Cash Holdings, Competition, and Innovation*

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Abstract

We demonstrate theoretically and empirically that strategic considerations are important in shaping cash policies of innovative firms. In our model, firms decide whether to invest in innovation while facing uncertainty regarding the structure of ensuing product markets. Cash holdings reduce innovative firms' dependence on external financing and, therefore, serve as a commitment device for future investment. We show that firms' equilibrium cash holdings are related to expected intensity of competition in future product markets and that this relation is affected by the degree of financial constraints that firms face. We test our model using a sample of firms that are direct competitors in innovation. Consistent with the strategic motive for hoarding cash, we show that firms' cash holdings are negatively affected by their rivals' cash holding choices, more so when competition is expected to be intense. In addition, we examine two instances of exogenous shocks to firms' costs of external financing and show that financial constrains influence the relation between firms' cash holdings and expected competition intensity in ways consistent with the model's predictions.

Key words: Cash holdings, Strategic interactions, Innovation

JEL Codes: G32, L13

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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 2013, the mean cash–to–assets ratio of firms belonging to the top quintile of R&D–to–assets ratio approached 56%, 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., Gamba and Triantis (2008) and Bolton, Chen, and Wang (2011)). In such an uncertain environment, internal cash holdings may have an important impact on the likelihood of developing innovations (e.g., Kamien and Schwartz (1978) and Schroth and Szalay (2010)).

Importantly, innovation does not happen in isolation: products resulting from firms' R&D are likely to be substitutes (e.g., Cockburn and Henderson (1994)). 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. There is a large theoretical industrial organization literature modeling strategic interactions among innovative firms (e.g., Scherer (1967), Dasgupta and Stiglitz (1980), Reinganum (1982), Harris and Vickers (1987), and Aghion and Griffith (2005) among many others). Such strategic interactions are also found in empirical studies of innovative industries (e.g., Cockburn and Henderson (1994) for the case of pharmaceuticals and Lerner (1997) for the case of disk drives).

Our focus is on the ways strategic interactions among innovative firms shape their cash holding policies. We begin by analyzing theoretically innovative firms' choices of cash holdings using a simple static model that incorporates strategic interactions. First, firms choose their cash holdings. Then they realize the costs required for innovation development and decide whether to invest in R&D using internal resources and, potentially, external funds. Importantly, firms may be financially constrained in the investment stage, in which case they have to rely on internal

[1] See, for example, Klette and Kortum (2004), Kogan, Papanikolaou, Seru, and Stoffman (2012), and Acemoglu, Akcigit, Bloom, and Kerr (2013) for the impact of innovation on growth and Himmelberg and Petersen (1994), Hall and Lerner (2009), and Brown and Petersen (2011) 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] Opler, Pinkowitz, Stulz, and Williamson (1999) and Bates, Kahle, and Stulz (2009) report that cash holdings are positively correlated with R&D expenditures, controlling for various other determinants of cash.

resources. Firms that invest in innovation are particularly vulnerable to potential inability to access external capital markets.[4] Because of the possibility of not having access to external funds, a firm with relatively large cash holdings is more likely to invest in innovation than a firm with smaller cash holdings. A firm's expected return to investment in innovation depends on the expected output market profit, which, in turn, depends on the future output market structure, i.e. whether the firm's competitor has also invested in innovation. A firm's innovation reduces the expected return to innovation by the firm's competitor and, as a consequence, it reduces the competitor's incentives to invest in R&D, which indirectly benefits the firm.

Our model has two important empirical implications. The first one is the negative impact of innovative firms' cash holdings on their competitors' cash holding policies. The intuition is that an increase in a firm's cash raises the likelihood of its investment in innovation, thus reducing the rival firm's expected profit and marginal benefit of holding cash. The strength of this negative effect is increasing in the intensity of competition between firms or, in other words, in the substitutability of products resulting from firms' innovations. The reason is that the closer substitutes the future products are, the larger the impact of one firm's innovation on the other firm's expected return from investment in R&D and the larger the impact of the firm's cash holdings on the marginal benefit of rival's cash.

The model's second empirical implication is that firms' equilibrium cash holdings are expected to be related to the extent of competitive interaction in future output markets. The magnitude (and, potentially, the sign) of the relation between cash holdings and expected competition intensity depends 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 less constrained firms, on the other hand, the relation between equilibrium cash holdings and competition intensity is weaker and potentially negative.

The intuition is as follows. There are two effects at play. The first one is precautionary: the more fierce the output market competition, the lower the expected marginal benefit of investing in innovation and the lower the firm's optimal cash holdings. The second effect, which we focus on, is strategic: higher cash holdings raise the firm's likelihood of investing in innovation and deter the rival from investing in its own innovation. Importantly, the strategic effect is only present when the firm is likely to be financially constrained, i.e. when it may need to rely exclusively on internal resources to finance investment in innovation, and the importance of strategic consid-

[4]One potential reason is that intangible capital cannot typically be pledged as collateral (e.g., Falato, Kadyrzhanova, and Sim (2013) Himmelberg and Petersen (1994) and Brown and Petersen (2011) 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." Hall and Lerner (2009) conclude that "large established firms [also] appear to prefer internal funds for financing R&D investments".

erations is larger the higher the degree of financial constraints that the firm faces. As a result, the relation between cash holdings and the expected competition intensity is more positive for relatively financially constrained firms, for which the strategic effect dominates.

Our model belongs to an emerging theoretical effort that bridges the literature on the relation between competition and innovation,[5] and the literature that examines the effects of interaction among firms in output markets on firms' financial policies.[6] 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 output market competeition on firms' optimal cash holdings.

The model that is most closely related to ours is Ma, Mello, and Wu (2013). Similar to us, they examine the joint choices of cash holdings and R&D investments by innovative firms. There are two main differences between the two models. First, we focus on the intensity of competition among firms in future output markets, as opposed to the "winner takes all" setting in Ma, Mello, and Wu (2013). Second, we study the effects of financial constraints on the relation between the intensity of competition and optimal cash holdings, and show that a firm's access to external funds plays a crucial role in shaping the relation between cash holdings and the competition intensity.

Another related paper is Morellec, Nikolov, and Zucchi (2014), who examine the effect of competition on optimal cash holdings in competitive industries. Differently from them, we focus on firms' cash holding choices in concentrated industries, in which strategic considerations play a major role. In addition, we focus on expected competition among innovative firms in future product markets, as opposed to current competition in existing product markets.

To examine the empirical importance of strategic choices of cash holdings by innovative firms, we begin by constructing a sample of firms that are direct competitors in innovation. We first identify all firms that are active innovators using the NBER Patent Citations Data Project, which provides information on firms' patents granted during the period 1976-2006 and citations to these patents. Among these firms, we search for firm–pairs that seem to compete directly in innovation. To identify such pairs, we examine pairwise similarities in the quantity, quality, and areas of innovation, and focus on firm–pairs that seem to be innovating in related areas and to have achieved innovations with comparable impact.

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, we show using a simultaneous equations framework, which accounts for the joint determination of competing firms' cash holdings, that an increase in a firm's cash holdings leads to a reduction in cash holdings of the

[5] See, for example, Aghion, Bloom, Blundell, Griffin, and Howitt (2005) and Vives (2008).

[6] See, for example, Telser (1966) and Bolton and Scharfstein (1990) for the case of cash holdings; Brander and Lewis (1986), Maksimovic (1988), and Showalter (1995) for the case of capital structure; Hackbarth and Miao (2012) and Bernile, Lyandres, and Zhdanov (2012) for the case of mergers and acquisitions; and Chod and Lyandres (2011) for the case of initial public offerings.

firm's competitor. This negative effect is stronger the higher the expected intensity of competitive interaction in future output markets between the two firms.

Second, we demonstrate that the effect of expected competition intensity on firms' cash holding choices depends crucially on the degree of financial constraints that firms face. We begin by splitting the sample into subsamples of relatively constrained and unconstrained firms using common measures of financial constraints, and estimating the relation between expected competition intensity and cash holdings within these subsamples. We show that the intensity of 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.

The association between cash holdings and competition intensity within subsamples of firms with varying degrees of financial constraints does not necessarily imply a causal effect of competition intensity on cash holdings, highlighted in our model. In addition, Farre-Mensa and Ljungqvist (2014) argue that common proxies for financial constraints may fail to identify firms that behave as constrained. Thus, we move beyond the cross-sectional analysis and examine the effects of exogenous changes in firms' financial constraints on the relation between expected competition intensity and firms' cash holdings. In particular, we use two shocks to firms' ability to raise external financing.

First, we focus on the contraction in the supply of credit in 1989, driven by the collapse of the junk bond market, which was especially pronounced in the Northeastern part of the United States (e.g., Jordan (1998), Owyang, Piger, and Wall (2005) and Lemmon and Roberts (2010)). Our difference-in-differences analysis shows that following the negative shock to the supply of credit, the association between expected competition intensity and cash holdings increased dramatically for firms headquartered in the Northeast, while firms headquartered elsewhere did not experience such an increase.

Second, we examine a series of monetary policy surprises in 1994, a year in which the Fed Funds target rate increased by cumulative 300 basis points. Over 20% of this increase (65 basis points) has been unanticipated by the capital markets (e.g., Kuttner (2001)). Importantly, this increase in the costs of external financing was not accompanied by an economic contraction, which could affect firms' incentives to invest in innovation. Our identification strategy relies on the differences in responses of large versus small firms to monetary supply shocks (e.g., Gertler and Gilchrist (1994) and Leary (2007)). Consistent with the model's prediction and with small firms' access to capital markets being affected more by monetary policy shocks than that of large ones, we find that the relation between expected competition intensity and cash holdings increased substantially for relatively small firms following the 1994 monetary policy shock, while no such effect was present for larger firms.

Realizing that cash holdings may not be a firm's only source of liquidity (e.g., Lins, Servaes, and Tufano (2010), Colla, Ippolito, and Li (2013), and Acharya, Almeida, Ippolito, and Perez (2014)), we examine whether our findings of the strategic effect of cash and the impact of competition intensity on observed cash holdings are robust to extending the analysis to firms' overall liquidity, which combines cash holdings and bank lines of credit. While the use of Capital IQ data on credit lines restricts our analysis to a short period encompassing years 2002 to 2006, our evidence suggests that the inclusion of credit lines in a measure of total liquidity does not impact our main findings.

Our empirical analysis provides new insights on the nature of the relation between the extent of competition in output markets and firms' cash holdings (e.g., Haushalter, Klasa, and Maxwell (2007) and Hoberg, Phillips, and Prabhala (2014)). First, we complement Hoberg, Phillips, and Prabhala (2014) by using a novel measure of expected competition intensity, which is based on firms' innovation activities. The advantage of our measure in the context of innovating firms is that it focuses on expected competition in markets created following successful innovation, as opposed to future competition in existing product markets. Second, we complement both Haushalter, Klasa, and Maxwell (2007) and Hoberg, Phillips, and Prabhala (2014) by showing that the relation between cash holdings and the extent of competition among innovative firms depends on the degree of financial constraints. Overall, our empirical analysis shows that cash serves an important strategic role for firms that compete in innovation, in addition to its precautionary role.

The remainder of the paper is organized as follows. In the next section we present a stylized model of strategic cash holdings in the context of competition in innovation. In Section 3, we discuss data and sample construction. Section 4 presents tests of the strategic effect of cash holdings. In Section 5, we examine the effects of expected competition intensity and of financial constraints on firms' cash holding choices. Section 6 contains robustness tests, in which we examine the strategic effect of total liquidity and the relation between liquidity and the intensity of competition. Section 7 summarizes and concludes. Appendix A contains proofs of the model's results. Appendix B provides a detailed description of the variables used in the empirical analysis.

