many times higher than realized annual capital expenditures. Such high cash-to-capital expenditure ratios are common in high tech sectors, such as IT and bio-pharmaceutical.

The empirical part of the paper provides strong support for the theoretical model. Using a sample of 57 most research-intensive industries from 1987 to 2011, we find that R&D alone can "explain" around 50% of the variation in the cash-to-capx ratios across industries. The model's predictions of the cross-sectional determinants of industry cash holdings and R&D intensity are also supported by the data. Both cash holdings and R&D ratios increase with the skewness of the market share distribution, our proxy for the winner's advantage, and decrease with the industry profit margin, our proxy for entry costs. We also find a non-monotonic relation between the R&D-to-cash ratio and firm size. As the firm size increases, the R&D-to-cash ratio first decreases and then increases. This is consistent with the idea that small innovating firms hold cash primarily to finance R&D, while bigger firms hold cash to finance R&D as well as to launch and market innovations.

Our paper is part of the literature that examines the interaction between product market competition and corporate finance.[3] We differ from the previous papers by modeling explicitly the impact of winner's advantage in the product market on firms' financial policy. Also, we contribute to the literature on the frictions of external finance.[4] Unique in our work is that financing costs are represented by the time delay in gathering funds necessary for product market competition, rather than by a monetary cost. In a highly competitive product market, the cost of time delays is much more important than the monetary cost of financing. We believe that time delays in getting outside financing can be very helpful in understanding firms' financial and investment decisions.

The strategic role of cash, or a "deep pocket", in product market competition has

[3]For example, Brander and Lewis (1986) and Maksimovic (1988).

[4]The classic contributions in this area are Jensen and Meckling (1976) and Myers and Majluf (1984). Hennessy and Whited (2007) provide a structural estimation of external financing costs.

been discussed by Telser (1966), Baskin (1987) and Bolton and Scharfstein (1990). These authors emphasize the use of cash in predatory pricing and entry deterrence. Schroth and Szalay (2010) show both theoretically and empirically that firms with more cash and assets are more likely to win patent races. They highlight the importance of cash in financing R&D, while we consider the role of cash in implementing product innovation after the R&D success. Lyandres and Palazzo (2012) examine the determinants of cash holdings by innovating firms. In their model, large cash holdings lower the financing costs and allow a firm to commit to an aggressive strategy in implementing technological innovations, which in turn lowers its rivals' incentive to engage in R&D. However, they do not consider the time to finance and winner's advantage. Firms receive the R&D outcome at the same time, compete in the product market simultaneously, and obtain the same market share. In contrast, we focus on the role of cash in the race to become the first to bring the innovation to the market. The winner's advantage naturally leads to a heterogeneous distribution of market share ex post. Another important difference is that the number of firms in the R&D competition is exogenous in their model, while it is endogenous in ours. This allows us to uncover a rich relation between industry structure and cash holdings.

Morellec, Nikolov, and Zucchi (2013) and Della Seta (2011) investigate the impacts of competition on cash policy in dynamic settings. They show that firms in more competitive industries in general hold more cash. Unlike us, these authors focus on the role of cash in financing operating losses and preventing inefficient asset sales and closure, instead of financing investment and product innovations. Surely, cash holdings serve as an important hedge against financial distress. However, the precautionary saving against financial distress cannot explain cash holdings of the set of firms we wish to examine. Thus, our model and theirs discuss complementary issues. Fresard (2010) shows empirically that large cash reserves lead to systematic future market share gains at the expense of industry rivals. Fresard and Valta (2013) find that firms increase cash holdings in response to tougher competition from foreign firms triggered by trade liberalization. These findings are consistent with our model.

The rest of the paper is organized as follows. Section 1 describes the model setup and firms' optimization problem. Section 2 characterizes the R&D intensity, cash holdings, and the number of firms participating in the competition in a symmetric equilibrium. Section 3 presents comparative static analysis. Section 4 examines empirically the relation between R&D and cash holdings, and investigates how industry cash holdings and R&D intensity are related to the winner's advantage and other industry characteristics. Section 5 uses a simple example to illustrate why the winner's advantage leads to cash holdings substantially higher than annual capital expenditures, and presents empirical evidence showing that the correlation between cash holdings and R&D intensity cannot be simply explained by firms holding cash to finance R&D. Section 6 concludes. All proofs are in the Appendix.

1 The Model

1.1 Setup

There are N risk-neutral firms in the industry, indexed by $i = 1, 2, ..., N$. Later we show how the number N is endogenously derived. The N firms compete in product innovation. The competition consists of two stages. In the first, the R&D stage, firms compete to develop a new technology. In the second, the implementation stage, firms raise funds to launch and market the technology. A firm succeeding in R&D can bring its product to the market by investing a lump-sum amount.

Each firm chooses an optimal rate of R&D expenditure D_i, and an optimal amount of cash to hold. We assume that entry costs, planned R&D expenditures, and initial cash holdings come from the firms' retained earnings generated in other operations, or agreements with outside lenders arranged ahead of time.[5] For analytical simplicity, we

[5] Since the only cost for external financing in our model is time delay, such arrangements can be made at no cost as long as they are planned sufficiently ahead of time. However, we do not allow financing contracts contingent on the success of the R&D or unconditional lines of credit, as lenders need information about the actual breakthrough in making lending decisions. In practice, lines of credit come with covenants, often

assume a zero risk-free rate.

The R&D success, i.e., a technological breakthrough, arrives with a Poisson process with intensity $\lambda_i = \lambda(D_i) > 0$, where λ is an increasing function, i.e., $\lambda'(D) > 0$. This illustrates the idea that higher R&D expenditure speeds up the innovation process. The arrivals of R&D successes are independent across firms. Let $\tau_{i,D}$ denote the arrival time of the first success in innovation for firm i. Then $\tau_{i,D}$ follows an exponential distribution. The probability density function and the cumulative probability distribution function for $\tau_{i,D}$ are

$$f(\tau_{i,D}) = \lambda(D_i)e^{-\lambda(D_i)\tau_{i,D}}, \forall i = 1, 2, ..., N,$$

and

$$F(\tau_{i,D}) = 1 - e^{-\lambda(D_i)\tau_{i,D}}, \forall i = 1, 2, ..., N, \tag{1}$$

respectively.

Once firm i succeeds in R&D, it finances the implementation of the product. The project requires a lump-sum investment I. Financing the project with internal cash holdings takes no time. Hence, if the cash holding of firm i, C_i, is greater than or equal to I, the project can be financed instantaneously. Financing the project with external funds (or through the accumulation of future earnings), on the other hand, takes time. We call this the time to finance. Specifically, the time to finance, $\tau_{i,F}$, is a function of cash holdings C_i and the amount of investment needed I, denoted by $g(C_i, I)$:

$$\tau_{i,F} = g(C_i, I) \begin{cases} > 0 & \text{if } C_i < I, \\ = 0 & \text{if } C_i \geq I. \end{cases} \tag{2}$$

If internal cash holdings are insufficient for the investment, i.e., $C_i < I$, we assume that $g(C, I)$ strictly increases with the investment expenditure I and decreases with the cash

require collateral, and can be revoked by banks if the borrower's financial situation or market conditions deteriorate significantly. Sometimes borrowers are also required to pay a fee for the unused amount of the approved line of credit.

holdings C. This implies:

$$\frac{\partial g}{\partial I} > 0, \quad \frac{\partial g}{\partial C_i} < 0, \text{ for } C_i < I. \tag{3}$$

The total time spent by firm i to succeed in innovating *AND* financing the project is therefore

$$\tau_i = \tau_{i,D} + \tau_{i,F}. \tag{4}$$

The firm whose τ_i is the smallest among all N firms is the winner of the competition.

The product market has the feature of a winner's advantage. In the extreme case of winner-takes-all, the winner can capture the whole market with a market share 1. At the other extreme, the winner shares equally with the other $N-1$ firms and therefore has a market share of $\frac{1}{N}$. In general, we expect the market share for the winner to be between the two extreme cases, and can be expressed as $\kappa + (1-\kappa)\frac{1}{N} = \frac{N-1}{N}\kappa + \frac{1}{N}$, where $\kappa \in (0, 1]$ characterizes the degree of the winner's advantage. $\kappa = 1$ corresponds to the case of winner-takes-all, while $\kappa \to 0$ corresponds to the case of no winner's advantage. Other $N-1$ firms share the rest of the market equally, each with a market share $\frac{1}{N-1}[1-(\frac{N-1}{N}\kappa + \frac{1}{N})] = \frac{1-\kappa}{N}$.[6] Accordingly, the profit V_i of firm i at τ_i, which represents the present value of all future profits (net of the investment costs I), is:

$$V_i = V[(\frac{N-1}{N}\kappa + \frac{1}{N})\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}} + \frac{1-\kappa}{N}\mathbb{I}_{\tau_i > min_{j\neq i}\{\tau_j\}}], \forall i = 1, 2, ..., N, \tag{5}$$

where V is the profit of the whole market and $\mathbb{I}$ is an indicator function. When $\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}} = 1$, firm i is the winner. Since $\mathbb{I}_{\tau_i > min_{j\neq i}\{\tau_j\}} = 1 - \mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}}$, Equation (5) can be rearranged as:

$$V_i = V(\frac{1-\kappa}{N} + \kappa\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}}), \forall i = 1, 2, ..., N. \tag{6}$$

[6] $\frac{1-\kappa}{N}$ can be interpreted as the expected share of profit in future competitions among the remaining firms, as long as V and κ are adjusted to reflect the expected costs of future competitions. We exclude the case with $\kappa = 0$, as this implies that followers can completely free-ride on the innovation of the leader.

Intuitively, a firm's share of the profit is the share of a losing firm, $\frac{1-\kappa}{N}$, plus the extra share from being the winner, κ, adjusted by the probability of becoming a winner.

1.2 Firms' problem

Intuitively, increasing C_i and D_i increases the probability of winning. On the other hand, holding cash is costly and firms incur a per period cost of γ per dollar of cash held.[7] The R&D expenditure is also a cost. Hence, each firm i chooses its C_i and D_i to optimize its expected firm value, U_i.[8] We are interested in the symmetric equilibrium where all firms optimally choose the same amount of cash holdings and R&D expenditure, i.e. $C_i = C^*$ and $D_i = D^*, \forall i$. Given that other firms $j \neq i$ hold cash $C_j = C^*$ and choose R&D expenditure $D_j = D^*$, the expected value of firm i, U_i, is given in Proposition 1 below.

Proposition 1. *Conditional on other firms $j \neq i$ holding cash $C_j = C^*$ and choosing R&D expenditure $D_j = D^*$, the expected firm value U_i for firm i is a function of firm i's cash holdings C_i and R&D expenditure D_i:*

$$\begin{aligned} U_i \;=\; & V\frac{1-\kappa}{N} + V\kappa\frac{\lambda(D_i)}{\lambda(D_i)+\lambda(D^*)(N-1)}e^{-\lambda(D^*)(N-1)g(C_i,I)+\lambda(D^*)(N-1)g(C^*,I)} \\ & -\frac{\gamma C_i + D_i}{\lambda(D_i)+\lambda(D^*)(N-1)}. \end{aligned} \tag{7}$$

Proof: See the Appendix.

The first term on the right-hand side is the profit for a losing firm. The second term, as shown in Appendix A.1, is the "bonus" to the winner of the competition, times the probability of becoming a winner. The third term is the expected present value of cash holding and R&D costs.

