Cash Holdings, Competition, and Innovation*

Evgeny Lyandres†
Boston University

Berardino Palazzo‡
Boston University

This version: September 2014

Abstract

We demonstrate theoretically and empirically that strategic considerations are important in shaping cash policies of innovative firms. In our model, firms that successfully innovate compete in product markets with uncertain structure using cash as a commitment device for implementation of successful innovations. We show that firms' equilibrium cash holdings are related to expected intensity of competition in future product markets and to their innovation efficiency. The signs and magnitudes of these relations depend on firms' financial constraints. Our empirical evidence demonstrates that expected competition intensity and innovation efficiency are associated with cash holdings in ways consistent with the model's predictions.

Key words: Cash holdings, Strategic interactions, Innovation

JEL Codes: G32, L13

*We thank Sumit Agarwal, Rui Albuquerque, Michael Brennan, Jiřì Chod, Sudipto Dasgupta, Ran Duchin, Laurent Frésard, Fangjian Fu, Xiaodan Gao, Paul Hsu, Zsuzsa Huszar, Karthik Krishnan, Bart Lambrecht, Vikram Nanda, Kasper Nielsen, Grzegorz Pawlina, Fabiana Penas, David Reeb, Duong Truong, Alex Wagner, Motohiro Yogo, and seminar participants at Boston University, Carnegie Mellon University, Hong Kong University of Science and Technology, Lancaster University, Nanyang Technological University, National University of Singapore, Singapore Management University, University of Hong Kong, University of Manchester, 2011 Minnesota Asset Pricing Mini-Conference, 2012 Eastern Finance Association Meeting, 2012 Entrepreneurial Finance and Innovation Conference, 2012 Western Finance Association Meeting, 2012 European Finance Association Meeting, 2013 European Winter Finance Summit, 2014 China International Conference in Finance, and 2014 SIFR Conference on the Financial Economics of Innovation and Entrepreneurship for helpful comments and suggestions. All remaining errors are our own responsibility.

†Department of Finance, Boston University School of Management. Email: lyandres@bu.edu. Web: http://people.bu.edu/lyandres

‡Department of Finance, Boston University School of Management. Email: bpalazzo@bu.edu. Web: http://people.bu.edu/bpalazzo

1 Introduction

In this paper we examine theoretically and empirically the *strategic* motive for innovative firms' cash holding choices. Understanding the drivers of cash policy of companies that engage in innovation is important. Innovation is one of the key determinants of growth, and internal cash holdings are of a paramount importance in financing innovation.[1]

Innovative firms' cash holdings are large relative to those of "old–economy" firms. In 2012, the mean cash–to–assets ratio of firms belonging to the top quintile of R&D–to–assets ratio approached 45%, while the mean cash–to–assets ratio of firms that did not report R&D expenditures was about 17%. While relatively large cash holdings of market leaders in the high-tech and biotech sectors are often discussed in popular press,[2] small innovative firms also tend to hold more cash than their old–economy counterparts.[3]

Existing literature that examines cash holdings of innovative firms tends to focus on the *precautionary* motive for holding cash, arising from uncertain future expenditures (e.g., **?** and **?**). Because of the relatively high degree of information asymmetry between innovative firms and the capital market participants, such firms may be subject to severe financing constraints (e.g., **?**, **?**, and **?**). As a result, internal cash holdings may have an important impact on the likelihood of developing and implementing innovations (e.g., **?** and **?**). **?** and **?** examine empirically the relation between firms' R&D investments and their cash holdings and conclude that "because of capital market imperfections, the flow of internal finance is the principal determinant of the rate at which small, high–tech firms acquire technology through R&D." **?** conclude that "large established firms [also] appear to prefer internal funds for financing R&D investments".

In this paper, we focus on an additional, strategic motive for holding cash and show that innovative firms' cash holding choices are not driven solely by precautionary considerations. Our main contribution is in demonstrating that strategic considerations matter for understanding cash holding policies of innovative firms.

Innovation does not happen in isolation. There is a large theoretical industrial organization literature modeling strategic interactions among innovative firms (e.g., **?**, **?**, **?**, **?**, **?**, among many others). Such strategic interactions are also found in empirical studies of innovative industries (e.g., **?** for the case of pharmaceuticals and **?** for the case of disk drives). Importantly, firms interact strategically not only when they develop and implement their innovations, but also in the ensuing output markets. In particular, while firms' innovation efforts may be complementary due to R&D spillovers (e.g., **?**), products resulting from firms' innovations are likely to be substitutes

[1] See, for example, **?**, **?**, and **?** for the impact of innovation on growth and **?**, **?**, and **?** for the importance of cash holdings for funding innovation.

[2] E.g., The Economist (November 3, 2012). At the end of 2012, General Electric, Microsoft, Google, Cisco, and Apple held over 300 billion dollars of cash in total.

[3] **?** and **?** report that cash holdings are positively correlated with R&D expenditures, controlling for various other determinants of cash holdings.

(e.g., ?). In other words, the innovation game is typically not a "winner takes all" one and, in many instances, innovations by multiple firms result in imperfectly substitutable products, which capture substantial market shares.[4] Thus, the interaction among innovative firms when they implement their innovations and compete in future output markets may play an important role in shaping their cash holdings choices.

Surprisingly, despite the seemingly high importance of strategic considerations for innovative firms, the literature examining *strategic choices of cash* by such firms is limited. Our model is one of the first to illustrate the strategic role of cash for innovative firms facing varying degrees of financial constraints. We analyze firms' choices of cash holdings using a simple static model that incorporates strategic interactions among firms. Firms first choose their cash holdings. Then they develop their innovations. Successful firms have the option to implement their innovations using internal resources and, potentially, external funds, thus obtaining profits that depend on the resulting output market structure.

The innovation implementation stage of the game is key for understanding the strategic role of cash holdings. Firms may be financially constrained in the implementation stage, in which case they have to rely on internal resources. Because of the possibility of not having access to external funds, a firm with relatively high cash holdings is more likely to finance its innovation implementation than a firm with relatively low cash holdings.[5] Successful implementation of a firm's innovation reduces expected profits of successful competitors and, as a consequence, it reduces these firms' incentives to implement their innovations. Thus, large cash holdings by a firm reduce other firms' likelihood of innovation implementation, indirectly benefiting the firm.

Our model results in two important empirical predictions. First, due to the strategic effect of cash, firms' optimal cash holdings depend on the intensity of expected product market competition. Importantly, the magnitude and sign of this relation depend on the degree of financial constraints that a firm faces. For relatively financially constrained firms, the proportion of cash in firm value is increasing in the intensity of future product market competition. For sufficiently unconstrained firms, on the other hand, equilibrium cash holdings are decreasing in the intensity of competition.

The intuition is as follows. There are two effects at play. The first one is precautionary: the more fierce the competition in the output market, the lower the expected marginal benefit of investing in future innovation implementation and the lower the optimal cash holdings. The second effect, which we focus on, is strategic: higher cash holdings raise the likelihood of future innovation implementation and deter the rival from developing and implementing its own innovation. Importantly, the strategic effect is only present when a firm is likely to be financially constrained, i.e.

[4]There are industries in which successful innovators produce imperfectly substitutable products and compete in output markets. For example, throughout the last ten years, Intel captured between 51% and 72% of the CPU market, while AMD's market share ranged between 28% and 49%.

[5]An example of a firm' insufficient cash holdings having a negative impact on innovation implementation is the inability by Intel in the early eighties to build manufacturing plants for its newly developed microprocessors based on the 80286 chip (e.g., ?)

when it may need to rely exclusively on internal resources while implementing innovation. Thus, the importance of the strategic effect is larger the higher the degree of financial constraints. For relatively unconstrained firms this effect is weak, resulting in an overall negative relation between expected output market competition intensity and cash holdings as a proportion of firm value. This relation is reversed for relatively constrained firms, for which the strategic effect dominates.

The second prediction of the model is that innovation efficiency, i.e. the likelihood of obtaining successful innovation, also affects optimal cash holdings in a non–trivial way. For relatively unconstrained firms, cash holdings as a proportion of firm value increase in innovation efficiency, while the relation is reversed for relatively constrained ones.

The intuition is as follows. Higher innovation efficiency is associated with higher firm values. It also increases the likelihood of implementing innovation and the marginal benefit of cash. Importantly, the marginal benefit of cash is decreasing in the level of cash. Thus, for relatively constrained firms, whose equilibrium cash holdings are high, an increase in innovation efficiency results in a modest increase in optimal cash holdings, leading to a negative relation between innovation efficiency and the proportion of cash in firm value. For relatively unconstrained firms, whose equilibrium cash holdings are low, an increase in innovation efficiency has a large impact on optimal cash holdings, resulting in a positive relation between cash as a proportion of firm value and innovation efficiency.

Importantly, a key driver of these results is the uncertainty that innovative firms face regarding the existence and structure of future output markets. This uncertainty is one of the defining characteristics of innovative firms, and the cash policies derived in our model reflect this feature.

Our paper belongs to an emerging theoretical effort that bridges the literature on the relation between competition and innovation[6] and the literature that examines the effects of interaction among firms in output markets on firms' financial policies.[7] In the context of cash holdings of innovative firms, our model belongs to a small set of contemporaneous working papers that focus on the impact of industry structure and strategic considerations on firms' optimal cash holdings.

The model that is most closely related to ours is **?**. Similar to us, they examine the joint choices of cash holdings and R&D investments by innovative firms. Different from us, they focus on the "winner's advantage", as opposed to oligopolistic competition following innovation by multiple firms. In their model, cash facilitates faster innovation implementation, deterring competitors from implementing their innovations. While this strategic reason for holding cash is broadly similar to ours, the implications of the two models are very different. First, unlike **?**, we focus on the intensity of competitive interaction among firms in future output markets (e.g., future products similarity/substitutability). Second, we show that the effect of expected competitive interaction on equilibrium cash holdings depends crucially on the degree of financial constraints.

[6] See, for example, **?** and **?**.

[7] See, for example, **?** and **?** for the case of cash holdings; **?**, **?**, and **?** among others for the case of capital structure; **?** and **?** for the case of mergers and acquisitions; and **?** for the case of initial public offerings.

Third, we show that financial constraints are also instrumental for the relation between innovation efficiency and optimal cash holdings.

Another related contemporaneous theoretical paper is the one by **?**, who examine the effect of competition on optimal cash holdings. There are many important distinctions between the two models. First, we focus on firms' strategic cash holdings choices in concentrated industries, while **?** examine competitive industries, in which strategic considerations are absent. Second, we focus on expected competition among innovative firms in future product markets, as opposed to current competition in existing product markets. Third, our model focuses specifically on innovative firms, i.e. firms that face uncertainty regarding the existence and structure of future output markets, while the model of **?** describes optimal cash management decisions of any firm that operates in a competitive environment.

In the second part of the paper we test our model's empirical predictions using data obtained from the NBER Patent Citations Data Project. We use this dataset to construct a sample of innovative firms and to define proxies for the intensity of future expected output market competition and for innovation efficiency. We then examine empirical relations between firms' cash holdings and these measures.

Our empirical results strongly support the model's predictions and, more generally, highlight the importance of the strategic role of cash for innovating firms. First, the intensity of expected product market competition is positively related to observed cash holdings of relatively financially constrained firms, while the relation between cash holdings of relatively unconstrained firms and competition intensity is significantly weaker and often negative. Second, the association between innovation efficiency and cash holdings is significantly stronger for unconstrained firms than for constrained ones. We show that these results are significant not only statistically, but also economically. Importantly, we obtain these results while controlling for known determinants of cash holdings identified in the literature (e.g., **?**), and in particular for the degree of current (as opposed to future) competition, as in **?** and for the importance of winner's advantage, as in **?**.

Our empirical analysis provides new insights for the relation between the extent of current and future competition in output markets on one hand and firms' cash holdings on the other hand (e.g., **?** and **?**). First, we complement **?** by using a novel measure of expected future competition, which is based on firms' innovation activities. The advantage of our measure in the context of innovating firms is that it allows to focus on expected competition in markets created following successful innovation, as opposed to future competition in existing product markets. Second, we complement both **?** and **?** by showing that the direction of the relation between cash holdings and the extent of competition among innovative firms depends on the degree of financial constraints. This is in contrast with the positive relation between competition and cash holdings within the general population of U.S. public companies. Third, we extend existing empirical literature on the determinants of cash holdings by documenting an economically and statistically significant relation between firms' cash holdings and their innovation efficiency. Overall, our empirical analysis shows that cash serves an important strategic role for firms that compete in innovation development and implementation, in addition to its precautionary role.

The remainder of the paper is organized as follows. In the next section we present our model of strategic cash holdings in the context of competition in innovation. In Section 3, we discuss our data and empirical methods, and present the results of empirical tests of the model's predictions. Section 4 summarizes and concludes. The Appendix contains proofs of the model's results, an extended, less parsimonious but more realistic model, and a detailed description of variables used in the empirical analysis.

2 Model

2.1 Setup and assumptions

Assume that an industry consists of two firms, i and j.[8] Each firm is engaged in research and development (R&D) of an innovative product. The outcome of R&D is uncertain: a firm may succeed or fail in its innovative efforts. Following successful R&D, a firm can (but does not have to) invest in an implementation of its innovation using internal and possibly external resources. Given the uncertainties involved in innovation development and implementation, a firm that has implemented its innovation may either become a monopolist in the output market or it may compete in the output market with another firm that has successfully implemented its innovation.

In the beginning of the game each firm hoards cash to finance the implementation of successful innovation, C_i for firm i. Following the cash holding decision each firm observes the realization of an exogenous shock to its R&D output (success/failure). We assume that each firm's probability of R&D success is given by an exogenous parameter δ_i for firm i, and that R&D outcomes are independent across the two firms.[9] In what follows, we refer to δ_i as firm i's degree of innovation efficiency. If firm i's R&D is successful, the firm is subject to the second shock, which relates to the required investment in the implementation of innovation. In particular, firm i's successful R&D can be implemented by paying an investment cost of an exogenously determined size I_i. We assume that I_i is stochastic, is independent across the two firms, and is distributed uniformly in [0, 1].[10]

Finally, each firm realizes an independent shock to its ability to obtain external financing that may be required for implementation of its innovation. In particular, we assume that with probability α_i, firm i is shut out of capital markets and can only invest up to its cash holdings,

[8] All of the model's qualitative results hold for the case of multiple firms. We choose to present a two-firm version in order to focus on the basic intuition behind the results.

[9] It follows immediately from this assumption that in the baseline model we assume away possible complementarities among the two firms' innovation efforts.

[10] Alternatively, we can assume a shock to firms' cash holdings, C_i instead of to the required investment in innovation implementation, I_i. All the results of the model are robust to this alternative assumption.

C_i, in the implementation of its innovation. With probability $1 - \alpha_i$, firm i can obtain unlimited external funds to supplement its cash holdings if necessary, i.e. it may choose to raise $I_i - C_i > 0$.[11] In what follows, we refer to α_i as firm i's degree of financial constraints. Our way of modeling financial constraints does not drive any of the results. They are robust to an alternative assumption that firms face positive wedge between the costs of external and internal funds.[12]

In order to present the most parsimonious model possible and to focus on the strategic reasons for holding cash, in the basic version of the model we assume that R&D does not require cash outlays. We present an extended version of the model in the Appendix, in which we make R&D investment costly, endogenize the likelihood of R&D success, and account for possible R&D spillovers among firms. The results of this extended model are fully consistent with those of a more parsimonious version described above.

Importantly, our assumption that firms are unconstrained in their initial cash holding choices but may be potentially constrained in their ability to raise cash in the innovation implementation stage is suitable for the case of established firms that generate cash flows and engage in innovation development. Empirical and anecdotal evidence on large cash holdings of R&D-intensive firms, discussed in the introduction, suggests that such firms' cash holdings are driven mostly by their dividend/payout decisions, as opposed to capital raising decisions. This is consistent with future financial constraints being potentially more binding than current ones. We focus on such firms in the model to be consistent with our empirical analysis, which is based on a sample of relatively large, publicly–traded innovative firms.

After observing the investment and financing shocks, firms that have successfully innovated decide whether to implement their innovations. Firms that implement their innovations produce and realize output market profits. Given the uncertainties inherent in innovation development and implementation, the structure of the output market is not known ex–ante. In particular, the number of firms that successfully implement their innovations is either zero, or one, or two. If only one firm implements its innovation, it obtains monopolistic profit, $\pi_M > 0$. If both firms implement their innovations, each of them realizes duopolistic profit, $\pi_D(\gamma) > 0$, where γ is the degree of intensity of output market competition (i.e., product heterogeneity/substitutability). To simplify the exposition, we assume that each firm makes its innovation implementation decision without being able to observe the outcome of the other firm's innovation efforts. We show in the extended version of the model in the Appendix that all the results hold when we assume that firms can condition their innovation implementation decisions on other firms' R&D success.

We do not need to assume a specific form of product market competition and, as a consequence, our results hold under any type of competition in heterogenous goods. The only assumptions that

[11] We verify numerically that the qualitative results are not driven by the assumption of independence across the two firms' shocks to R&D outcomes, required investments in innovation implementation, and availability of external financing.

[12] In particular, we examined a setup in which if the required investment, I_i exceeds firm i's cash holdings, C_i, the firm may raise the difference externally by paying proportional issuance cost $\alpha_i(I_i - C_i)$.

we make is that the duopolistic profit is lower than the monopolistic one, $\pi_D(\gamma) < \pi_M$, and that the duopolistic profit is decreasing in the intensity of output market competition, $\pi'_D(\gamma) < 0$. Without loss of generality, we normalize the monopolistic profit to one: $\pi_M = 1$. To simplify the notation, we use π_D instead of $\pi_D(\gamma)$, and Δ_π, which denotes the difference between monopolistic and duopolistic profits ($\Delta_\pi = \pi_M - \pi_D > 0$).

To generate a meaningful cash holding policy, we assume that the gross discount rate between the cash holding decision on one hand and the implementation of innovation and realization of potential output market profits on the other hand, R, is higher than the internal accumulation rate of cash between these two points in time, $r < R$.[13] We also assume that firm owners are risk–neutral and maximize their firms' expected values. The structure of the game is summarized in Figure 1.

2.2 Solution

We solve the model by backwards induction, starting from the innovation implementation decision.

2.2.1 Implementation of innovation

If firm i has access to external finance and is not limited by its cash holdings, it would invest in implementing its innovation as long as the expected product market profit, $\mathbb{E}\pi_i$, exceeds the cost of investment, I_i. In other words, the unconstrained investment threshold of firm i is

$$I_{i,un} = \mathbb{E}\pi_i = \omega_j \pi_D + (1 - \omega_j)\pi_M, \tag{1}$$

where ω_j is the likelihood that firm i's competitor (firm j) implements its innovation. If firm i does not have access to external finance, then it would invest in innovation as long as the required investment is lower than the lowest of the cash on hands and expected output market profit. Thus, the constrained investment threshold is

$$I_{i,co} = \min[\mathbb{E}\pi_i, C_i]. \tag{2}$$

In equilibrium, firms would never choose cash holdings that exceed their expected output market profits. The reason is that if C_i were higher than $\mathbb{E}\pi_i$, some cash (i.e. $C_i - \mathbb{E}\pi_i > 0$) would never be used for implementation of innovation, resulting in a reduction in firm value equal to $\frac{(C_i - \mathbb{E}\pi_i)(R-r)}{R}$. Hence, in equilibrium we have $I_{i,co} = C_i$.