2 Model

2.1 Setup and assumptions

Assume that an industry consists of two firms, i and j. Each firm is engaged in research and development (R&D) of an innovative product. The cost of R&D is initially uncertain. Following the realization of the cost required for obtaining successful R&D, a firm decides whether to make the R&D investment using internal and possibly external resources. Given the initial uncertainty regarding the costs of the two firms' R&D activities, a firm that has invested in R&D may either become a monopolist in the output market or it may compete in it with another firm that has also made the investment in innovation.

In the beginning of the game each firm chooses the amount of cash to finance its future investment, C_i for firm i. Following Holmstrom and Tirole (1998), we assume that the size of required investment is stochastic and the each firm only knows its distribution when choosing its cash holdings. After the cash holding decision, each firm observes its realization of the investment in R&D that is required for successful innovation, I_i for firm i. We assume that I_i is independent across the two firms, and is distributed uniformly in [0,1]. This is a reduced-form way of modeling an R&D process, in which we focus on the cost of the last stage of innovation activity, while assuming that the initial stage(s) of R&D process, in which firms acquire information on the required cost of successfully completing their R&D, are costless.[7] Note that the setting in which the required investment cost is uncertain ex-ante is especially suitable for innovative firms, which are the focus of our paper.

In addition, each firm realizes an independent shock to its ability to obtain external financing that may be required for R&D investment. 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, C_i, in 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 $I_i - C_i > 0$. In what follows, we refer to α_i as firm i's degree of financial constraints.[8]

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 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 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, the two firms decide simultaneously and non-cooperatively whether to invest in R&D. Firms that make the investment produce and realize output market profits. The number of firms that end up competing in the output market is either

[7] An extended model, which features costly first-stage R&D is available upon request. The results of the reduced-form model presented here are qualitatively similar to those of the extended model.

[8] The assumption of independence of firms' required investment and the shock to external financing, as well as the distributional assumptions simplify the algebra but do not affect the qualitative results. In addition, 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.

zero, or one, or two. If only one firm innovates, it obtains monopolistic profit, $\pi_M > 0$. If both firms innovate, 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).

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 we make are 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 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 investment in innovation and realization of output market profits on the other hand, R, is higher than the internal accumulation rate of cash between these two points in time, $r < R$.[9] We also assume that firm owners are risk–neutral and maximize their firms' expected values.

2.2 Solution

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

2.2.1 Investment in innovation

If firm i has access to external finance and is not limited by its cash holdings, it would invest in R&D as long as the expected product market profit, $\mathbb{E}\pi_i$, exceeds the cost of R&D 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) invests in 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

[9] This assumption may be justified by a carry cost of liquid assets (e.g., Opler, Pinkowitz, Stulz, and Williamson (1999) and Morellec, Nikolov, and Zucchi (2014)), tax considerations (e.g., Riddick and Whited (2009)), or agency costs (e.g., Eisfeldt and Rampini (2009)).

be used for investment in 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 invests in R&D, ω_j, is

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

where $F(I_{j,un}) = I_{j,un}$ and $F(C_j) = C_j$ are the probabilities of firm j investing in innovation (i.e., the probabilities that the realization of the investment shock is lower than the unconstrained investment threshold or than cash holdings, in the unconstrained and constrained cases respectively). Firm j's probability of investing in innovation is affected by several variables: (i) the likelihood of firm j being shut out of the external finance market, α_j; (ii) firm j's unconstrained innovation threshold, $I_{j,un}$, which depends on its expected product market profit; (iii) 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 threshold in Equation (1) and a symmetric expression for ω_i into a similar equation for firm j's unconstrained investment threshold. The solution of this system of equations delivers the following optimal unconstrained innovation threshold for firm i as a function of both firms' cash holdings:

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

and a similar threshold for firm j.

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

Lemma 1 *Firm i's equilibrium unconstrained innovation 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 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 invest in innovation in the constrained state, which raises the unconditional likelihood that firm j would invest in 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 firm j's financial constraints, α_j, and the lower the duopoly profit, π_D (i.e. the larger the product substitutability between the two firms, γ). The intuition is as follows. Rival's cash has a stronger negative effect on a firm's expected profit when the rival is more 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 larger (since strategic considerations are only important when firms' actions have a material impact on their rivals' values).

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

2.2.2 Cash holdings

Firm i maximizes its value, V_i, with respect to its cash holdings:

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

Firm i decides to hold C_i/r, which is carried over as C_i to the investment stage. If the firm is shut out of the external capital markets (which happens with probability α_i) then under the uniform distribution assumption its likelihood of investing equals C_i, and the expected product market profit conditional on investing is $(I^*_{i,un} - C_i/2)$. Similarly, if the firm has access to external funds, its likelihood of investing in innovation is $I^*_{i,un}$, and its expected profit conditional on investing is $I^*_{i,un}/2$.

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

$$C^*_i(C_j) = \frac{r(1+\alpha_i-\Phi_i) - R\left(1-(1-\alpha_i)\Phi_i\right) - r\alpha_i(1-\alpha_j)\Delta_\pi \pi_D}{r\alpha_i(1-\Phi_i)} - \frac{\alpha_j \Delta_\pi}{1-\Phi_i} C_j, \tag{6}$$

where $\Phi_i = (1-\alpha_j)\,\Delta^2_\pi$. Differentiating firm i's cash holdings in Equation (6) with respect to firm j's cash holdings leads to the following result, which describes the effect of firms' cash holding decisions on their rival's choice of cash holdings.

Proposition 1 *1) Firm i's reaction function in cash holdings, $C^*_i(C_j)$, is downward sloping:* $\frac{\partial C^*_i(C_j)}{\partial C_j} < 0$.
2) The slope of the reaction function, $\frac{\partial C^*_i(C_j)}{\partial C_j}$, is decreasing in the intensity of output market competition, γ: $\frac{\partial^2 C^*_i(C_j)}{\partial C_j \partial \gamma} < 0$.

The reason for the negative effect of firm 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 invest in innovation in the constrained state. Higher probability of investment in innovation in the constrained state leads to higher rival's unconditional likelihood of investing in innovation, and to lower firm's expected product market profit, leading to lower marginal benefit of holding cash and lower resulting optimal cash holdings. This negative effect is stronger the larger the impact of rival's innovation on the firm's expected profit, i.e. the higher the intensity of future output market competition.

Using the two firms' optimal cash holdings reaction functions, we can derive the following expressions for firm i's equilibrium cash holdings and unconstrained investment threshold:

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

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

Similar expressions hold for firm j.

Two remarks are in order regarding Equation (7) and Equation (8). First, the equilibrium unconstrained investment threshold is always higher than equilibrium cash holdings: $I_{i,un}^{EQ} - C_i^{EQ} = \frac{R-r}{\alpha_i r} > 0$. 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. Since 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:

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

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 the likelihood of being financially constrained, α_i, since the marginal benefit of cash is increasing in the likelihood of the 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 constraint parameters:

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

for firm i, and a similar restriction for firm j's financial constraints parameter, α_j. The intuition is that for a 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 innovative firms' (positive) cash holdings, we assume that the conditions in Equation (9) and/or Equation (10) are satisfied.

The equilibrium value of firm i is

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

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

We proceed by analyzing the effect of the intensity of future output market competition between firms i and j, γ, on their equilibrium cash holdings. Since a change in γ affects firm values even when their cash holdings are held constant, in what follows we normalize a 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 discuss the comparative statics of firm i's normalized equilibrium cash holdings.[10]

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

Abstracting from the strategic effect of cash, discussed in Lemma 1, it follows from Equation (5) that the marginal benefit of holding cash is $\alpha_i\left(\mathbb{E}\pi_i - C_i\right)/R$. An increase in γ leads to a reduction in π_D, and, as a consequence, to a reduction 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 its marginal benefit (i.e., when $\mathbb{E}\pi_i = \frac{R-r}{\alpha_i}$). 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

[10] $\widetilde{C}_i^{EQ}$ in Equation (12) 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, $\widetilde{C}_i^{EQ} = \frac{C_i^{EQ}/r}{V_i^{EQ}}$.

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 increasing in 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 investment in innovation if cash is useful (i.e., in situations in which access to external capital is restricted) and if the 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.

2.3 Summary of empirical predictions

The off-equilibrium results on firms' reaction functions in cash holdings, summarized in Proposition 1, lead to the following empirical prediction.

Prediction 1
1) The effect of a change in a firm's cash holdings on its rival's cash holdings is expected to be negative.
2) The strength of this negative effect is expected to be increasing in the intensity of expected future output market competition.

The comparative statics in Proposition 2 concern the relative magnitudes of the effect of the intensity of output market competition on equilibrium cash holdings of relatively constrained and unconstrained firms.

Prediction 2
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.

3 Data and sample construction

3.1 Data sources

We employ two data sources in our empirical tests. The first one is the NBER Patent Citations Data Project,[11] which we use to identify industries in which firms innovate, to develop a measure

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

of expected product market competition intensity, and to construct a sample of firms that compete in innovation. The second data source is the CRSP/Compustat Merged Database, which provides information on various accounting variables that we use in our analysis.

The NBER Patent Data Citations Project contains data on all utility patents granted by the U.S. Patent and Trademark Office (USPTO) between 1976 and 2006. For each patent, the dataset provides 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 Hall, Jaffe, and Trajtenberg (2001), and the number of times a patent has been cited.

3.2 Construction of sample of competitors in innovation

Our model focuses on firms whose cash holding choices are partly motivated by strategic considerations, i.e. firms that attempt to influence cash holdings and investment choices of their rivals. As a consequence, to test the model's predictions empirically, we need to identify a sample of firms for which strategic considerations are important. In our setting, these are firms that are likely to be close competitors in innovation. Our procedure for identifying firms that closely compete in innovation is as follows.

We begin by splitting the sample into three sub–periods, or "cohorts": 1977-1986, 1987-1996, and 1997-2006. Within each of the three cohorts we identify firm-pairs that satisfy the following criteria that are aimed at finding close competitors. First, we restrict our attention to firm-pairs that operate in the same 4-digit SIC industries because a definition of industry boundaries using 4-digit SIC codes allows for a better identification of firms that overlap both in the technology space and in future product markets.[12]

Second, since we are interested in firms that interact with each other strategically, we require that each firm in a pair would have non-missing cash holdings data for 10 years. Third, since strategic interactions are more likely among firms that are similar in size, we focus on firm-pairs that have similar sales on average throughout the cohort period. In particular, we restrict the sample to firm-pairs in which the average ratio of sales of the larger firm to sales of the smaller one does not exceed 5.[13]

Fourth, and perhaps most importantly, for each firm-pair we estimate a measure of the intensity of expected output market competition. Our measure is based on the idea that competition

[12]For example, consider two companies that belong to 2-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 these two companies are not likely to be competing in future product markets, highlighting an importance of a finer industry classification.

[13]The results are insensitive to variations in either of the two restrictions.

intensity is increasing in product substitutability (e.g., Syverson (2004) and Goettler and Gordon (2014)). 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 the proximity between firms' R&D activities and to the expected similarity of the impacts of the firms' innovations. For example, products of two firms that operate in the same industry, file all of their patents in the same set of patent categories, and whose patents have similar citation counts are likely to be more substitutable than products of two firms that have little overlap in patent areas and impact. 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 Hoberg, Phillips, and Prabhala (2014) in order to focus on *expected (future)* competition, which is based on proximity of firms' innovations. We discuss the construction of our measure of expected competition intensity in the next subsection.

Finally, after computing a measure of innovation proximity for each pair of firms that satisfy the aforementioned criteria, we focus on pairs that we consider to be the closest competitors in innovation. In particular, two firms are considered close competitors if there is no other pair within the same 4-digit SIC industry that includes one of the two firms and has a higher measure of innovation proximity.[14] As a result of this exercise, we are able to identify 786 firm-pairs over one of the three 10-year cohorts, for a total of 15,720 firm-year observations.