[7] This assumption is standard in the cash literature. See for example, Kim, Mauer, and Sherman (1998) Riddick and Whited (2009), and Bolton, Chen, and Wang (2011). The cost of carrying cash may arise from agency issues associated with free cash in the firm, or from the difference between the corporate tax rate and the personal tax rate on interest income.

[8] More precisely, U_i is the contribution of the innovation opportunity to the total firm value. We assume that value additivity holds.

2 Industry Equilibrium

Given the function of time to finance in Equation (2), it can be shown that any strategy of holding cash $C_i > I$ is strictly dominated by a strategy of holding cash $C_i = I$. Therefore, $C_i^* \leq I$ in any equilibrium.

We focus on the symmetric equilibrium where all firms play the same strategy. Note that since all firms hold the same amount of cash, the firm that first makes the technological breakthrough is the winner of the product innovation competition. Let $\Omega > 0$ denote the entry costs for the industry. Proposition 2 below specifies the conditions for a symmetric equilibrium.

Proposition 2. *A symmetric equilibrium satisfies the following three conditions:*

1. *Depending on the parameter values, the optimal cash holding (C^*) falls into either of the two cases:*

   (a) interior solution: $C^* < I$, and

$$-V\kappa\lambda^2(D^*)(N^*-1)\frac{\partial g}{\partial C}(C^*, I) - \gamma = 0, \tag{8}$$

   (b) corner solution: $C^* = I$, and

$$-V\kappa\lambda^2(D^*)(N^*-1)\frac{\partial g}{\partial C}(C^*, I) - \gamma \geq 0, \tag{9}$$

2. *The optimal R&D expenditure (D^*) satisfies the first-order condition:*

$$V\kappa(N^*-1)\lambda(D^*)\lambda'(D^*) + (\gamma C^* + D^*)\lambda'(D^*) - N^*\lambda(D^*) = 0, \tag{10}$$

3. *The equilibrium number of firms N^* is the integer part of the real number N that satisfies the constraint:*

$$\frac{V}{N} - \frac{\gamma C^* + D^*}{N\lambda(D^*)} = \Omega. \tag{11}$$

The participation constraint (11) is very intuitive. Since firms are identical, each firm has an equal chance to win the competition, so *ex ante*, the expected gain is $\frac{V}{N}$. The arrival rate of the first R& D success is $N\lambda(D^*)$. Therefore, the expected R&D and cash holding costs till the first technological breakthrough is $\frac{\gamma C^*+D^*}{N\lambda(D^*)}$. In equilibrium, the expected gains minus the expected costs equal the entry costs Ω.

To obtain explicit formulas for the optimal cash holding C^*, the optimal R&D expenditure D^*, and the equilibrium number of firms N^*, we need to specify the time to finance function $g(C, I)$ and the R&D production function $\lambda(D)$. We assume the following functional form of $g(C, I)$:

$$g(C, I) = \begin{cases} \beta log(\frac{I}{C}) & \text{if } C < I, \\ 0 & \text{if } C \geq I, \end{cases} \tag{12}$$

where the parameter $\beta > 0$ characterizes the speed of external financing and could depend on credit market conditions. Effectively, $g(C, I)$ is the time needed for the amount of money to grow from C to I at the continuously compounded rate of $\frac{1}{\beta}$. For a given β, a larger project size I increases the time to finance by increasing the financing gap.

We assume a functional form of λ(D) that allows for decreasing-returns-to-scale in R&D:

$$\lambda(D) = \alpha\sqrt{\frac{D}{I}}, \tag{13}$$

where $\alpha > 0$ characterizes the efficiency of R&D. Higher R&D, relative to the required investment cost I, increases the arrival rate of success λ, but at a decreasing rate.

Define the optimal normalized cash holding ratio as $c^* = \frac{C^*}{I}$, the normalized R&D expenditure as $d^* = \frac{D^*}{I}$, the normalized market value as $v = \frac{V}{I}$, and the normalized entry costs as $\omega = \frac{\Omega}{I}$. Proposition 3 gives the optimal cash holding ratio c^*, the optimal R&D expenditure ratio d^*, and the number of firms N^* in the symmetric equilibrium.

Proposition 3. *Given Equations* (12) *and* (13)*, there exists a unique symmetric equilib-*

rium with $N^* \geq 1$ as long as $v > \omega + \frac{2\sqrt{\gamma}}{\alpha}$. Depending on the parameter values, the unique symmetric equilibrium falls into either of the two cases:

1. *Case I (interior c^*):*

$$c^* = \frac{\alpha^2 \beta \kappa v (N^* - 1)}{\gamma} d^* < 1, \tag{14}$$

$$d^* = [\frac{\alpha \kappa v (N^* - 1)}{2N^* - 1 - \alpha^2 \beta \kappa v (N^* - 1)}]^2, \tag{15}$$

and N^* is the integer part of the real number N that solves the following equation:

$$\alpha^2 \beta \kappa^2 v^2 (N-1)^2 + \kappa v (N-1) + (N\omega - v)[2N - 1 - \alpha^2 \beta \kappa v (N-1)] = 0. \tag{16}$$

2. *Case II (corner solution):*

$$c^* = 1, \tag{17}$$

$$d^* = \frac{\alpha \kappa v (N^* - 1) + \sqrt{\alpha^2 \kappa^2 v^2 (N^* - 1)^2 + 4\gamma (2N^* - 1)}}{2(2N^* - 1)}, \tag{18}$$

and N^* is the integer part of the real number N that solves the following equation:

$$[\alpha \kappa v (N-1) + \alpha (v - N\omega)]^2 + 2\alpha N (N\omega - v)[\alpha \kappa v (N-1) + \alpha (v - N\omega)] + 4\gamma N^2 = 0. \tag{19}$$

Proof: See the Appendix.

3 Comparative Static Analysis

For the base case parameterization, we set the per dollar cost of holding cash as $\gamma = 1.5\%$ per year, the winner's advantage as $\kappa = 0.3$, the market profitability as $v = 10$, the entry cost as $\omega = 0.25$, the efficiency of the R&D as $\alpha = 0.1$, and the parameter associated with the time to finance as $\beta = 0.06$. For this base case, there are $N^* = 33$ firms in the industry in equilibrium, firms' cash holdings are $c^* = 8.4\%$, and firms' R&D expenditures are $d^* = 2.2\%$. The cash-to-R&D ratio is 3.8, in close accordance with its empirical counterpart ($2.265/0.607 = 3.7$ from Table 2). The time to finance is $\beta \times log(\frac{1}{c^*}) = 1.8$ months. The expected waiting time for the first industry-wide R&D breakthrough is $\frac{1}{N^* \alpha * \sqrt{d^*}} = 2.0$ years. Our comparative static results are robust to alternative choices of the parameter values.

Next we vary the exogenous industry-wide parameters, one at a time around the benchmark values. We wish to see: (1) the dependence of c^*, d^*, and N^* on the industry-wide parameters; and (2) the endogenous relation between cash holdings and R&D expenditure.

3.1 Winner's advantage

Panel A of Figure 1 shows that cash holdings increase and reach a maximum $c^* = 1$ as the winner's advantage κ increases. Panels B and C show that R&D expenditure increases and the number of firms competing to innovate decreases, as winner's advantage increases. Since a larger winner's advantage means that the profit gap between the winning firm and non-winning firms widens, firms have higher incentives to win and, therefore, choose to hold higher cash holdings and spend more on R&D. The number of firms in the industry declines, since it costs more to participate in the inducstry. Panel D shows the endogenous relationship between cash holdings and R&D expenditures. Cash holdings and R&D expenditures move in the same direction.

3.2 Entry costs

Varying entry costs ω does not affect the first order conditions with respect to cash holdings and R&D expenditures. It only affects the equilibrium number of firms through the participation constraint. As expected, and seen in Panel C of Figure 2, as entry costs increase, the number of firms decreases.

Panels A and B of Figure 2 show that cash holdings and R&D decrease as the entry cost declines and, accordingly, the number for firms decreases. With lower entry costs, fewer firms enter the industry in equilibrium. Cash holdings and R&D decrease for two reasons. First, less competition reduces the incentives to hold cash and spend on R&D. Second, fewer firms doing R&D means that the expected waiting time till the first R&D breakthrough becomes longer. This increases the expected costs of cash holdings and R&D. Panel D shows that cash holdings and R&D expenditures are positively correlated.

3.3 Market profitability

Panels A, B, and C of Figure 3 show that as the expected profitability of the market for the innovation, v, increases, cash holdings, R&D expenditures, and the number of firms in the industry increase. As the market profitability increases, more firms are attracted to the industry, firms have higher incentives to win and therefore choose higher cash holdings and higher R&D expenditures. Panel D shows that cash holdings and R&D expenditures are positively correlated.

It is worth noting that the expected profitability of the new product is different from the expected profitability for each firm. Since more profitable innovations attract more firms to the competition, the expected profit for each firm, after accounting for expected costs of cash holdings and R&D, just equals to the entry costs, as shown by Equation (11).

3.4 R&D efficiency

Panels A and B of Figure 4 show that as R&D efficiency α increases, cash holdings and R&D expenditure also increase. Intuitively, as R&D becomes more efficient, competition is more intense. Firms are more motivated to spend on R&D and to hold cash. Interestingly, the number of firms shows a U-shape dependence on R&D efficiency. The intuition is as follows. There are two offsetting effects of R&D efficiency on the number of firms. First, increasing R&D efficiency increases cash holdings and R&D expenditures. This effectively increases the cost of entering the industry, and therefore reduces the number of firms. Second, increasing R&D reduces the expected waiting time for the first R&D breakthrough. This reduces the expected costs of holding cash and conducting R&D, which in turn increases the number of participating firms. The first effect is more pronounced when R&D efficiency is low, and the second effect is more pronounced when R&D efficiency is high. This creates the observed U-shape relationship. Again, Panel D shows that cash holdings and R&D expenditures are positively correlated.

3.5 Time to finance

As the time needed to finance the introduction of the new product increases (i.e., as β increases), we expect firms to hold more cash. This is confirmed by Panel A of Figure 5. Interestingly, R&D also increases, albeit only slightly, as shown by Panel B. This positive dependence of R&D on β is evident in Equation (15). Intuitively, a higher β increases cash holdings. To reduce the effective cost of holding a large amount of cash, firms increase R&D intensity to shorten the expected waiting time till the first R&D breakthrough. Overall, the total cost of competition increases as β increases, and therefore the number of firms decreases, as seen in Panel C. Again, Panel D shows that cash holdings and R&D expenditures are positively correlated.

4 Empirical Analysis

We now examine the empirical support for our theoretical model. We first test a key prediction of the model, that there exists a strong positive relation between R&D expenditures and cash holdings across industries. We then examine the cross-sectional determinants of industry cash holdings and R&D ratios.

4.1 The relation between R&D and cash holdings

One of the key predictions of our model is the robust relation between R&D intensity and cash holdings. This relation is positive independently of the source of exogenous variation in the model. We now test how strong this connection is in the data.

To construct our sample, we start with the merged annual Compustat and Center for Research in Security Prices (CRSP) database over the period 1987-2011. We start in 1987 because Compustat reports historical SIC codes (SICH) starting from that year. We exclude financial companies (SIC 6000-6999), utilities (SIC 4900-4999), non-US companies (entries in Compustat with International Standards Organization country code not equal to USA), companies engaged in public administration (SIC 9000-9999), as well as firm-years with missing historical SIC codes.