The probability that firm j implements its innovation, ω_j, is

$$\omega_j = \delta_j \left[(1 - \alpha_j)F(I_{j,un}) + \alpha_j F(C_j)\right] = \delta_j[(1 - \alpha_j)I_{j,un} + \alpha_j C_j], \tag{3}$$

where $F(I_{j,un}) = I_{j,un}$ and $F(C_j) = C_j$ are the probabilities of firm j implementing its innovation conditional on it being successful (i.e., the probabilities that the realization of the investment shock

[13] This assumption may be justified by a carry cost of liquid assets (e.g., **?** and **?**), tax considerations (e.g., **?**), or agency costs (e.g., **?**).

is lower than the unconstrained investment threshold or than cash holdings, in the unconstrained and constrained cases respectively). Firm j's likelihood of innovation implementation is affected by several variables: (i) the probability of firm j's innovation being successful (δ_j); (ii) the likelihood of firm j being shut out of the external finance market (α_j); (iii) firm j's unconstrained innovation threshold, $I_{j,un}$, which depends on its expected product market profit; (iv) cash available to firm j when external funds are unavailable (C_j).

We can derive firms i and j's equilibrium unconstrained investment thresholds by solving a system of two equations in two unknowns. The system obtains by plugging ω_j in Equation (3) into firm i's unconstrained implementation threshold in Equation (1) and a symmetric expression for ω_i into a similar equation for firm j's unconstrained investment implementation threshold. The solution of this system of equations delivers the following optimal unconstrained implementation threshold for firm i as a function of both firms' cash holdings:

$$I^*_{i,un} = \frac{1 - \delta_j(1-\alpha_j)\Delta_\pi + \delta_i\delta_j\alpha_i(1-\alpha_j)\Delta_\pi^2 C_i - \delta_j\alpha_j\Delta_\pi C_j}{1 - \delta_i\delta_j(1-\alpha_i)(1-\alpha_j)\Delta_\pi^2}, \tag{4}$$

and a similar threshold for firm j.

We use the investment implementation threshold in Equation (4) to study the roles that a firm's own and its rival's cash holdings have on the likelihood of implementing a firm's innovation in the unconstrained case.

Lemma 1 *Firm i's equilibrium unconstrained innovation implementation threshold, $I^*_{i,un}$, is increasing in its own cash holdings, C_i, and is decreasing in its rival's cash holdings, C_j.*

The negative relation between a firm's innovation implementation threshold and its competitor's cash holdings is the first manifestation of the *strategic effect of cash*. The reason for this negative relation is that firm j's cash holdings increase the likelihood that it would implement its innovation in the constrained state, which raises the overall unconditional likelihood that firm j would implement its innovation and reduces firm i's expected product market profit as a result.

The strategic effect of firm j's cash holdings is stronger the higher the degree of its innovation efficiency, δ_j, the higher the degree of firm j's financial constraints, α_j, and the lower the duopoly profit, π_D (i.e. the larger the product substitutability across the two firms). The intuition is as follows. Rival's cash has a larger negative effect on a firm's expected profit when the likelihood of its innovation being successful is high (since cash holdings are only useful when innovation is successful), when the rival is financially constrained (since cash is only important when a firm is shut out of external capital markets), and when the difference between monopolistic and duopolistic profits is large (since strategic considerations are only important when firms' actions have a material impact on their rivals' values).

The positive effect of a firm own's cash holdings on its unconstrained implementation threshold is indirect. Firm i's cash holdings have a negative impact on firm j's expected likelihood of implementing its innovation, leading to higher firm i's expected product market profit and higher innovation implementation threshold in the unconstrained state.

2.2.2 Cash holdings choice

Firm i maximizes its value, V_i, with respect to cash that it raises:

$$\begin{aligned}\max_{C_i} V_i &= -\frac{C_i}{r} + \frac{1}{R}\left[C_i + \delta_i\left(\alpha_i \int_{\underline{I}}^{C_i} f(I_i)\left(\mathbb{E}_i(\pi) - I_i\right) dI_i + (1-\alpha_i)\int_{\underline{I}}^{I^*_{i,un}} f(I_i)\left(\mathbb{E}_i(\pi) - I_i\right) dI_i\right)\right] \\ &= -\frac{C_i}{r} + \frac{1}{R}\left[C_i + \delta_i\left(\alpha_i C_i\left(I^*_{i,un} - C_i/2\right) + \frac{1}{2}(1-\alpha_i)(I^*_{i,un})^2\right)\right]. \end{aligned} \quad (5)$$

Firm i raises C_i/r, which is carried over as C_i to the investment implementation stage. Firm i's innovation is successful with probability δ_i, which pre-multiplies the expression for expected product market profit net of implementation cost. If the firm is shut out of the external capital markets (which happens with probability α_i), under the uniform distribution assumption, its likelihood of implementing innovation conditional on it being successful equals C_i, and the expected product market profit conditional on implementing the innovation is $(I^*_{i,un} - C_i/2)$. Similarly, if the firm has access to external funds, its likelihood of implementing innovation conditional on successful R&D is $I^*_{i,un}$, and its expected profit conditional on implementing the innovation is $I^*_{i,un}/2$.

Differentiating firm i's value function in Equation (5) with respect to C_i delivers firm i's optimal cash holdings reaction function to firm j's cash holdings:

$$C_i^*(C_j) = \frac{r + r\alpha_i\delta_i - R\left(1 - (1-\alpha_i)\Phi_i\right) - r\Phi_i - r\alpha_i(1-\alpha_j)\delta_i\delta_j\Delta_\pi\pi_D}{r\alpha_i\delta_i(1-\Phi_i)} - \frac{\alpha_j\delta_j\Delta_\pi}{1-\Phi_i}C_j, \quad (6)$$

where $\Phi_i = (1-\alpha_j)\,\delta_i\delta_j\Delta_\pi^2$. Differentiating firm i's cash holdings in (6) with respect to firm j's cash holdings leads to the second manifestation of the strategic effect of cash:

Lemma 2 *Firm i's reaction function in cash holdings, $C_i^*(C_j)$, is downward sloping, $C_i^{*'}(C_j) < 0$.*

The reason for the negative effect of firm's rival's cash holdings on the firm's optimal cash holdings is intuitive. The higher the rival's cash, the higher the likelihood that the rival would implement its innovation in the constrained state, in which the rival's access to external capital is restricted. Higher implementation probability in the constrained state leads to higher rival's overall unconditional implementation likelihood, and to lower firm's expected product market profit, leading to lower marginal benefit of holding cash and lower resulting optimal cash holdings.

Using the two firms' optimal cash holdings reaction functions, we can derive the following expressions for the equilibrium choices of cash holdings and the unconstrained equilibrium implementation threshold:

$$C_i^{EQ} = \frac{(r-R)\left(1-\delta_i\Delta_\pi\left(\alpha_i+(1-\alpha_i)\delta_j\Delta_\pi\right)\right)+r\alpha_i\delta_i\left(1-\delta_j\Delta_\pi\right)}{\alpha_i\delta_i r\left(1-\delta_i\delta_j\Delta_\pi^2\right)}, \tag{7}$$

$$I_{i,un}^{EQ} = \frac{(R\Delta_\pi+r\pi_D)\left(1-\delta_j\Delta_\pi\right)}{r\left(1-\delta_i\delta_j\Delta_\pi^2\right)}. \tag{8}$$

Similar expressions hold for firm j.

Two remarks are in order regarding the expressions in Equations (7) and (8). First, the equilibrium unconstrained implementation threshold is always higher than equilibrium cash holdings: ($I_{i,un}^{EQ} - C_i^{EQ} = \frac{R-r}{\alpha_i\delta_i r} > 0$). The reason is that at $C_i^{EQ} = I_{i,un}^{EQ}$ the marginal benefit of increasing C_i by one unit equals the marginal benefit of increasing $I_{i,un}$ by one unit, while the marginal cost of holding cash is higher, since the internal accumulation rate, r, is lower than the inter-period discount rate, R. Given that the marginal benefit of cash is decreasing in the level of cash, $C_i^{EQ} < I_{i,un}^{EQ}$ in equilibrium.

Second, we need to impose a restriction on the relation between the discount rate, R, and the internal accumulation rate, r, that ensures positive cash holdings of the two firms in equilibrium:

$$R < \min\left[r\left(1+\frac{\delta_i\alpha_i\left(1-\delta_j\Delta_\pi\right)}{1-\delta_i\Delta_\pi\left(\alpha_i+(1-\alpha_i)\delta_j\Delta_\pi\right)}\right), r\left(1+\frac{\delta_j\alpha_j\left(1-\delta_i\Delta_\pi\right)}{1-\delta_j\Delta_\pi\left(\alpha_j+(1-\alpha_j)\delta_i\Delta_\pi\right)}\right)\right], \tag{9}$$

The intuition for this restriction is that if R is substantially higher than r then the marginal cost of holding even the first unit of cash outweighs its marginal benefit. The largest admissible wedge for firm i between the discount rate and the internal accumulation rate is increasing in innovation efficiency, δ_i (the marginal benefit of cash is increasing in the likelihood of an innovation being successful), and in the likelihood of being financially constrained, α_i (the marginal benefit of cash is increasing in the likelihood of a firm being shut out of external capital markets).

Another way to write the condition in Equation (9) is in terms of restrictions on the firms' financial constraints parameters:

$$\alpha_i > \frac{(R-r)\left(1-\delta_i\delta_j\Delta_\pi^2\right)}{\delta_i(1-\delta_j\Delta_\pi)\left(R\Delta_\pi+r\pi_D\right)}, \tag{10}$$

for firm i, and a similar restriction for firm j's financial constraints parameter, α_j. The intuition is that for given discount rate, R, and internal accumulation rate, r, a high enough probability of an adverse financing shock is required in order for the benefit of holding cash to outweigh its cost. In what follows, since we are interested in the determinants of innovating firms' (positive) cash holdings, we assume that conditions in Equation (9) and/or Equation (10) are satisfied.

The equilibrium value of firm i conditional on successful innovation is

$$V_i^{EQ} = \frac{(R-r)^2\left(1-\delta_i\delta_j\Delta_\pi^2\right)^2+\delta_i^2\alpha_i r\left(1-\delta_j\Delta_\pi\right)^2\left(R\Delta_\pi+r\pi_D\right)}{2\delta_i\alpha_i r^2 R\left(1-\delta_i\delta_j\Delta_\pi^2\right)^2} - \frac{\delta_i\alpha_i(R-r)(1-\delta_j\Delta_\pi)\left(R\Delta_\pi+r\pi_D\right)\left(2-\delta_i\left(1-\delta_j\Delta_\pi\right)\Delta_\pi\right)}{2\delta_i\alpha_i r^2 R\left(1-\delta_i\delta_j\Delta_\pi^2\right)^2}. \tag{11}$$

We derive Equation (11) by incorporating firm's equilibrium cash holdings and unconstrained implementation threshold in Equations (7) and (8) respectively into the value function in Equation (5). A similar expression obtains for firm j.

In the next section, we analyze the effects of firm i's innovation efficiency, δ_i and intensity of future output market competition, γ, on its equilibrium cash holdings. Since changes in δ_i and γ, affect firm i's value even when its cash holdings are held constant, in what follows we normalize the firm's equilibrium cash holdings in Equation (7) by the sum of its equilibrium value pre-cash, V_i^{EQ}, and its equilibrium cash holdings, C_i^{EQ}/r:

$$\widetilde{C}_i^{EQ} = \frac{C_i^{EQ}/r}{V_i^{EQ} + C_i^{EQ}/r}. \tag{12}$$

Because of symmetry, we only present the comparative statics of firm i's normalized equilibrium cash holdings.[14]

2.3 Comparative statics

The first proposition illustrates the relation between the intensity of future output market competition, γ, and optimal cash holdings.

Proposition 1 *Firm i's equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$, is decreasing in the intensity of future output market competition, γ, for $\alpha_i < \overline{\alpha_i}$, and it is increasing in γ for $\alpha_i > \overline{\alpha_i}$, where* $\overline{\alpha_i} = 1 - \frac{(r(1-\delta_i\delta_j+\delta_i\pi_D(1+\delta_j))-R(1-\delta_i\Delta_\pi))^2}{\delta_i^2(1-\delta_j\Delta_\pi)^2(R\Delta_\pi+r\pi_D)^2}$.

Abstracting from the two manifestations of the strategic effect of cash holdings, discussed in Lemma 1 and Lemma 2, it follows from Equation (5) that the marginal benefit of holding cash is $\delta_i\alpha_i\left(\mathbb{E}\pi_i - C_i\right)/R$. An increase in γ leads to a reduction in π_D, and, as a consequence, in the expected profit, $\mathbb{E}\pi_i$. Since the marginal cost of holding cash is independent of γ, optimal cash holdings are decreasing in γ, reaching zero when the marginal cost of holding cash equals the marginal benefit of holding cash (i.e., when $\mathbb{E}\pi_i = \frac{R-r}{\delta_i\alpha_i}$). Abstracting from the strategic effect of cash holdings, the negative elasticity of equilibrium cash holdings with respect to γ is larger in absolute terms than the negative elasticity of firm value with respect to γ. Thus, in the absence of the strategic effect of cash, the relation between the intensity of output market competition, γ, and equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$ would be negative.

However, in the presence of a sufficiently strong strategic effect of cash, this relation is reversed. As follows from Equation (4), the strength of the strategic effect is proportional to the degree of financial constraints that the firm faces and to the difference between the output market profits in the monopolistic and duopolistic scenarios. The reason is that cash can only deter a rival's

[14] Since $\frac{C_i^{EQ}/r}{V_i^{EQ}+C_i^{EQ}/r} = \frac{C_i^{EQ}/r}{V_i^{EQ}}/\left(1+\frac{C_i^{EQ}/r}{V_i^{EQ}}\right)$, $\frac{C_i^{EQ}/r}{V_i^{EQ}+C_i^{EQ}/r}$ is monotonically increasing in $\frac{C_i^{EQ}/r}{V_i^{EQ}}$. Thus, all the qualitative results hold for a definition of cash–to–value ratio in which value excludes cash, $\widetilde{C}_i^{EQ} = \frac{C_i^{EQ}/r}{V_i^{EQ}}$.

investment in innovation implementation if cash is useful (i.e., in situations in which access to external capital is restricted) and if the implementation of a firm's innovation has a material impact on the rival's expected profit. Thus, the higher the α_i, the more important the strategic role of cash, the less steep the negative relation between the intensity of product market competition and equilibrium cash holdings. For substantially high α_i, the relation between γ and $\widetilde{C}_i^{EQ}$ changes sign and becomes positive.

We illustrate graphically the relation between the intensity of competition, γ, and firm's equilibrium cash–to–value ratio in Figure 2. While the relation between the intensity of competition and cash holdings does not depend on the particular form of output market competition, as shown in Proposition 1, for purposes of graphical illustration, we assume a specific form of product market competition: Bertrand competition in heterogenous goods with substitutability parameter γ, linear demand for the firms' products, and zero marginal costs.[15] The parameters in Figure 2 are as follows: $r = 1.03$, $R = 1.10$, $\alpha_j = 0.4$, $\delta_i = 0.6$, $\delta_j = 0.6$. We vary the competition intensity parameter, γ, between 0 and 0.9, and examine two separate scenarios. In the first one, depicted in Panel A of Figure 2, firm i is relatively financially unconstrained, $\alpha_i = 0.15$. In the second scenario, depicted in Panel B, firm i is relatively financially constrained, $\alpha_i = 0.8$.

In both Panels A and B, the solid line represents firm i's equilibrium cash holdings, C_i^{EQ}/r, the dashed line represents its equilibrium value, V_i^{EQ}, and the dashed-dotted line represents its equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$. Not surprisingly, equilibrium firm value is decreasing in the intensity of output market competition, as more intense competition is associated with lower expected output market profit. In addition, the marginal benefit of holding cash is decreasing in expected output market profit, leading to a negative relation between equilibrium cash holdings and the intensity of competition. Importantly, as shown in Proposition 1, the cash–to–value ratio is decreasing in γ in the low financial constraints case, depicted in Panel A, and it is increasing in γ in the high financial constraints case, illustrated in Panel B.

Next, we examine the relation between firm i's innovation efficiency, δ_i, and its equilibrium cash holdings.

Proposition 2 *Firm i's equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$, is increasing in its innovation efficiency parameter, δ_i, for $\alpha_i < \overline{\alpha_i}$, and it is decreasing in δ_i for $\alpha_i > \overline{\alpha_i}$, where $\overline{\alpha_i} = 1 - \frac{(r(1-\delta_i\delta_j+\delta_i\pi_D(1+\delta_j))-R(1-\delta_i\Delta_\pi))^2}{\delta_i^2(1-\delta_j\Delta_\pi)^2(R\Delta_\pi+r\pi_D)^2}$.*

The intuition for the result in Proposition 2 is as follows. Keeping cash holdings and the unconstrained implementation threshold constant, firm i's value in Equation (5) is linear in its

[15] In particular, demand takes the following form: $D(\eta_i, \eta_j) = a - b\eta_i + c\eta_j$, where η_i and η_j are firm i's and its rival's output market prices. In a standard model of a representative consumer with quadratic utility $U(q_i, q_j) = \mu \sum_{i=1}^{k} q_i - \frac{1}{2}\left(\sum_{i=1}^{k} q_i^2 + 2\gamma \sum_{j\neq i} q_i q_j\right)$, where q_i and q_j are quantities consumed of products produced by firms i and j, the resulting coefficients of the demand function are $a = \frac{\mu}{1+\gamma}$, $b = \frac{1}{(1+\gamma)(1-\gamma)}$, and $c = \frac{\gamma}{(1+\gamma)(1-\gamma)}$ (e.g., Vives(2000)).

innovation efficiency. The marginal benefit of cash holdings, $\delta_i\alpha_i(I^*_{i,un}-C_i)/R$, is linearly increasing in δ_i and in α_i, and it is decreasing in C_i. The marginal cost of cash holdings, $\frac{(R-r)}{R}$ is independent of C_i, α_i, and δ_i. Thus, the relation between firm i's optimal cash holdings, C_i^{EQ}/r, and its innovation efficiency, δ_i, is increasing and concave. For relatively low α_i, optimal cash holdings are low, and they are more sensitive to changes in δ_i than firm value is. For relatively high α_i, optimal cash holdings are high, and they are less sensitive to changes in δ_i than firm value is. This leads to a positive relation between $\widetilde{C}_i^{EQ}$ and δ_i for relatively low α_i and to a negative relation for relatively high α_i.

An illustration of the relation between firm i's equilibrium cash–to–value ratio and its innovation efficiency is presented in Figure 3 (low financial constraints case, $\alpha_i = 0.15$, in Panel A and high financial constraints case, $\alpha_i = 0.8$, in Panel B). The parameters are the same as in Figure 2, with the exception of γ, which we assume to equal 0.5, and δ_i, which we vary between 0.6 and 0.95. Both equilibrium cash holdings (solid line) and firm value (dashed line) are increasing in innovation efficiency, δ_i. Higher δ_i leads to higher likelihood of successful innovation, raising firm value. In addition, higher δ_i raises the marginal benefit of holding cash, since the likelihood of having to use cash for innovation implementation increases as well. Importantly, as shown in Proposition 2, the sign of the relation between a firm's cash–to–value ratio (dashed–dotted line) and its innovation efficiency depends on the degree of its financial constraints. When financial constrains are low (Panel A), the relation between cash–to–value ratio and innovation efficiency is positive. When financial constraints are high (Panel B), the relation between cash–to–value ratio and innovation efficiency is negative.

Next, we summarize the empirical predictions following from Propositions 1–2.