3.3 Measure of expected competition intensity

To measure how close two firms' R&D activities are and how intense the competition between them is expected to be, we follow Bena and Li (2014) and adopt a measure of innovation proximity based on Jaffe (1986). 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 two–digit technological subcategories, and $C_{i,t,k}$ is the number of citations to firm i's patents awarded in class k in year t. We use the number of citations to patents as a measure of R&D outcome, since Hall, Jaffe, and Trajtenberg (2005) 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.

We measure the number of citations to each patent following Bena and Li (2014). First, we consider only patents granted in year t that have an application year that precedes the granting year by at most three years. Then, for each patent we evaluate the total number of citations that the patent received within three years from the granting year. Since NBER patent data end in 2006,

[14]For example, consider an industry with 4 firms: a, b, c, and d. The pairwise innovation proximities, which we denote $\gamma_{i,j}$ are as follows: $\gamma_{a,b} = 0.5$, $\gamma_{a,c} = 0.2$, $\gamma_{a,d} = 0.4$, $\gamma_{b,c} = 0.1$, $\gamma_{b,d} = 0.3$, and $\gamma_{c,d} = 0.9$. For the pair $\{a, b\}$, there is no other pair that includes either a or b and has higher proximity than $\gamma_{a,b}$. The same is true for the pair $\{c, d\}$. On the other hand, if $\gamma_{a,b}$ were equal 0.3, then the only pair of competitors in the industry would be $\{c, d\}$.

to obtain the number of citations to patents granted in years 2004–2006, we supplement the NBER patent data with patent citations data for years 2007–2009, discussed in Kogan, Papanikolaou, Seru, and Stoffman (2012).

We proceed by calculating the quantity $\gamma_{i,j,t}$, defined as the pairwise innovation proximity of firm-pair i, j in year t:

$$\gamma_{i,j,t} = \frac{\sum_{k=1}^{K} \min[C_{i,t,k}, C_{j,t,k}]}{\max[\sum_{k=1}^{K} C_{i,t,k}, \sum_{k=1}^{K} C_{j,t,k}]}. \quad (13)$$

$\gamma_{i,j,t}$ is bounded between 0 and 1. If $\gamma_{i,j,t}$ equals 1, then firms i and j have the exact same numbers of citations to patents in each of 36 two-digit technological categories. On the other hand, if $\gamma_{i,j,t}$ equals 0, then the two firms do not share citations to patents assigned to any two-digit technological category. To compute a pair-cohort-level measure of innovation proximity, $\gamma_{i,j}$, we average $\gamma_{i,j,t}$ over the cohort period.[15]

3.4 Examples of competitors

Table 1 presents a sample of top 10 competitors in innovation (i.e. firm-pairs with the highest measures of innovation proximity) in each of the three cohorts. By construction, top competitors have high innovation proximity, which is a result of firms not only performing R&D in related technological areas, but also having similar degree of success in their innovations, as evident from the total number of citations to patents granted to firms within each pair. The sales ratio, which by construction can be as high as 5, is close to one in many cases, indicating that firms that we identify as close competitors often have very similar sizes.

Importantly, a comparison of verbal descriptions of firms' business activities (Compustat item `BUSDESC`) suggests that we are successful at identifying firms that are likely to be competing in future markets for products that result from current investments in innovation.

3.5 Measures of financial constraints and control variables

We merge our sample of firms competing in innovation with Compustat to construct measures of financial constraints, as well as control variables that were found in past studies to be related to firms' cash holdings.

Measures of financial constraints

[15]Consider Criticare Systems Inc. (firm i) and Somanetics Corp. (firm j), two competitors in our sample. Somanetics has 220 citations to patents granted in 1996 in only one technological category (Surgery and Medical Instruments). Criticare Systems has 255 citations in the same category as Somanetics and 13 citations in other categories (3 in Gas and 10 in Nuclear and X–rays). It follows that $\sum_{k=1}^{K} \min[C_{i,t,k}, C_{j,t,k}]$ is 220, while $\max[\sum_{k=1}^{K} C_{i,t,k}, \sum_{k=1}^{K} C_{j,t,k}]$ equals 268. The pairwise proximity in 1996 is 0.821.

One of the most important determinants of financial constraints is the degree of information asymmetry between a firm and the capital market (e.g. Leland and Pyle (1977) and Myers and Majluf (1984)). 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., Gilchrist and Himmelberg (1995) and Erickson and Whited (2000)) and the cash holdings literature (e.g., Han and Qiu (2007)) 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. Therefore, we use the size–age (SA) index, proposed by Hadlock and Pierce (2010) as our first measure of firm-level financing constraints.

Whited and Wu (2006) 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 financial constraints.

Finally, following Fazzari, Hubbard, and Petersen (1988), Cleary (1999), and Han and Qiu (2007) 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.

Control variables

The cash holdings literature has identified a set of key variables that help explain firms' cash holding choices. We follow Bates, Kahle, and Stulz (2009) and include in our analysis of cash holdings the following variables: Market-to-book ratio, to control for future investment opportunities; Size, to control for economies of scale to raising cash; Cash flow, since firms with higher cash flows are likely to require lower precautionary cash holdings; Industry-level cash flow volatility, which may increase the precautionary savings motive; Net working capital, since it can be considered a substitute for cash; Investment, defined as capital expenditures plus acquisitions, since they 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. In addition, following Pinkowitz, Stulz, and Williamson (2012), we use a dummy variable that equals one if a firm can be classified as a multinational and equals zero otherwise.

3.6 Summary statistics

Table 2 reports summary statistics for the dependent variable (cash–to–assets ratio) and independent variables. The first row shows that the mean (median) cash–to–assets ratio of a firm in our sample is 0.15 (0.08), higher than the respective values in Opler, Pinkowitz, Stulz, and Williamson (1999) and in Almeida, Campello, and Weisbach (2004). 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 four rows summarize the U.S. patent citations data used to construct our measure of pairwise competition intensity based on innovation proximity among firms. The average (median) number of patents that firms in our sample are granted annually is 20 (2). The distribution of patent grants is highly right–skewed and its standard deviation is large (80). 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 40 (1) and the standard deviation of the number of citations is 205. Many firms are granted patents in multiple technology classes: the mean number of classes in which firms are granted patents in a given year is 3, while the maximum is 35. Our measure of γ based on innovation proximity has mean (median) of 0.3 (0.27). There is a large variation in γ, which ranges from 0.001 to 0.854 (in the case of Cortex Pharmaceuticals and Marina Biotech in the last cohort, as shown in Panel C of Table 1).

The next three rows present the statistics for our three financial constraint measures. The correlation between the SA–index and WW-index is 0.81, a value almost identical to the 0.80 reported in Hadlock and Pierce (2010). Around 69% of firms in our sample pay a dividend or repurchase shares in a given year.

The mean (median) market-to-book ratio is 2.08 (1.42), 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 natural logarithm of the total book value of assets adjusted for inflation (in millions, using 1984 dollars as the base) – of 5.45, corresponding to 233 million in assets and generates cash flow of 3% of assets, while the median firm has book assets worth 233 million and cash-flow-to-assets ratio of 7%. The net working capital – evaluated net of cash holdings – of the average (median) firm is 0.14 (0.16). The mean (median) investment–and–acquisitions–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 0.22 (0.19), somewhat lower than typical in capital structure studies (e.g., Frank and Goyal (2009)) and consistent with the negative relation between growth options and optimal leverage (e.g., Rajan and Zingales (1995) and Barclay, Morellec, and Smith (2006)). R&D expenditures-to-assets ratio takes the average value of 0.06 and more than 50% of firms in our sample have R&D expenditures over assets larger than 0.027. Around 60% of our sample can be classified as multinationals.

4 Strategic effect of cash

One of the main takeaways from our model is the impact of a firm's cash holdings on the optimal choice of the its rival's cash holdings, implying strategic considerations in cash holding policies. In particular, Prediction 1 states that a firm's cash is expected to have a negative impact on its rival's optimal cash, and that the magnitude of this negative effect is expected to be increasing in the intensity of interaction between firms in future output markets. In this section, we test this prediction.

The obvious concern when estimating the impact of one firm's cash holdings on the choice of another firm's cash is that both firms' cash holdings are chosen endogenously in equilibrium. To address the endogeneity of cash holdings, we follow Denis and Sibilkov (2010) and Harford, Klasa, and Maxwell (2014) and estimate a system of equations in which the two firms' cash holdings are jointly determined, which corresponds to the theoretical cash holdings reaction functions in Equation (6).[16] In particular, we estimate the following system of two equations while employing a two-stage least squares (2SLS) methodology:

$$\begin{cases} \Delta Cash_{i,t} = \beta_{rival}\Delta Cash_{j,t} + \beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_t + \nu I_k + \varepsilon_{i,t}, \\ \\ \Delta Cash_{j,t} = \beta_{rival}\Delta Cash_{i,t} + \beta_{\mathbf{1}}\mathbf{X_{j,t}} + \phi D_t + \nu I_k + \varepsilon_{j,t}, \end{cases} \tag{14}$$

where $\Delta Cash_{i,t}$ ($\Delta Cash_{j,t}$) is the change in firm i's (j's) cash holdings between years $t-1$ and t, $\mathbf{X_{i,t}}$ ($\mathbf{X_{j,t}}$) is the vector of cross-sectional determinants of firm i's (j's) year-to-year change in cash holdings, and D_t and I_k are year and industry fixed effects respectively, as in Harford, Klasa, and Maxwell (2014). Following Palazzo (2012), the vector of control variables includes lagged cash holdings, size, market–to–book, cash flow, investment plus acquisitions, and net debt issuance.[17] The system of equations in 14 corresponds to cash holding reaction function in the model.

In the first stage of the 2SLS estimation, we estimate two OLS regressions of the change in each firm's cash holdings on its determinants, discussed above. Then, we simultaneously estimate the second-stage regressions while including the predicted values of changes in firms' cash holdings

[16] Denis and Sibilkov (2010) estimate equilibrium choices of cash holdings and investment when both are chosen endogenously, while Harford, Klasa, and Maxwell (2014) estimate simultaneous choices of cash holdings and debt maturity.

[17] We depart from Palazzo (2012) and do not include net equity issuance in the vector of explanatory variables. The reason is that large parts of net equity issuance proceeds are kept as cash (e.g., McLean (2011). Therefore, net equity issuances are a way to implement a cash holdings policy, not necessarily a determinant of the policy.

from the first-stage regressions in the set of explanatory variables. As in Harford, Klasa, and Maxwell (2014), we cluster standard errors at the firm level.[18]

Table 3 reports the results of estimating the system of equations in 14. In column 1, for comparison purposes, we report the results of the OLS estimation, which ignores the effect of a firm's cash holdings on its rival's cash holdings. Columns 2–5 report the results of the second-stage estimation of 2SLS, which accounts for the simultaneous choices of both firms' cash holdings while including/excluding industry and year fixed effects.

Column 1 shows that a pooled OLS regression is unable to uncover the strategic effect of a change in a firm's cash holdings on its rival's cash holdings. The coefficient on β_{rival} is very close to zero and not statistically significant. On the other hand, the results of the 2SLS specification show that a change in a firm's cash holdings has a statistically significant impact on the change in its rival's cash holdings. Equally important, the effect of firm's cash on its rival's cash holdings choice is economically large. In all four specifications, a one percentage point increase in firm's cash holdings leads to a 0.11 to 0.14 percentage points reduction in the firm's rival's cash holdings. Alternatively, a one-standard deviation increase in firm's cash holdings (0.19, from Table 2) leads to a reduction of over 2 percentage points in the firm's rival's cash holdings.[19]

The second part of Prediction 1 states that the effect of a firm's cash holdings on its rival's cash holdings is expected to be stronger when the intensity of future competition, γ, is higher. To test this prediction, we separate the sample into subsamples that include firm-pairs for which the estimated γ is above median and below median in a given year, and estimate 2SLS regressions within the high-γ and low-γ subsamples.