Following the convention in the literature, we use cash and short-term investments (CHE in Compustat) to measure cash, and treat missing R&D (XRD in Compstat) as zero. To account for inflation, we convert all nominal values into the year 2005 dollar values using the GDP deflator.

We define an industry by the 3-digit SICH codes from Compustat. We exclude the industry-years with less than 10 firms, and require an industry to have at least 10 firms in 10 out of the 25 sample years. 113 industries satisfy these criteria, including 10839 firms and 88909 firm-year observations. Since our model is mainly about firms active in product innovations, we focus our analysis on industries that are R&D intensive. For this purpose, we calculate the time-series average of the asset-weighted industry R&D-to-total-asset ratio for each industry, and exclude 56 industries for which this ratio is below the median level. Our final sample consists of 57 industries, with 7515 firms and 60243 firm-year observations.

We examine the relation between cash and R&D at the industry level. Since we focus on the symmetric equilibrium in our theoretical analysis, our model is silent about the variation within each industry. For each industry, we calculate the following ratios at the annual frequency: cash to total assets (AT), cash to capital expenditures (CAPX), R&D to total assets, and R&D to capital expenditures. We first calculate these ratios at the firm level, and truncate them at the 1st and 99th percentiles of the whole sample. We then average them across firms, using the denominator of each ratio as the weight.

Table 2 shows the names of the 57 industries in our sample, and their time-series averages of the R&D-to-asset, cash-to-asset, R&D-to-capx, and cash-to-capx ratios. The average R&D-to-asset and R&D-to-capx ratios across industries are 2.7% and 60.7%, respectively, while the average cash-to-asset and cash-to-capx ratios are 9.4% and 2.265, respectively. Not surprisingly, the drug industry is the most research-intensive, with an R&D-to-asset ratio of 9.7%, and an R&D-to-capx ratio of 2.352. Its cash-to-asset and cash-to-capx ratios are also among the highest, 18.1% and 4.791, respectively. Table 3 presents the summary statistics of these ratios at the industry-year level, together with some other industry characteristics.

The positive correlation between industry R&D ratios and cash holdings is evident in Table 2. To illustrate this more clearly, we plot the cash-to-asset against the R&D-to-asset ratio in Panel (A), and the cash-to-capx against the R&D-to-capx ratio in Panel (B) of Figure 6, together with the fitted lines from linear regressions. Both graphs show a strong positive relation.

Table 4 shows the relation between the two endogenous variables in univariate regressions. In Panel (A), we regress the cash-to-asset ratio on the R&D-to-asset ratio. In Panel (B), we regress the cash-to-capx ratio on the R&D-to-capx ratio. For both panels, column (1) shows results when both the dependent variable and the independent variable are the time-series averages across the sample years, which correspond to the fitted lines plotted in Figure 6. Column (2) shows the Fama-MacBeth regression results using annual industry data, where the regression coefficients are the time-series averages of 25 year-by-year cross-sectional regressions, and the t-statistics are the Newey-West adjusted for autocorrelation up to lag 5. Column (3) shows the pooled regression results for the whole sample, with t-statistics adjusted by the clustering of errors at both the industry and the year levels. All models in both panels confirm a strong positive relation between cash holdings and R&D intensity, significant at the 1% level. Panel (A) shows that the R&D-to-asset ratio alone can "explain" around 30% to 40% of the variation in the cash-to-asset ratio across industries, while Panel (B) shows the R&D-to-capx ratio can "explain" around 50% of the variation in the cash-to-capx ratio. These results strongly support a key prediction of our model.

4.2 Determinants of cash holdings and R&D ratios

According to our model, cash holdings and R&D intensity increase with the winner's advantage, and decrease with entry costs. Next we test these predictions using our industry level data.

We use the skewness coefficient of the market share distribution to proxy for the winner's advantage. The skewness of a random variable is defined as its third central moment normalized by the third power of its standard deviation. It is a standard statistical measure of asymmetry. A negative skewness value indicates that the left tail of a distribution is longer than the right tail and that the bulk of the observations lie to the right of the mean. A positive skewness value indicates the opposite. Since there are more small firms than large ones in most industries, market share is generally positively skewed. According to our model, if the winner's advantage is weak, market share is distributed across firms relatively equally, and the skewness coefficient is small. If, on the contrary, the winner's advantage is large, then a small number of winning firms will end up controlling a big fraction of the market. These firms become outliers on the right tail of the market share distribution, generating a large positive skewness coefficient. Therefore, the skewness of the market share distribution reflects winner's advantage in past competitions. It should also reflect the nature of current competitions, as long as the degree of winner's advantage, as an industry characteristics, is persistent over time. Our theory predicts that cash holdings and R&D expenditures are positively related to the skewness of market share.

In each year, we calculate the market share of each firm in its industry based on sales revenue. We then calculate the skewness of the market share for each industry on an annual basis.[9] Not surprisingly, the skewness is positive in all the 1245 industry-year observations in our sample. Table 3 shows that the average skewness is 3.38, with a standard deviation of 2.50.

We use the profit margin, defined as the ratio of operating income before depreciation (OIBDP in Compustat) to sales, of the median firm in an industry to proxy for entry costs.[10] Due to the free entry assumption, the expected profit at the firm level is determined by the entry costs in equilibrium (Equation (11)). An industry as a whole can maintain a high profit margin only if it is difficult for outsiders to enter, for either economic or regulatory reasons. Otherwise the profit margin will be competed away by new entrants. Therefore, the profit margin is a natural proxy for entry costs. Our theory predicts that cash holdings and R&D expenditures are negatively related to the profit margin.

We control for other industry characteristics that can potentially affect cash holdings and R&D intensity. These characteristics are not explicit in our model. One of them is the firm size, which is measured by the logarithm of the average asset size across firms. If there are some fixed costs in raising cash, then larger firms are likely to hold less cash, as a percentage of their total assets. Also, larger firms may engage in multiple R&D projects simultaneously. Knowing that they are unlikely to be the winner in all projects, they do not hold cash to back up all potential innovations. Therefore their cash holdings do not increase linearly with their asset size. Finally, the average firm size in an industry may itself be an indicator of entry costs. If this size is large, presumably it is more difficult for a new firm to enter, as it is less likely that the firm is big enough to compete with existing firms. For these reasons, we expect the average firm size to be negatively related to industry cash holdings.

Another variable is the Tobin's Q, defined as the ratio of the market value of firm assets to their replacement costs. Empirically, the market value is usually measured by

[9] Since the skewness measure is invariant to the scaling of the random variable, this is equivalent to calculating the skewness of sales revenue directly.

[10] OIBDP in Compustat represents sales minus the sum of costs of goods sold and selling, general and administrative expenses.

the market value of the common equity plus the book values of preferred stock and debt, while the asset replacement cost is measured by the total book value of the common equity, preferred stock, and debt. We follow this convention, and calculate the Tobin's Q at the firm level on an annual basis. We truncate the firm-level Q at the 1st and 99th percentiles of the whole sample, and then aggregate it to the industry level, weighting each firm by its book value. Table 3 shows that the average Tobin's Q is 2.24 across industry-years, with a standard deviation of 1.02. Since a higher Q indicates better future investment opportunities, we expect firms in a high Q industry to hold more cash in order to take advantage of those opportunities.

To account for the effects of uncertainty on cash holdings and R&D intensity, we examine the stock volatility of each industry portfolio. We extract the stock returns of our sample firms from the CRSP US stock database and form value-weighted industry portfolios, and then calculate the annualized volatility of each industry using the daily portfolio returns. Table 3 shows that the average volatility of industry portfolios in our sample is 24.5%, with a standard deviation of 0.11. The precautionary motive of cash saving suggests that the stock volatility should be positively related to cash holdings, although its relation with R&D intensity is unclear.

Table 5 shows how industry cash holdings are related to industry characteristics. The dependent variable is the industry cash-to-asset ratio in columns (1) to (3), and is the cash-to-capx ratio in columns (4) to (6). Columns (1) and (4) show results when both the dependent variable and the independent variable are the time-series averages across years; columns (2) and (5) show the Fama-MacBeth regression results using annual industry data, while columns (3) and (6) show the pooled regression results with correction for error clusterings at both the industry and the year levels.

The results are remarkably consistent across the columns. In all six models, industry cash holdings are positively related to the skewness of the market share distribution, the proxy for the winner's advantage, and negatively related to the profit margin, the proxy for entry costs. The economic magnitude is significant as well. Take model (2) as an example. A single standard deviation increase of the skewness measure is associated with an increase of the industry cash-to-asset ratio by 2.25 percentage points (=2.496*0.009). At the same time, a single standard deviation increase of the profit margin is associated with a decrease of the industry cash-to-asset ratio by 1.56 percentage points (=0.087*(-0.179)). These results strongly support our model.

The volatility of industry stock returns is positively related to cash holdings in all models. This is consistent with the precautionary motive of cash holdings. The logged average asset size is negatively related to the cash ratios. Its coefficient is significant at the 1% level in five out of the six models. This is consistent with the existence of fixed costs in raising cash or diversification across investment projects. It is also consistent with firm size being an indicator of entry costs. The Tobin's Q is also highly significant in predicting the industry cash-to-asset ratio, with an expected positive coefficient. Its relation with the industry cash-to-capx ratio is positive but insignificant.

Table 6 shows the cross-sectional determinants of industry R&D ratios. The dependent variable is the R&D-to-asset ratio in columns (1) to (3), and is the R&D-to-capx ratio in columns (4) to (6). Here again we report results using three different estimation methods. As our model predicts, the coefficient of the skewness of the market share distribution is positive, while the coefficient of the profit margin is negative. Both coefficients are significant at the 1% level in all six models. The economic magnitude is significant as well. Again, take model (2) as an example. A single standard deviation increase of the skewness value predicts an increase of the industry R&D-to-asset ratio by 1.50 percentage points (=2.496*0.006), while a single standard deviation increase of the profit margin predicts a decrease of the industry cash-to-asset ratio by 0.87 percentage points (=0.087*(-0.100)). The control variables do not seem to have a robust relation with the industry R&D ratios.

Overall, the results in Tables 4 to 6 provide strong support to our theory. Cash holdings and R&D intensity are strongly correlated. Both of them increase with the winner's advantage, and decrease with entry costs. For robustness checks, we have also used the skewness of operating income before depreciation to proxy for the winner's advantage, and used the median value of return on assets (ROA), defined as the ratio of operating income before depreciation to operating assets (total asset minus cash and short-term investment), to proxy for entry costs. The results are very similar.

5 Discussion

Section 4 shows that the cross-sectional prediction of our model that industry cash holdings and R&D intensity are strongly related is supported by the data. However, it remains an open question whether our model can generate under reasonable parameter values the high cash-to-capx ratio observed in the R&D intensive industries. In addition, can the strong correlation between cash holdings and R&D simply arise because firms that hold cash in order to finance R&D? We analyze these questions in this section.

5.1 Why are cash holdings much larger than capital expenditures?

Cash holdings are exceptionally high in some industries, usually the more R&D intensive ones. For example, the Communications Equipment industry, which has the second highest R&D-to-capx ratio among all industries, 2.243, has a cash-to-capx ratio of 6.485. At the first glance, this may seem to contradict our model, as firms in our model do not hold more cash than the capital expenditures required to implement the product innovation. However, a simple numerical example can show why this is not so. For simplicity, we set the winner's advantage as $\kappa = 1$, and other parameters to their benchmark values. The investment is normalized to be $I = 1$.

