Volatility of Research and Development Investment and Corporate Cash Holdings

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Abstract

This study explores the role of financing frictions and Research and Development (R&D) investment in determining the changes in corporate cash holdings. This is done by studying the impact of the volatility of R&D investment on cash-cash flow sensitivity. We argue that firms increase their cash holdings when they are concerned about the fluctuations in their R&D investment. This is because deviating from optimal R&D investment is costly. Therefore, higher R&D volatility leads firms to save cash out of their cash flows and increase cash holdings. This is more pronounced in financially constrained firms. Building on this view, the impact of financing frictions on corporate cash holdings is examined by using data for 1,554 US listed non-financial firms during the period 1980 to 2014. The results show that cash–cash flow sensitivity increases with R&D volatility, especially when firms are financially constrained. Our findings provide new insights into the importance of R&D volatility in shaping corporate decisions.

JEL classification: G31; G32

Keywords: Financial constraints; R&D investment volatility; Cash holdings; Cash flow sensitivity of cash; Liquidity management

1. Introduction

What determines firms to hold large amounts of cash reserves? This question has been extensively examined recently in the corporate finance literature (see, e.g., Ozkan and Ozkan, 2004; Faulkender and Wang, 2006; Denis and Siblikov, 2010; Kusnadi and Wei, 2011). Various explanations have been provided as to the incentives of firms to hold large cash balances. It is recognized that cash provides low cost financing for firms whilst raising external finance costs more, due to the presence of asymmetric information between firms and external investors (Myers and Majluf, 1984); costly agency problems such as underinvestment and asset substitution (Myers, 1977; Jensen and Meckling, 1976); transaction costs and other financial restrictions. Additionally, it is argued in the literature that firms maintain excess liquidity for “precautionary” or "speculative" motives. While the precautionary motive suggests that firms keep liquidity to meet unexpected contingencies (Keynes, 1936). The speculative motive postulates that firms maintain excess liquidity to take advantage of profitable future investment opportunities (Kim et al., 1998). Lastly, Brown and Petersen (2011) explore the smoothing motive for cash holdings where firms use cash reserves to smooth their Research and Development (R&D) investment.

Firms will attempt to maintain sufficient internal financial slack in order to minimize the costs associated with external financing. However, when cash flows or other sources of finances are not sufficient to serve all firms’ demand for capital, then cash holdings can become very valuable, especially for firms that are likely to face greater frictions in raising outside financing. That is, financially constrained firms can use available cash savings to finance the necessary expenditures. Consistent with this view, among others, studies of Kim et al., (1998), Harford (1999) and Opler et al., (1999) find that firms which experience greater difficulty in accessing external funds tend to hoard more cash. Similarly, Almeida et al.,

(2004) investigate the relation between financial constraints and cash balances of firms and find that financially constrained firms, compared to unconstrained firms, have a higher propensity to save cash out of their cash flow to safeguard against future investment needs.

The critical rise in R&D investment in last few decades has important but unexplored implications for the management of corporate liquidity. Innovative firms maintain financial slack in order to either finance R&D projects that are riskier to be funded by outside investors (Hambrick and Snow, 1977), or to maintain R&D funding during operating shortfalls (Bromiley, 1991). Firms investing intensively in innovation sustain financial slack in order to have readily available financing sources when R&D opportunities are discovered (Bourgeois, 1981; Chakravarthy, 1986; Singh, 1986; Nohria and Gulati, 1996). Obtaining external finance could be very time-consuming and costly each time a firm increases R&D expenditures over its historic levels, which makes financial slack more valuable.

This paper provides a new approach to examine the nature of the relationship between financing frictions and corporate cash holdings. We explore the idea that factors that lead firms to save cash out of their cash flows, may also increase cash holdings when firms are financially constrained. One such factor is the volatility of R&D investment (VR&D henceforth). [1] Firms with more volatile R&D investments are more likely to save cash, as such resources mitigate funding problems of volatile R&D investment and thus increase the sustainability of firm's investment policy. Prior literature argues that there is an optimal R&D investment policy for firms, determined by firm characteristics related to capital market

[1] R&DIV is a measure of the fluctuation in the firms' level R&D spending over time. A firm that invests about the same amount on R&D for each time period will have relatively low R&D spending volatility. A firm that changes its R&D expenditure frequently and substantially over time will show relatively high R&D spending volatility. The firm's level of R&D expenditure volatility over time evaluates whether the firm is proactively managing its R&D function.

imperfections (see, e.g., Brown and Petersen, 2009). We argue that firms increase cash holdings if they are concerned about the fluctuations in their optimal R&D investment. Thus, higher VR&D will motivate firms to save more cash out of cash flows in order to sustain their investment in future as higher cash holdings generally increase firms' capacity to undertake profitable investment opportunities, even when they experience shortfalls in their cash flows. Building on this view, we argue that VR&D itself may affect the cash position of the firm. We argue that VR&D level of firms can also affect the impact of the financial constraints on cash savings. That is, the extent to which cash balances of firms are determined by capital market imperfections, and hence financial constraints, may in turn depend on firms' VR&D status. This view simply allows VR&D to play a more substantial role in determining firms' cash reserves, namely a hedging role. Our argument is simple to follow. If VR&D motivates firms to hedge with cash reserves against the fluctuation of R&D investment, then those firms that have highly volatile R&D investment and are financially constrained will be more vulnerable against the fluctuations in cash flow. Therefore, they are expected to show a significant demand for greater cash balances in an attempt to reduce the impact of financing frictions on the availability of internal funds on cash holdings and to safeguard against future volatility of R&D investment.