2.4 Summary of empirical predictions

The comparative statics discussed in the previous subsection concern the effects of the intensity of output market competition (i.e. product substitutability) and innovation efficiency on firms' equilibrium choices of cash holdings. In what follows, "cash holdings" refer to equilibrium normalized cash holdings in the model. Since the model is too stylized to be calibrated, we do not have a threshold in the data that corresponds to $\overline{\alpha_i} = 1 - \frac{(r(1-\delta_i\delta_j+\delta_i\pi_D(1+\delta_j))-R(1-\delta_i\Delta_\pi))^2}{\delta_i^2(1-\delta_j\Delta_\pi)^2(R\Delta_\pi+r\pi_D)^2}$ in Propositions 1 and 2. Thus, the empirical predictions concern the relative magnitudes of the effects of the intensity of output market competition and of the degree of innovation efficiency on optimal cash holdings of relatively constrained and relatively unconstrained firms.

Prediction 1. The relation between the intensity of output market competition and cash holdings is expected to be less positive (more negative) for relatively unconstrained firms than for relatively constrained ones.

Prediction 2. The relation between innovation efficiency and cash holdings is expected to be more positive (less negative) for relatively unconstrained firms than for relatively constrained ones.

In the next section, we test these predictions empirically employing data on patent grants and citations, which we use to identify a sample of innovative firms and to develop proxies for the intensity of expected future output market competition and for innovation efficiency.

3 Empirical tests

3.1 Data, empirical specification, variables, and summary statistics

In this section, we describe the data sources, the empirical specifications that we adopt to test the model's predictions, and the summary statistics.

3.1.1 Data sources

We employ two data sources in our empirical tests. The first one is the NBER Patent Citations Data Project,[16] which we use to construct a sample of innovating firms, to identify industries in which firms innovate, and to develop measures of expected product market competition intensity and of innovation efficiency. The second one is the CRSP/Compustat Merged Database, which provides information on various accounting variables that we employ in our analysis.

The NBER Patent Data Project contains data on all utility patents granted by the U.S. Patent and Trademark Office between 1976 and 2006. For each patent, the dataset contains an assigned GVKEY, which we use to match patent data to Compustat, the date when the patent was granted, the patent's technology field – defined according to one of the 36 two–digit technological subcategories developed by **?** – and the number of times a patent has been cited. Naturally, our analysis includes only firms that were awarded at least one utility patent. Restrictions on Compustat data availability result in a final sample of $33,097$ firm–years with patent grants.

3.1.2 Empirical specification

The empirical predictions summarized at the end of the previous section concern determinants of firms' cash holdings, in particular the degree of financial constraints that a firm faces, the industry-level expected product market competition intensity, and the firm–level innovation efficiency. Our empirical specifications relate proxies for these factors to cash holdings, while incorporating the fact that the magnitudes and signs of the relations between cash holdings and some of their determinants may crucially depend on the severity of a firm's financing constraints.

Our basic empirical specification takes the following form:

$$Cash_{i,t} = \beta_0 + \beta_1 \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \tag{13}$$

[16] https://sites.google.com/site/patentdataproject/Home

The dependent variable, $Cash_{i,t}$, is cash–to–assets ratio, which is a commonly accepted measure of cash holdings (e.g., **?**, **?**, **?**, **?**, and **?**);[17] $\mathbf{X_{i,t}}$ is a vector of explanatory variables similar to those used in aforementioned empirical studies of the determinants of cash holdings; D_t is a vector of year dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. We provide a detailed description of the variables used in Equation (13) below.

The model's specific empirical predictions are cross-sectional in nature. Thus, the regression in Equation (13) is estimated using year fixed effects. We cluster standard errors at the industry level because we use industry-wide regressors (e.g., **?**).

3.1.3 Measures of innovation efficiency, and intensity of competition

Measures of innovation efficiency

Following **?**, **?**, **?**, and **?** among others, our first measure of a firm's innovation efficiency is based on the number of citations that the firm's patents generate per dollar of R&D spending. In particular, for each firm–year, we compute the number of citations to firm's patents granted in that year and divide this measure by a measure of the firm's expenditures on R&D required to generate these patents. We use the number of citations to patents as a measure of R&D outcome, since **?** find that it is important to account for the "quality of innovation", measured by the number of citations per patent, as well as for the "quantity of innovation", measured by the number of patents per million dollars of R&D expenditure.

We measure the number of citations to each patent following **?**. First, we consider only patents granted in year t that have an application year that precedes the granting year by at most three years (variable *Pat*). Then for each patent we evaluate the total number of citations that the patent receives within three years from the granting year (variable *Cit*). To measure the firm's expenditures on R&D we follow **?** and build a measure of firm–level capital stock in year t (*R&D Stock*) by summing the depreciated capital expenditures from year $t-4$ to year t. Following **?**, we set the rate of depreciation to 15%.[18] Our first measure of firm i's innovation efficiency in year t, is, thus, estimated as

$$\delta_{i,t}^{CIT} = \log\left(1 + \frac{\sum_{j\in(i,t)} Cit_{j,i,t}}{R\&Dstock_{i,t-3}}\right), \tag{14}$$

where $Cit_{j,i,t}$ is the number of citations generated by patent j filed by firm i in year t, and $R\&Dstock_{i,t-3}$ is firm i's estimated R&D stock in year $t-3$.

[17] We verify that our results are robust to using the cash-to-net-assets ratio, as in some specifications in **?** and **?**, despite the fact that cash-to-net assets ratio generates extreme outliers for firms with most of their assets in cash.

[18] We get almost identical results to those reported if we (1) evaluate the firm–level R&D capital stock using a perpetual inventory method approach as suggested by **?**; (2) use the value of R&D expenditure in a given year; (3) sum the past five years values of R&D expenditure, while setting the depreciation rate to 20% as in **?**; (4) sum the past five years values of R&D expenditure, while setting the depreciation rate to zero; (5) replace missing capital expenditures observations with zeroes when evaluating the R&D capital stock.

Given that some of the firms in our sample are awarded patents that do not receive any citations within a three year window, we also adopt a second measure of R&D efficiency using the number of patents granted to firm i in year t

$$\delta_{i,t}^{PAT} = \log\left(1 + \frac{Pat_{i,t}}{R\&Dstock_{i,t-3}}\right), \tag{15}$$

where $Pat_{i,t}$ is the total number of patents awarded to firm i in year t. To simplify notation, in what follows, we use δ^{CIT} and δ^{PAT} instead of $\delta_{i,t}^{CIT}$ and $\delta_{i,t}^{PAT}$, respectively.

Measures of product market competition intensity

Our measures of the intensity of expected output market competition is based on the idea that competition intensity is increasing in product substitutability (e.g., **?** and **?**). Since our focus is on firms' innovation activities, we are interested in the substitutability of future products that would result from current innovation. This substitutability of future products is likely to be positively related to how close firms' R&D activities are. For example, products of two firms that operate in the same industry and that file all of their patents in the same set of patent categories are likely to be more substitutable than products of two firms that have little overlap in patent categories. Thus, we depart from accepted measures of *current* product market competition, such as the price-cost margin, the Herfindahl index, or the product market fluidity measure of **?** that utilizes firms' product descriptions from 10-Ks to measure (current) competition intensity.[19] Instead, we focus on measures of *future* expected product market competition, based on firms' current innovation activities.

To measure how close a firm's R&D activity is to that of its industry competitors, we follow **?** and adopt a firm-level measure of technological overlap based on **?**. For each firm i in year t, we capture the scope of innovation in a vector $S_{i,t} = [S_{i,t,1}, ..., S_{i,t,k}, ...S_{i,t,K}]$, where $k = 1, ..., K = 36$ is the number of two–digit technological subcategories. $S_{i,t,k}$ is the ratio of the number of patents awarded to firm i in class k in year t over the total number of patents awarded to firm i in year t. Then we calculate the quantity $\gamma_{i,j,t}^{PAT}$, defined as the pairwise technological proximity of firm i with each firm $j \neq i$ that belongs to the same industry – defined using three–digit SIC codes – in year t:

$$\gamma_{i,j,t}^{PAT} = \frac{S_{i,t}S'_{j,t}}{\sqrt{S_{i,t}S'_{i,t}}\sqrt{S_{j,t}S'_{j,t}}} \in [0,1].$$

If $\gamma_{i,j,t}^{PAT}$ equals 1, then there is perfect technological overlap between firm i and firm j. On the other hand, if $\gamma_{i,j,t}^{PAT}$ equals 0, then there is no technological overlap between the two firms. Our first measure of the intensity of product market competition is based on firm-level technological

[19] In addition, there is a practical limitation to using a product market fluidity-based measure of competition, since the fluidity-based data only start in 1996, reducing our sample size by two thirds.

overlap, and is given for firm i in year t by the average value of $\gamma_{i,j,t}^{PAT}$:

$$\gamma_{i,t}^{PAT} = \frac{\sum_{j \neq i}^{N} \gamma_{i,j,t}^{PAT}}{N-1},$$

where N is the total number of firms in firm i's three–digit SIC industry in year t.

We believe that our identification of industry boundaries using three-digit SIC codes allows us to identify firms that overlap both in the technology and the expected future product market space. As an example, consider two companies that belong to two–digit SIC code 37 (transportation equipment) in year 2003: Rockwell Collins Inc. (SIC 3728), a company mainly developing and producing aviation electronic systems, and Fleetwood Enterprises Inc. (SIC 3716), a producer of recreational vehicles and mobile homes. It seems safe to assume that while these two companies may potentially overlap in the R&D space, they are not likely be competing in future product markets. In this example, we compute γ^{PAT} of Rockwell Collins Inc. relative to its three-digit SIC industry 372 (aircraft and parts) and γ^{PAT} of Fleetwood Enterprises Inc. relative to its three-digit SIC industry 371 (motor vehicles and motor vehicle equipment). Importantly, the empirical analysis performed using 2–digit SIC industries delivers similar results to those reported below.

We also adopt an additional measure of competition intensity, based on citations similarity. For each firm i in year t, we construct a vector $C_{i,t} = [C_{i,t,1}, ..., C_{i,t,k}, ...C_{i,t,K}]$, where $k = 1, ..., K = 36$ is the number of the two–digit technological subcategories. $C_{i,t,k}$ is the ratio of the number of citations to patents awarded in class k in year t over the total number of citations to patents awarded in year t. Then we calculate the quantity $\gamma_{i,j,t}^{CIT}$, defined as the pairwise similarity of firm i with each firm $j \neq i$ that belongs to the same three-digit SIC industry in year t:

$$\gamma_{i,j,t}^{CIT} = \sum_{k=1}^{K} \min[C_{i,t,k}, C_{j,t,k}] \in [0, 1].$$

If $\gamma_{i,j,t}^{CIT}$ equals 1, then firms i and j have the exact same proportions of citations across the 36 two-digit technological subcategories. On the other hand, if $\gamma_{i,j,t}^{CIT}$ equals 0, then the two firms do not share any citations in two-digit technological subcategory. Our second measure of the intensity of future expected competition is given for firm i in year t by the average value of $\gamma_{i,j,t}^{CIT}$:

$$\gamma_{i,t}^{CIT} = \frac{\sum_{j \neq i}^{N} \gamma_{i,j,t}^{CIT}}{N-1},$$

Finally, we compute industry-wide measures of expected product market competition intensity, which for industry n equal

$$\gamma_{n,t}^{CIT} \equiv \gamma^{CIT} = \sum_{i \in n} \frac{\delta_{i,t}^{CIT}}{N}, \tag{16}$$

for the citation–based measure, and

$$\gamma_{n,t}^{PAT} \equiv \gamma^{PAT} = \sum_{i \in n} \frac{\delta_{i,t}^{PAT}}{N}. \tag{17}$$

for the patent–based measure.

3.1.4 Measures of financial constraints and control variables

Measures of financial constraints

One of the most important determinants of financial constraints is the degree of information asymmetry between a firm and the capital market (e.g. **?** and **?**). Thus, to measure the severity of a firm's financial constraints, we employ three different proxies for the degree of information asymmetry.

The investment-cash flow sensitivity literature (e.g., **?** and **?**) and the cash holdings literature (e.g., **?**) suggest that firm size is inversely related to the extent of information asymmetry. In addition, older, more established firms are likely to be characterized by a lower degree of information asymmetry and lower costs of external financing than younger firms. For these reasons, we use the size–age (SA) index, proposed by **?** as our first measure of firm-level financing constraints.[20]

? use a structural model of financing and investment decisions to derive an index of firms' financing constraints via GMM estimation of an investment Euler equation. We use the Whited and Wu (WW) index, based on a linear combination of cash flow, sales growth, long-term debt, size, dividend policy, and a firm's three-digit industry sales growth, as our second measure of firm–level financing constraints.[21]

Finally, following **?**, **?**, and **?** among others, our third proxy for the cost of external financing is an indicator variable that equals one if the firm paid dividends (item `DV`> 0) or repurchased shares (item `PRSTKL`> 0) in a given year and equals zero otherwise.[22]

Control variables

The cash holdings literature has identified a set of key variables that help explain firms' cash hoarding behavior. We follow **?** and include in our cash holdings analysis the following variables: Industry-level cash flow volatility, which may increase the precautionary savings motive; Market-to-book ratio to control for future investment opportunities; Size because there are economies of scale to raising cash; Cash flows, since firms with higher cash flows are likely to require lower precautionary cash holdings; Net working capital, since it can be considered a substitute for cash; Capital expenditures plus acquisitions, since these investments create assets that can be used as collateral, reducing the need for precautionary cash; Leverage, both because firms may use cash to reduce leverage and because cash can serve as a hedge for highly levered firms; and R&D expenditures because firms with low tangibility have a larger precautionary savings motive.

[20]Studies that use the size–age index to measure the degree of financing constraints include **?**, **?**, **?**, **?**, and **?** among others.

[21]Studies that use the WW index to measure the degree of financing constraints include **?**, **?**, **?**, and **?**, among others.

[22]Another popular measure of financial constraints used in past literature is the availability of debt ratings (e.g., **?**). We do not use this measure, as debt of our sample firms is seldom rated.

In addition, ? show that cash balances of multinational firms are different from the ones of purely domestic firms. We use a dummy variable that takes the value of one if a firm can be classified as a multinational and zero otherwise. Finally, to ensure that our results are not driven by the effects studied in ? and in ?, we augment the regressions by the determinants of cash holdings identified in these studies: Herfindahl index, which proxies for current (as opposed to future, expected) competition, as in ?, and market share skewness that proxies for the winner's advantage, i.e. the importance of being the first to implement innovation, as in ?. Appendix C provides detailed definitions of all the variables discussed above.

3.1.5 Summary statistics

Table 1 summarizes the U.S. patent data used in the empirical analysis. The average (median) number of patents that firms in our sample are granted annually is 26 (3). The distribution of patent grants is highly right–skewed and its standard deviation is large (105). The same is true for the distribution of citations: the mean (median) number of citations in the subsequent three years to patents granted to a firm in a given year is 60 (5) and the standard deviation of the number of citations is 308. A typical firm files patents in multiple technology classes: the mean (median) number of classes in which firms are granted patents in a given year is 4 (2).

Table 2 reports summary statistics for the dependent variable (cash–to–assets ratio) and non–patent–based independent variables used in the empirical analysis. The first row shows that the mean (median) cash–to–assets ratio of a firm in our sample is 0.17 (0.08), higher than the respective values in ? and in ?. Given that ours is a sample of R&D–intensive firms, this is consistent with the evidence that innovating firms tend to hold more cash. The next three rows present the statistics for our three financial constraints measures. The average value of the SA–index is −3.31, while the average value of the WW–index is −0.29. The correlation coefficient between these two financial constraints indexes is 0.81, a value almost identical to the 0.80 reported in ?. Around 64% of firms in our sample pay a dividend or repurchase shares in a given year.

The mean (median) market-to-book ratio is 2.12 (1.41), which is somewhat higher than the mean and median market-to-book ratios of Compustat firms, consistent with firms in our sample deriving a relatively large part of their value from growth options. The average firm in our sample has size – measured as the total book value of assets adjusted for inflation (using 1984 dollars as the base) – of $\$1,962M$ and generates no cash flows, while the median firm has $\$182M$ in assets and generates cash flows equal to 7% of total assets. The net working capital – evaluated net of cash holdings – of the average (median) firm is 0.13 (0.14). The mean (median) investment–and–acquisition–to–assets ratio, which is computed net of sales of property, plant and equipment, is 0.06 (0.05). The mean (median) book leverage is 0.23 (0.20), somewhat lower than typical in capital structure studies (e.g., ?) and consistent with the negative relation between growth options and optimal leverage (e.g., ? and ?). R&D expenditures over assets takes the average value of

0.08 and more than 50% of firms in our sample have R&D expenditures over assets larger than 0.03. Around 60% of the firms in our sample can be classified as multinationals.

In the last three rows of Table 2, we report summary statistics of three (three-digit SIC) industry-level variables that were shown in recent studies to be related to cash holdings. The first one is the industry-level coefficient of variation of cash flows. The second one is HHI, industry Herfindahl–Hirschman index in year t, used as a proxy for the intensity of current product market competition (e.g., **?**). The third one is *Winner Advantage*, the skewness of market share within an industry, used as a measure of winner's advantage, following **?**.

Table 3 reports industry-level measures of product market competition intensity, γ^{CIT} and γ^{PAT} (Panel A) computed as averages of firm-level values across three-digit SIC industries, and firm–level measures of innovation efficiency, δ^{CIT} and δ^{PAT} (Panel B). A typical industry in our sample has an average (median) value of citations overlap, γ^{CIT}, of 0.25 (0.21) and an average (median) value of patents overlap, γ^{PAT}, of 0.30 (0.25).

The mean (median) number of citations generated per \$1M of cumulative R&D spending (in 1984 dollars), δ^{CIT}, is 0.74 (0.78), while the median number of patens generated per \$1M of cumulative R&D, δ^{PAT}, is 0.58 (0.59). Our two measures of intensity of output market competition are highly positively correlated, as are the two measures of innovation efficiency. The correlation coefficient between γ^{CIT} and γ^{PAT} equals 0.80 and it is statistically significant at the 1% level. The correlation between δ^{CIT} and δ^{PAT} is 0.69 and is also significant at the 1% level.

3.2 Determinants of cash holdings

In this section we test the model's predictions by examining the relation between proxies for the intensity of future product market competition and innovation efficiency on one hand, and firms' normalized cash holdings on the other hand. In these tests we account for the fact that the signs and magnitudes of the relations between cash holdings on one hand and intensity of competition and innovation efficiency on the other hand depend on the degree of financial constraints.

3.2.1 Baseline regressions

We begin by estimating the regression in (13) within the full sample, and proceed to testing the theoretical model's predictions by augmenting the basic regression by measures of competitive interaction and innovation efficiency, interacted with measures of financial constraints. The first column of Table 4 reports the results of regressions in which we estimate the relation between cash holdings and variables that were found in past studies to be related to cash–to–assets ratios. The results are generally consistent with past studies and with intuition. Similar to **?**, the coefficients on size, cash flows, net working capital, investment, and leverage are negative, while the coefficients on the market–to–book ratio, R&D expenditures, and industry–level cash flow variability are positive. We also find that multinational firms have, on average, lower cash–to–assets ratios (around 4 percentage points lower) than purely domestic firms. The coefficient on the industry Herfindahl index is negative, consistent with the findings of **?**. The coefficient on industry-level market share skewness is positive, similar to **?**.