With this set of parameters, there are $N^* = 19$ firms in this industry in equilibrium. The normalized cash holdings are $c^* = 1$ and the normalized R&D expenditures are $d^* = 0.24$.

From Equation (A.6), the average time to observe the first R&D breakthrough, as well as the investment, is $\frac{1}{N^*\lambda(D^*)} = \frac{1}{N^*\alpha\sqrt{d^*}}$ in the model. Since this is a winner-takes-all market, the first winner's investment is also the investment of the whole industry. Hence, in expectation, the industry-wide annual capital expenditures are $N^*\alpha\sqrt{d^*}$. Since the industry-wide R&D expenditures are N^*D^* per year, the average industry-wide yearly R&D-to-capx ratio is $\frac{R\&D}{CAPX} = \frac{N^*D^*}{N^*\alpha\sqrt{d^*}} = \frac{d^*}{\alpha\sqrt{d^*}} = 4.9$. Similarly, the average industry-wide yearly cash-to-capx ratio is $\frac{Cash}{CAPX} = \frac{N^*C^*}{N^*\alpha\sqrt{d^*}} = \frac{c^*}{\alpha\sqrt{d^*}} = 20.5$. These numbers are two to three times as high as those observed in the Communications Equipment industry.

This simple example is obviously an extreme illustration, as it assumes complete winner's advantage. It also ignores the fact that firms engage in multiple R&D projects at the same time. Knowing that they are unlikely to be the winner in all projects, firms may optimally choose not to hold cash for all potential projects. Nevertheless, it illustrates an important mechanism in the model that generates equilibrium cash holdings well above capital expenditures. Winner's advantage plays a key role in this mechanism. All firms in the industry hold sufficient cash to back up the potential investment project, but only the winner of the R&D competition actually ends up making the full-scale investment. Firms that do not win the competition may still invest, but they optimally cut back on their investments. As a result, industry cash holdings can be many times larger than realized capital expenditures. This mechanism is particularly strong in sectors where the winner takes all, since firms that do not win the R&D competition become distant seconds and many exit the market completely.

5.2 Cash for R&D?

The strong positive correlation between cash holdings and R&D intensity arises in our model because cash allows a firm to quickly introduce a product innovation. A simple alternative explanation for this correlation is that firms hold cash in order to finance R&D. Due to the uncertainty of R&D outcomes, and the intangibility of knowledge capital impossible to collaretalize, it is often difficult to obtain outside finance for R&D activities. Therefore, firms more active in R&D should hold more cash. There is clearly some truth in the cash-for-R&D argument; however, it is unlikely to be the whole story.

There are firms that specialize in doing R&D, but seldom implement their own innovations. Instead these firms are acquired by other firms after making breakthroughs in R&D. Such firms are usually small and highly specialized, and do not have comparative advantages in raising finance, producing and bringing new products to market. As a result, they hold cash only to fund R&D, and not for the potential larger investment after a technological breakthrough.

If firms hold cash to finance R&D only, then the R&D-to-cash ratio should increase monotonically with firm size, because smaller firms are likely to be more financially constrained, and should therefore hold a larger amount of cash relative to their R&D scale.[11] If, however, for the reasons discussed previously, small firms hold cash to finance R&D, while firms above a certain size threshold hold cash for both R&D and to implement innovations, then the relation between R&D-to-cash ratio and firm size is non-monotonic. As firm size increases, the R&D-to-cash ratio decreases, because the firm is increasingly more likely to hold cash for both R&D and capital investment. As firm size increases further, the R&D-to-cash ratio is likely to increase. This is because, as mentioned earlier, the largest firms may engage in multiple R&D projects, and optimally choose not to hold cash for all potential investments, as they know that the chance to be the winner in all projects is quite small. We now investigate which of these two different scenarios receives greater empirical support.

Within each of the 57 industries in our sample, we divide in each year the firms into 5 size groups by total assets. We calculate the annual R&D-to-cash ratio of each size group in each industry by taking a simple average across firms.[12] We then average across years to

[11] Brown, Fazzari, and Petersen (2009) show that both cash flow and public share issuance are very important for young U.S. firms during the 1990s R&D boom, but they have little impact on R&D investment of mature firms. See Hall and Lerner (2010) for a survey of the literature on the financing of R&D.

[12] We focus on the R&D-to-cash instead of the cash-to-R&D ratio because the latter is not defined for firms with zero R&D.

get the R&D-to-cash ratio of each size group in each industry. Finally, we average across industries to get the R&D-to-cash ratio of each size group. The results are plotted in Figure 7, which shows a remarkable V-shaped relation between R&D-to-cash ratio and asset size. Both the smallest (group 1) and the largest (group 5) firms within each industry show a high R&D-to-cash ratio, 0.67 and 0.68, respectively. The middle group shows the lowest, 0.56, with a gap of around 11 percentage points. The other two groups fall in between.

The V-shaped relation between the R&D-to-cash ratio and the asset size provides support to the cash-for-investment motive highlighted in our model. The increase of cash holdings (relative to R&D) from the bottom firm size group to the median group is hard to explain using the simple cash-for-R&D argument, but is consistent with the idea that smaller innovating firms hold cash primarily to finance just R&D, while the bigger firms hold cash both to finance R&D and to finance the investment in production and marketing subsequent to the R&D success. The substantial decrease of cash relative to R&D from the median to the largest size group is consistent with the idea that the largest firms conduct R&D in many areas, and choose not to hold cash to back up all potential investments at the same time.

6 Conclusion

Empirical studies have documented a rapid and massive increase of firms' cash holdings in the past few decades. It has been shown that such increase is driven almost entirely by innovating firms. In this paper, we build a model of competition in product innovation to investigate the R&D and cash holding policies in innovating industries. The model captures two important features of these industries: (a) the winner's advantage and (b) the time to gather outside finance. We derive the industry equilibrium, in which cash holdings, R&D intensity, and the number of firms are endogenously determined by a number of industry characteristics, including the degree of winner's advantage and entry costs.

Our model generates a strong positive correlation between cash holdings and R&D

intensity. In contrast, the relation between the number of firms and cash holdings is ambiguous, depending on the source of exogenous variation. If industry concentration is the result of high entry costs, then concentration indicates weak competition, and is accompanied by both low R&D and low cash holdings. However, in an industry with a large winner's advantage, the number of firms is small, but competition is intense, which manifests itself as intense R&D spending and large cash holdings. This explains why firms with strong market power, such as Google, Microsoft, and Cisco hold a very large amount of cash.

Our model highlights a mechanism generating the high level of cash holdings in the R&D intensive industries. Competition pushes all firms to hold a large amount of cash so that they can react quickly to positive technological breakthroughs. However, the winner's advantage implies that firms that do not win the competition end up not using most of their cash to invest. This dramatically increases cash holdings relative to the *realized* capital expenditures. As a result, cash holdings can be a high multiple of capital expenditures, as it is observed in the information technology and pharmaceutical industries.

The empirical evidence provides strong support to our model. Using a sample of 57 most research-intensive industries from 1987 to 2011, we find that R&D alone can "explain" around 50% of variation in the cash-to-capx ratios across industries. The model's predictions about the cross-sectional determinants of industry cash holdings and R&D intensity are strongly supported by the data. Both cash holdings and R&D ratios increase with the winner's advantage, and decrease with entry costs. Overall, our paper contributes to the understanding of corporate cash policy by considering the strategic role of cash in product market competition.

A Appendix

A.1 Proof of Proposition 1

Suppose other firms than i hold cash $C_j = C^*$ and pay R&D cost D^*. Firm i chooses to hold cash C_i and pay the flow cost of R&D D_i. The expected firm value U_i for firm i is:

$$\begin{aligned}
U_i &= \mathbb{E}[V_i - \int_0^{min_j\{\tau_{j,D}\}} (\gamma C_i + D_i) ds] \\
&= V\frac{1-\kappa}{N} + V\kappa\mathbb{E}[\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}}] - (\gamma C_i + D_i)\mathbb{E}[min_j\{\tau_{j,D}\}] \\
&= V\frac{1-\kappa}{N} + V\kappa\mathbb{E}\{\mathbb{E}[\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}}|\tau_i]\} - (\gamma C_i + D_i)\mathbb{E}[min_j\{\tau_{j,D}\}]. \qquad (A.1)
\end{aligned}$$

Since $\tau_i = \tau_{i,D} + g(C_i, I), \forall i$, and since the arrival of the technological success is independent, we have:

$$\begin{aligned}
\mathbb{E}[\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_j\}}|\tau_i] &= \mathbb{E}[\mathbb{I}_{\tau_i < min_{j\neq i}\{\tau_{j,D}+g(C_j,I)\}}|\tau_i] \\
&= \mathbb{E}[\prod_{j\neq i} \mathbb{I}_{\tau_{j,D}+g(C^*,I)>\tau_i}|\tau_i] \\
&= \prod_{j\neq i} \mathbb{E}[\mathbb{I}_{\tau_{j,D}>\tau_i - g(C^*,I)}|\tau_i] \\
&= \prod_{j\neq i} \mathbb{P}(\tau_{j,D} > \tau_i - g(C^*, I)|\tau_i) \\
&= \prod_{j\neq i} e^{-\lambda(D^*)(\tau_i - g(C^*,I))} \\
&= e^{-\lambda(D^*)(N-1)\tau_i + \lambda(D^*)(N-1)g(C^*,I)}. \qquad (A.2)
\end{aligned}$$

Then,

$$\begin{aligned}
U_i =& V\frac{1-\kappa}{N} + V\kappa\mathbb{E}[e^{-\lambda(D^*)(N-1)\tau_i + \lambda(D^*)(N-1)g(C^*,I)}] - (\gamma C_i + D_i)\mathbb{E}[min_j\{\tau_{j,D}\}] \\
=& V\frac{1-\kappa}{N} + V\kappa e^{\lambda(D^*)(N-1)g(C^*,I)}\mathbb{E}[e^{-\lambda(D^*)(N-1)\tau_i}] - (\gamma C_i + D_i)\mathbb{E}[min_j\{\tau_{j,D}\}]. \qquad (A.3)
\end{aligned}$$

It can be shown that

$$\begin{aligned}
\mathbb{E}[e^{-\lambda(D^*)(N-1)\tau_i}] &= e^{-\lambda(D^*)(N-1)g(C_i,I)}\mathbb{E}[e^{-\lambda(D^*)(N-1)\tau_{i,D}}] \\
&= e^{-\lambda(D^*)(N-1)g(C_i,I)}\int_0^\infty \lambda(D_i)e^{-\lambda(D_i)\tau_{i,D}}e^{-\lambda(D^*)(N-1)\tau_{i,D}}d\tau_{i,D} \\
&= e^{-\lambda(D^*)(N-1)g(C_i,I)}\int_0^\infty \lambda(D_i)e^{-(\lambda(D_i)+\lambda(D^*)(N-1))\tau_{i,D}}d\tau_{i,D} \\
&= \frac{\lambda(D_i)}{\lambda(D_i)+\lambda(D^*)(N-1)}e^{-\lambda(D^*)(N-1)g(C_i,I)}. \qquad \text{(A.4)}
\end{aligned}$$