Table 4 presents the results of the subsample estimation of the system of equations 14. To save space, we only report the coefficients on the change in rival's cash, β_{rival}. The first row reports β_{rival} for the low-γ subsample. β_{rival} ranges between -0.025 and -0.062, and in all 4 specifications it is statistically insignificant. By contrast, in the second row, which reports the results for the high-γ subsample, the coefficients are 3–6 times larger in absolute value and are highly statistically significant. In the subsample of firms expecting intense future competitive interactions, the effect of an increase of \$1 in firm's cash leads to 16–19 cent reduction in its rival's cash holdings. Moreover, the differences in β_{rival} between the two subsamples are statistically significant at the 10% level. These results are consistent with the strategic effect of cash holdings being more pronounced in the subsample of innovative firms that expect to compete intensely in future output markets.

[18] We also perform a three–stage least square (3SLS) estimation to take into account the simultaneous correlation across errors in the system of equations. The 3SLS estimates are very close to the 2SLS estimates reported below.

[19] Statistics reported at the bottom of Table 3 suggest that our instruments are jointly significant, valid, and the model is identified and it does not suffer from the weak identification problem.

5 Cash holdings, competitive interaction, and financial constraints

5.1 Cross-sectional regressions

The model's second empirical prediction concerns the effect of expected output market competition on cash holding choices of firms facing various degrees of financial constraints. We begin by examining the cross-sectional association between our measure of competition intensity, γ, and firms' cash holdings for subsamples of relatively unconstrained and constrained firms. Our empirical specification takes the following form:

$$Cash_{i,t} = \beta_0 + \beta_\gamma \gamma_{i,j,t} + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t}, \tag{15}$$

The dependent variable, $Cash_{i,t}$, is cash–to–assets ratio;[20] $\gamma_{i,j,t}$ is the intensity of competition that firm i is expected to face, proxied by innovation proximity between firm i and its closest rival, firm j; $\mathbf{X_{i,t}}$ is a vector of control variables; D_t is a vector of year dummy variables; and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term.

In Table 5, we report results of estimating Equation (15) for subsamples of firms classified as relatively financially unconstrained and relatively financially constrained. In columns 1 and 2, firms are classified as unconstrained (constrained) if they belong to the bottom 50% (top 50%) of the annual SA–index distribution. In columns 3 and 4, firms that belong to the bottom 50% (top 50%) of the annual WW–index distribution are classified as unconstrained (constrained). In columns 5 and 6, firms are classified as unconstrained (constrained) if their dividends and repurchases are positive (equal to zero). Panel A of Table 5 presents results of estimating Equation (15) while excluding the control variables ($\mathbf{X_{i,t}}$), while Panel B reports the results that include the control variables.

According to Prediction 2, the relation between the intensity of product market competition and cash holdings is expected to be more positive for relatively constrained firms than for relatively unconstrained ones. Therefore, the variable of interest in Table 5 is $\Delta\beta_\gamma$, the difference in estimated coefficients on the measure of competition intensity between the unconstrained and constrained subsamples. The results in both Panels A and B are consistent with the empirical prediction: the sensitivity of cash holdings to competition intensity is larger within the relatively constrained subsamples than within the relatively unconstrained ones. This result holds across the three

[20] We verify that our results are robust to using the cash-to-net-assets ratio, as in some specifications in Bates, Kahle, and Stulz (2009) and Opler, Pinkowitz, Stulz, and Williamson (1999). In addition, the results are robust to using cash-to-value ratio, 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`)), to ensure consistency with the cash holdings measure in our model.

subsample formation criteria and survives the inclusion of the control variables.[21]

The economic significance of the results in Table 5 is substantial. For example, increasing the measure of competition intensity by one standard deviation (0.197) raises the gap between cash holdings of relatively constrained and unconstrained firms by 1.2–2.6 percentage points, ceteris paribus.

The coefficients on control variables in Panel B are generally consistent with past studies and with intuition. Similar to Bates, Kahle, and Stulz (2009), the coefficients on size, cash flow, 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 than purely domestic firms.

The results in this subsection demonstrate that the association between firms' cash holdings and expected competition intensity depends on the degree of financial constraints that firms face. However, this evidence does not necessarily imply a causal relation between expected competition intensity and cash holdings. Another potential concern with interpreting the cross-sectional results in the previous subsection is the evidence in Farre-Mensa and Ljungqvist (2014) that common proxies for financial constraints, such as those that we use, may fail to correctly identify firms that are actually financially constrained. Thus, in the next two subsections, we analyze the effects of exogenous changes in the availability and cost of external financing on the relation between intensity of firms' expected output market competition and their cash holdings. In particular, we use two shocks to the firm's ability to raise financing in capital markets.

5.2 A shock to credit supply

The first shock that we examine is the near-disappearance of below-investment-debt credit in 1989, detailed in Lemmon and Roberts (2010). Three near-simultaneous events in 1989 led to the collapse of the junk bond market. The first was the disappearance of Drexel Burnham Lambert, an investment bank that had the lion's share of that market. The second was the passage of the Financial Institutions Reform, Recovery, and Enforcement Act (FIRREA), which required thrifts to liquidate their holdings of junk debt. The third was the near-disappearance of the market for private placements of junk debt funded by life insurance companies due to a combination of regulation and weaker balance sheet of insurers.[22]

The majority of firms in our sample are not rated and are significantly dependent on below-investment-grade debt for external financing of investments. Thus, examining the effect of the collapse of the junk bond market on the sensitivity of firms' cash holdings to expected intensity

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

[22] See Lemmon and Roberts (2010) for a detailed discussion of all three events.

of output market competition can provide causal evidence on the effect of financial constraints on the relation between cash holdings and expected competition intensity. However, it is possible that the collapse of the junk bond market was related to a decline in investment opportunities, which by itself may affect the sensitivity of cash holdings to competition intensity. While the three events discussed above were mostly independent of the demand side of the economy (e.g., Lemmon and Roberts (2010)), the economy was moving into a recession at the same time (e.g., Owyang, Piger, and Wall (2005)).

We follow Lemmon and Roberts (2010) in disentangling the effects of reduction in the availability of capital from demand-side effects. Our identification strategy relies on a difference-in-differences approach. In particular, a natural substitute for below-investment-grade debt is bank debt (e.g., Lemmon and Roberts (2010)). However, the years 1989-1990 were characterized by a significant drop in the availability of bank capital, which was especially pronounced in the Northeastern part of the U.S. (e.g., Jordan (1998) and Owyang, Piger, and Wall (2005)), due to declining real estate prices in the Northeast (e.g., Bernanke and Lown (1991) and Peek and Rosengren (1995)). Thus, following the evidence in Bharath, Dahiya, Saunders, and Srinivasan (2007) that public firms tend to borrow from local banks, our difference-in-differences identification relies on examining the changes in the sensitivity of cash holdings to expected competition intensity from the "pre-credit-crunch" period (1987–1988) to the "crunch" period (1989–1990) for firms headquartered in the Northeast and those headquartered elsewhere. As in Lemmon and Roberts (2010), Northeast includes the following states: CT, MA, ME, NH, NJ, NY, PA, RI, and VT.

To focus on the differential effect of the change in the availability of capital on the sensitivity of cash holdings to expected competition intensity for companies in the Northeast and elsewhere, we estimate the following regression:

$$Cash_{i,t} = \beta_0 + \beta_1 Post + \beta_2 NE + \beta_3 Post \times NE + \eta_0 \gamma_{i,t} + \eta_1 \gamma_{i,t} \times Post + \\ + \eta_2 \gamma_{i,t} \times NE + \eta_3 \gamma_{i,t} \times Post \times NE + \delta \mathbf{X_{i,t}} + \varepsilon_{i,t}, \tag{16}$$

where $Post$ is an indicator variable that takes the value of one in the years 1989–1990 and zero in the years 1987–1988; NE is an indicator that equals one if the firm is headquartered in one of the nine Northeastern states and equals zero otherwise; $Post \times NE$ is the interaction of these two indicator variables; $\gamma_{i,t} \times Post$, $\gamma_{i,t} \times NE$ and $\gamma_{i,t} \times Post \times NE$ are interactions between expected competition intensity, $\gamma_{i,t}$ and each of the three indicator variables; $\mathbf{X_{i,t}}$ is a vector of control variables identical to the one used in estimating Equation (15).

The results of estimating Equation (16) are reported in Table 6. Our model predicts that an increase in the severity of financing constraints magnifies the effect of competition intensity on cash holdings. Consistent with the model's prediction, the coefficient on $\gamma_{i,t} \times Post \times NE$, which equals 0.1 in the specification without control variables and 0.19 in the specification with controls, is highly statistically significant. This result indicates that the change in the sensitivity of cash holdings to competition intensity was larger for firms headquartered in the Northeast, which faced a more severe credit crunch than other regions. In fact, in non-Northeastern states, the sensitivity decreased by 0.05–0.1, consistent with the reduction in economic activity during the credit crunch, while in the Northeast the sensitivity increased by 0.05–0.08 (as follows from the combinations of the coefficients on $\gamma_{i,t} \times Post$ and $\gamma_{i,t} \times Post \times NE$).

Importantly, a crucial identifying assumption in the difference-in-differences estimation is that absent the treatment effect, the difference-in-differences is zero. A common way to analyze the validity of this assumption is to examine the trends in the cash holdings–competition intensity relation prior to the shock to financial constraints – the "parallel trends" assumption. To analyze the trends in this relation, we estimate the regression in Equation (15) separately for each year during the 1987–1990 period. The evolution of the sensitivity of cash holdings to expected competition intensity is presented in Figure 1. The left panel of Figure 1 presents the evolution of the coefficient on the measure of expected competition intensity, β_γ, during the four-year sample period. The dashed line represents the evolution of β_γ in the Northeast subsample, while the solid line represents its evolution in the non-Northeast subsample.

While the sensitivity of cash holdings to expected competition intensity is higher before the collapse of the junk bond market for firms incorporated in the Northeast than for those incorporated elsewhere, the evolution of this sensitivity prior to the crunch is similar for the two subsets of firms. By contrast, the trends in sensitivity diverge in 1989, the first "treatment" year. The right panel of Figure 1 illustrates the same evidence in a different way: it presents annual differences in the β_γ coefficients between the two subsamples. The only year in which the difference in the cash holdings–competition intensity relation between the two subsamples changes dramatically is the first year of the collapse of the junk bond market, consistent with the parallel trends assumption.

Overall, the evidence in this subsection suggests that the effect of financial constraints on the relation between cash holdings and expected competition intensity is indeed causal, consistent with our model's prediction. To further validate our results, in the next subsection we examine the effects of another shock to financial constraints on the sensitivity of firms' cash holdings to competition.

5.3 A shock to monetary policy

In this subsection, we examine the effects of a sharp increase in the cost of obtaining external financing on the relation between cash holdings and expected competition intensity . In particular, we focus on year 1994, in which the Fed Funds target rate increased by cumulative 300 basis points, over 20% of which (65 basis points) was unanticipated by the capital markets (e.g., Kuttner (2001)). Despite the fact that this increase in the costs of external financing was not accompanied by an economic contraction, which could influence firms' incentives to invest in innovation and to hoard cash, we need to be careful in disentangling the increase in the cost of external funds from demand-side shocks. Our identification strategy relies on the differences in responses of large versus small firms to monetary supply shocks. In particular, smaller firms are typically more responsive to shocks to borrowing costs than larger firms (e.g., Gertler and Gilchrist (1994) and Leary (2007)).