Because of the importance of financial constraints for our theoretical results and empirical tests, in columns 2-4 of Table 4 we augment the baseline regression by one of the three measures of financial constraints. In column 2, we use the SA index–based measure of financial constraints, in column 3 we use the WW index–based measure, while in column 4 we use the dividend and repurchases dummy. To ease the interpretation of the results, in columns 2 and 3 we define dummy variables that equal one if SA index (WW index) is above its annual median.

There is a positive relation between all three measures of financial constraints and cash holdings, which is statistically and economically significant. Firms with SA index above median (i.e. relatively constrained ones) have 4.9 percentage points higher cash–to–assets ratios than firms with SA index below median (relatively unconstrained firms), ceteris paribus. Similarly, relatively constrained firms according to WW index have 3.2 percentage points higher cash holdings than relatively unconstrained firms. Finally, firms that pay dividends or repurchase shares have cash holdings that are on average 4.7 percentage points lower than non-dividend-paying and non-repurchasing firms. These numbers are large in comparison with mean cash–to–assets ratio (17%) and its standard deviation (21%). Unreported tests employing piecewise-linear regressions with finer partitions of the sample based on SA and WW indices show monotonically increasing relations between measures of financial constraints and cash holdings. These results are consistent with the literature that explores the effects of financial constraints on cash holdings policies (e.g., **?** and **?**).

3.2.2 Intensity of product market competition and cash holdings

Our model predicts that the effect of expected future competition intensity on a firm's cash holdings policy depends crucially on the firm's degree of financial constraints. To test this prediction we estimate the following regression:

$$\begin{aligned} Cash_{i,t} &= \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\gamma\times NFC}(\gamma_{n,t}\times NFC_{i,t}) + \beta_{\gamma\times FC}(\gamma_{n,t}\times FC_{i,t}) \quad (18)\\ &\quad +\beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \end{aligned}$$

where $\gamma_{n,t}$ is one of the two industry-wide measures of intensity of product market competition (γ^{CIT} and γ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes the value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes the value of 1 if a firm is financially constrained and zero otherwise, $\gamma_{n,t}\times NFC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $NFC_{i,t}$, $\gamma_{n,t}\times FC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term.

The quantity of interest in Equation (18) is the difference between the competition intensity coefficient of relatively unconstrained firms ($\beta_{\gamma\times NFC}$) and that of relatively constrained firms ($\beta_{\gamma\times FC}$). We call this difference $\Delta\beta_{\gamma} = \beta_{\gamma\times NFC} - \beta_{\gamma\times FC}$. To save space, we only report the estimated values of $\beta_{\gamma\times NFC}$, $\beta_{\gamma\times FC}$, and $\Delta\beta_{\gamma}$ in Table 5.[23]

Regressions in columns 1 to 3 of Table 5 do not include control variables, while regressions in columns 4 to 6 include all of the control variables reported in Table 4 plus a measure of innovation efficiency (δ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if their dividends and repurchases are positive (equal to zero).

According to Prediction 1, the relation between the intensity of product market competition and cash holdings is expected to be more positive (less negative) for relatively constrained firms than for relatively unconstrained ones. Panel A in Table 5 reports the results when we measure industry-level competition intensity using citations-based similarity, γ^{CIT}. The difference in estimated coefficients on competition intensity between unconstrained and constrained firms ($\Delta\beta_{\gamma}$) is negative and significantly different from zero in all six specifications, as follows from the Wald F–statistics. When the regressions include control variables (Columns 4 to 6), the magnitudes of the coefficient on competition intensity become smaller for financially constrained firms, however the estimates of $\beta_{\gamma\times FC_{i,t}}$ remain statistically significant, as do the differences in coefficients between unconstrained and constrained firms, $\Delta\beta_{\gamma}$.

Panel B reports the results when we measure industry-level competition intensity using patent–based similarity, γ^{PAT}. The results are consistent with the ones reported in Panel A, showing that the effect of competition intensity on cash holdings does not depend on the particular proxy for the intensity of competition.

The economic significance of the results in Table 5 is substantial. For example, increasing the measure of competition intensity by one standard deviation (0.125 and 0.181 for γ^{CIT} and γ^{PAT} respectively) raises the gap between cash holdings of financially constrained and financially unconstrained firms by 2.7–6.2 percentage points, ceteris paribus.

To summarize, the results in Table 5 strongly support our model's prediction regarding the relation between product market competition intensity and cash holdings. The effect of the intensity of product market competition on observed cash holdings depends crucially on firms' financial constraints. For relatively constrained firms, this relation is positive and strongly statistically significant. For relatively unconstrained firms, the relation is insignificantly negative. Consistent with the model's prediction, the difference between the coefficient on competition intensity for

[23] The coefficients on control variables are consistent with those reported in Table 4.

relatively unconstrained firms and the one for relatively constrained firms is highly significant.

3.2.3 Innovation efficiency and cash holdings

Prediction 2 states that the relation between innovation efficiency and cash holdings is expected to be more positive (less negative) for firms facing relatively low financial constraints than for firms facing relatively high financial constraints. To test this prediction, we estimate a model with interaction terms similar to the specification in Equation 5:

$$\begin{aligned} Cash_{i,t} &= \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\delta \times NFC}(\delta_{i,t} \times NFC_{i,t}) + \beta_{\delta \times FC}(\delta_{i,t} \times FC_{i,t}) \\ &\quad + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \end{aligned} \tag{19}$$

The quantity of interest in Equation (19) is the difference between the innovation efficiency coefficient of relatively constrained firms ($\beta_{\delta \times NFC}$) and relatively unconstrained firms ($\beta_{\delta \times FC}$). We call this difference $\Delta\beta_\delta = \beta_{\delta \times NFC} - \beta_{\delta \times FC}$. Similar to Table 5, we only report the estimated values of $\beta_{\delta \times NFC}$, $\beta_{\delta \times FC}$, and $\Delta\beta_\delta$ in Table 6.

The layout of Table 6 is similar to that of Table 5. Panel A reports the results for citations–based measure of innovation efficiency, δ^{CIT}. Consistent with the model's prediction, the relation between innovation efficiency and cash holdings is positive and significant for financially unconstrained firms. This result holds across the three different measures of financial constraints and survives the inclusion of control variables and a measure of competition intensity (γ^{CIT}). On the other hand, innovation efficiency has no significant impact on the cash holdings of financially constrained firms. When we use δ^{CIT} to measure innovation efficiency, $\Delta\beta_\delta$ is always positive and is statistically significant in five cases out of six cases. Consistent with the model's prediction, the relation between innovation efficiency and cash holdings is significantly stronger for unconstrained firms than for constrained ones.

Panel B of Table 6 reports the results for the patents-based measure of innovation efficiency, δ^{PAT}. In this case, $\Delta\beta_\delta$ is always significantly positive. The results are also economically sizable: the difference between cash holdings of constrained and unconstrained firms is decreasing by $1.3 - 3.1$ percentage points for a one standard deviation increase in δ^{CIT} or δ^{PAT} (0.78 and 0.59 respectively from Table 3), ceteris paribus.

Overall, the results in Table 6 strongly support the model's prediction that the effect of innovation efficiency on cash holdings is significantly stronger for relatively unconstrained firms than for relatively constrained ones.

3.3 Robustness Checks

3.3.1 Different definition of cash holdings

In the empirical specification in Equation (13), following the large cash holdings literature (e.g., **?**, **?**, and **?**, among many others), cash holdings are defined as the ratio of cash and marketable securities (Compustat item CHE) and book value of assets (item AT). In the model, however, we normalize cash holdings by the firm's market value. In order to ensure that this disconnect between the theoretical definition of normalized cash holdings and its accepted empirical counterpart is not responsible for our empirical results, we align the empirical analysis with the model by repeating the tests of the model's predictions while using the cash–to–value ratio instead of the cash–to–assets ratio as the dependent variable. The cash–to–value ratio is defined as the sum of the firm's market value of equity (the product of the number of shares outstanding (item CSHO) and price per share (item PRCC_F)) and the book value of debt (the sum of long-term debt (item DLTT) and debt in current liabilities (item DLC)). The results are reported in Tables 7–8, which have the same layout as Tables 5–6

In Table 7, when the intensity of product market competition is measured using γ^{CIT}, the difference between the competition intensity coefficient of financially unconstrained firms and that of financially constrained firms is always negative and is highly statistically significant in five cases out of six. When we use γ^{PAT} as a measure of competition intensity, $\Delta\beta_{\gamma}$ is negative in all specifications but is only statistically significant in regressions that do not include control variables.

The results in Table 8 are very strong: the relation between firm-level innovation efficiency and cash–to–value ratios is significantly more negative for financially constrained firms than for financially unconstrained ones for both measures of innovation efficiency, for all three measures of financial constraints, and regardless of whether control variables are included in the regressions.

Overall, the results in Tables 7–8 demonstrate that our empirical findings are not due to the normalization of cash holdings by book assets, common in the empirical cash holdings literature, and that the relations between measures of cash holdings on one hand, and intensity of expected product market competition and innovation efficiency on the other hand are robust to various definitions of normalized cash holdings.

3.3.2 Subsample analysis

In Tables 9 and 10 we perform subsample analyses, aimed at further highlighting the differences between the effects of innovation efficiency and intensity of competition on cash holdings of financially constrained and unconstrained firms. The first difference between the tests in this section and those in Section 3.2 is that the coefficients on control variables are now allowed to vary across different subsamples. The second difference is that we now use finer financial-constraints-based partitions of the sample.[24]

We form subsamples using our three different proxies for financial constraints. When the proxy is the SA index or WW index, firms are classified as not financially constrained (NFC) if they

[24] An additional advantage of a split-sample analysis is that we do not have to include both the financial constraints indices and some of their components (such as cash flow in the case of WW index) in the set of explanatory variables.

belong to the bottom 25% of the annual SA index (WW index) distribution and as financially constrained (FC) if they belong to the top 25% of the annual SA index (WW index). When the proxy is the dividend and repurchases dummy, firms are classified as financially constrained if the dummy is zero, otherwise they are considered to be not financially constrained.

Table 9 reports the results of estimating the relation between firms' cash holdings and the intensity of expected competition. We estimate the following regression within each subsample:

$$Cash_{i,t} = \beta_0 + \beta_\gamma \gamma_{n,t} + \beta_\mathbf{1} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \tag{20}$$

where $\gamma_{n,t}$ is one of the two industry-level product market competition intensity measures, γ^{CIT} and γ^{PAT}.

Similar to Table 5, the variable of interest in Table 9 is $\Delta\beta_\gamma$, the difference in estimated coefficients on competition intensity between the most constrained and least constrained subsamples. The results are consistent with the baseline analysis in Table 5: an increase in the measure of competition intensity leads to a significant increase in the gap between cash holdings of relatively constrained and unconstrained firms.[25] This result holds across the three subsample formation criteria and survives the inclusion of control variables.

Table 10 reports the results of estimating the relation between cash holdings and innovation efficiency. We estimate the following regression within each subsample:

$$Cash_{i,t} = \beta_0 + \beta_\delta \delta_{i,t} + \beta_\mathbf{1} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \tag{21}$$

where $\delta_{i,t}$ is one of the two firm–level innovation efficiency measures.

As in Table 6, the variable of interest in Table 10 is $\Delta\beta_\delta$, the difference in estimated coefficients on innovation efficiency between the most constrained and least constrained subsamples. The results are consistent with the baseline analysis: an increase in the measure of innovation efficiency leads to a significant increase in the gap between cash holdings of financially unconstrained and financially constrained firms in nine of the twelve specifications considered.

3.3.3 Industry–level variation in innovation efficiency

The relation between innovation efficiency and cash holdings may be partially driven by time–varying heterogeneity in innovation efficiency levels across different industries. To address this concern, we follow **?** and re–estimate the regressions in Table 6 while including industry–year fixed effects and clustering standard errors at the firm level.[26] The results, reported in Table 11, are consistent with the baseline findings. Overall, the magnitude of the differences between the innovation efficiency coefficient of constrained firms and unconstrained ones ($\Delta\beta_\delta$) is around

[25] We estimate the significance of the variable $\Delta\beta_\gamma$ while taking into account the cross–subsample covariance by performing a seemingly unrelated estimation.

[26] In this case, we exclude all industry–year level independent variables from regressions that include industry–year fixed effects.

60% of the ones reported in Table 6. Similar to the baseline case, $\Delta\beta_\delta$ is positive in all twelve specifications and is statistically significant in eleven of them.

4 Conclusion

We develop a model of cash holdings by innovating firms. Firms engage in R&D activities, which may result in technological innovations. Firms that succeed in developing their innovations obtain an option to implement them while using internal and, possibly, external funds, and compete in the ensuing output markets.

Our model illustrates the strategic reason for hoarding cash by innovating firms, which have to make cash holding choices while facing uncertainty regarding their participation in future output markets and the structure of these markets. In the presence of financial constraints, a successful firm that has access to a larger pool of internal funds at the innovation implementation stage commits to implement the innovation in more states of the world. This commitment lowers the payoff to the firm's competitors from both investing in R&D and from implementing successful innovations, which indirectly benefits the firm.

Our model leads to two important empirical implications. First, firms' cash holdings are expected to depend on the intensity of competition among innovators in future output markets. Importantly, the magnitude and sign of this relation is different for relatively financially constrained and unconstrained firms. For sufficiently constrained firms, the proportion of cash in firm value is increasing in the intensity of future product market competition, while for relatively unconstrained firms, cash holdings are decreasing in the intensity of competition. Second, innovation efficiency also affects optimal cash holdings in a non-trivial way. For relatively unconstrained firms, cash holdings increase in innovation efficiency, while the relation is reversed for relatively constrained ones.

We test our model's predictions using data obtained from the NBER Patent Citations Data Project, which are instrumental in identifying firms' areas of technological innovation and in constructing measures of intensity of future output market competition and of innovation efficiency. Consistent with the model's prediction, we find that the intensity of expected product market competition is positively related to cash holdings, but only for relatively constrained firms. Consistent with another prediction of the model, we document that innovation efficiency is positively related to cash holdings of relatively financially unconstrained firms, while it is negatively related to cash holdings of relatively constrained firms.

To summarize, we believe that our model and empirical results demonstrate some of the driving forces behind innovative firms' cash holdings choices. In particular, our paper highlights the importance of the strategic motivation behind cash policies of innovative firms.

A Proofs

A.1 Proof of Lemma 1

The first derivative of $I^*_{i,un}$ in Equation (4) with respect to C_j equals

$$\frac{\partial I^*_{i,un}}{\partial C_j} = \frac{-\delta_j \alpha_j \Delta_\pi}{1 - \delta_i \delta_j (1-\alpha_i)(1-\alpha_j)\Delta_\pi^2}. \tag{22}$$

Since $\Delta_\pi > 0$, $\delta_j > 0$, and $\alpha_j > 0$, the numerator of Equation (22) is negative. Since $\alpha_i > 0$, $\alpha_j > 0$, $\delta_i < 1$, and $\delta_j < 1$, the denominator of Equation (22) is positive. Therefore, $\frac{\partial I^*_{i,un}}{\partial C_j} < 0$. The first derivative of $I^*_{i,un}$ in Equation (4) with respect to C_i equals

$$\frac{\partial I^*_{i,un}}{\partial C_i} = \frac{\delta_i \delta_j \alpha_i (1-\alpha_j)\Delta_\pi^2}{1 - \delta_i \delta_j (1-\alpha_i)(1-\alpha_j)\Delta_\pi^2}. \tag{23}$$

Both the numerator and the denominator of Equation (23) are positive, therefore $\frac{\partial I^*_{i,un}}{\partial C_j} > 0$.

A.2 Proof of Lemma 2

The first derivative of $C^*_i(C_j)$ in Equation (6) with respect to C_i equals

$$\frac{\partial C^*_i(C_j)}{\partial C_j} = \frac{-\delta_j \alpha_j \Delta_\pi}{1 - (1-\alpha_j)\,\delta_i \delta_j \Delta_\pi^2}. \tag{24}$$

Since $\Delta_\pi > 0$, $\delta_j > 0$, and $\alpha_j > 0$, the numerator of (24) is negative. In addition, since $\delta_i < 1$ and $\delta_j < 1$, the denominator of (24) is positive, leading to $\frac{\partial C^*_i(C_j)}{\partial C_j} < 0$.

A.3 Proof of Proposition 1

The first derivative of $\frac{C_i^{EQ}}{V_i^{EQ}}$ with respect to π_D is

$$\frac{-2rR\alpha_i\delta_i\left((R-r)(1+\delta_j(2\delta_i\Delta_\pi)\Delta_\pi) + \delta_j(\delta_i\delta_j\Delta_\pi^2 + 1 - \delta_i\Delta_\pi)\right)\Gamma}{\Psi} \tag{25}$$

The denominator of Equation (25), Ψ, is a quadratic form and is positive. $2rR\alpha_i\delta_i$ is positive by assumption ($r > 0$, $R > 0$, $\alpha_i > 0$, and $\delta_i > 0$). $(R-r)(1+\delta_j(2\delta_i\Delta_\pi)\Delta_\pi$ and $\delta_j(\delta_i\delta_j\Delta_\pi^2 + 1 - \delta_i\Delta_\pi)$ are positive by assumption as well ($R > r$, $\delta_j > 0$, $0 < \Delta_\pi < 1$, and $0 < \delta_i < 1$,). Thus, the sign of Equation (25) is the opposite of the sign of Γ.[27]

The derivative of Γ with respect to α_i is

$$\frac{\partial \Gamma}{\partial \alpha_i} = \delta_i^2 (1-\delta_j\Delta_\pi)^2 (R\Delta_\pi + r\pi_D)^2 > 0. \tag{26}$$

In addition, $\Gamma = 0$ when $\alpha_i = \overline{\alpha_i} = 1 - \frac{(r(1-\delta_i\delta_j+\delta_i\pi_D(1+\delta_j)) - R(1-\delta_i\Delta_\pi))^2}{\delta_i^2(1-\delta_j\Delta_\pi)^2(R\Delta_\pi + r\pi_D)^2}$. Thus, the numerator of Equation (25) is positive if $\alpha_i < \overline{\alpha_i}$ and it is negative if $\alpha_i > \overline{\alpha_i}$.

Since $\frac{\partial \pi_D}{\partial \gamma} < 0$ and $\frac{C_i^{EQ}/r}{V_i^{EQ} + C_i^{EQ}/r}$ is monotonically increasing in $\frac{C_i^{EQ}}{V_i^{EQ}}$, the derivative of $\frac{C_i^{EQ}/r}{V_i^{*} + C_i^{EQ}/r}$ w.r.t. γ is negative when $\alpha_i < \overline{\alpha_i}$ and positive when $\alpha_i > \overline{\alpha_i}$.

[27] The expression for Γ is available upon request.

A.4 Proof of Proposition 2

The first derivative of $\frac{C_i^{EQ}}{V_i^{EQ}}$ with respect to δ_i is

$$\frac{-2rR\alpha_i(1-\delta_j\Delta_\pi)(R\Delta_\pi + r\pi_D)\Gamma}{\Psi}. \tag{27}$$

The denominator of Equation (27), Ψ, is a quadratic form and is positive. $2rR\alpha_i$ is positive by assumption ($r > 0$, $R > 0$, $\alpha_i > 0$). $(1-\delta_j\Delta_\pi)(R\Delta_\pi + r\pi_D)$ is positive by assumption as well ($\delta_j < 1$, $\pi_D > 0$, $0 < \Delta_\pi < 1$). Thus, the sign of Equation (27) is the opposite of the sign of Γ.