To calculate $\mathbb{E}[min_j\{\tau_{j,D}\}]$, we first have:

$$\begin{aligned}
\mathbb{P}[min_j\{\tau_{j,D}\} > x] &= \prod_j \mathbb{P}(\tau_{j,D} > x) \\
&= \mathbb{P}(\tau_{i,D} > x)\prod_{j\neq i}\mathbb{P}(\tau_{j,D} > x) \\
&= e^{-[\lambda(D_i)+\lambda(D^*)(N-1)]x}. \qquad \text{(A.5)}
\end{aligned}$$

The cumulative distribution function for $min_j\{\tau_{j,D}\}$ is then:

$$F(min_j\{\tau_{j,D}\} \leq x) = 1 - e^{-[\lambda(D_i)+\lambda(D^*)(N-1)]x}.$$

The probability distribution function for $min_j\{\tau_j\}$ is then:

$$f(min_j\{\tau_{j,D}\} = x) = [\lambda(D_i) + (N-1)\lambda(D^*)]e^{-[\lambda(D_i)+\lambda(D^*)(N-1)]x}.$$

Therefore, we have:

$$\begin{aligned}
\mathbb{E}[min_j\{\tau_{j,D}\}] &= \int_0^\infty [\lambda(D_i) + (N-1)\lambda(D^*)]e^{-[\lambda(D_i)+\lambda(D^*)(N-1)]x}xdx \\
&= \frac{1}{\lambda(D_i)+\lambda(D^*)(N-1)}. \qquad \text{(A.6)}
\end{aligned}$$

Substituting (A.4) and (A.6) into (A.3), we get (7). $\square$

A.2 Proof of Proposition 2

In our model, any equilibrium strategy of $C_i > I$ is strictly dominated by an alternative strategy of $C_i = I$. Therefore, firms' unconstrained optimization problem is equivalent to an constrained optimization problem with a constraint $C_i \leq I$. We can define the Lagrangian for each firm as $\mathcal{L}_i = U_i - l_i(C_i - I)$, where U_i is given in (7) and $l_i \geq 0$ is the Kuhn-Tucker multiplier associated with the constraint $C_i \leq I$. In the symmetric industry equilibrium, we have $l_i = l, \forall i$. The following four conditions characterize the symmetric industry equilibrium:

1. The complementary slackness condition:

$$l(C^* - I) = 0. \tag{A.7}$$

2. The optimal cash holding C^* satisfies the first order condition:

$$\frac{\partial \mathcal{L}_i}{\partial C_i}|_{C_i=C^*,D_i=D^*} = \frac{\partial U_i}{\partial C_i}|_{C_i=C^*,D_i=D^*} - l = 0. \tag{A.8}$$

With Equation (A.7), Equation (A.8) can be converted into two cases:

(a) interior solution: $C^* < I$, and

$$\frac{\partial U_i}{\partial C_i}|_{C_i=C^*,D_i=D^*} = 0. \tag{A.9}$$

(b) corner solution: $C^* = I$, and

$$\frac{\partial U_i}{\partial C_i}|_{C_i=C^*,D_i=D^*} \geq 0. \tag{A.10}$$

3. The first order condition with respect to D_i holds:

$$\frac{\partial \mathcal{L}_i}{\partial D_i}|_{C_i=C^*,D_i=D^*} = \frac{\partial U_i}{\partial D_i}|_{C_i=C^*,D_i=D^*} = 0. \tag{A.11}$$

4. The participation constraint condition for firm i holds in equilibrium:

$$U_i(C^*, D^*) = \Omega. \tag{A.12}$$

With U_i given in (7), Equations (A.10) to (A.12) translate into (9) to (11), respectively. $\square$

A.3 Proof of Proposition 3

Since $\lambda(D) = \alpha\sqrt{\frac{D}{I}}$ and $g(C,K) = \beta log(\frac{I}{C})$, we have: $\lambda'(D) = \frac{1}{2}\alpha\frac{1}{\sqrt{DI}}$, $\frac{\partial g}{\partial C} = -\frac{\beta}{C}$. Substituting these expressions into Equations (9) and (11) and expressing these equations in terms of the normalized cash holding c^* and R&D expenditure d^*, we have:

$$\alpha^2\beta\kappa v d^*(N-1) - \gamma c^* = 0, \quad for \quad c^* < 1, \tag{A.13}$$

$$\alpha^2\beta\kappa v d^*(N-1) - \gamma c^* \geq 0, \quad for \quad c^* = 1, \tag{A.14}$$

$$\alpha\kappa v(N-1) + \frac{\gamma c^*}{\sqrt{d^*}} - (2N-1)\sqrt{d^*} = 0, \tag{A.15}$$

and

$$v - \frac{\gamma c^*}{\alpha\sqrt{d^*}} - \frac{d^*}{\alpha\sqrt{d^*}} = N\omega. \tag{A.16}$$

Depending on the parameter values, there are two possible cases of equilibrium.

Case I: $c^* < 1$, Equations (A.13), (A.15), and (A.16) hold. Combining (A.13) and A.15), we have Equation (15), substituting which into (A.13) leads to (14). Substituting Equations (14) and (15) into (A.16) gives (16).

Case II: $c^* = 1$. Equations (A.15) and (A.16) hold. Substituting $c^* = 1$ into Equation (A.15) and solving for d^* leads to (18). Substituting $c^* = 1$ and (18) into (A.16) gives (19).

Next, we prove the existence and uniqueness of the symmetric equilibrium by proving the following three facts.

A. Case I equilibrium is unique if it exists. We need to show that there exists an unique N in the open interval $(1, \frac{v}{\omega})$ that solves Equation (16). We denote the left hand side of Equation (16) by $A(N)$. It can be easily shown that $A(N=1) = \omega - v < 0$ and $A(N = \frac{v}{\omega}) = \alpha^2\beta\kappa^2 v^2(\frac{v}{\omega} - 1)^2 + \kappa v(\frac{v}{\omega} - 1) > 0$. This implies that there exists an unique N in the open interval $(1, \frac{v}{\omega})$ that solves Equation (16), since $A(N)$ is a quadratic equation of N.

B. Case II equilibrium is unique if it exists. We need to show that there exists an unique N in the open interval $(1, \frac{v}{\omega})$ that solves Equation (19). We denote the left hand side of Equation (19) by $B(N)$. It can be easily shown that $B(N=0) = \alpha^2(1-\kappa)^2 v^2 > 0$, $B(N = 1) = -\alpha^2(v-\omega)^2 + 4\gamma < 0$ (due to $v > \omega + \frac{2\sqrt{\gamma}}{\alpha}$), and $B(N = \frac{v}{\omega}) = \alpha^2\kappa^2 v^2(\frac{v}{\omega} - 1)^2 + 4\gamma\frac{v^2}{\omega^2} > 0$. This implies that there exists an unique N in the open interval $(1, \frac{v}{\omega})$ that solves Equation (16), since $B(N)$ is a cubic equation of N.

C. Either Case I equilibrium or Case II equilibrium exists and two equilibria do not coexist.

Combining Equations (A.15) to (A.16), we have:

$$c^* = \frac{1}{\gamma}\frac{\alpha^2}{4N^2}[\kappa v(N-1) + (v - N\omega)][(2N-1)(v - N\omega) - \kappa v(N-1)], \tag{A.17}$$

and

$$\alpha^2\beta\kappa v(N-1)[\kappa v(N-1) + (v - N\omega)]\frac{1}{(2N-1)(v-N\omega) - \kappa v(N-1)}\begin{cases} = 1 & \text{if } c^* < 1 \\ \geq 1 & \text{if } c^* = 1 \end{cases}. \tag{A.18}$$

For notational convenience, we define the right hand side of Equation (A.17) as a function of N: $f_1(N) = \frac{1}{\gamma}\frac{\alpha^2}{4N^2}[\kappa v(N-1) + (v - N\omega)][(2N-1)(v - N\omega) - \kappa v(N-1)]$; we also define the left hand side of Equation (A.18) as a function of N: $f_2(N) = \alpha^2\beta\kappa v(N - 1)[\kappa v(N-1) + (v - N\omega)]\frac{1}{(2N-1)(v-N\omega)-\kappa v(N-1)}$. For Case I equilibrium, $f_1 < 1$ and $f_2 = 1$. For Case II equilibrium, $f_1 = 1$ and $f_2 \geq 1$. Note that rearrangement of $f_1(N) = 1$ and

$f_2(N) = 1$ leads to Equations (19) and (16) respectively. Therefore, given $v > \omega + \frac{2\sqrt{\gamma}}{\alpha}$, there is a unique $N \in (1, \frac{v}{\omega})$ such that $f_1(N) = 1$ and a unique $N' \in (1, \frac{v}{\omega})$ such that $f_2(N') = 1$.

We show that $f_1(N)$ is a decreasing function over the interval $[1, \frac{v}{\omega}]$, or equivalently, $\frac{\partial f_1}{\partial N} < 0$ for $N \in [1, \frac{v}{\omega}]$. Simple algebra shows that $\frac{\partial f_1}{\partial N}$ has the same sign as $h_1(N) = (\kappa - 1)v[(2N-1)(v - N\omega) - \kappa v(N-1)] + [\kappa v(N-1) + (v - N\omega)][(1-\kappa)v - 2N^2\omega]$, a cubic function of N. It can be easily verified that $h_1(N = 0) > 0$, $h_1(N = 1) < 0$, and $h_1(N = \frac{v}{\omega}) < 0$. To show $h_1(N) < 0$ for $N \in [1, \omega]$, it is sufficient to show that there are no three roots of $h_1(N)$ over the interval $(0, \frac{v}{\omega})$. It is then sufficient to show that there is no root of $h_1''(N)$ over the interval $(0, \frac{v}{\omega})$. Since $h_1''(N) = 12N\omega(\omega - \kappa v)$ can not equal zero for any $N \in (0, \frac{v}{\omega})$, we prove that $f_1(N)$ is a decreasing function over the interval $[1, \frac{v}{\omega}]$.

C1. If there exists a Case I equilibrium, then there does not exist a Case II equilibrium. We prove this by contradiction. Suppose a Case I equilibrium exists with the number of firms as $N_1 \in (1, \frac{v}{\omega})$. That means for the unique N_1 such that $f_2(N_1) = 1$ holds, we have $f_1(N_1) < 1$. For Case II equilibrium, we have $f_1(N_2) = 1$ and $f_2(N_2) \geq 1$. Since $f_1(N)$ is a decreasing function over the interval $[1, \frac{v}{\omega}]$, $f_1(N_1) < 1$ and $f_1(N_2) = 1$ imply $N_2 < N_1$. We then show that $f_2(N)$ is an increasing function over the interval $[N_2, N_1]$. Define $h_2(N) = (2N-1)(v - N\omega) - \kappa v(N-1)$, a quadratic function of N. From Equation (A.18), we have $h_2(N_2) > 0$ and $h_2(N_1) > 0$. Since $h_2(N)$ is a quadratic function of N with a negative coefficient on the quadratic term, we then have $h_2(N) > 0$ for $N \in [N_2, N_1]$. Simple algebra shows that $\frac{\partial f_2}{\partial N}$ has the same sign as $h_3(N) = [\kappa v(N-1) + (v - N\omega)](v - N\omega) + (N-1)\kappa v h_2(N) + 2\kappa v\omega(N-1)^2 + 2\kappa v\omega(N-1)^3$. Therefore, $h_3(N) > 0$ for $N \in [N_2, N_1]$ and $f_2(N)$ is an increasing function over the interval $[N_2, N_1]$. Given that $N_2 < N_1$, we then expect $f_2(N_2) < f_2(N_1)$. This contradicts to $f_2(N_2) \geq 1$ and $f_2(N_1) = 1$.