To implement this strategy, we estimate the following regression:

$$Cash_{i,t} = \beta_0 + \beta_1 Post + \beta_2 Small + \beta_3 Post \times Small + \eta_0 \gamma_{i,t} + \eta_1 \gamma_{i,t} \times Post + \\ + \eta_2 \gamma_{i,t} \times Small + \eta_3 \gamma_{i,t} \times Post \times Small + \delta \mathbf{X_{i,t}} + \varepsilon_{i,t}, \tag{17}$$

where $Post$ is an indicator variable that takes the value of one in the years 1995–1996 and zero in the years 1992–1994; $Small$ is an indicator that equals one if the value of firm's assets is below the median in the year 1992 and equals zero otherwise; $Post \times Small$ is the interaction of these two indicator variables; $\gamma_{i,t} \times Post$, $\gamma_{i,t} \times Small$ and $\gamma_{i,t} \times Post \times Small$ are interactions between expected competition intensity, $\gamma_{i,t}$, and each of the three indicator variables; and $\mathbf{X_{i,t}}$ is a vector of control variables, and $\mathbf{X_{i,t}}$ is a vector of control variables identical to the one used in estimating Equation (15).

Table 7 presents the results of estimating Equation (17). The coefficient on $\gamma_{i,t} \times Post \times Small$ ranges between 0.1 and 0.14 in the two specifications and is highly statistically significant in both. This result shows that the change in the sensitivity of cash holdings to competition intensity was larger for small firms than for large ones, consistent with small firms being affected more strongly by an increase in the cost of external funds.

Figure 2 examines the "parallel trends" assumption. In particular, we estimate Equation (15) separately for each year during the 1992–1996 period. Similar to Figure 1, the left panel of Figure 2 presents the evolution of the β_γ coefficient during the five-year sample period, while the right panel presents annual differences in the β_γ coefficients between the subsamples of small and large firms. The evolution of this sensitivity prior to 1994 is similar between the two subsamples, whereas the trends in the cash holdings–competition intensity relation are very different in 1994, the year of the monetary shock.

Overall, similar to the results of the analysis based on the 1989 junk bond market collapse, the results of the tests based on the 1994 monetary shock are consistent with the causal interpretation of the effect of financial constraints on the sensitivity of cash holdings to expected competition intensity.

6 Strategic effects and determinants of overall liquidity

Cash is not the only source of liquidity that firms can use to reduce the costs of external financing. Another important source of liquidity is credit lines (e.g., Sufi (2009), Yun (2009), Lins, Servaes, and Tufano (2010), Colla, Ippolito, and Li (2013), and Acharya, Almeida, Ippolito, and Perez (2014)). While credit lines are an imperfect substitute for cash – the latter is unconditional liquidity, while the former is conditional on firm performance – both can have strategic effects.[23] Thus, the intuition for optimal cash holding choices generally carries over to credit lines, particularly in light of the evidence in Lins, Servaes, and Tufano (2010) that firms not only use credit lines as insurance against negative profitability shocks, but also in anticipation of the need to finance future investment opportunities.

To examine whether access to pre–committed liquidity through credit lines is important for our empirical results, we use credit line data from Capital IQ to create a measure of total liquidity given by the sum of cash holdings and available credit lines. We use this measure to analyze the strategic effects of total liquidity by examining the effects of a change in firms' total liquidity on their rivals' total liquidity. In addition, we examine the effects of financial constraints on the relation between firms' total liquidity and the expected competition intensity. Since credit lines data from Capital IQ are available starting from 2002, and patent citation data are available until 2006, the empirical tests in this section are restricted to years 2002–2006. During that period, our sample firms' credit lines as a percentage of assets averaged 6.75%, which is lower than the averages reported in Lins, Servaes, and Tufano (2010) and Sufi (2009), suggesting that the use of credit lines is less prevalent among innovative firms than among old-economy ones.

In Table 8, we examine the effects of firms' total liquidity on their rivals' liquidity, while accounting for the endogeneity of firms' liquidity choices using 2SLS estimation, as in Equation (14). The structure of Table 8 is identical to that of Table 3. Similar to the evidence on the strategic effects of cash in Table 3, the OLS regression that treats rivals' total liquidity as exogenous leads to close-to-zero and insignificant relation between changes in firms' total liquidity and changes in their competitors' total liquidity. More importantly, when we account for the endogeneity of total liquidity, the results (Columns 2 to 5) become statistically significant and economically large. The effect of a 1 percentage point increase in firm's total liquidity lowers firm's rival's total liquidity by 0.17–0.26 percentage points. These estimates are larger than the corresponding ones for the strategic effect of cash holdings in Table 3 and are similar to the unreported strategic effects of cash for the sub-period 2002–2006, which imply that a one percentage point increase in a firm's

[23] Another important difference between cash and credit lines is that because of bank monitoring of credit lines, the agency problems associated with them are lower than those associated with cash (e.g., Sufi (2009) and Yun (2009)).

cash holdings lead to a reduction in the rival's cash of 0.16–0.23 percentage points.

In Table 9, we examine whether the strategic effect of liquidity is larger within the subsample of firms expected to face more intense output market competition, as predicted by our model. In particular, as in Table 4, we estimate the system of two equations separately for the low-γ and high-γ subsamples. In all specifications in Table 9, the strategic effect of total liquidity within the high-γ subsample, which ranges between 0.26 to 0.31 in absolute value, is higher than that within the low-γ subsample, in which it ranges between 0.12 and 0.21 in absolute value.

In Table 10, we estimate the relation between firms' total liquidity and expected competition intensity, γ, for subsamples of relatively financially constrained and unconstrained firms. As in Table 5, we use three measures of financial constraints – the WW index, the SA index, and total payout. We only estimate regressions that include all the control variables in Equation (15) and, to save space, we report only the coefficients on γ for all subsamples. As in Table 5, the variable of interest is $\Delta\beta_{\gamma}$, the difference in estimated coefficients on the measure of expected competition intensity between the unconstrained and constrained subsamples. The results for total liquidity are consistent with those for cash holdings in Table 5 and with the model. The relation between total liquidity and expected competition intensity is 1.5–2.5 times stronger within the three relatively constrained subsamples than within the three unconstrained ones.

Overall, the evidence in this section suggests that the empirical results are robust to inclusion of credit lines in a measure of total liquidity.

7 Conclusions

In this paper we develop a model of cash holdings by innovating firms. Firms finance R&D investments using internal and, possibly, external funds, while taking into account cash and R&D investment strategies of their competitors.

Our model illustrates the strategic motive for hoarding cash by innovating firms, which make cash holding choices while facing uncertainty regarding the cost of innovating and the structure of output markets for products resulting from successful innovations. In the presence of financial constraints, a firm that has access to a larger pool of internal funds commits to invest in innovation in more states of the world. This commitment lowers the payoff to the firm's competitor investing in R&D, which indirectly benefits the firm.

Our model has implications both for off-equilibrium effects of innovative firms' cash holdings on optimal cash holdings of their competitors, which we refer to as the *strategic effect of cash*, and for the equilibrium relation between cash holdings and the intensity of expected product market competition. In particular, the impact of a firm's cash holdings on its rival's optimal cash holdings is negative, more so when the expected intensity of competition between firms is strong. The equilibrium relation between equilibrium cash holdings and competition intensity is more positive for firms that are financially constrained, i.e. firms for which the strategic motivation for holding cash is stronger.

To test our model's predictions, we construct a sample of patent-filing firms whose innovations are closely related. Using this sample, we first examine the effect of firms' cash holdings on their rivals' cash holding choices, while accounting for the endogeneity of cash holdings, and find that the relation is significantly negative, especially within a subsample of firms that are expected to compete more intensely in output markets. Second, we examine, using cross-sectional regressions and quasi-natural experiments, the relation between observed cash holdings and expected competition intensity, and find that this relation is significantly more positive for relatively financially constrained firms and for firms that experienced adverse shocks to the availability and cost of external financing.

To summarize, we believe that our model and empirical results demonstrate that strategic considerations are important in shaping innovative firms' cash holding choices. In addition, we demonstrate that financial constraints are crucial in determining the relation between firms' cash holdings and the intensity of expected competition in future output markets.

A Proofs

Proof of Lemma 1

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

$$\frac{\partial I^*_{i,un}}{\partial C_i} = \frac{\alpha_i(1-\alpha_j)\Delta_\pi^2}{1-(1-\alpha_i)(1-\alpha_j)\Delta_\pi^2}. \tag{18}$$

Since $0 < \alpha_i < 1$, $0 < \alpha_j < 1$, and $0 < \Delta_\pi < 1$, both the numerator and the denominator of Equation (18) are 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_j equals

$$\frac{\partial I^*_{i,un}}{\partial C_j} = \frac{-\alpha_j\Delta_\pi}{1-(1-\alpha_i)(1-\alpha_j)\Delta_\pi^2}. \tag{19}$$

Since $\Delta_\pi > 0$ and $\alpha_j > 0$, the numerator of Equation (19) is negative. Since $\alpha_i < 1$, $\alpha_j < 1$ and $\Delta_\pi < 1$, the denominator of Equation (19) is positive. Therefore, $\frac{\partial I^*_{i,un}}{\partial C_j} < 0$.

Proof of Proposition 1

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

$$\frac{\partial C_i^*(C_j)}{\partial C_j} = \frac{-\alpha_j\Delta_\pi}{1-(1-\alpha_j)\,\Delta_\pi^2}. \tag{20}$$

Since $\Delta_\pi > 0$ and $\alpha_j > 0$, the numerator of Equation (20) is negative. In addition, since $\alpha_i < 1$ and $\Delta_\pi < 1$, the denominator of Equation (20) is positive, leading to $\frac{\partial C_i^*(C_j)}{\partial C_j} < 0$.

The derivative of Equation (20) with respect to γ equals

$$\frac{\partial^2 C_i^*(C_j)}{\partial C_j \partial\gamma} = \frac{-\alpha_j(1-(1-\alpha_j)\,\Delta_\pi^2) - 2\alpha_j(1-\alpha_j)\Delta_\pi^2}{(1-(1-\alpha_j)\,\Delta_\pi^2)^2} * \frac{\partial\Delta_\pi}{\partial\gamma}. \tag{21}$$

The first term in Equation (21) is negative. The second term is positive since $\frac{\partial\Delta_\pi}{\partial\gamma} = -\frac{\partial\pi_D(\gamma)}{\partial\gamma} > 0$, therefore $\frac{\partial^2 C_i^*(C_j)}{\partial C_j\partial\gamma} < 0$.

Proof of Proposition 2

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

$$\frac{2rR\alpha_i\left((R-r)(1+(2\Delta_\pi)\Delta_\pi)+(\Delta_\pi^2+1-\Delta_\pi)\right)\Gamma}{\Psi}. \tag{22}$$

The denominator of Equation (22), Ψ, is a quadratic form and is positive. $2rR\alpha_i$ is positive by assumption ($r > 0$, $R > 0$, and $\alpha_i > 0$). $(R-r)(1+(2\Delta_\pi)\Delta_\pi$ and $(\Delta_\pi^2+1-\Delta_\pi)$ are positive by assumption as well ($R > r$ and $0 < \Delta_\pi < 1$). Thus, the sign of Equation (22) is equal to the sign of Γ.[24]

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

The derivative of Γ with respect to α_i is

$$\frac{\partial \Gamma}{\partial \alpha_i} = (1-\Delta_\pi)^2 (R\Delta_\pi + r\pi_D)^2 > 0. \tag{23}$$

In addition, $\Gamma = 0$ when $\alpha_i = \overline{\alpha_i} = 1 - \frac{(2r\pi_D - R(1-\Delta_\pi)^2}{(1-\Delta_\pi)^2 (R\Delta_\pi + r\pi_D))^2}$. Thus, the numerator of Equation (22) is positive if $\alpha_i < \overline{\alpha_i}$ and it is negative if $\alpha_i > \overline{\alpha_i}$.

Since $\frac{\partial \Delta_\pi}{\partial \gamma} > 0$ 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 $\frac{C_i^{EQ}/r}{V_i^{*} + C_i^{EQ}/r}$ with respect to γ is negative when $\alpha_i < \overline{\alpha_i}$ and positive when $\alpha_i > \overline{\alpha_i}$.