The derivative of Γ with respect to α_i is given in (26) and is positive. In addition, $\Gamma = 0$ when $\alpha_i = \overline{\alpha_i} = 1 - \frac{(r(1-\delta_i\delta_j+\delta_i\pi_D(1+\delta_j))-R(1-\delta_i\Delta_\pi))^2}{\delta_i^2(1-\delta_j\Delta_\pi)^2(R\Delta_\pi+r\pi_D)^2}$. Thus, the numerator of Equation (27) is positive (negative) if $\alpha_i < \overline{\alpha_i}$ ($\alpha_i > \overline{\alpha_i}$).

Since $\frac{C_i^{EQ}/r}{V_i^{EQ}+C_i^{EQ}/r}$ is monotonically increasing in $\frac{C_i^{EQ}}{V_i^{EQ}}$, the derivative of $\frac{C_i^{EQ}/r}{V_i^{*}+C_i^{EQ}/r}$ w.r.t. δ_i is positive when $\alpha_i < \overline{\alpha_i}$ and negative when $\alpha_i > \overline{\alpha_i}$.

B Extended model

The baseline model in Section 2 is based on three restrictive assumptions. First, R&D activity is costless. Second, each firm's R&D success probability is exogenous. Third, firms' R&D success is independent of the success of the other firm engaged in related R&D. The model in this section relaxes these restrictive assumptions: we assume that endogenously chosen, costly R&D investment affects the likelihood of innovation success. In addition, following the evidence in **?**, we allow for potential complementarities (spillovers) across firms' R&D activities by assuming that firm i's and firm j's R&D investment, RD_i and RD_j, translate into the likelihood of firm is initial innovation success of $p(RD_i, RD_j)$, which has the following properties: $p'(RD_i) > 0$, $p''(RD_i) \leq 0$, $p'(RD_j) > 0$, $p''(RD_j) \leq 0$, $p(0,0) = 0$, $p(\infty, \cdot) \longrightarrow 1$, $p(\cdot, \infty) \longrightarrow 1$. In particular, we assume the following functional form for the probability of initial innovation success:

$$p_i = 1 - \exp(-\delta_i(RD_i + \upsilon RD_j)), \tag{28}$$

where $\upsilon \geq 0$ is the degree of complementarity between the two firms' R&Ds. $\upsilon = 0$ corresponds to the limiting case of no complementarities, in which the likelihood of successful innovation reduces to $p_i = 1 - \exp(-\delta_i RD_i)$. Finally, we assume that firms make their innovation implementation decisions after observing the outcome (success or failure) of the other firm's innovation effort.

as in the baseline model, we solve the extended model by backwards induction. We start with a choice by each firm that has innovated successfully of whether to implement its innovation following realizations of the shocks to the access to external funds and to the required implementation cost.

When neither of the two firms has successfully innovated, their payoffs equal their discounted cash holdings, C_i/R for firm i. In case one firm (say firm i) has successfully innovated, its innovation implementation threshold equals monopoly profit,

$$I_{i,un}^{alone} = \pi_M = 1, \tag{29}$$

where the superscript *alone* refers to only one firm having successfully innovated.

Note that because firms can condition their innovation implementation threshold on the outcome of the other firm's innovation, it is now possible that firm i's cash holdings are higher than expected product market profit, $C_i > \mathbb{E}\pi_i$. This is possible because each firm now chooses cash holdings while accounting for the possibility of being a monopolist in the output market, in which case the marginal benefit of cash is higher. Whether equilibrium cash holdings would exceed the unconstrained implementation threshold in the case in which both firms have successfully innovated depends on the marginal cost of cash holdings relative to their expected marginal benefit. If the marginal cost is very low (i.e., $r \rightarrow R$), firms would choose high levels of cash holdings and would be unconstrained in the duopolistic output market. On the other hand, if the marginal cost of cash holdings is high enough, firms would choose cash holdings lower than the unconstrained implementation threshold in the duopolistic market.

In the case in which the marginal cost of cash holdings is sufficiently low, cash holdings play no strategic role, in the sense that a firm's level of cash holdings does not impact its rival's optimal choice of cash holdings, its level of investment in innovation, or the likelihood of implementing the innovation. Since the strategic motive for holding cash is the focal point of our analysis, we concentrate on the case in which firms are constrained in the duoploistic output market. We do that by choosing parameter values that ensure that both firms' equilibrium cash holdings choices are lower than expected output market profit, i.e. that $C_i^* < \mathbb{E}\pi_i$. Therefore, in the case in which both firms have successfully innovated, the equilibrium unconstrained optimization thresholds are the same as tyne ones in the baseline model (see Equation (4)). In what follows, we rename the unconstrained optimal investment implementation threshold for this case, $I_{i,un}^{both}$, where the superscript *both* refers to both firms having successfully innovated, in which cash plays a strategic role.

In the beginning of the game, the two firms choose their levels of R&D investment and cash holdings. In particular, firm i has the following objective function:

$$\begin{aligned}
\max_{RD_i,C_i} V_i &= -RD_i - C_i/r + \exp(-\delta_i(RD_i + \upsilon RD_j))C_i/R + \\
&+ (1-\exp(-\delta_i(RD_i+\upsilon RD_j)))\exp(-\delta_i(RD_j+\upsilon RD_j))\Bigg[C_i + \Bigg(\alpha_i\int_{\underline{I}}^{C_i} f(I_i)\,(\pi_M - I_i)\,dI_i + \\
&+ (1-\alpha_i)\int_{\underline{I}}^{I_{i,un}^{alone}} f(I_i)\,(\pi_M - I_i)\,dI_i\Bigg)\Bigg]/R + \\
&+ (1-\exp(-\delta_i(RD_i+\upsilon RD_j)))\,(1-\exp(-\delta_i(RD_j+\upsilon RD_j)))\Bigg[C_i + \Bigg(\alpha_i\int_{\underline{I}}^{C_i} f(I_i)\,(\mathbb{E}_i(\pi) - I_i)\,dI_i + \\
&+ (1-\alpha_i)\int_{\underline{I}}^{I_{i,un}^{both}} f(I_i)\,(\mathbb{E}_i(\pi) - I_i)\,dI_i\Bigg)\Bigg]/R
\end{aligned} \tag{30}$$

The first line in Equation (30) contains firm i's investment in R&D, cash raised to be potentially used for implementation of innovation, and the likelihood of firm i's innovation effort being unsuccessful, multiplied by the discounted cash holdings. The second and third lines in Equation (30) refer to the case in which firm i is successful in innovation, while firm j is not. In this case, if firm i's innovation turns out successful and if it decides to implement it, it becomes a monopolist in the output market, and realizes profit $\pi_M = 1$. The fourth and fifth lines in Equation (30) refer to the case in which both firms have succeeded in their innovations and is similar to the value function in the baseline model in Section 2.

Differentiating firm i's value function in Equation (30) with respect to C_i and RD_i, equating the resulting two F.O.C.s, which are linear in C_i and RD_i, to zero, and solving for C_i and RD_i generates the reaction functions of firm i's cash holdings and R&D investment. These reaction functions are firm i's optimal choices of cash holdings and investment in innovation as functions of firm j's cash holdings and investment in innovation. We call these functions $C_i^*(C_j, RD_j)$ and $RD_i^*(C_j, RD_j)$, respectively. It is easy to show that these reaction functions are downward-sloping,

$\frac{\partial C_i^*}{\partial C_j} < 0$, $\frac{\partial C_i^*}{\partial RD_j} < 0$, $\frac{\partial RD_i^*}{\partial C_j} < 0$, $\frac{\partial RD_i^*}{\partial RD_j} < 0$.[28]

The reason for the negative effect of firm j's cash holdings on firm i's optimal cash holdings is that firm j's higher cash holdings increase the likelihood of firm j implementing its innovation, which, in turn, reduces firm i's expected output market profit and the marginal benefit of holding cash, resulting in lower equilibrium cash holdings, $C_i^*(C_j, RD_j)$. This is one of the strategic benefits of holding cash, discussed in Section 2. (An additional strategic benefit of cash holdings, discussed in Section 2 and present here, is that firm j's cash holdings reduce firm i's unconstrained investment implementation threshold, $I_{i,un}^{both}$).

The reason for the negative relation between C_i^* and RD_j is due to the combination of two effects. First, RD_j increases the likelihood of firm j's innovation success, leading to lower payoff of firm i's innovation, lower marginal benefits of holding cash, and lower optimal cash holdings. The second, mitigating, effect is that in the case of $\upsilon > 0$ (i.e positive R&D spillovers), RD_j increases the likelihood of firm i's successful innovation, leading to higher marginal benefits of cash holdings and higher optimal cash. However, as long as $\upsilon < 1$ (i.e. own R&D is more important for innovation success than others' R&D), the first (negative) effect of RD_j on C_i^* dominates.

The reason for the negative relation between RD_i^* and C_j is a manifestation of the third strategic benefit of holding cash, that of reducing rival's investment in innovation. Because of the two strategic effects of cash holdings discussed above, higher C_j is associated with lower expected firm i's output market profit and resulting lower marginal benefit of investing in R&D, and lower optimal investment in R&D. In the baseline model in Section 2 we have abstracted from this interaction between cash holdings and investment. With this interaction present, the strategic effect of cash holdings becomes even stronger.

Writing similar F.O.C.s of firm j for C_j and RD_j and solving the resulting system of four equations in four unknowns leads to firms' equilibrium choices: RD_i^{EQ}, RD_j^{EQ}, C_i^{EQ}, and C_j^{EQ}. In what follows, we re-examine the relations between firm i's cash–to–value ratio, $\widetilde{C_i^{EQ}} = \frac{C_i^{EQ}/r}{V_i^{EQ}+C_i^{EQ}/r}$, on one hand, and the intensity of expected output market competition, γ, and innovation efficiency, δ_i, on the other hand.

Figure 4 illustrates the relation between the intensity of competition, γ, and firm's equilibrium cash–to–value ratio. The parameters are identical to those used in the construction of Figure 2. We vary the competition intensity parameter, γ, between 0 and 0.9, and examine two separate scenarios: a relatively constrained one ($\alpha_i = 0.15$ in Figure 4A) and a relatively unconstrained one ($\alpha_i = 0.8$ in Figure 4B). In both figures, the dashed–dotted line depicts firm i's equilibrium cash–to–value ratio, $\widetilde{C_i^{EQ}}$, for the case of no R&D complementarities ($\upsilon = 0$), while the dashed line presents the case of $\upsilon = 0.5$.

The shape of the relation between $\widetilde{C_i^{EQ}}$ and γ for the cases of $\upsilon = 0$ and $\upsilon = 0.5$ is consistent with that in Figure 2: the effect of γ on $\widetilde{C_i^{EQ}}$ depends on the degree of financial constraints: it

[28] A proof is available upon request.

is negative in the low–financing–constraints case, in which strategic considerations are relatively unimportant, and it is positive in the high–financing–constraints case, in which strategic considerations dominate the relation. Notably, the qualitative relations between $\widetilde{C_i^{EQ}}$ and γ are not affected by R&D complementarities.[29]

In Figure 5, we depict the relation between firm i'sinnovation efficiency, δ_i, and its equilibrium cash holdings for the case of low financial constraints, $\alpha_i = 0.15$ (in Figure 5A), and for the case of high financial constraints, $\alpha_i = 0.8$ (in Figure 5B). As in the baseline analysis, we vary δ_i between 0.6 and 0.95. The parameter values are identical to those in Figure 3. As in Figure 4, the solid (dashed) line corresponds to the case of $\upsilon = 0$ ($\upsilon = 0.5$). Similar to the baseline model, the relation between cash–to–value ratio and innovation efficiency depends on the degree of financial constraints. When a firm is relatively unconstrained, its cash–to–value ratio is increasing in innovation efficiency, while the opposite is true for a relatively constrained firm. The reason is identical to the one discussed in the baseline model: the sensitivity of cash holdings to innovation efficiency is higher when equilibrium cash holdings are low (i.e. when α_i is low) than when cash holdings are high (i.e. when α_i is high).

Overall, the extended model in this Appendix, which is different from the baseline model in that it allows for endogenous R&D choices and outcomes, for possible complementarities between the two firms' R&Ds, and for an opportunity to condition a firm's innovation implementation threshold on the outcome of rival's R&D, results in similar qualitative relations between normalized cash holdings on one hand, and intensity of output market competition and innovation efficiency, on the other hand, as the baseline model in Section 2. This finding is important as it demonstrates that the roles of future output market competition intensity and of innovation efficiency in determining optimal cash holdings of innovative firms are robust.

[29] This result holds for all $0 \leq \upsilon \leq 1$.

C Definitions of Variables

We obtain accounting variables used in the empirical analysis from the CRSP/Compustat Merged Database. The three proxies for the firm–level degree of financial constraints are:

- The Size–Age (SA) index, computed in **?** as $SA_{i,t} = -0.737 * SIZE_{i,t} + 0.043 * SIZE_{i,t}^2 - 0.04 * AGE_{i,t}$, where $SIZE_{i,t}$ is the log of the book value of assets adjusted for inflation using the GDP deflator and $AGE_{i,t}$ is the difference between year t and the first year firm i has appeared in Compustat, capped at 37.

- The Whited–Wu (WW) index, computed in **?** as $WW_{i,t} = -0.091 * CF_{i,t} - 0.062 * DIVPOS_{i,t} + 0.021 * TLTD_{i,t} - 0.044 * LNTA_{i,t} + 0.102 * ISG_{i,t} - 0.035 * SG_{i,t}$, where CF is the ratio of cash flows (item `IB` plus item `DP`) to total assets (item `AT`), $DIVPOS$ is an indicator that takes the value of one if a firm pays cash dividends (item `DVC` plus item `DVP`), $TLTD$ is the ratio of the long term debt (item `DLTT`) to total assets (item `AT`), $LNTA$ is the log of the book value of assets adjusted for inflation using the GDP deflator , ISG is the firm's 3-digit industry sales growth, SG is firm sales growth, both derived from item `SALE`.

- A dividend dummy that takes the value of one if the sum of dividends (item `DV`) and repurchases (item `PRSTKC`, set to zero when missing) is positive and zero otherwise.

The literature on the determinants of cash holdings has identified a set of key variables associated with firms' cash holdings. We follow **?** and include in our cash holdings analysis the following variables. All balance sheet and income statement items are scaled by the contemporaneous value of total assets (Compustat item `AT`), if not specified otherwise.

- *Cash* is the amount of cash and cash equivalents (item `CHE`).

- *Market-to-book* is the ratio of the firm's market value over the firm's book value. We define the book value as the value of total assets (item `AT`) and the market value as the book value minus the book value of equity (item `CEQ`) plus the market value of equity (item `CSHO` × item `PRCC_F`).

- *Size* is the book value of assets (item `AT`) deflated using the Consumer Price Index (CPI).

- *Cash flow* is defined as earnings before depreciation (item `OIBDP`) net of interest (item `XINT`, set to zero when missing), dividends (item `DVC`), and taxes (item `TXT`).

- *Net working capital* is computed as the difference between working capital (item `WCAP`) and cash (item `CHE`).

- *Investment and acquisitions* is defined as investment in physical capital (item `CAPX`) net of sales of property, plant and equipment (item `SPPE`, set to zero when missing) plus acquisitions (item `AQC`, set to zero when missing).

- *Leverage* is the sum of long-term debt (item `DLTT`) and debt in current liabilities (item `DLC`) at time t.

- *R&D* is R&D expenditures (item `XRD`). This variable is set equal to zero when R&D expenditures values are missing.[30]

- Following **?**, we identify multinationals using data on foreign income and taxes. In particular, we create the dummy variable *Multinational* that takes value of one if a firm reports a positive foreign pretax income (item `PIFO`) or a positive foreign tax expense (item `TXFO`) in at least one of the previous three years and zero otherwise.

- *Industry CFCV* is a measure of cash flow volatility. Following **?**, we calculate the cash flow coefficient of variation (CFCV) at the firm level using the previous 16 quarters. A quarterly cash flow is defined as net income before extraordinary items (item `IBQ`) plus depreciation (item `DPQ`) in quarter j over the value of total assets (item `ATQ`) in quarter $j-1$. *Industry CFCV* is the industry (two–digit SIC code) average value. We require at least five observations in each industry–year.

In addition, following recent studies of the determinants of cash holdings (**?** and **?**), we include the following two control variables:

- *HHI* is the Herfindahl-Hirshman index of sales, computed as the sum of squared sales (item `SALE`) of all firms belonging to a two-digit SIC industry divided by squared industry sales.

- *Winner advantage* is the skewness of sales (item `SALE`) within a two-digit SIC industry.

[30]Normalizing R&D expenditures by sales, as in **?** does not affect the results.

Table 1: Patent Data Summary Statistics

	Mean	Std. Dev.	25%	50%	75%	Min	Max	N
Patents	26.087	104.847	1	3	10	1	2,905	33,097
Citations	59.578	307.794	1	5	19	0	11,987	33,097
Classes	3.940	5.076	1	2	4	1	35	33,097

This table reports the mean, standard deviation, 25th percentile, 50th percentile, 75th percentile, minimum value, maximum value, and number of firm-year observations with non-zero patent grants. *Patents* is the number of patents granted to a firm in year t. We consider only patents that have an application year that precedes the granting year by at most three years. *Citations* is the total number of citations that a firm's patents granted in year t receive within three years from the granting year. *Classes* is the number of unique technology classes assigned to patents granted to a firm in year t.

Table 2: Compustat Data Summary Statistics

	Mean	Std. Dev.	25%	50%	75%	Min	Max	N
				Dependent Variable				
Cash	0.174	0.214	0.026	0.082	0.235	0.000	0.899	33,097
				Financing Constraints Measures				
SA	-3.311	0.949	-4.108	-3.354	-2.742	-4.627	1.091	32,509
WW	-0.290	0.131	-0.385	-0.297	-0.205	-0.545	0.262	30,919
Dividend	0.636	0.481	0.000	1.000	1.000	0.000	1.000	33,097
				Firm–Level Control Variables				
Market-to-book	2.116	2.090	1.059	1.408	2.208	0.643	14.029	30,252
Size	1,962	5,408	38	184	1,073	1	36,151	33,097
Cash flow	-0.007	0.265	0.015	0.066	0.103	-1.549	0.252	32,896
Net working capital	0.134	0.204	0.017	0.142	0.269	-0.738	0.543	32,564
Investment & Acq.	0.065	0.062	0.028	0.050	0.082	-0.027	0.401	32,605
Leverage	0.226	0.204	0.065	0.198	0.322	0.000	1.119	33,042
R&D–to–Assets	0.081	0.142	0.007	0.032	0.091	0.000	0.947	33097
Multinational	0.557	0.497	0.000	1.000	1.000	0.000	1.000	33,097
				Industry–Level Control Variables				
Industry CFCV	2.067	1.233	1.050	1.997	2.897	0.154	14.589	29,962
HHI	0.440	0.293	0.178	0.364	0.654	0.064	1.000	32,857
Winner Advantage	3.180	2.159	1.499	2.747	4.991	-1.117	8.792	31,329

Table 2: Compustat Data Summary Statistics (continued)

This table reports the mean, standard deviation, 25th percentile, 50th percentile, 75th percentile, minimum value, maximum value, and number of available observations for the variables used in the empirical analysis. All balance sheet and income statement items are scaled by the contemporaneous value of total assets (Compustat item AT), if not specified otherwise. *Cash* is the amount of cash and cash equivalents (item CHE). *SA* is the firm–level financial constraints index proposed by Hadlock and Pierce (2010). *WW* is the firm–level financial constraints index proposed by Whited and Wu (2010). *Dividend* is a dummy variable that takes the value of one if the sum of dividends (item DV) and repurchases (item PRSTKC, set to zero when missing) is positive and zero otherwise. *Market-to-book* is the ratio of the firm's market value over the firm's book value. We define the book value as the value of total assets (item AT) and the market value as the book value minus the book value of equity (item CEQ) plus the market value of equity (item CSHO × item PRCC_F). *Size* is the book value of assets (item AT) deflated using the Consumer Price Index (CPI) and reported in millions of 1984 dollars. *Cash flow* is defined as earnings before depreciation (item OIBDP) net of interest (item XINT, set to zero when missing), dividends (item DVC), and taxes (item TXT). *Net working capital* is computed as the difference between working capital (item WCAP) and cash (item CHE). *Investment & Acq.* is defined as investment in physical capital (item CAPX) net of sales of property, plant and equipment (item SPPE, set to zero when missing) plus acquisitions (item AQC, set to zero when missing). *Leverage* is the sum of long-term debt (item DLTT) and debt in current liabilities (item DLC) at time t. *R&D–to–Assets* is the ratio of R&D expenditures (item XRD) to total assets (item AT). This variable is set equal to zero when R&D expenditures are missing. *Multinational* is a dummy variable that takes value of one if a firm reports a positive foreign pretax income (item PIFO) or a positive foreign tax expense (item TXFO) in at least one of the previous three years and zero otherwise. We calculate the cash flows coefficient of variation at the firm level using the previous 16 quarters. A quarterly cash flow is defined as net income before extraordinary items (item IBQ) plus depreciation (item DPQ) in quarter j over the value of total assets (item ATQ) in quarter $j-1$. *Industry CFCV* is the average value of $CFCV$ of all firms that belong to the same 3–digit SIC industry. *HHI* is the 3–digit SIC industry Herfindahl Index. *Winner advantage* is the skewness of the market share within a 3–digit SIC industry. The data are at the annual frequency over the period 1976–2003 and all the variables are winsorized at the top and bottom 1%. Appendix C provides extended definitions of these variables.