C2. If there does not exist a Case I equilibrium, then there exists a Case II equilibrium. Suppose there does not exist a Case I equilibrium. Then for the unique N_1 such that $f_2(N_1) = 1$ holds, we have: $f_1(N_1) \geq 1$. In the case of $f_1(N_1) = 1$, a Case II equilibrium with the number of firms as N_1 exists. In the case of $f_1(N_1) > 1$, for the unique N_2 such that $f_1(N_2) = 1$, we have: $N_2 > N_1$, since as shown above $f_1(N)$ is a decreasing function over the interval $[1, \frac{v}{\omega}]$. Similar to the proof of C1, we can show that $f_2(N)$ is an increasing function over the interval $[N_1, N_2]$. Then, we have: $f_2(N_2) > f_2(N_1) > 1$. Since $f_1(N_2) = 1$ and $f_2(N_2) > 1$, a Case II equilibrium with the number of firms as N_2 exists. $\square$

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Table 1: **Base case parameter values**

This table summarizes the parameter values we use for the base case.

Parameter	Symbol	Value
Cost of cash holding	γ	0.015
Winner's advantage	κ	0.3
Entry costs	ω	0.25
Market profitability	v	10
R&D efficiency	α	0.1
Time to finance coefficient	β	0.06

Table 2: **R&D and cash holdings by industry: 1987-2011**

This table shows the 57 most R&D intensive industries (based on the 3-digit SIC codes) during the period 1987-2011. The R&D-to-asset, cash-to-asset, R&D-to-capx, and cash-to-capx ratios are first calculated at the firm level on an annual basis, and then aggregated to the industry level by taking weighted averages across firms. The table reports the time-series averages of these ratios at the industry level. Cash holdings include both cash and short-term investments.

SIC Code	Industry Name	$\frac{R\&D}{AT}$	$\frac{Cash}{AT}$	$\frac{R\&D}{CAPX}$	$\frac{Cash}{CAPX}$
512	Drugs, Proprietaries, And Sundries	0.004	0.07	0.257	3.904
489	Communications Services, Nec	0.004	0.092	0.05	1.225
291	Petroleum Refining	0.004	0.049	0.044	0.563
203	Preserved Fruits And Vegetables	0.005	0.033	0.105	0.763
820	Educational Services	0.005	0.225	0.092	3.621
206	Sugar And Confectionery Products	0.005	0.09	0.077	1.482
481	Telephone Communications	0.005	0.034	0.05	0.397
870	Engineering And Management Services	0.005	0.139	0.126	3.691
807	Medical And Dental Laboratories	0.005	0.081	0.111	1.736
344	Fabricated Structural Metal Products	0.006	0.072	0.138	1.908
225	Knitting Mills	0.006	0.054	0.083	0.655
871	Engineering And Architectural Services	0.007	0.099	0.135	3.9
209	Miscellaneous Food And Kindred Products	0.007	0.082	0.124	1.35
138	Oil And Gas Field Services	0.007	0.086	0.06	0.922
262	Paper Mills	0.007	0.027	0.111	0.449
220	Textile Mill Products	0.009	0.048	0.144	0.768
738	Miscellaneous Business Services	0.009	0.125	0.198	2.824
509	Miscellaneous Durable Goods	0.009	0.042	0.185	1.007
335	Nonferrous Rolling And Drawing	0.011	0.079	0.224	2.443
281	Industrial Inorganic Chemicals	0.013	0.053	0.169	0.69
596	Nonstore Retailers	0.013	0.145	0.494	4.524
204	Grain Mill Products	0.014	0.033	0.221	0.601
308	Misc. Plastic Products, Nec	0.014	0.057	0.29	1.311
363	Household Appliances	0.015	0.055	0.299	1.138
287	Agricultural Chemicals	0.015	0.07	0.365	1.489
342	Cutlery, Hand Tools, And Hardware	0.017	0.047	0.34	1.243
349	Miscellaneous Fabricated Metal Products	0.017	0.05	0.461	1.522
352	Farm And Garden Machinery	0.018	0.022	0.429	0.561
358	Refrigeration And Service Machinery	0.018	0.066	0.496	1.845
353	Construction And Related Machinery	0.02	0.046	0.408	0.982
354	Metalworking Machinery	0.021	0.031	0.538	0.802
364	Electric Lighting And Wiring Equipment	0.023	0.094	0.521	2.929
289	Miscellaneous Chemical Products	0.023	0.066	0.44	1.385
286	Industrial Organic Chemicals	0.023	0.069	0.458	1.262
10	Agricultural Production - Crops	0.024	0.068	0.439	1.403
356	General Industrial Machinery	0.027	0.075	0.702	2.062
284	Soap, Cleaners, And Toilet Goods	0.029	0.078	0.548	1.621

Table 2 continued.

SIC Code	Industry Name	$\frac{R\&D}{AT}$	$\frac{Cash}{AT}$	$\frac{R\&D}{CAPX}$	$\frac{Cash}{CAPX}$
371	Motor Vehicles And Equipment	0.029	0.09	0.589	2.056
381	Search And Navigation Equipment	0.029	0.059	0.976	2.281
369	Misc. Electrical Equipment And Supplies	0.031	0.1	0.717	2.582
399	Miscellaneous Manufactures	0.031	0.157	0.622	3.041
282	Plastics Materials And Synthetics	0.034	0.053	0.597	1.124
394	Toys And Sporting Goods	0.036	0.144	0.99	4.1
362	Electrical Industrial Apparatus	0.038	0.08	0.89	2.246
372	Aircraft And Parts	0.041	0.068	1.325	2.406
365	Household Audio And Video Equipment	0.043	0.087	1.025	2.053
267	Miscellaneous Converted Paper Products	0.048	0.049	0.711	0.812
386	Photographic Equipment And Supplies	0.049	0.046	0.975	0.988
384	Medical Instruments And Supplies	0.061	0.118	1.436	3.041
737	Computer And Data Processing Services	0.062	0.237	1.326	5.532
873	Research, Development, And Testing Services	0.066	0.28	1.075	4.796
382	Measuring And Controlling Devices	0.068	0.138	1.932	4.474
357	Computer And Office Equipment	0.075	0.192	1.649	5.414
355	Special Industry Machinery	0.076	0.219	2.243	7.145
367	Electronic Components And Accessories	0.087	0.235	0.995	2.784
366	Communications Equipment	0.09	0.194	2.243	6.485
283	Drugs	0.097	0.181	2.352	4.791
	Mean	0.027	0.094	0.607	2.265
	Median	0.018	0.075	0.440	1.736

Table 3: **Summary statistics at the industry-year level.**

This table shows summary statistics at the industry-year level. Our sample includes 57 3-digit SIC industries with above-median R&D-to-asset ratio from 1987 to 2011. Altogether it has 7515 firms with 60243 firm-year observations. **Skewness** is the skewness of the distribution of market shares within the industry, based on sales; **Profit Margin** is the ratio of operating income before depreciation to sales for the median firm in the industry; **Assets** is the average asset size in the industry; **TobinQ** is the ratio of the market value of firm assets to the book value; **Volatility** is the annual volatility of the value-weighted industry stock portfolio. Cash/asset, Cash/capx, R&D/asset, R&D/capx, and TobinQ in a given year are average across all firms in the industry, weighted by the denominator of each ratio respectively.

	Mean	Median	Std	Dev
Cash/asset	0.100	0.076	0.074	1245
Cash/capx	2.419	1.559	2.539	1245
R&D/asset	0.029	0.020	0.026	1245
R&D/capx	0.649	0.431	0.720	1245
Skewness	3.381	2.615	2.496	1245
Profit Margin	0.088	0.097	0.087	1245
Assets (Million $)	2164.695	795.572	4415.637	1245
TobinQ	2.244	1.990	1.022	1245
Volatility	0.245	0.219	0.107	1245

Table 4: **Industry cash holdings and R&D ratios**

This table shows the relation between industry cash holdings and R&D intensity. The sample includes 57 most R&D intensive industries (based on 3-digit SIC codes) from year 1987 to 2011. Column (1) shows results when both the dependent variable and the independent variable are the time series averages across years, column (2) shows the Fama-MacBeth regression results using annual industry data, while column (3) shows the pooled regression results with correction for error clusterings at both the industry and and the year levels. The t-statistics for the Fama-MacBeth regressions are Newey-West adjusted for autocorrelation up to lag 5.

Panel (A) Cash-to-asset and R&D-to-asset ratios

	(1) Cash/Asset	(2) Cash/Asset	(3) Cash/Asset
R&D/Asset	1.610***	1.548***	1.507***
	(5.88)	(7.72)	(5.70)
Constant	0.051***	0.058***	0.057***
	(5.64)	(10.08)	(6.26)
Observations	57	1245	1245
R^2	0.415	0.293	0.293

* p < 0.1, ** p < 0.05, *** p < 0.01

Panel (B) Cash-to-capx and R&D-to-capx ratios

	(1) Cash/Capx	(2) Cash/Capx	(3) Cash/Capx
R&D/Capx	1.992***	1.635***	2.491***
	(7.56)	(4.58)	(8.35)
Constant	1.056***	1.297***	0.802***
	(4.90)	(6.94)	(3.46)
Observations	57	1245	1245
R^2	0.522	0.499	0.499

* p < 0.1, ** p < 0.05, *** p < 0.01

Table 5: **Industry cash holdings**

This table shows the cross-sectional determinants of industry-level cash holdings. The sample includes 57 most R&D intensive industries (based on 3-digit SIC codes) from year 1987 to 2011. Columns (1) and (4) show results when both the dependent variable and the independent variable are the time-series averages across years, columns (2) and (5) show the Fama-MacBeth regression results using annual industry data, while columns (3) and (6) show the pooled regression results with correction for error clusterings at both the industry and and the year levels. The t-statistics for the Fama-MacBeth regressions are Newey-West adjusted for autocorrelation up to lag 5. **Skewness** is the skewness of the distribution of market shares within the industry, based on sales; **Profit Margin** is the ratio of operating income before depreciation to sales for the median firm in the industry; **Assets** is the average asset size in the industry; **TobinQ** is the average ratio of the market value to the book value of firm assets, weighted by the book value; **Volatility** is the annual volatility of the value-weighted industry stock portfolio.