B 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 financial constraints are:

- The Size–Age (SA) index, computed in Hadlock and Pierce (2010) 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 Whited and Wu (2006) 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`.

- 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 Bates, Kahle, and Stulz (2009) 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 its book value. We define book value as the value of total assets (item `AT`) and market value as book value minus book value of equity (item `CEQ`) plus market value of equity (item `CSHO` $\times$ item `PRCC_F`).

- *Size* is 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 the difference between working capital (item `WCAP`) and cash (item `CHE`).
- *Investment* is 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).
- *Industry CFCV* is a measure of cash flow volatility. Following Han and Qiu (2007), 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.
- *Leverage* is the sum of long-term debt (item `DLTT`) and debt in current liabilities (item `DLC`).
- *Netdebtissuance* is the difference between long-term debt issuance (item `DLTIS`) and long-term debt reduction (item `DLTR`)
- *R&D* is R&D expenditures (item `XRD`, set to zero when missing).
- Following Jang (2013), we identify multinationals using data on foreign income and taxes. In particular, dummy variable *Multinational* takes the 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.

Table 1: Top Competitors by Cohort

Company 1	Company 2	γ	Business 1	Business 2	Cit. 1	Cit. 2	Sales Ratio
Panel A: Period 1977–1986							
Lilly (Eli) & Co	Pfizer Inc	0.718	develops, manufactures, and sells pharmaceutical	develops, manufactures, and sells pharmaceutical	830	719	1.222
Amoco Corp	Chevron Corp	0.709	offers exploration and production services for oil and gas	offers exploration and production services for oil and gas	1,641	1,347	1.436
Digital Equipment	Data General Corp	0.7	provides implementation and supporting networked business solutions	Designs, makes, markets and supports open computer systems	280	245	4.489
Syntex Corp	Schering-Plough	0.699	pharmaceutical products and medical diagnostics systems	pharmaceutical products	331	240	2.517
Pharmacia Corp	Squibb Corp	0.63	pharmaceutical products	pharmaceutical products	990	1,128	3.739
Rohm And Haas Co	Dow Corning Corp	0.627	manufacturer of speciality chemicals	silicon-based materials	741	742	2.488
Fluke Corp	Teradyne Inc	0.6	electronic test tools and software	automatic test equipment	39.4	35.3	1.367
Aluminum Co Of Canada Ltd	Reynolds Metals Co	0.591	aluminum and related products	aluminum and related products	141	193	1.246
Petrolite Corp	Betzdearborn Inc	0.573	chemical treatment programs and performance-enhancing additives	water treatment, wastewater treatment, and process system solutions	175	159	1.135
Fischer & Porter Co	Foxboro Co	0.565	design and manufacture of process instrumentation	software, automation, information technology	121	107	3.032
Panel B: Period 1987–1996							
Utah Medical Products Inc	Empi Inc	0.833	medical devices for the healthcare industry	medical devices for the healthcare industry	125	118	1.5
Cas Medical Systems Inc	Bio-Logic Systems Corp	0.773	medical devices for non-invasive patient monitoring	computer-based electro-diagnostic systems	12.6	16.9	2.722
Activision Inc	Timberline Software Corp	0.772	publishes interactive entertainment software and peripheral products	software for construction and real estate industries	6.3	8.2	2.692
Bristol-Myers Squibb Co	Pfizer Inc	0.728	biopharmaceutical products	biopharmaceutical products	3,001	2,920	1.452

Continued on next page

Table 1: Top Competitors by Cohort (continued)

Company 1	Company 2	γ	Business 1	Business 2	Cit. 1	Cit. 2	Sales Ratio
Amoco Corp	Texaco Inc	0.705	refines and sells petrol products	refines and sells petrol products	4,369	3,887	1.436
National Semiconductor Corp	Advanced Micro Devices	0.703	analog and mixed-signal integrated circuits and sub-systems	develops computer processors and related technologies	2,956	3,423	1.605
Wallace Computer Svcs Inc	Standard Register Co	0.684	printed products and print management services	management and execution of critical communications	182	156	1.516
Ballard Medical Products	Medex Inc	0.669	specialized medical products	critical care medical products	164	133	1.634
Shell Oil Co	Occidental Petroleum Corp	0.666	oil and gas	oil and gas	1,032	779	1.965
Gish Biomedical Inc	Electro Catheter Corp	0.665	disposable medical devices for various surgical specialties	emergency care, invasive and non-invasive cardiology	35.1	35.7	2.333
Panel C: Period 1997–2006							
Cortex Pharmaceuticals Inc	Marina Biotech Inc	0.854	biopharmaceutical products	develops nucleic acid-based therapies	16.4	14.5	4.259
Vision-Sciences Inc	Cardiogenesis Corp	0.839	endoscopy products	laser transmyocardial revascularization technologies	153	156	2.006
Onyx Pharmaceuticals Inc	Genelabs Technologies Inc	0.813	biopharmaceutical products	biopharmaceutical products	95.8	89.6	4.372
Icu Medical Inc	Merit Medical Systems Inc	0.773	medical devices	medical devices	251	214	1.561
Realnetworks Inc	Netmanage Inc	0.773	software products and services	software and service solutions	39.2	40.4	3.265
Cadence Design Systems Inc	Synopsys Inc	0.764	electronic design automation (EDA) software	electronic design automation (EDA) software	1,165	1,200	1.531
Somanetics Corp	Criticare Systems Inc	0.761	medical devices	patient monitoring systems	116	143	4.192
Nokia Corp	Ericsson	0.756	telecommunications equipment and services	telecommunications equipment and services	10,064	12,429	1.789
Urigen Pharmaceuticals Inc	Vericel Corp	0.751	biopharmaceutical products	development of cell-based therapies	12.2	18.1	4.418
Ford Motor Co	Honda Motor Co Ltd	0.748	vehicles, parts, and accessories	vehicles, parts, and accessories	20,209	17,307	2.737

Table 1: Top Competitors by Cohort (continued)

This table reports top ten competitor pairs by cohort. We split the sample into three non–overlapping cohorts of ten years: 1977–1986, 1987–1996, and 1997–2006. To be considered as a top competitor in a cohort, a firm is required to report total assets (item AT) and cash holdings (item CHE) for all 10 cohort years. To form competitor pairs, we only consider firms in the same 4–digit SIC industry and exclude firms that have less than one citation to its patents per year on average. We then construct all potential firm–pairs within the industry and exclude firm–pairs in which the average sales of one firm is over 5 times the average sales of the other firm). For each firm–pair, we evaluate their average pairwise innovation proximity, γ, defined in Subection 3.3. If a value for γ is missing for a given year, we replace it with zero. Two firms are considered potential rivals if there is not any other pair, within the same industry-cohort, that includes one of the two firms and has a higher average proximity. There are 786 firm–pairs over the period 1977–2006 for a total of 15,720 firm–year observations, corresponding to 7,860 annual pairs. Column *Company 1* reports the name of the first firm in the pair, while *Company 2* reports the name of the second firm in the pair (item CONM). Column γ reports the average innovation proximity of the two competitors over the 10 cohort years. Column *Business 1* (*Business 2*) reports a brief description on the first (second) company line of business (item BUSDESC). Column *Cit. 1* (*Cit. 2*) reports the average yearly number of citations of the first (second) company during the ten–year–period. Column *Sales Ratio* reports the average sales ratio of the two firms, calculated using the larger average sale value as the numerator.

Table 2: Summary Statistics

	Mean	Std. Dev.	25%	50%	75%	Min	Max	N
Dependent Variable								
Cash	0.154	0.188	0.025	0.078	0.208	0.000	0.931	15,720
USPTO Data								
Patents	19.817	80.538	0	2	8	0	1,972	15,720
Citations	40.306	205.325	0	1	12	0	4,845	15,720
Classes	3.139	4.833	0	1	4	0	35	15,720
γ	0.297	0.197	0.124	0.266	0.440	0.001	0.854	15,720
Financing Constraints Measures								
SA–Index	-3.504	0.847	-4.240	-3.555	-2.979	-4.627	1.091	15,400
WW–Index	-0.295	0.123	-0.383	-0.302	-0.216	-0.545	0.262	15,276
Dividend dummy	0.685	0.465	0.000	1.000	1.000	0.000	1.000	15,720
Control Variables								
Market–to–book	2.081	2.427	1.081	1.421	2.141	0.524	32.851	15,101
Size	5.458	2.218	3.859	5.426	7.063	-2.121	9.703	15,720
Cash flow	0.030	0.244	0.035	0.073	0.108	-4.194	0.292	15,667
Industry CFCV	2.902	1.905	1.390	2.782	4.015	0.112	26.043	15502
Net working capital	0.143	0.257	0.034	0.156	0.277	-4.041	0.571	15,408
Investment	0.061	0.056	0.025	0.048	0.081	-0.096	0.500	15,529
Leverage	0.221	0.213	0.066	0.194	0.313	0.000	2.501	15,664
Net debt issuance	0.010	0.089	-0.015	0.000	0.021	-0.384	0.589	14,593
R&D	0.062	0.107	0.005	0.027	0.075	0.000	0.828	15,720
Multinational	0.602	0.489	0.000	1.000	1.000	0.000	1.000	15,720

Table 2: Summary Statistics (continued)

This table reports the mean, standard deviation, 25% percentile, 50% percentile, 75% percentile, minimum value, maximum value, and number of available observations for the variables used in the empirical analysis. All accounting variables are scaled by the contemporaneous value of total assets (Compustat item AT), if not specified otherwise. The data are at an annual frequency over the period 1977–2006 and all Compustat–based ratios are winsorized at the top and bottom 1%. *Cash* is the amount of cash and cash equivalents (item CHE). *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. γ is the average proximity throughout the 10-year cohort period. *SA–Index* is the financial constraints index proposed by Hadlock and Pierce (2010). *WW–Index* is the financial constraints index proposed by Whited and Wu (2010). *Dividend dummy* is a dummy variable that takes 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 its book value. We define book value as the value of total assets (item AT), and market value as book value minus book value of equity (item CEQ) plus market value of equity (item CSHO × item PRCC_F). *Size* is the natural logarithm of 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). The cash flow coefficient of variation at the firm level is computed 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 average value in the first quarter of year t. *Net working capital* is computed as the difference between working capital (item WCAP) and cash (item CHE) at time t. *Investment* 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. *Net debt issuance* is the difference between long–term debt issuance (item DLTIS) and long–term debt reduction (item DLTR). *R&D* is R&D expenditures.