Table 3: Competition and Efficiency

Panel A: Industry–level measures of intensity of competition

	Mean	Std. Dev.	25%	50%	75%	Min	Max	N
γ^{CIT}	0.247	0.125	0.159	0.206	0.339	0.000	1.000	31,571
γ^{PAT}	0.300	0.181	0.182	0.250	0.414	0.000	1.000	31,745

Panel B: Firm–level measures of innovation efficiency

	Mean	Std. Dev.	25%	50%	75%	Min	Max	N
δ^{CIT}	0.736	0.778	0.171	0.501	1.041	0.000	7.051	22,056
δ^{PAT}	0.582	0.588	0.179	0.387	0.776	0.000	4.841	22,056

This table reports the mean, standard deviation, 25% percentile, 50% percentile, 75% percentile, minimum value, maximum value, and number of available observations for industry–level measures of product market competition intensity (Panel A) and firm–level measures innovation efficiency (Panel B). Industries are defined using three–digit SIC codes. γ^{CIT} (γ^{PAT}) is the industry average of firm-level citations-based (patents-based) similarity. δ^{CIT} (δ^{PAT}) is the firm–level citations-based (patents-based) innovation efficiency measure. Section 3.1.3 provides extended definitions of the variables.

Table 4: Cash–to–Assets Ratio and Financial Constraints

	(1)	(2)	(3)	(4)
SA		0.049***		
		(0.010)		
WW			0.032***	
			(0.010)	
Dividend				-0.047***
				(0.014)
Cash flow volatility	0.001	0.001	0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.002)
Market-to-Book	0.012***	0.013***	0.013***	0.012***
	(0.003)	(0.003)	(0.003)	(0.003)
Size	-0.014***	-0.007***	-0.008***	-0.010***
	(0.001)	(0.003)	(0.003)	(0.002)
Cash Flow	0.030**	0.020	0.023*	0.026**
	(0.013)	(0.013)	(0.014)	(0.013)
Net Working Capital	-0.352***	-0.341***	-0.350***	-0.344***
	(0.037)	(0.035)	(0.037)	(0.034)
Investment & Acq.	-0.436***	-0.448***	-0.442***	-0.441***
	(0.077)	(0.078)	(0.078)	(0.077)
Leverage	-0.394***	-0.389***	-0.397***	-0.403***
	(0.025)	(0.024)	(0.025)	(0.025)
R&D–to–Assets	0.193***	0.182***	0.186***	0.180***
	(0.037)	(0.038)	(0.037)	(0.036)
Multinational	-0.049**	-0.040**	-0.046**	-0.046**
	(0.020)	(0.018)	(0.019)	(0.018)
HHI	-0.063***	-0.058***	-0.061***	-0.059***
	(0.018)	(0.017)	(0.017)	(0.016)
Winner Advantage	0.014***	0.014***	0.014***	0.013***
	(0.004)	(0.004)	(0.004)	(0.003)
Constant	0.363***	0.296***	0.318***	0.382***
	(0.034)	(0.026)	(0.027)	(0.036)
Obs.	25,716	25,716	25,716	25,716
R^2–adj	0.516	0.522	0.518	0.523
Year FE	YES	YES	YES	YES

Table 4: Cash–to–Assets Ratio and Financial Constraints (continued)

This table reports the estimates of the following regression:

$$Cash_{i,t} = \beta_0 + \beta_\alpha \alpha_{i,t} + \beta_1 \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\alpha_{i,t}$ is a measure of financial constraints, $\mathbf{X_{i,t}}$ is a vector of variables that includes *Cash flow CV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment & Acq.*, *Leverage*, *R&D to sales*, *Multinational*, *HHI*, and *Winner advantage*, $D_{i,t}$ is a vector of year dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. We use three measures of financial constraints: SA that equals one if a firm's SA index is above the annual median, WW that equals one if a firm's WW index is above the annual median, and *Dividend* that equals one if a firm paid dividends or repurchased shares in a given year. The quantity of interest is β_α, the regression coefficients on the firm-level measures of financial constraints. Appendix C reports detailed definitions of all of the variables included in the regression. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at an annual frequency over the period 1976–2003 and all accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 5: Cash–to–Assets Ratio and Competition Intensity

Panel A: $\gamma^{\mathbf{CIT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\gamma\times NFC}$	-0.009	0.014	0.001	-0.024	-0.021	-0.019
	(0.053)	(0.072)	(0.060)	(0.024)	(0.026)	(0.019)
$\beta_{\gamma\times FC}$	0.359**	0.367**	0.475***	0.215***	0.197**	0.253***
	(0.178)	(0.178)	(0.172)	(0.077)	(0.076)	(0.083)
$\Delta\beta_{\gamma}$	-0.368***	-0.353***	-0.475***	-0.239***	-0.218***	-0.272***
F-stat	7.950	9.659	16.040	14.51	13.13	13.41
pvalue	0.005	0.002	0.000	0.000	0.000	0.000
Obs.	31,745	31,745	31,745	19,271	19,271	19,271
R^2–adj	0.547	0.528	0.542	0.731	0.729	0.733
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Innovation	No	No	No	Yes	Yes	Yes

Panel B: $\gamma^{\mathbf{PAT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\gamma\times NFC}$	-0.062	-0.019	-0.023	-0.042	-0.044	-0.041
	(0.100)	(0.129)	(0.105)	(0.043)	(0.046)	(0.032)
$\beta_{\gamma\times FC}$	0.511**	0.522**	0.650***	0.253**	0.237**	0.303**
	(0.240)	(0.242)	(0.243)	(0.122)	(0.118)	(0.136)
$\Delta\beta_{\gamma}$	-0.573***	-0.541***	-0.673***	-0.296***	-0.281***	-0.344***
F-stat	14.61	18.01	17.34	10.70	11.10	8.260
pvalue	0.000	0.000	0.000	0.001	0.001	0.005
Obs.	31,571	31,571	31,571	19,257	19,257	19,257
R^2–adj	0.550	0.529	0.542	0.730	0.728	0.731
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Innovation	No	No	No	Yes	Yes	Yes

Table 5: Cash–to–Assets Ratio and Competition Intensity (continued)

This table reports the estimates of the following regressions:

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\gamma\times NFC}(\gamma_{n,t} \times NFC_{i,t}) + \beta_{\gamma\times FC}(\gamma_{n,t} \times FC_{i,t}) + \phi D_t + \varepsilon_{i,t},$$

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\gamma\times NFC}(\gamma_{n,t} \times NFC_{i,t}) + \beta_{\gamma\times FC}(\gamma_{n,t} \times FC_{i,t}) + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\gamma_{n,t}$ is one of the two industry-wide measures of intensity of product market competition (γ^{CIT} and γ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes value of 1 if a firm is financially constrained and zero otherwise, $\gamma_{n,t} \times NFC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $NFC_{i,t}$, $\gamma_{n,t} \times FC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. Regressions in columns 1 to 3 do not include control variables, while regressions in columns 4 to 6 include all of the control variables in Table 4 plus a measure of innovation efficiency (δ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if dividends and repurchases are positive (equal to zero). Panel A reports the results when product market competition intensity is measured with γ^{CIT}, while Panel B reports the results when product market competition intensity is measured with γ^{PAT}. In each panel, we report estimates of $\beta_{\gamma\times NFC}$, the competition intensity coefficient of financially unconstrained firms, and $\beta_{\gamma\times FC}$, the competition intensity coefficient of financially constrained firms. The quantity of interest is $\Delta\beta_\gamma = \beta_{\gamma\times NFC} - \beta_{\gamma\times FC}$, the difference in the competition intensity coefficient between financially unconstrained and financially constrained firms. $F - stat$ is the Wald F–statistic for testing the equality between these two coefficients. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 6: Cash–to–Assets Ratio and Innovation Efficiency

Panel A: $\delta^{\mathbf{CIT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta\times NFC}$	0.017**	0.032***	0.028***	0.013**	0.023***	0.014***
	(0.007)	(0.007)	(0.005)	(0.006)	(0.007)	(0.004)
$\beta_{\delta\times FC}$	-0.003	-0.001	-0.004	-0.004	-0.005	-0.010
	(0.017)	(0.016)	(0.021)	(0.005)	(0.005)	(0.007)
$\Delta\beta_{\delta}$	0.020	0.033**	0.031*	0.017*	0.028**	0.024**
F-stat	1.912	6.573	2.796	2.697	6.300	6.352
pvalue	0.168	0.011	0.096	0.100	0.013	0.013
Obs.	22,056	22,056	22,056	19,271	19,271	19,271
R^2–adj	0.555	0.534	0.534	0.727	0.726	0.728
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Competition	No	No	No	Yes	Yes	Yes

Panel B: $\delta^{\mathbf{PAT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta\times NFC}$	0.015*	0.029***	0.027***	0.014*	0.021**	0.007*
	(0.009)	(0.009)	(0.007)	(0.008)	(0.008)	(0.004)
$\beta_{\delta\times FC}$	-0.045**	-0.036*	-0.041	-0.034***	-0.031***	-0.046***
	(0.022)	(0.021)	(0.025)	(0.011)	(0.010)	(0.013)
$\Delta\beta_{\delta}$	0.061**	0.064***	0.068**	0.049***	0.052***	0.053***
F-stat	5.285	7.166	6.734	7.963	9.632	12.70
pvalue	0.023	0.008	0.010	0.008	0.004	0.001
Obs.	22,056	22,056	22,056	19,271	19,271	19,271
R^2–adj	0.560	0.537	0.536	0.729	0.728	0.730
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Competition	No	No	No	Yes	Yes	Yes

Table 6: Cash–to–Assets Ratio and Innovation Efficiency (continued)

This table reports the estimates of the following regressions:

$$Cash_{i,t} = \beta_{NFC}NFC_{i,t} + \beta_{FC}FC_{i,t} + \beta_{\delta\times NFC}(\delta_{i,t}\times NFC_{i,t}) + \beta_{\delta\times FC}(\delta_{i,t}\times FC_{i,t}) + \phi D_t + \varepsilon_{i,t},$$

$$Cash_{i,t} = \beta_{NFC}NFC_{i,t} + \beta_{FC}FC_{i,t} + \beta_{\delta\times NFC}(\delta_{i,t}\times NFC_{i,t}) + \beta_{\delta\times FC}(\delta_{i,t}\times FC_{i,t}) + \beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\delta_{i,t}$ is one of the two firm–level measures of innovation efficiency (δ^{CIT} and δ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes value of 1 if a firm is financially constrained and zero otherwise, $\delta_{i,t}\times NFC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $NFC_{i,t}$, $\delta_{i,t}\times FC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. Regressions in columns 1 to 3 do not include control variables, while regressions in columns 4 to 6 include all of the control variables in Table 4 plus a measure of product market competition intensity (γ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if dividends and repurchases are positive (equal to zero). Panel A reports the results when innovation efficiency is measured with δ^{CIT}, while Panel B reports the results when innovation efficiency is measured with δ^{PAT}. In each panel, we report estimates of $\beta_{\delta\times NFC}$, the innovation efficiency coefficient of financially unconstrained firms, and $\beta_{\delta\times FC}$, the innovation efficiency coefficient of financially constrained firms. The quantity of interest is $\Delta\beta_\delta = \beta_{\delta\times NFC} - \beta_{\delta\times FC}$, the difference in the innovation efficiency coefficient between financially unconstrained and financially constrained firms. $F-stat$ is the Wald F–statistic for testing the equality between these two coefficients. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 7: Cash–to–Value Ratios and Competition Intensity

Panel A: $\gamma^{\mathbf{CIT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\gamma\times NFC}$	-0.058***	-0.044**	-0.045**	-0.034*	-0.035**	-0.030*
	(0.016)	(0.018)	(0.018)	(0.018)	(0.018)	(0.015)
$\beta_{\gamma\times FC}$	0.078*	0.075	0.100**	0.009	0.008	0.012
	(0.046)	(0.048)	(0.047)	(0.027)	(0.028)	(0.032)
$\Delta\beta_{\gamma}$	-0.136***	-0.118***	-0.145***	-0.043**	-0.043**	-0.042
F-stat	11.09	9.115	12.82	4.984	3.669	2.347
pvalue	0.001	0.003	0.000	0.027	0.058	0.128
Obs.	28,973	28,973	28,973	19,271	19,271	19,271
R^2–adj	0.434	0.431	0.426	0.608	0.609	0.609
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Efficiency	No	No	No	Yes	Yes	Yes

Panel B: $\gamma^{\mathbf{PAT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\gamma\times NFC}$	-0.126***	-0.102**	-0.096***	-0.055*	-0.060*	-0.056**
	(0.035)	(0.039)	(0.036)	(0.031)	(0.031)	(0.026)
$\beta_{\gamma\times FC}$	0.096	0.090	0.118	-0.009	-0.005	0.003
	(0.067)	(0.070)	(0.074)	(0.042)	(0.043)	(0.051)
$\Delta\beta_{\gamma}$	-0.223***	-0.191***	-0.214***	-0.046	-0.055	-0.059
F-stat	18.07	13.99	10.43	2.305	2.491	1.610
pvalue	0.000	0.000	0.001	0.131	0.117	0.207
Obs.	28,814	28,814	28,814	19,257	19,257	19,257
R^2–adj	0.435	0.432	0.427	0.608	0.609	0.609
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Efficiency	No	No	No	Yes	Yes	Yes

.

Table 7: Cash–to–Value Ratios and Competition Intensity (continued)

This table reports the estimates of the following regressions:

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\gamma\times NFC}(\gamma_{n,t} \times NFC_{i,t}) + \beta_{\gamma\times FC}(\gamma_{n,t} \times FC_{i,t}) + \phi D_t + \varepsilon_{i,t},$$

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\gamma\times NFC}(\gamma_{n,t} \times NFC_{i,t}) + \beta_{\gamma\times FC}(\gamma_{n,t} \times FC_{i,t}) + \beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-value ratio, $\gamma_{n,t}$ is one of the two industry-wide measures of intensity of product market competition (γ^{CIT} and γ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes value of 1 if a firm is financially constrained and zero otherwise, $\gamma_{n,t} \times NFC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $NFC_{i,t}$, $\gamma_{n,t} \times FC_{i,t}$ is an interaction term formed using the variables $\gamma_{n,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. Regressions in columns 1 to 3 do not include control variables, while regressions in columns 4 to 6 include all of the control variables in Table 4 plus a measure of innovation efficiency (δ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if dividends and repurchases are positive (equal to zero). Panel A reports the results when product market competition intensity is measured with γ^{CIT}, while Panel B reports the results when product market competition intensity is measured with γ^{PAT}. In each panel, we report estimates of $\beta_{\gamma\times NFC}$, the competition intensity coefficient of financially unconstrained firms, and $\beta_{\gamma\times FC}$, the competition intensity coefficient of financially constrained firms. The quantity of interest is $\Delta\beta_\gamma = \beta_{\gamma\times NFC} - \beta_{\gamma\times FC}$, the difference in the competition intensity coefficient between financially unconstrained and financially constrained firms. $F - stat$ is the Wald F–statistic for testing the equality between these two coefficients. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 8: Cash–to–Value Ratios and Innovation Efficiency

Panel A: $\delta^{\mathbf{CIT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta \times NFC}$	0.001	0.005	0.009**	0.002	0.008**	0.005*
	(0.005)	(0.005)	(0.003)	(0.003)	(0.004)	(0.003)
$\beta_{\delta \times FC}$	-0.013***	-0.012***	-0.016***	-0.007***	-0.008***	-0.012***
	(0.004)	(0.004)	(0.005)	(0.002)	(0.002)	(0.002)
$\Delta\beta_{\delta}$	0.014**	0.017**	0.025***	0.010***	0.016***	0.017***
F-stat	5.295	6.281	17.66	8.246	15.68	30.77
pvalue	0.022	0.013	0.000	0.005	0.000	0.000
Obs.	21,223	21,223	21,223	19,271	19,271	19,271
R^2–adj	0.447	0.446	0.437	0.608	0.609	0.609
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Competition	No	No	No	Yes	Yes	Yes

Panel B: $\delta^{\mathbf{PAT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta \times NFC}$	0.002	0.005	0.012**	-0.002	0.003	0.001
	(0.008)	(0.008)	(0.006)	(0.005)	(0.005)	(0.004)
$\beta_{\delta \times FC}$	-0.032***	-0.031***	-0.037***	-0.022***	-0.021***	-0.033***
	(0.007)	(0.007)	(0.007)	(0.004)	(0.004)	(0.004)
$\Delta\beta_{\delta}$	0.034***	0.035***	0.049***	0.020***	0.024***	0.033***
F-stat	11.45	11.44	27.46	10.04	13.83	42.33
pvalue	0.001	0.001	0.000	0.002	0.000	0.000
Obs.	21,223	21,223	21,223	19,271	19,271	19,271
R^2–adj	0.451	0.449	0.440	0.609	0.610	0.611
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Competition	No	No	No	Yes	Yes	Yes

Table 8: Cash–to–Value Ratios and Innovation Efficiency (continued)

This table reports the estimates of the following regressions:

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\delta \times NFC}(\delta_{i,t} \times NFC_{i,t}) + \beta_{\delta \times FC}(\delta_{i,t} \times FC_{i,t}) + \phi D_t + \varepsilon_{i,t},$$

$$Cash_{i,t} = \beta_{NFC} NFC_{i,t} + \beta_{FC} FC_{i,t} + \beta_{\delta \times NFC}(\delta_{i,t} \times NFC_{i,t}) + \beta_{\delta \times FC}(\delta_{i,t} \times FC_{i,t}) + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-value ratio, $\delta_{i,t}$ is one of the two firm–level measures of innovation efficiency (δ^{CIT} and δ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes value of 1 if a firm is financially constrained and zero otherwise, $\delta_{i,t} \times NFC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $NFC_{i,t}$, $\delta_{i,t} \times FC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. Regressions in columns 1 to 3 do not include control variables, while regressions in columns 4 to 6 include all of the control variables in Table 4 plus a measure of product market competition intensity (γ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if dividends and repurchases are positive (equal to zero). Panel A reports the results when innovation efficiency is measured with δ^{CIT}, while Panel B reports the results when innovation efficiency is measured with δ^{PAT}. In each panel, we report estimates of $\beta_{\delta \times NFC}$, the innovation efficiency coefficient of financially unconstrained firms, and $\beta_{\delta \times FC}$, the innovation efficiency coefficient of financially constrained firms. The quantity of interest is $\Delta\beta_\delta = \beta_{\delta \times NFC} - \beta_{\delta \times FC}$, the difference in the innovation efficiency coefficient between financially unconstrained and financially constrained firms. $F-stat$ is the Wald F–statistic for testing the equality between these two coefficients. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 9: Cash–to–Assets Ratio and Competition Intensity (Subsample Analysis)

	SA index			WW index			Dividend dummy	
	NFC	Middle	FC	NFC	Middle	FC	NFC	FC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: γ^{CIT}, Without control variables								
β_γ	-0.012	0.150	0.340*	0.027	0.140	0.354*	0.008	0.445**
	(0.031)	(0.140)	(0.174)	(0.067)	(0.129)	(0.182)	(0.061)	(0.175)
Obs	7,698	15,574	8,473	7,372	14,762	9,611	20,038	11,707
R^2–adj	0.042	0.152	0.215	0.025	0.140	0.200	0.058	0.188
$\Delta\beta_\gamma$	Δ=-0.352** $\chi^2 = 5.317$			Δ=-0.327** $\chi^2 = 6.536$			Δ=-0.437*** $\chi^2 = 12.70$	
Panel B: γ^{CIT}, With control variables								
β_γ	-0.015	0.055	0.170***	-0.006	0.040	0.193***	-0.003	0.225***
	(0.014)	(0.047)	(0.056)	(0.020)	(0.046)	(0.059)	(0.020)	(0.070)
Obs	5,307	9,769	4,195	4,728	9,480	5,063	12,127	7,144
R^2–adj	0.385	0.541	0.472	0.517	0.558	0.475	0.498	0.474
$\Delta\beta_\gamma$	Δ=-0.184*** $\chi^2 = 10.61$			Δ=-0.199*** $\chi^2 = 15.60$			Δ=-0.228*** $\chi^2 = 13.51$	
Panel C: γ^{PAT}, Without control variables								
β_γ	-0.056	0.199	0.453*	0.024	0.187	0.500**	-0.007	0.605**
	(0.061)	(0.214)	(0.231)	(0.115)	(0.204)	(0.245)	(0.105)	(0.249)
Obs	7,666	15,474	8,431	7,347	14,660	9,564	19,893	11,678
R^2–adj	0.046	0.150	0.210	0.024	0.137	0.199	0.058	0.185
$\Delta\beta_\gamma$	Δ=-0.509*** $\chi^2 = 7.231$			Δ= -0.475** $\chi^2 = 9.334$			Δ= -0.612*** $\chi^2 = 12.62$	
Panel D: γ^{PAT}, With control variables								
β_γ	-0.022	0.057	0.190**	-0.018	0.050	0.228**	-0.018	0.270**
	(0.025)	(0.075)	(0.088)	(0.035)	(0.072)	(0.095)	(0.035)	(0.110)
Obs	5,305	9,758	4,194	4,727	9,471	5,059	12,115	7,142
R^2–adj	0.385	0.540	0.469	0.517	0.558	0.471	0.498	0.471
$\Delta\beta_\gamma$	Δ= -0.212** $\chi^2 = 5.947$			Δ= -0.246*** $\chi^2 = 9.368$			Δ= -0.289*** $\chi^2 = 9.344$	

Table 9: Cash–to–Assets Ratio and Competition Intensity (Subsample Analysis, continued)

This table reports the estimates of the following regressions:

$$
\begin{aligned}
Cash_{i,t} &= \beta_0 + \beta_\gamma \gamma_{n,t} + \phi D_t + \varepsilon_{i,t}, \\
Cash_{i,t} &= \beta_0 + \beta_\gamma \gamma_{n,t} + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},
\end{aligned}
$$

where $\gamma_{n,t}$ is one of the two industry-wide measures of intensity of product market competition, γ^{CIT} and γ^{PAT}, $\mathbf{X_{i,t}}$ is a vector of variables that includes *Cash flow CV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment & Acq.*, *Leverage*, *R&D to sales*, *Multinational*, *HHI*, and *Winner advantage*, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The quantity of interest is β_γ, the regression coefficients on the industry-level measures of product market competition intensity. We run regressions on different subsamples of firms sorted by their degree of financing constraints. We use three proxies for financial constraints. When the proxy is the SA index or WW index (columns 1–3 and 4–6 respectively), firms are classified as not financially constrained (NFC) if they belong to the bottom 25% of the annual SA index (WW index) distribution and as financially constrained (FC) if they belong to the top 25% of the annual SA index (WW index). When the proxy is the dividend and repurchases dummy (columns 7 and 8), firms are classified as financially constrained if the dummy is zero, otherwise they are considered to be not financially constrained. For each measure of product market competition, we report estimates of β_γ both in the regression without control variables and the one with control variables. At the bottom of each panel, Δ is the difference in β_γ between the most constrained and least constrained subsamples. χ^2 is the Wald chi-square statistic for testing the difference between these two coefficients which takes into account the cross–subsample covariance performing a seemingly unrelated estimation. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 10: Cash–to–Assets Ratio and Innovation Efficiency (Subsample Analysis)

	SA index			WW index			Dividend dummy	
	NFC	Middle	FC	NFC	Middle	FC	NFC	FC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: δ^{CIT}, Without control variables								
β_δ	0.005	0.013	-0.012	0.021	0.023**	-0.010	0.025***	-0.001
	(0.012)	(0.011)	(0.015)	(0.014)	(0.009)	(0.016)	(0.005)	(0.019)
Obs	6,069	11,164	4,823	5,633	10,634	5,789	14,143	7,913
R^2–adj	0.051	0.160	0.199	0.031	0.150	0.188	0.084	0.127
$\Delta\beta_\delta$	Δ=0.016 $\chi^2 = 1.369$			Δ=0.031** $\chi^2 = 5.286$			Δ= 0.027* $\chi^2 = 2.901$	
Panel B: δ^{CIT}, With control variables								
β_δ	0.009*	0.009***	-0.003	0.018***	0.011***	-0.004	0.008***	0.001
	(0.005)	(0.004)	(0.003)	(0.006)	(0.004)	(0.003)	(0.003)	(0.003)
Obs	5,307	9,769	4,195	4,728	9,480	5,063	12,127	7,144
R^2–adj	0.385	0.541	0.472	0.517	0.558	0.475	0.498	0.474
$\Delta\beta_\delta$	Δ=0.012* $\chi^2 = 3.830$			Δ= 0.022*** $\chi^2 = 10.750$			Δ= 0.007* $\chi^2 = 3.395$	
Panel C: δ^{PAT}, Without control variables								
β_δ	-0.020	-0.019*	-0.040*	-0.008	-0.005	-0.033	0.017**	-0.024
	(0.012)	(0.010)	(0.024)	(0.014)	(0.009)	(0.024)	(0.007)	(0.020)
Obs	6,069	11,164	4,823	5,633	10,634	5,789	14,143	7,913
R^2–adj	0.054	0.160	0.208	0.024	0.144	0.194	0.074	0.130
$\Delta\beta_\delta$	Δ=0.020 $\chi^2 = 1.012$			Δ=0.025 $\chi^2 = 1.449$			Δ= 0.040** $\chi^2 = 4.705$	
Panel D: δ^{PAT}, With control variables								
β_δ	0.001	-0.001	-0.024***	0.010	-0.003	-0.016*	-0.006	-0.018***
	(0.006)	(0.006)	(0.009)	(0.009)	(0.006)	(0.009)	(0.005)	(0.006)
Obs 5,307	9,769	4,195	4,728	9,480	5,063	12,127	7,144	
R^2–adj	0.383	0.540	0.474	0.513	0.557	0.476	0.497	0.475
$\Delta\beta_\delta$	Δ=0.026** $\chi^2 = 6.053$			Δ= 0.025** $\chi^2 = 4.219$			Δ=0.012* $\chi^2 = 2.896$	

Table 10: Cash–to–Assets Ratio and Innovation Efficiency (Subsample Analysis, continued)

This table reports the estimates of the following regressions:

$$\begin{aligned} Cash_{i,t} &= \beta_0 + \beta_\delta \delta_{n,t} + \phi D_t + \varepsilon_{i,t}, \\ Cash_{i,t} &= \beta_0 + \beta_\delta \delta_{n,t} + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \end{aligned}$$

where $\delta_{n,t}$ is one of the two industry-wide measures of innovation efficiency, δ^{CIT} and δ^{PAT}, $\mathbf{X_{i,t}}$ is a vector of variables that includes *Cash flow CV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment & Acq.*, *Leverage*, *R&D to sales*, *Multinational*, *HHI*, and *Winner advantage*, D_t is a vector of time dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The quantity of interest is β_δ, the regression coefficients on the industry-level measures of innovation efficiency. We run regressions on different subsamples of firms sorted by their degree of financing constraints. We use three proxies for financial constraints. When the proxy is the SA index or WW index (columns 1–3 and 4–6 respectively), firms are classified as not financially constrained (NFC) if they belong to the bottom 25% of the annual SA index (WW index) distribution and as financially constrained (FC) if they belong to the top 25% of the annual SA index (WW index). When the proxy is the dividend and repurchases dummy (columns 7 and 8), firms are classified as financially constrained if the dummy is zero, otherwise they are considered to be not financially constrained. For each measure of innovation efficiency, we report estimates of β_δ both in the regression without control variables and the one with control variables. At the bottom of each panel, Δ is the difference in β_δ between the most constrained and least constrained subsamples. χ^2 is the Wald chi-square statistic for testing the difference between these two coefficients which takes into account the cross–subsample covariance performing a seemingly unrelated estimation. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the industry level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 11: Cash–to–Assets Ratio and Innovation Efficiency (Industry–Year Fixed Effects)

Panel A: $\delta^{\mathbf{CIT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta\times NFC}$	0.014**	0.028***	0.026***	0.012***	0.022***	0.014***
	(0.006)	(0.006)	(0.004)	(0.005)	(0.005)	(0.003)
$\beta_{\delta\times FC}$	0.011***	0.013***	0.013***	0.003	0.001	-0.001
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)
$\Delta\beta_{\delta}$	0.003	0.015**	0.013**	0.009*	0.021***	0.015***
F-stat	0.210	4.425	6.159	2.927	12.67	10.18
pvalue	0.647	0.036	0.013	0.087	0.000	0.001
Obs.	22,056	22,056	22,056	19,271	19,271	19,271
R^2–adj	0.374	0.356	0.349	0.524	0.522	0.522
Industry–Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: $\delta^{\mathbf{PAT}}$

	No Controls			Controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	SA-Index	WW-Index	Dividend	SA-Index	WW-Index	Dividend
$\beta_{\delta\times NFC}$	0.016**	0.027***	0.026***	0.010	0.017**	0.001
	(0.008)	(0.009)	(0.005)	(0.006)	(0.007)	(0.005)
$\beta_{\delta\times FC}$	-0.020***	-0.011**	-0.011*	-0.028***	-0.026***	-0.035***
	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.006)
$\Delta\beta_{\delta}$	0.035***	0.038***	0.037***	0.038***	0.042***	0.037***
F-stat	17.39	15.36	25.48	27.30	27.67	33.87
pvalue	0.000	0.000	0.000	0.000	0.000	0.000
Obs.	22,056	22,056	22,056	19,271	19,271	19,271
R^2–adj	0.375	0.354	0.346	0.526	0.523	0.524
Industry–Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Table 11: Cash–to–Assets Ratio and Innovation Efficiency (Industry–Year Fixed Effects, continued)

This table reports the estimates of the following regressions:

$$Cash_{i,t} = \beta_{NFC}NFC_{i,t} + \beta_{FC}FC_{i,t} + \beta_{\delta\times NFC}(\delta_{i,t}\times NFC_{i,t}) + \beta_{\delta\times FC}(\delta_{i,t}\times FC_{i,t}) + \phi D_{n,t} + \varepsilon_{i,t},$$

$$Cash_{i,t} = \beta_{NFC}NFC_{i,t} + \beta_{FC}FC_{i,t} + \beta_{\delta\times NFC}(\delta_{i,t}\times NFC_{i,t}) + \beta_{\delta\times FC}(\delta_{i,t}\times FC_{i,t}) + \beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_{n,t} + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\delta_{i,t}$ is one of the two firm–level measures of innovation efficiency (δ^{CIT} and δ^{PAT}), $NFC_{i,t}$ is a dummy variable that takes value of 1 if a firm is not financially constrained and zero otherwise, $FC_{i,t}$ is a dummy variable that takes value of 1 if a firm is financially constrained and zero otherwise, $\delta_{i,t}\times NFC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $NFC_{i,t}$, $\delta_{i,t}\times FC_{i,t}$ is an interaction term formed using the variables $\delta_{i,t}$ and $FC_{i,t}$, $\mathbf{X_{i,t}}$ is a vector of control variables, $D_{n,t}$ is a vector of industry–year dummies, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The set of control variables includes *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment & Acq.*, *Leverage*, *R&D to sales*, and *Multinational*. Regressions in columns 1 to 3 do not include control variables, while regressions in columns 4 to 6 include all of the control variables in Table 4 plus a measure of product market competition intensity (γ^{CIT}). In columns 1 and 4, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual SA index distribution. In columns 2 and 5, firms are classified as not financially constrained (financially constrained) if they belong to the bottom 50% (top 50%) of the annual WW index distribution. In columns 3 and 6, firms are classified as not financially constrained (financially constrained) if dividends and repurchases are positive (equal to zero). Panel A reports the results when innovation efficiency is measured with δ^{CIT}, while Panel B reports the results when innovation efficiency is measured with δ^{PAT}. In each panel, we report estimates of $\beta_{\delta\times NFC}$, the innovation efficiency coefficient of financially unconstrained firms, and $\beta_{\delta\times FC}$, the innovation efficiency coefficient of financially constrained firms. The quantity of interest is $\Delta\beta_{\delta} = \beta_{\delta\times NFC} - \beta_{\delta\times FC}$, the difference in the innovation efficiency coefficient between financially unconstrained and financially constrained firms. $F-stat$ is the Wald F–statistic for testing the equality between these two coefficients. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The data are at the annual frequency over the period 1976–2003 and all the accounting variables are winsorized at the top and bottom 1% to limit the influence of outliers. Standard errors clustered at the firm level are reported in parentheses. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Figure 1: Timing of Events