	(1) Cash/Asset	(2) Cash/Asset	(3) Cash/Asset	(4) Cash/Capx	(5) Cash/Capx	(6) Cash/Capx
Skewness	0.010***	0.009***	0.007***	0.288***	0.242*	0.155**
	(4.45)	(3.62)	(3.34)	(4.03)	(1.98)	(2.41)
Profit Margin	-0.182*	-0.179***	-0.161*	-6.587***	-6.302***	-6.081***
	(-1.72)	(-3.71)	(-1.77)	(-3.19)	(-5.66)	(-3.52)
Log(Asset)	-0.016***	-0.020***	-0.014***	-0.341***	-0.475***	-0.033
	(-3.60)	(-7.95)	(-3.42)	(-3.11)	(-5.25)	(-0.25)
TobinQ	0.020**	0.022***	0.016**	0.215	0.119	0.179
	(2.44)	(5.19)	(2.52)	(1.25)	(1.35)	(1.00)
Volatility	0.499***	0.239***	0.171***	10.439**	3.930*	3.980**
	(4.44)	(3.91)	(4.02)	(2.23)	(1.94)	(2.33)
Constant	0.019	0.118***	0.103***	1.232	4.465***	1.282
	(0.44)	(12.37)	(3.14)	(0.85)	(6.36)	(1.33)
Observations	57	1245	1245	57	1245	1245
R^2	0.702	0.371	0.372	0.585	0.110	0.136

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: **Industry R&D ratios**

This table shows the cross-sectional determinants of industry R&D ratios. The sample includes 57 most R&D intensive industries (based on 3-digit SIC codes) from year 1987 to 2011. Columns (1) and (4) show results when both the dependent variable and the independent variable are the time series averages across years, columns (2) and (5) show the Fama-MacBeth regression results using annual industry data, while columns (3) and (6) show the pooled regression results with correction for error clusterings at both the industry and and the year levels. The t-statistics for the Fama-MacBeth regressions are Newey-West adjusted for autocorrelation up to lag 5. **Skewness** is the skewness of the distribution of market shares within the industry, based on sales; **Profit Margin** is the ratio of operating income before depreciation to sales for the median firm in the industry; **Assets** is the average asset size in the industry; **TobinQ** is the average ratio of the market value to the book value of firm assets, weighted by the book value; **Volatility** is the annual volatility of the value-weighted industry stock portfolio.

	(1) R&D/Asset	(2) R&D/Asset	(3) R&D/Asset	(4) R&D/Capx	(5) R&D/Capx	(6) R&D/Capx
Skewness	0.007***	0.006***	0.006***	0.149***	0.127***	0.105***
	(4.34)	(9.89)	(4.12)	(3.81)	(4.07)	(4.36)
Profit Margin	-0.118***	-0.100***	-0.090***	-3.096***	-2.613***	-2.616***
	(-4.79)	(-13.05)	(-5.72)	(-5.20)	(-8.23)	(-8.27)
Log(Asset)	0.001	-0.001	-0.001	0.016	-0.027	0.066
	(0.35)	(-1.27)	(-0.38)	(0.28)	(-1.25)	(1.37)
TobinQ	0.001	0.003***	0.002	-0.033	0.009	0.012
	(0.22)	(6.79)	(1.48)	(-0.58)	(0.74)	(0.31)
Volatility	0.073	0.019	0.014	1.272	0.073	0.445
	(1.26)	(1.55)	(1.30)	(0.72)	(0.17)	(1.18)
Constant	-0.008	0.015**	0.014	0.063	0.661***	-0.055
	(-0.39)	(2.07)	(1.30)	(0.11)	(3.19)	(-0.19)
Observations	57	1245	1245	57	1245	1245
R^2	0.634	0.483	0.485	0.552	0.269	0.296

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

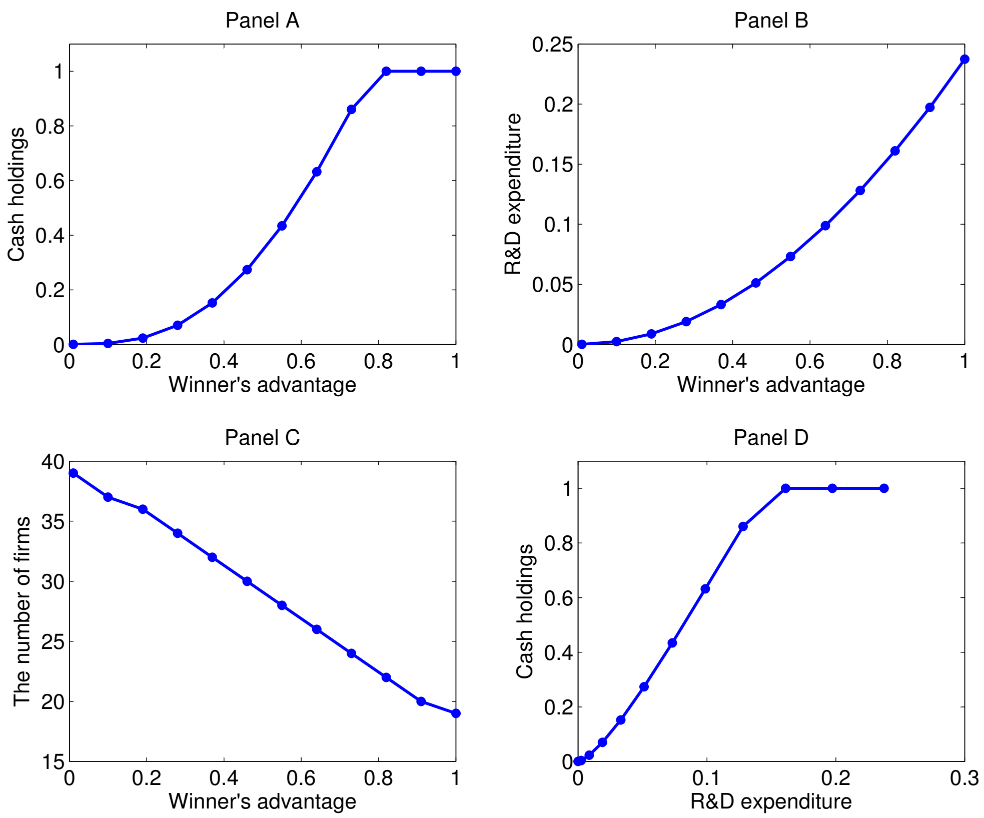


Figure 1: **Comparative statics with respect to winner's advantage** κ. Benchmark parameters are: $\gamma = 1.5\%$, $\omega = 0.25$, $\upsilon = 10$, $\alpha = 0.1$, $\beta = 0.06$. Panel A shows the dependence of normalized cash holdings on winner's advantage. Panel B shows the dependence of normalized R&D expenditure on winner's advantage. Panel C shows the dependence of the number of firms on winner's advantage. Panel D shows the endogenous relationship between cash holdings and R&D expenditures.

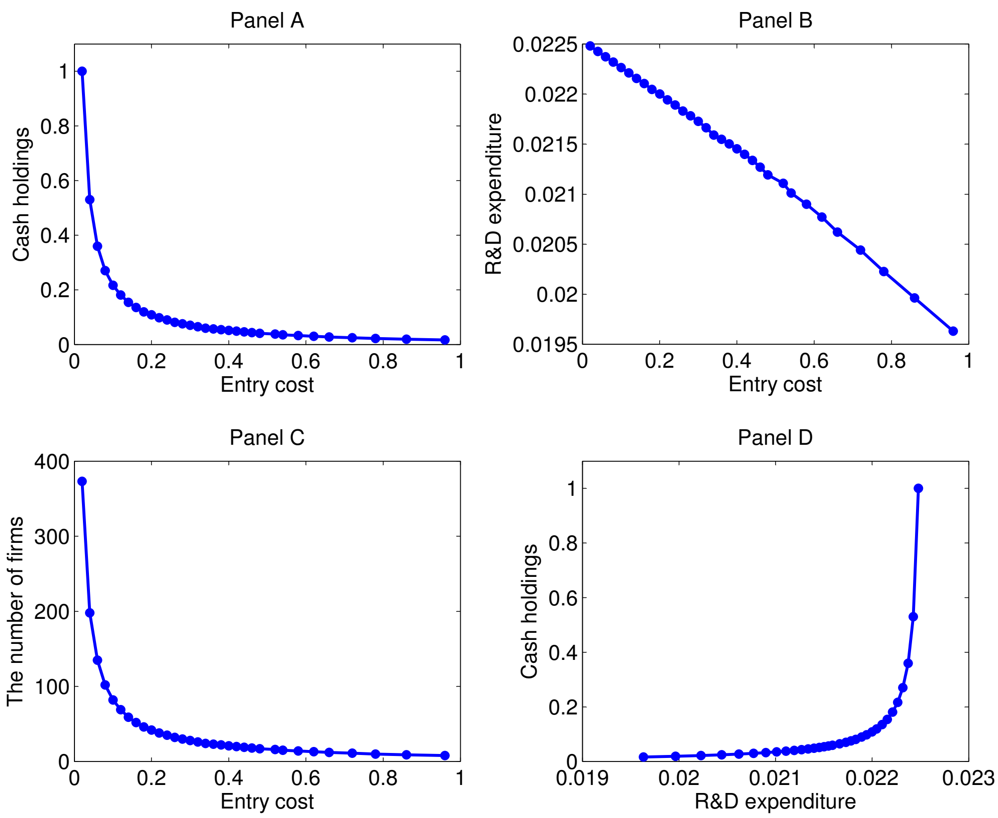


Figure 2: **Comparative statics with respect to entry costs** ω. Benchmark parameters are: $\gamma = 1.5\%$, $\kappa = 0.3$, $v = 10$, $\alpha = 0.1$, $\beta = 0.06$. Panel A shows the dependence of normalized cash holdings on entry costs. Panel B shows the dependence of normalized R&D expenditure on entry costs. Panel C shows the dependence of the number of firms on entry costs. Panel D shows the endogenous relationship between cash holdings and R&D expenditures.

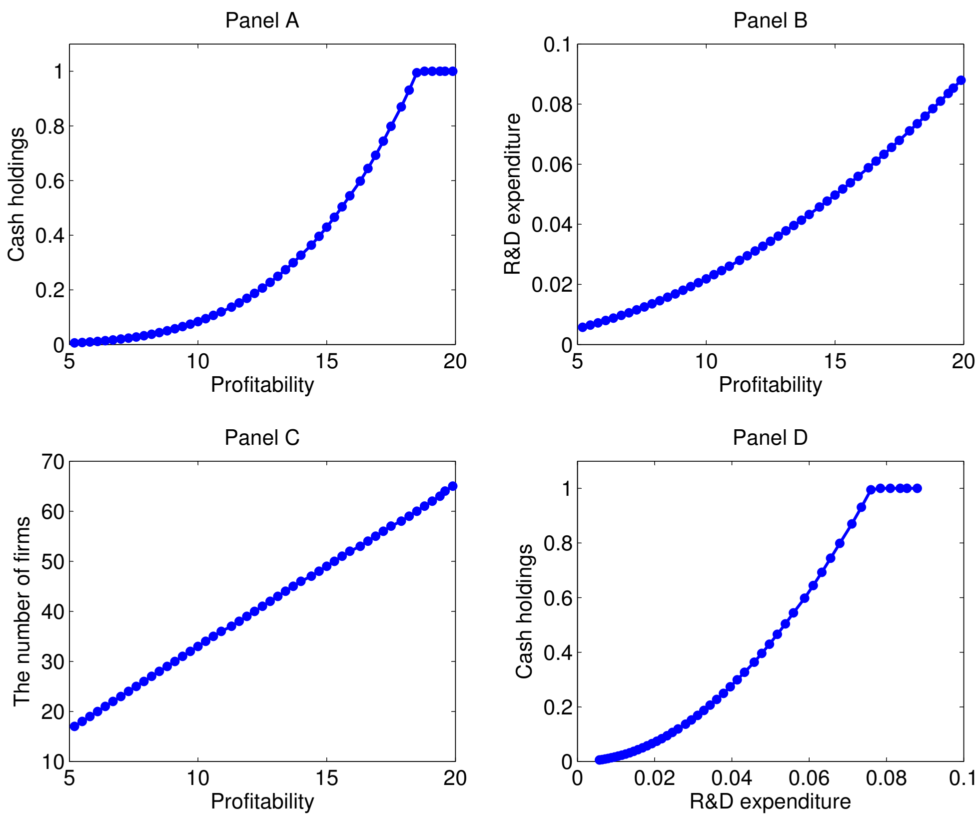


Figure 3: **Comparative statics with respect to market profitability** v. Benchmark parameters are: $\gamma = 1.5\%$, $\kappa = 0.3$, $\omega = 0.25$, $\alpha = 0.1$, $\beta = 0.06$. Panel A shows the dependence of normalized cash holdings on profitability. Panel B shows the dependence of normalized R&D expenditure on market profitability. Panel C shows the dependence of the number of firms on market profitability. Panel D shows the endogenous relationship between cash holdings and R&D expenditures.