Table 3: Strategic Effect of Rival's Cash

	I	II	III	IV	V
	OLS		2SLS		
Δ Rival's cash	**-0.013**	**-0.140*** **	**-0.130*** **	**-0.116*** **	**-0.107*** **
	(0.012)	**(0.039)**	**(0.038)**	**(0.038)**	**(0.038)**
Δ Cash$_{t-1}$	-0.222***	-0.211***	-0.216***	-0.213***	-0.217***
	(0.014)	(0.015)	(0.015)	(0.015)	(0.015)
Size	0.000	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Market-to-book	0.003***	0.002***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Cash flow	0.053***	0.053***	0.053***	0.054***	0.054***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Investment	-0.299***	-0.314***	-0.310***	-0.334***	-0.331***
	(0.018)	(0.019)	(0.019)	(0.020)	(0.020)
Net debt issuance	0.021	0.011	0.016	0.016	0.020
	(0.014)	(0.016)	(0.016)	(0.016)	(0.016)
Time FE	No	No	Yes	No	Yes
Industry FE	No	No	No	Yes	Yes
Obs.	13,435	11,816	11,816	11,812	11,812
R^2–adj	0.103	0.073	0.087	0.080	0.093
Validity		101.11***	101.46***	102.49***	103.00***
Joint significance		2.93***	2.49**	2.12**	1.71
Under–identification		167.04***	164.23***	167.833***	164.957***
Weak identification		205.86***	209.02***	210.53***	213.66***
Over–identification		2.914	1.851	3.462	2.180

Table 3: Strategic Effect of Rival's Cash (continued)

This table reports the estimation results of a system of equations that corresponds to the reaction functions in our model:

$$\begin{cases} \Delta Cash_{i,t} = \beta_{rival}\Delta Cash_{j,t} + \beta_{\mathbf{1}}\mathbf{X_{i,t}} + \phi D_t + \nu I_k + \varepsilon_{i,t}, \\ \\ \Delta Cash_{j,t} = \beta_{rival}\Delta Cash_{i,t} + \beta_{\mathbf{1}}\mathbf{X_{j,t}} + \phi D_t + \nu I_k + \varepsilon_{j,t}, \end{cases}$$

where $\mathbf{X_{i,t}}$ and $\mathbf{X_{j,t}}$ are vector of control variables for firm i and j respectively, D_t is time dummy variable, and I_k is industry dummy variable. The dependent variable is the change in cash holdings. The regressors include the lagged value of the dependent variable, size, market–to–book, cash flows, investment plus acquisitions, and net debt issuance. See Table 2 for variable definitions. In Column I we estimate a pooled OLS model without taking into account the potential endogeneity of changes in cash holdings. In Columns II to V, we estimate a two–stage least square (2SLS) model on the pooled data. Column II has no time and industry fixed effects. Column III has only time fixed effects. Column IV has only industry fixed effects. Column V has both time and industry fixed effects. We instrument the change in cash holdings of the rival firm ($\Delta Cach_{j,t}$) using the rival firm's control variables ($\mathbf{X_{j,t}}$, excluded instruments) and the firm's control variables ($\mathbf{X_{i,t}}$, included instruments). The reported standard errors (in parentheses) are robust to heteroskedasticity and are clustered at the firm level. *Validity* reports the partial R^2 measure to test the instruments' validity. *Joint significance* reports the Anderson–Rubin statistic for testing the joint significance of endogenous regressors. *Under–identification* reports the Kleibergen–Paap LM–statistic for testing whether the model is identified. *Weak identification* reports Cragg–Donald F–statistic to test if the set of instrument is weak. *Over–identification* reports the Hansen J–statistics to test if the instruments are uncorrelated with the error term. The data are at the annual frequency over the period 1977–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 4: Strategic Effect of Rival's Cash and Competition Intensity

	I	II	III	IV
Δ Rival's cash (low γ)	-0.062	-0.052	-0.035	-0.025
	(0.055)	(0.054	(0.053)	(0.051)
Δ Rival's cash (high γ)	-0.190***	-0.181***	-0.166***	-0.156***
	(0.052)	(0.051)	(0.049)	(0.049)
$\Delta\beta_{rival}$	**-0.128***	**-0.129***	**-0.131***	**-0.131***
p-value	0.090	0.082	0.084	0.074
Controls	Yes	Yes	Yes	Yes
Time FE	No	Yes	No	Yes
Industry FE	No	No	Yes	Yes

This table reports the results of estimating the system of equations described in Table 3 using 2SLS estimation for two subsamples. The first subsample (low–γ) contains firms–pairs that have an average value of γ below the median in a given cohort. The second subsample (high–γ) contains firms–pairs that have an average value of γ above the median in a given cohort. The table only reports the coefficient on the rival's cash holdings and omits the coefficients on the control variables. Δ Rival's cash (low γ) is the coefficient on the rival's cash holdings for the low–γ group, while Δ Rival's cash (high γ) is the coefficient on the rival's cash holdings for the high–γ group. $\Delta\beta_{rival}$ is the difference in the estimated coefficients between the two groups and *p-value* reports the significance of this difference. Column I has no time and industry fixed effects. Column II has only time fixed effects. Column III has only industry fixed effects. Column IV has both time and industry fixed effects. The reported standard errors (in parenthesis) are robust to heteroskedasticity and are clustered at the firm level. The data are at the annual frequency over the period 1977–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 5: Cash and Competition Intensity (Cross–Sectional Regressions)

Panel A: Without Control Variables						
	SA-Index		WW-Index		Dividend	
	NFC	FC	NFC	FC	NFC	FC
γ	**0.159*** **	**0.258*** **	**0.181*** **	**0.260*** **	**0.158*** **	**0.308*** **
	(0.022)	**(0.036)**	**(0.022)**	**(0.036)**	**(0.021)**	**(0.043)**
Constant	0.021***	0.037***	0.035***	0.057***	0.068***	-0.014
	(0.007)	(0.011)	(0.009)	(0.012)	(0.010)	(0.015)
$\Delta\beta_\gamma$	-0.088**		-0.065*		-0.131***	
F-stat	4.557		2.906		10.120	
p–value	0.033		0.089		0.002	
Obs.	7,700	7,700	7,631	7,769	10,505	4,895
R^2–adj	0.104	0.206	0.105	0.200	0.097	0.174
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Table 5: Cash and Competition Intensity (Cross–Sectional Regressions, continued)

Panel B: With Control Variables						
	SA-Index		WW-Index		Dividend	
	NFC	FC	NFC	FC	NFC	FC
γ	**0.056*** **	**0.163*** **	**0.095*** **	**0.157*** **	**0.081*** **	**0.189*** **
	(0.017)	**(0.027)**	**(0.020)**	**(0.026)**	**(0.015)**	**(0.033)**
Market-to-book	0.026***	0.010***	0.022***	0.010***	0.020***	0.009***
	(0.004)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
Size	-0.019***	0.008***	-0.020***	0.017***	-0.016***	0.013***
	(0.002)	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)
Cash flow	-0.273***	-0.031	-0.187***	-0.027	-0.018	-0.031
	(0.055)	(0.022)	(0.059)	(0.021)	(0.034)	(0.025)
Net working capital	-0.239***	-0.178***	-0.221***	-0.187***	-0.234***	-0.143***
	(0.025)	(0.034)	(0.052)	(0.031)	(0.056)	(0.037)
Investment	-0.305***	-0.493***	-0.315***	-0.492***	-0.397***	-0.527***
	(0.036)	(0.053)	(0.045)	(0.053)	(0.040)	(0.061)
Leverage	-0.215***	-0.392***	-0.258***	-0.374***	-0.338***	-0.334***
	(0.023)	(0.036)	(0.023)	(0.031)	(0.020)	(0.037)
R&D	0.671***	0.292***	0.456***	0.322***	0.332***	0.329***
	(0.088)	(0.057)	(0.096)	(0.056)	(0.063)	(0.062)
Industry CFCV	0.001	-0.002	0.004***	-0.004**	0.003***	-0.007***
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
Multinational	-0.024***	-0.031***	-0.026***	-0.035***	-0.019***	-0.044***
	(0.006)	(0.008)	(0.006)	(0.008)	(0.005)	(0.012)
Constant	0.284***	0.187***	0.332***	0.140***	0.298***	0.119***
	(0.026)	(0.026)	(0.041)	(0.025)	(0.033)	(0.033)
$\Delta\beta_\gamma$	-0.108***		-0.062**		-0.108***	
F-stat	11.69		4.248		10.35	
p–value	0.001		0.039		0.001	
Obs.	7,052	7,100	6,981	7,171	9,606	4,546
R^2–adj	0.427	0.460	0.473	0.463	0.480	0.428
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Table 5: Cash and Competition Intensity (Cross–Sectional Regressions, continued)

This table reports the estimates of the following regression:

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

for sub–samples of relatively unconstrained and constrained firms. $Cash_{i,t}$ is cash-to-assets ratio, $\gamma_{i,t}$ is the measure of technological proximity of firm i at time t with its rival, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a time dummy variable, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The set of control variables includes *Industry CFCV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment*, *Leverage*, *R&D*, and *Multinational*. See Table 2 for variable definitions. 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 columns 1 and 4, firms are classified as unconstrained (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 unconstrained (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 unconstrained (constrained) if dividends and repurchases are positive (equal to zero). The quantity of interest is $\Delta\beta_\gamma$, the difference in the competition intensity coefficient between unconstrained and constrained subsamples. $F - stat$ is the Wald F–statistic for testing the equality between these two coefficients. The data are at the annual frequency over the period 1977–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The reported standard errors (in parenthesis) are robust to heteroskedasticity and are clustered at the firm level. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 6: Cash and Competition Intensity (Shock to the Supply of Credit)

Constant	0.102***	0.398***
	(0.014)	(0.037)
Post	-0.008	-0.089**
	(0.008)	(0.036)
NE	0.040	-0.013
	(0.034)	(0.090)
Post × NE	-0.043**	-0.057
	(0.018)	(0.077)
γ	0.157***	0.136***
	(0.045)	(0.038)
γ × Post	-0.051**	-0.104***
	(0.024)	(0.025)
γ × NE	0.103**	0.191***
	(0.050)	(0.058)
$\boldsymbol{\gamma}$ × Post × NE	**0.103****	**0.188*****
	(0.050)	**(0.061)**
Controls	No	Yes
Obs.	1,944	1,774
R^2–adj	0.027	0.471

Table 6: Cash and Competition Intensity (Shock to the Supply of Credit, continued)

This table reports the estimates of the following regression:

$$Cash_{i,t} = \beta_0 + \beta_1 Post + \beta_2 NE + \beta_3 Post \times NE + \eta_0 \gamma_{i,t} + \eta_1 \gamma_{i,t} \times Post +$$

$$+ \eta_2 \gamma_{i,t} \times NE + \eta_3 \gamma_{i,t} \times Post \times NE + \delta \mathbf{X_{i,t}} + \varepsilon_{i,t},$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\gamma_{i,t}$ is the measure of technological proximity of firm i at time t with its rival, $Post$ is a dummy variable that takes value of one if the observation belongs to the period 1989–1990, NE is a dummy variable that takes value of one if the observation belongs to a firm with headquarters in the northeast region of the U.S., $\mathbf{X_{i,t}}$ is a vector of control variables, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The set of control variables includes *Industry CFCV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment*, *Leverage*, *R&D*, and *Multinational*. The regression in column 1 does not include control variables, while the regression in column 2 includes all control variables. The data are at the annual frequency over the period 1987–1990 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The reported standard errors (in parentheses) are robust to heteroskedasticity and are clustered at the firm level. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 7: Cash and Competition Intensity (1994 Monetary Policy Shock)

Constant	0.057***	0.233***
	(0.012)	(0.041)
Post	-0.003	-0.091**
	(0.007)	(0.042)
Small	0.054**	0.020
	(0.021)	(0.063)
Post $\times$ Small	-0.015	0.018
	(0.014)	(0.058)
γ	0.096***	0.040
	(0.034)	(0.030)
$\gamma \times$ Post	-0.019	-0.056**
	(0.018)	(0.025)
$\gamma \times$ Small	0.080	0.094*
	(0.065)	(0.054)
$\boldsymbol{\gamma} \times$ Post $\times$ Small	0.097**	0.139***
	(0.046)	(0.050)
Controls	No	Yes
Obs.	2,470	2,225
R^2–adj	0.116	0.499

Table 7: Cash and Competition Intensity (1994 Monetary Policy Shock, continued)

This table reports the estimates of the following regression:

$$
\begin{aligned}
Cash_{i,t} &= \beta_0 + \beta_1 Post + \beta_2 Small + \beta_3 Post \times Small + \eta_0 \gamma_{i,t} + \eta_1 \gamma_{i,t} \times Post + \\
&+ \eta_2 \gamma_{i,t} \times Small + \eta_3 \gamma_{i,t} \times Post \times Small + \delta \mathbf{X_{i,t}} + \varepsilon_{i,t},
\end{aligned}
$$

where $Cash_{i,t}$ is cash-to-assets ratio, $\gamma_{i,t}$ is the measure of technological proximity of firm i at time t with its rival, *Post* is a dummy variable that takes value of one if the observation belongs to the period 1995–1996, *Small* is a dummy variable that takes value of one if the observation belongs to the bottom 50% of the size (i.e., total assets) distribution in 1992, $\mathbf{X_{i,t}}$ is a vector of control variables, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The set of control variables includes *Industry CFCV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment*, *Leverage*, *R&D*, and *Multinational*. The regression in column 1 does not include control variables, while the regression in column 2 includes all of the control variables. The data are at the annual frequency over the period 1992–1996 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The reported standard errors (in parenthesis) are robust to heteroskedasticity and are clustered at the firm level. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 8: Strategic Effect of Rival's Total Liquidity