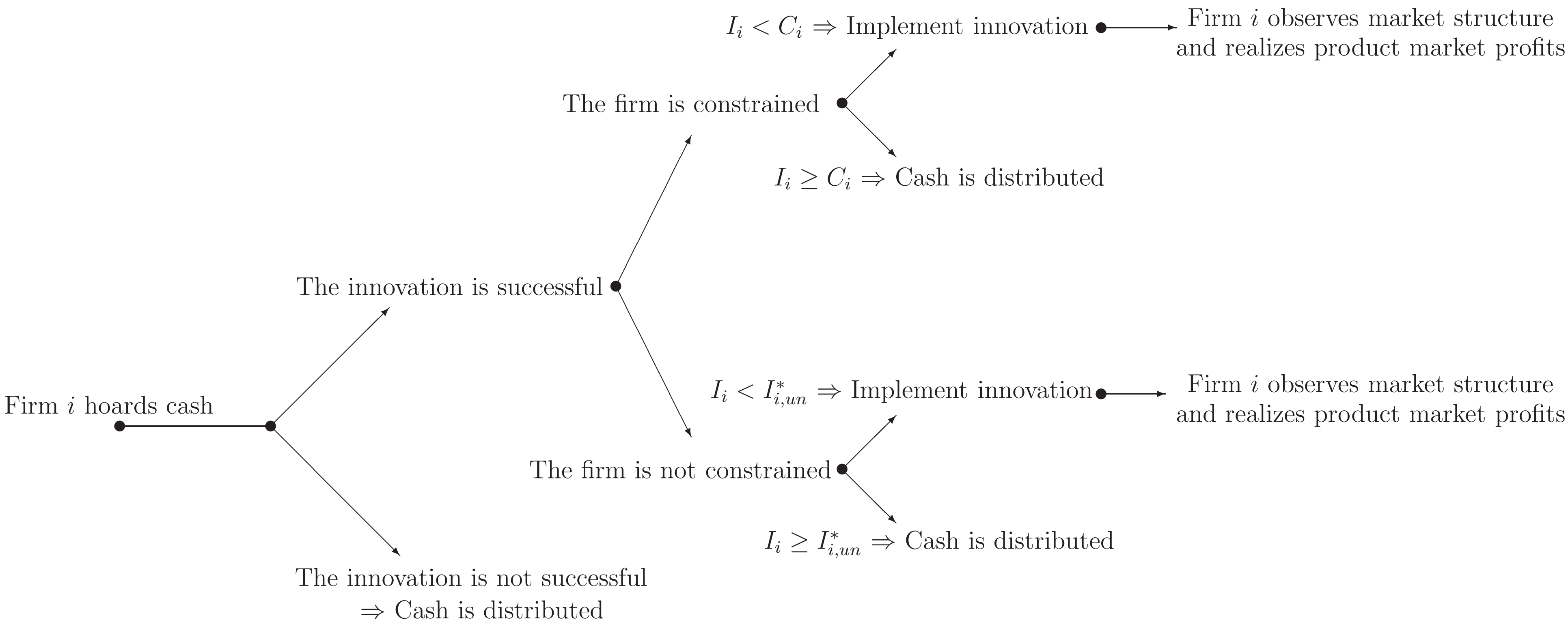
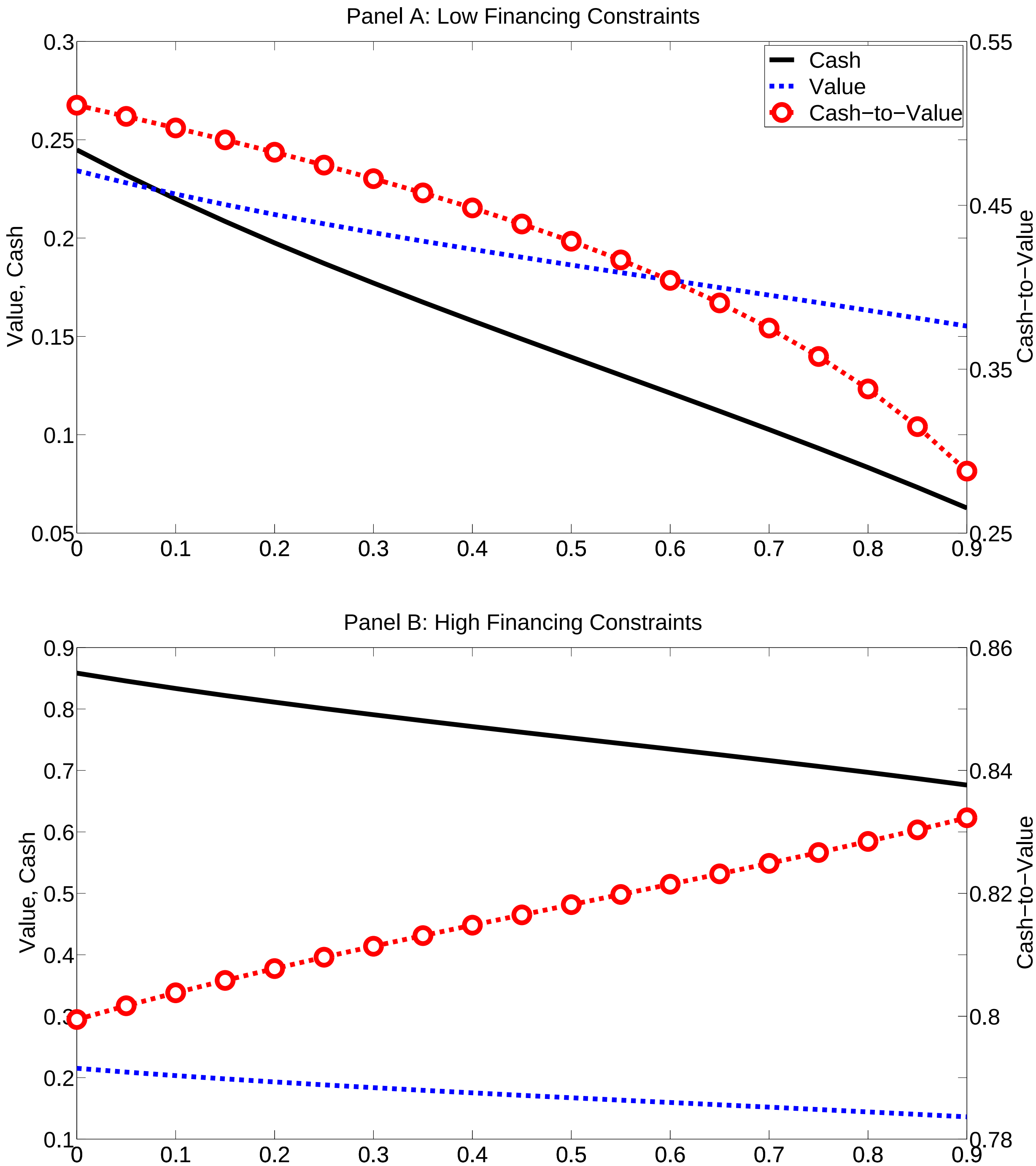
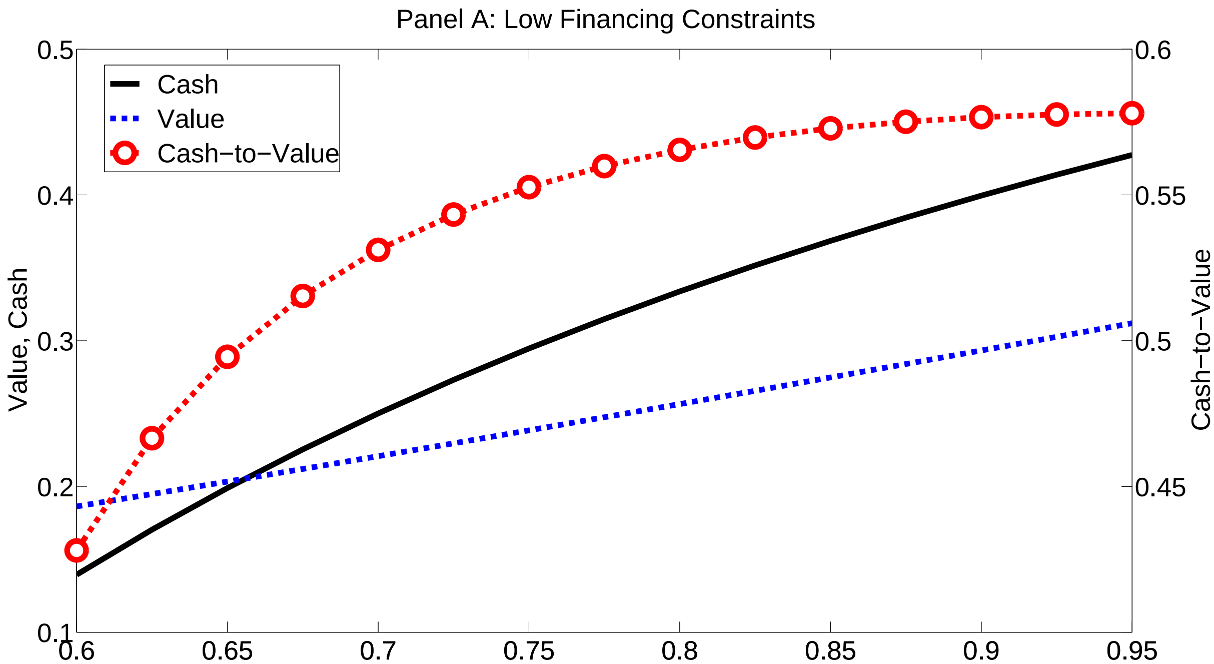


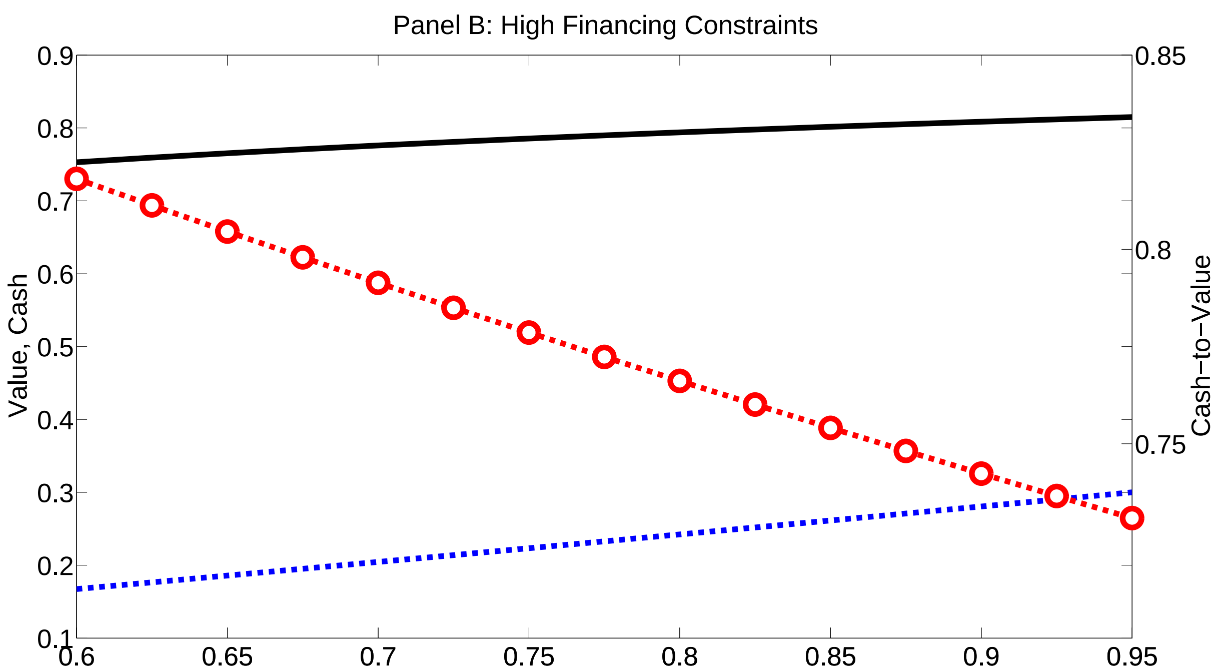
Figure 2: Competition Intensity, Firm Value, and Cash Holdings



The figure depicts the relation between equilibrium cash holdings, C_i^{EQ}/r and value, V_i^{EQ} (left y axis), and cash–to–value ratio, $\widetilde{C}_i^{EQ}$ (right y axis) and intensity of product market competition, γ (x axis). The solid line represents equilibrium cash holdings, the dashed line represents equilibrium firm value, and the dashed–dotted line represents equilibrium cash–to–value ratio. The parameters we use are: $r = 1.03$, $R = 1.10$, $\alpha_j = 0.4$, $\delta_i = \delta_j = 0.6$. We vary γ between 0 and 0.9. Panel A presents the case of low financial constraints, $\alpha_i = 0.15$, while Panel B depicts the case of high financial constraints, $\alpha_i = 0.8$.

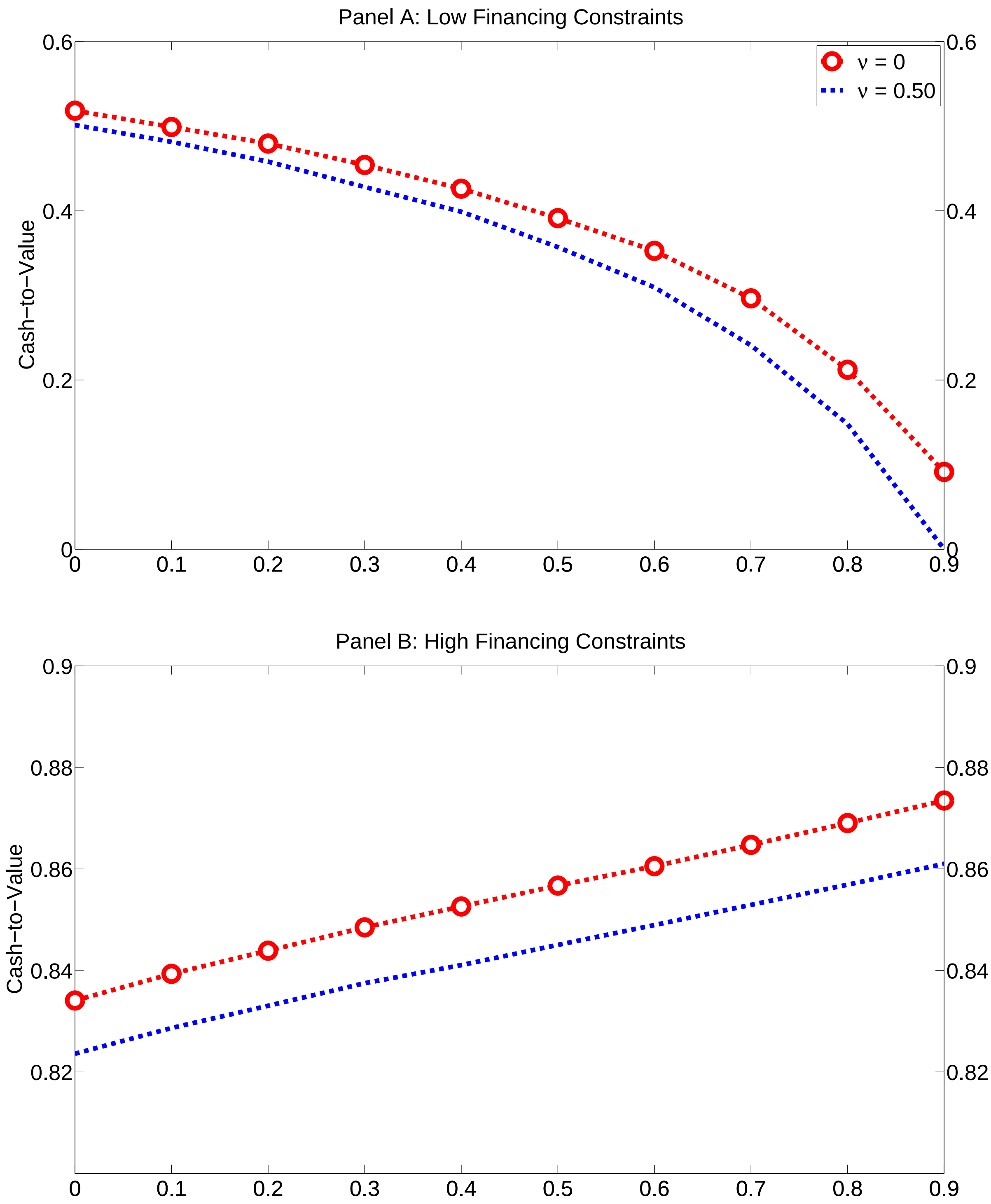
Figure 3: Innovation Efficiency, Firm Value, and Cash Holdings





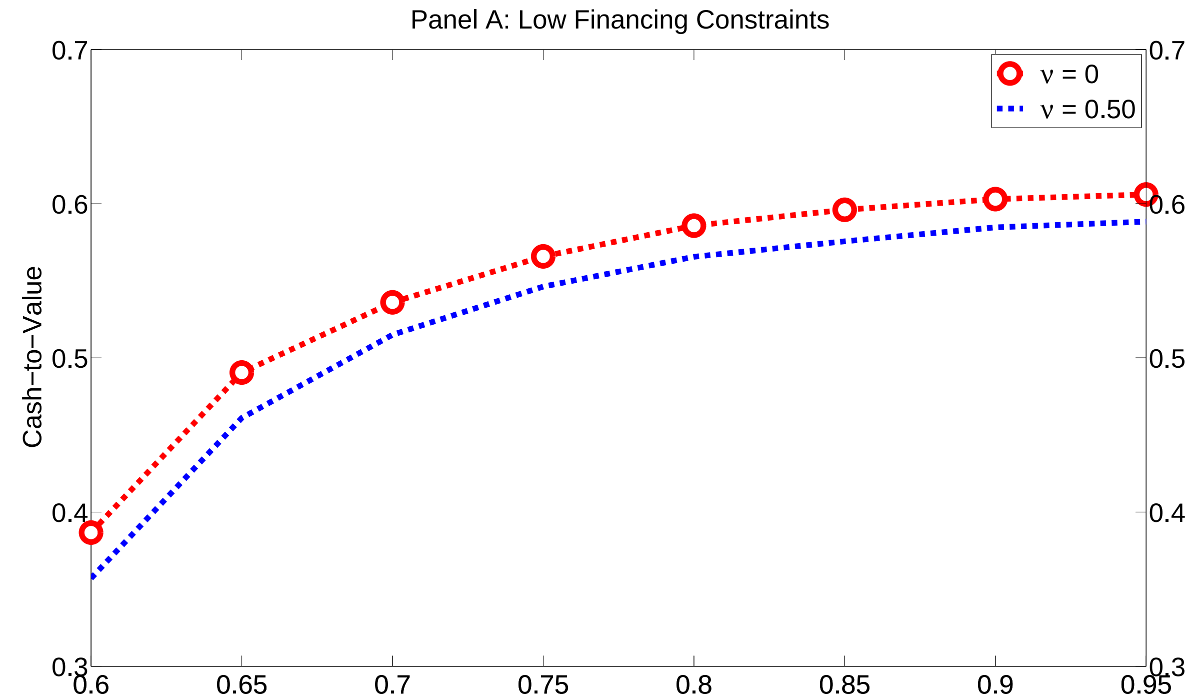
The figure depicts the relation between equilibrium cash holdings, C_i^{EQ}/r and value, V_i^{EQ} (left y axis), and cash–to–value ratio, $\widetilde{C}_i^{EQ}$ (right y axis) and firm–level innovation efficiency, δ_i (x axis). The solid line represents equilibrium cash holdings, the dashed line represents equilibrium firm value, and the dashed–dotted line represents equilibrium cash–to–value ratio. The parameters we use are: $r = 1.03$, $R = 1.10$, $\alpha_j = 0.4$, $\delta_j = 0.6$, $\gamma = 0.5$. We vary δ_i between 0.6 and 0.95. Panel A presents the case of low financial constraints, $\alpha_i = 0.15$, while Panel B depicts the case of high financial constraints, $\alpha_i = 0.8$.

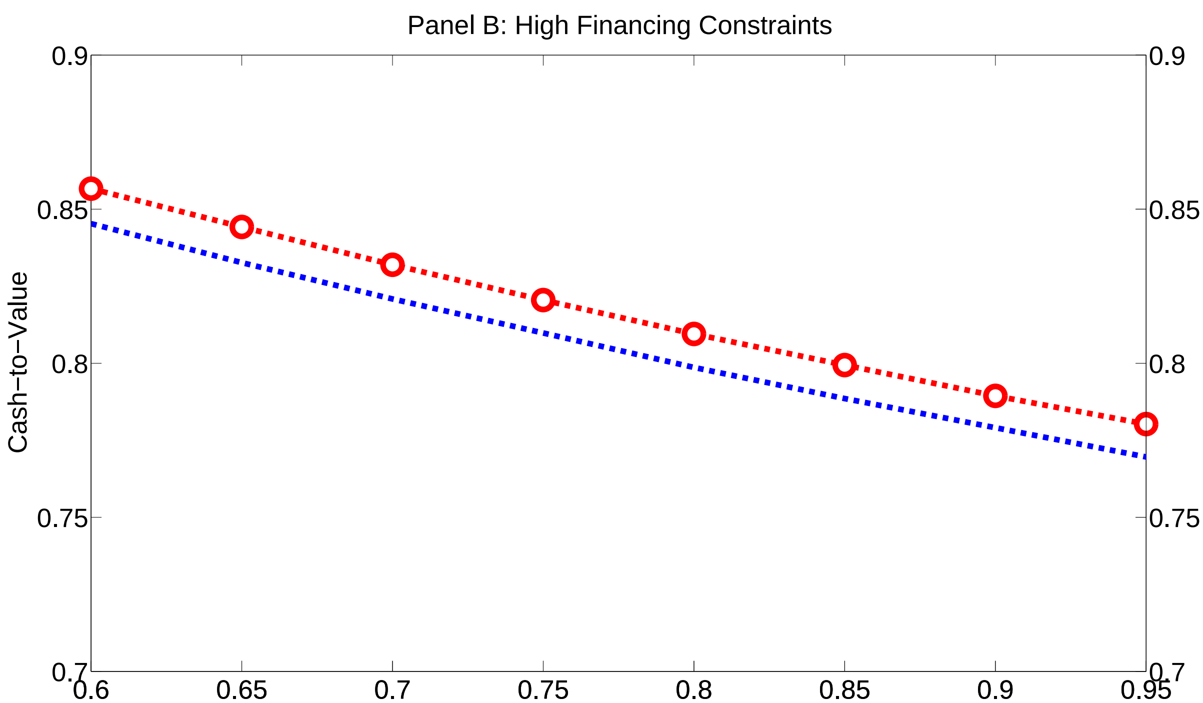
Figure 4: Competition Intensity, Firm Value, and Cash Holdings – Alternative Model



The figure depicts the relation between equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$, and intensity of product market competition, γ for two different values of R&D complementary. The the dashed–dotted line represents the case without complementarities ($\nu = 0$), while the dashed line represents the case with complemetarities ($\nu = 0.5$). The parameters we use are: $r = 1.03$, $R = 1.10$, $\alpha_j = 0.4$, $\delta_i = delta_j = 0.6$. We vary γ between 0 and 0.9. Panel A presents the case of low financial constraints, $\alpha_i = 0.15$, while Panel B depicts the case of high financial constraints, $\alpha_i = 0.8$.

Figure 5: Innovation Efficiency, Firm Value, and Cash Holdings – Alternative Model





The figure depicts the relation between equilibrium cash–to–value ratio, $\widetilde{C}_i^{EQ}$, and innovation efficiency, δ_i. The the dashed–dotted line represents the case without complementarities ($\nu = 0$), while the dashed line represents the case with complemetarities ($\nu = 0.5$). The parameters we use are: $r = 1.03$, $R = 1.10$, $\alpha_j = 0.4$, $\delta_j = 0.6$, $\gamma = 0.5$. We vary δ_i between 0.6 and 1. Panel A presents the case of low financial constraints, $\alpha_i = 0.15$, while Panel B depicts the case of high financial constraints, $\alpha_i = 0.8$.