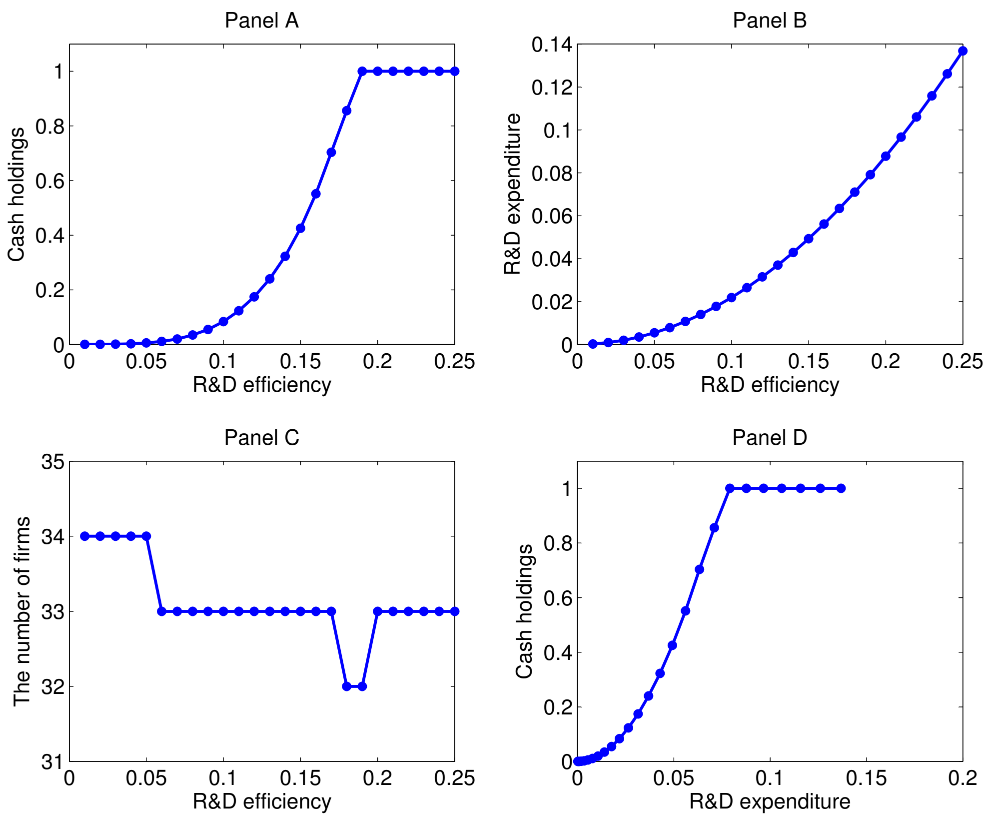


Figure 4: **Comparative statics with respect to R&D efficiency** α. Benchmark parameters are: $\gamma = 1.5\%$, $\kappa = 0.3$, $\omega = 0.25$, $\upsilon = 10$, $\beta = 0.06$. Panel A shows the dependence of normalized cash holdings on R&D efficiency. Panel B shows the dependence of normalized R&D expenditure on R&D efficiency. Panel C shows the dependence of the number of firms on R&D efficiency. Panel D shows the endogenous relationship between cash holdings and R&D expenditures.

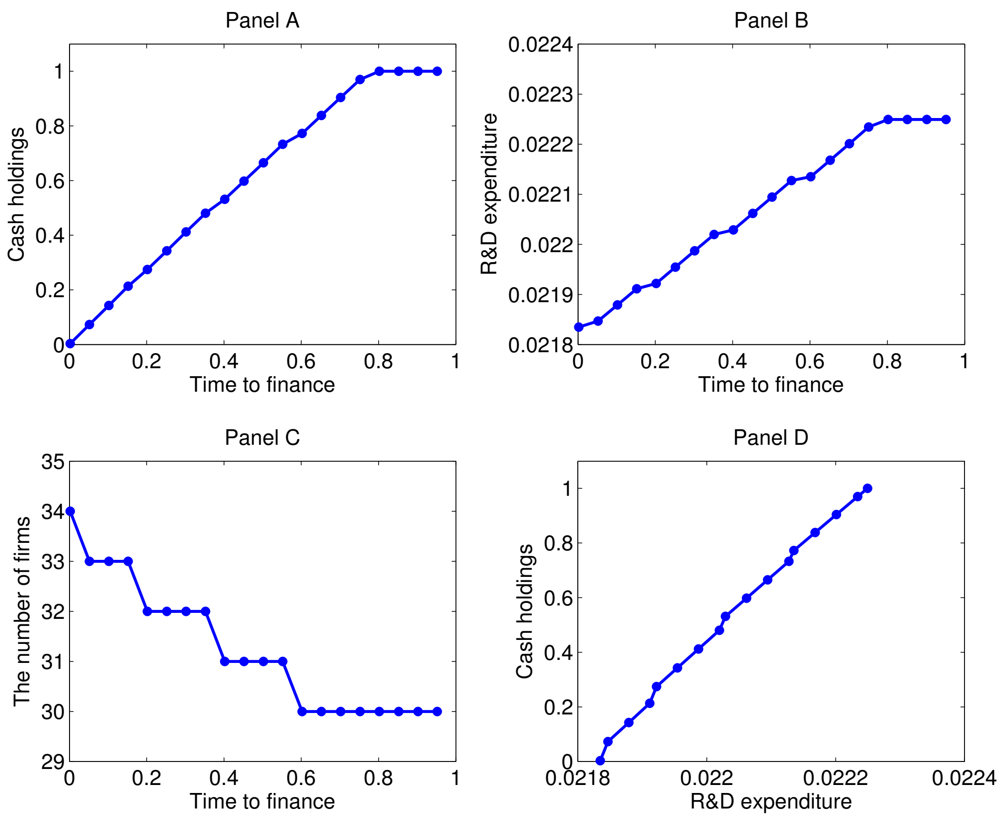
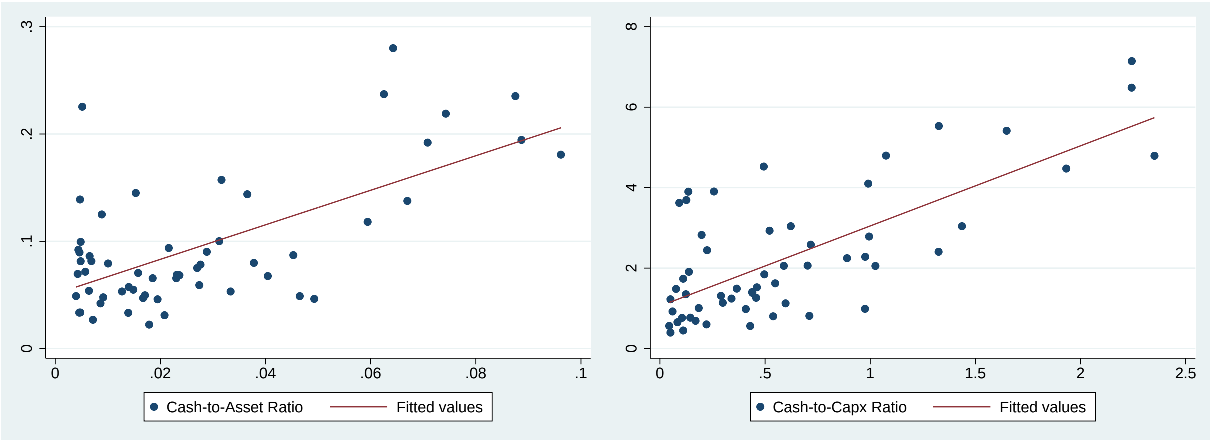


Figure 5: **Comparative statics with respect to the time to finance coefficient** β. Benchmark parameters are: $\gamma = 1.5\%$, $\kappa = 0.3$, $\omega = 0.25$, $v = 10$, $\alpha = 0.1$. Panel A shows the dependence of normalized cash holdings on time to finance. Panel B shows the dependence of normalized R&D expenditure ontime to finance. Panel C shows the dependence of the number of firms on time to finance. Panel D shows the endogenous relationship between cash holdings and R&D expenditures.



(a) R&D-to-asset and cash-to-asset ratios

(b) R&D-to-capx and cash-to-capx ratios

Figure 6: **R&D and cash holdings.** Panel (a) plots the ratio of cash to total assets against the ratio of R&D to total assets. Panel (b) plots the ratio of cash to capital expenditures against the ratio of R&D to capital expenditures. The sample includes the 57 most R&D intensive industries (based on 3-digit SIC codes) during the period 1987 to 2011. The ratios for each industry are calculated on an annual basis as weighted averages across firms (weighted by the denominators), and then averaged across years. Cash holdings include both cash and short-term investments.

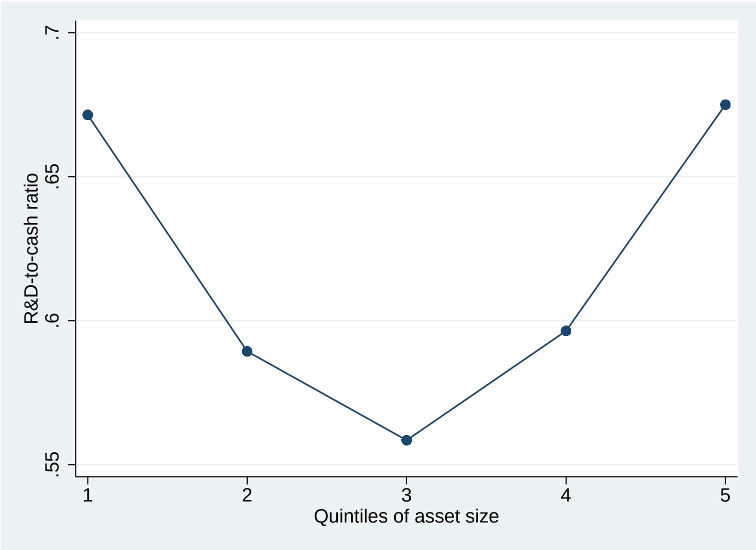


Figure 7: **R&D-cash ratio and firm size.** This figure shows the R&D-to-cash ratios of different size groups. Firms in each industry are divided into 5 size groups by total assets on an annual basis. The R&D-to-cash ratio for each size group is calculated by three steps of simple averaging. First, we average across firms to obtain the annual R&D-to-cash ratio of each size group in each industry. Second, we average cross years to get the R&D-to-cash ratio of each size group in each industry. Third, we average across industries to get the R&D-to-cash ratio of each size group.