	I	II	III	IV	V
	OLS		2SLS		
Δ Rival's liquidity	**-0.020**	**-0.256******	**-0.239******	**-0.181*****	**-0.172***
	(0.024)	**(0.095)**	**(0.092)**	**(0.091)**	**(0.089)**
Δ Liquidity$_{t-1}$	-0.224***	-0.204***	-0.217***	-0.214***	-0.227***
	(0.026)	(0.028)	(0.028)	(0.027)	(0.028)
Size	-0.004***	-0.004***	-0.004***	-0.006***	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Market-to-book	0.005***	0.004***	0.004***	0.005***	0.005***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Cash flow	0.056***	0.054***	0.053***	0.060***	0.059***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Investment	-0.385***	-0.409***	-0.388***	-0.488***	-0.463***
	(0.070)	(0.073)	(0.074)	(0.069)	(0.070)
Net debt issuance	-0.025	-0.029	-0.024	-0.022	-0.018
	(0.037)	(0.039)	(0.040)	(0.038)	(0.039)
Time FE	No	No	Yes	No	Yes
Industry FE	No	No	No	Yes	Yes
Obs.	2,448	2,240	2,240	2,240	2,240
R^2–adj	0.092	0.020	0.042	0.063	0.077
Validity		23.39***	23.99***	26.61***	27.05***
Joint significance		2.31**	2.33**	1.71	1.67
Under–identification		67.274***	69.008***	69.305***	70.788***
Weak identification		35.799***	37.044***	38.716***	27.054***
Over–identification		5.079	5.771	5.332	5.265

Table 8: Strategic Effect of Rival's Total Liquidity (continued)

This table reports the estimation results of a system of equations that corresponds to the reaction functions in our model:

$$\begin{cases} \Delta LIQ_{i,t} = \beta_{rival} \Delta LIQ_{j,t} + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \nu I_k + \varepsilon_{i,t}, \\ \\ \Delta LIQ_{j,t} = \beta_{rival} \Delta LIQ_{i,t} + \beta_{\mathbf{1}} \mathbf{X_{j,t}} + \phi D_t + \nu I_k + \varepsilon_{j,t}, \end{cases}$$

where $\mathbf{X_{i,t}}$ and $\mathbf{X_{j,t}}$ are vector of control variables for firm i and j respectively, D_t is a time dummy, and I_k is an industry dummy. The dependent variable is the change is firm's total liquidity, defined as the sum of cash (item CHE) and total line of credit over total assets (item AT). The regressors include the lagged value of the dependent variable, size, market–to–book, cash flows, investment plus acquisitions, and net debt issuance. See Table 2 for variable definitions. In Column I we estimate a pooled OLS model without taking into account the potential endogeneity of changes in cash holdings. In Columns II to V, we estimate a two–stage least square (2SLS) model on the pooled data. Column II has no time and industry fixed effects. Column III has only time fixed effects. Column IV has only industry fixed effects. Column V has both time and industry fixed effects. We instrument the change in cash holdings of the rival firm ($\Delta Cach_{j,t}$) using the rival firm's control variables ($\mathbf{X_{j,t}}$, excluded instruments) and the firm's control variables ($\mathbf{X_{i,t}}$, included instruments). The reported standard errors (in parentheses) are robust to heteroskedasticity and are clustered at the firm level. *Validity* reports the partial R^2 measure to test the instruments' validity. *Joint significance* reports the Anderson–Rubin statistic for testing the joint significance of endogenous regressors. *Under–identification* reports the Kleibergen–Paap LM–statistic for testing whether the model is identified. *Weak identification* reports Cragg–Donald F–statistic to test if the set of instrument is weak. *Over–identification* reports the Hansen J–statistics to test if the instruments are uncorrelated with the error term. The data are at the annual frequency over the period 2003–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 9: Strategic Effect of Rival's Total Liquidity and Competition Intensity

	I	II	III	IV
Δ Rival's cash (low γ)	-0.210*	-0.169	-0.145	-0.115
	(0.119)	(0.109)	(0.115)	(0.107)
Δ Rival's cash (high γ)	-0.308**	-0.307**	-0.258**	-0.258**
	(0.123)	(0.123)	(0.120)	(0.120)
$\Delta\beta_{rival}$	**-0.098**	**-0.138**	**-0.113**	**-0.143**
p-value	0.568	0.402	0.491	0.375
Controls	Yes	Yes	Yes	Yes
Time FE	No	Yes	No	Yes
Industry FE	No	No	Yes	Yes

This table reports the results of estimating the system of equations described in Table 8 using 2SLS for two sub–samples. The first subsample (low–γ) contains firms–pairs that have an average value of γ below the median in a given cohort. The second subsample (high–γ) contains firms–pairs that have an average value of γ above the median in a given cohort. The table only reports the coefficient on the rival's cash holdings and omits the coefficients on the control variables. Δ Rival's cash (low γ) is the coefficient on the rival's cash holdings for the low–γ group, while Δ Rival's cash (high γ) is the coefficient on the rival's cash holdings for the high–γ group. $\Delta\beta_{rival}$ is the difference in the estimated coefficients between the two groups and *p-value* reports the significance of this difference. Column I has no time and industry fixed effects. Column II has only time fixed effects. Column III has only industry fixed effects. Column IV has both time and industry fixed effects. The reported standard errors (in parenthesis) are robust to heteroskedasticity and are clustered at the firm level. The data are at the annual frequency over the period 2003–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Table 10: Total Liquidity and Competition Intensity

	SA-Index		WW-Index		Dividend	
	NFC	FC	NFC	FC	NFC	FC
γ	0.087**	0.130***	0.071*	0.136***	0.074**	0.181***
	(0.038)	(0.045)	(0.039)	(0.043)	(0.036)	(0.046)
$\Delta\beta_{\gamma}$	-0.043		-0.065		-0.107**	
F-stat	0.540		1.359		4.050	
p–value	0.463		0.244		0.045	
Obs.	1,126	1,151	1,125	1,152	1,404	873
R^2–adj	0.322	0.378	0.367	0.377	0.347	0.440
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

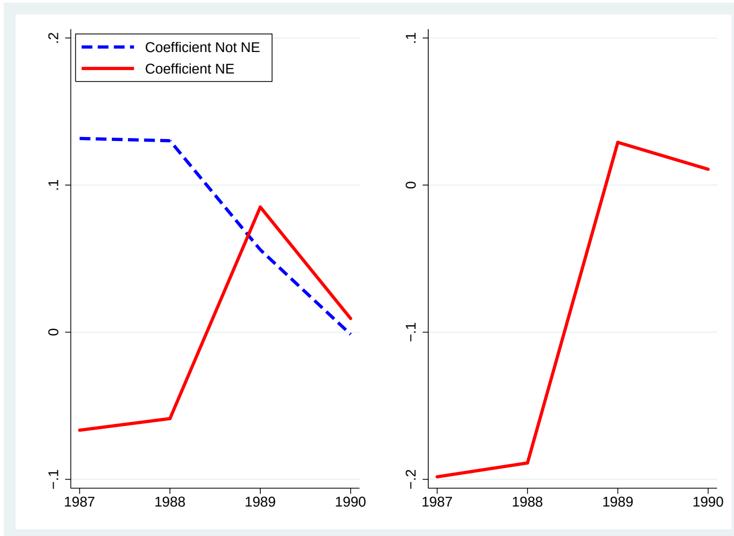
Table 10: Total Liquidity and Competition Intensity (continued)

This table reports the estimates of the following regression:

$$Liquidity_{i,t} = \beta_0 + \beta_\gamma \gamma_{i,j,t} + \beta_{\mathbf{1}} \mathbf{X_{i,t}} + \phi D_t + \varepsilon_{i,t},$$

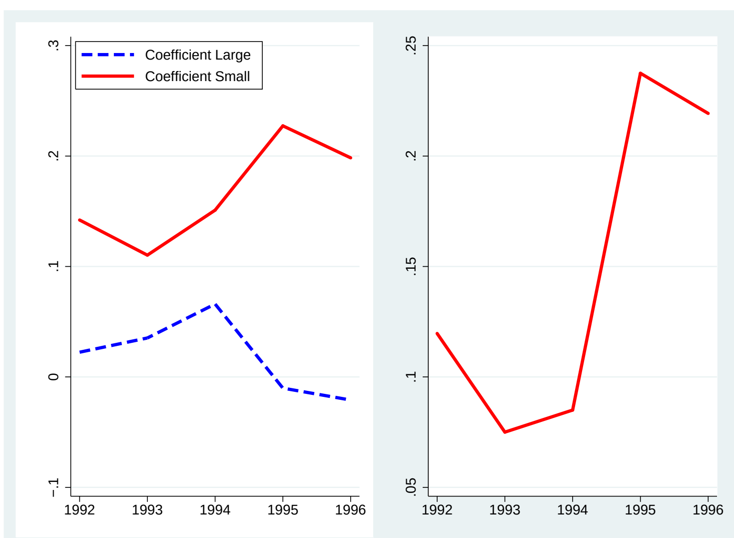
for sub–samples of relatively unconstrained and constrained firms. $Liquidity_{i,t}$ is the sum of cash (item CHE) and total line of credit over total assets (item AT), $\gamma_{i,t}$ is the measure of technological proximity of firm i at time t with its rival, $\mathbf{X_{i,t}}$ is a vector of control variables, D_t is a time dummy variable, and $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The set of control variables includes *Industry CFCV*, *Market-to-book*, *Size*, *Cash flow*, *Net working capital*, *Investment*, *Leverage*, *R&D*, and *Multinational*. See Table 2 for variable definitions. 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 columns 1 and 4, firms are classified as unconstrained (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 unconstrained (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 unconstrained (constrained) if dividends and repurchases are positive (equal to zero). The quantity of interest is $\Delta\beta_\gamma$, the difference in the competition intensity coefficient between unconstrained and constrained subsamples. $F - stat$ is the Wald F–statistic for testing the equality between these two coefficients. The data are at the annual frequency over the period 2003–2006 and all the accounting ratios are winsorized at the top and bottom 1% to limit the influence of outliers. The reported standard errors (in parenthesis) are robust to heteroskedasticity and are clustered at the firm level. *Obs.* is the number of firm-year observations and R^2–adj is the adjusted R-squared. The 1%, 5%, and 10% significance levels are denoted with ***, **, and *, respectively.

Figure 1: Shock to Credit Supply



The left panel of this figure reports the evolution of the sensitivity of cash holdings to expected competition intensity during the 1987–1990 period derived by estimating the regression in Equation (15) separately for each year. The solid line represents the evolution of β_γ in the Northeast subsample, while the dashed line represents its evolution in the non-Northeast subsample. The right panel of this figure reports the difference between the estimated coefficients within the two subsamples for each year during the 1987–1990 period.

Figure 2: Shock to Monetary Policy



The left panel of this figure reports the evolution of the sensitivity of cash holdings to expected competition intensity during the 1992–1996 period derived by estimating the regression in Equation (15) separately for each year. The dashed line represents the evolution of β_γ for the large firms subsample, while the solid line represents its evolution for the small firms subsample. The right panel of this figure reports the difference between the estimated coefficients within the two subsamples for each year during the 1992–1996 period.

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