This study acknowledges that firms desire to invest optimally in that they take up all the value-increasing (i.e. positive NPV) R&D investment opportunities. Consequently, VR&D is not desirable as it would indicate that firms are likely to be away from their optimal R&D investment at any point in time. Firms can be away from their optimal investment by overinvesting as well as underinvesting. Importantly, overinvestment can be as costly as underinvestment as it implies taking on negative NPV R&D investment opportunities. Furthermore, the efforts to lower VR&D are costly. The adjustment process of reverting back to the desired/optimal R&D investment level is often not instantaneous and involves costs which are determined by firm-specific as well as market-wide factors. For example, firms which are financially constrained, small, with greater growth opportunities, and/or subject to a greater degree of asymmetric information may find it difficult to raise external finance to invest as the cost of finance for such firms is higher.

Prior research on corporate investment has concentrated on cash flow volatility (see, e.g. Minton and Schrand, 1999 or Han and Qiu, 2007) while research on R&D investment has focused on the smoothing role of cash holdings (see Brown and Petersen, 2011). Since previous research has shown that R&D intensity is a powerful determinant of innovation and firms' performance (Pakes, 1985; Jaffe, 1986; Lev and Sougiannis, 1996; Hall et al., 2005), this paper assesses the impact of VR&D on cash flow sensitivity of cash and whether VR&D has explanatory power on a firm's cash holdings policy. There is no other study, to author's knowledge, investigating the role of R&D investment volatility (VR&D hereafter) in determining cash flow-cash sensitivity. Contemporary finance literature is very much focused on the role of financial constraints on firms' behaviour. However, it has not considered how obstacles to external financing may vary across different R&D firms' policies, namely cutting edge or routine R&D investment.

We formulate an empirical specification of the interplay between financial constraints and cash holdings. The effect of VR&D on cash flow sensitivities of cash holdings across different financial constraints classifications is compared by using a sample of 1,554 non-financial US firms which are investing in R&D projects as per the data obtained from Worldscope data source between 1980 and 2014. Our cash holding equations follow those of Almeida et al., (2004) but include an interaction term that captures the effect of VR&D on cash holding–cash flow sensitivities. We employ several estimation techniques to estimate the empirical specifications. Typically, the cash holdings equations are separately estimated across subsamples of constrained and unconstrained firms. The tests rely on *a priori* assigning firms into financial constraint categories, because VR&D is not a determinant of the firm's constraint status.[2] Firms are assigned into groups of constrained and unconstrained based on various firms' characteristics such as payout policy, size and firm age.

The empirical strategy of this study does not rely on a simple comparison of the levels of cash–cash flow sensitivities across constrained and unconstrained samples. Therefore, it is not a subject to the empirical problems that have been associated with the Almeida et al., (2004) approach of classifying firms into constrained and unconstrained groups and defining those firms with higher cash-cash flow sensitivity as financially constrained. Our approach investigates the idea that cash–cash flow sensitivities need not decrease monotonically with variables that impact financing constraints. We argue that this nonmonotonicity can be used in a positive way, to help uncover information about financing constraints that might be embedded in cash–cash flow sensitivities.

Our analysis reveals that VR&D plays an important role in determining corporate cash flow sensitivity of cash holdings in the US firms. We show that cash–cash flow sensitivities increase with the volatility of constrained firms' R&D investments. However, we find that VR&D has no effect on the cash flow sensitivities of financially unconstrained firms. The results also suggest that higher cash holdings are associated with lower levels of R&D expenditures, capital expenditures, leverage and dividend payments. Also, size has a negative effect on cash holdings, especially in case of constrained firms. We also provide evidence of a positive influence of cash flow and growth opportunities on cash holdings.

The rest of the paper is organized as follows: Section 2 formalizes our main hypothesis around the relation between cash holding–cash flow sensitivities, VR&D, and

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[2] Firms with high R&D investment volatility can be unconstrained too, because the volatility of R&D investment is a managerial decision, not a given financial variable like e.g., cash flow volatility (Hen and Qiu, 2007).

financial constraints. Section 3 proposes the methodology we use to test for financial constraints in a large sample of firms. Section 4 describes the data. Section 5 presents empirical results, whereas section 6 describes our robustness checks. Section 7 provides conclusions.

2. Volatility of R&D investment and financial constraints

The presence of financial constraints seems to be especially important for firms that engage in R&D investment due to the high risks associated with the investment (typically longer term projects with uncertain outcomes). Credit markets are not likely to be appropriate here. The wedge between internal and external financing faced by firms rises, and in effect a financing hierarchy appears. This problem is usually related to Akerlof's (1970) adverse selection in the 'market for lemons' (Leland and Pyle, 1977; Myers and Majluf, 1984). The problem of information asymmetries in R&D financing are magnified because firms are resistant to reveal information about their projects, as it might lead to the loss of a potential comparative advantage to their competitors. Furthermore, since the firm's internal knowledge stock is an intangible asset and not tradable, R&D-intensive firms have restricted ability to secure as much funding via external capital as firms with a greater level of tangible assets (Stiglitz and Weiss, 1981; Simerly and Li, 2000; Vincente-Lorente, 2001; and Hall, 2002). The empirical literature has therefore mainly focused on the role of internal finance as a financing source of R&D investment, providing evidence that firms first use internal funds to finance innovation projects as compared to external financing (see Hall and Lerner, 2010 for a review).

Innovative firms maintain some resources in excess of the level required to sustain production in the form of financial slack (Swift, 2008). There are two forms of financial slack, available (highly liquid) and potential (low levels of debt) slack. On the one hand, firms that sustain financial slack have discretionary financing sources that can be employed to fund innovation (Bourgeois, 1981). Financial slack allows firms to engage in or proceed with opportunities that are not recognized as viable by capital markets (Hambrick and Snow, 1977), and some of these opportunities can come out as major new innovations (March, 1991). Moreover, financial slack sustains innovation by helping to resolve goal conflict between opposing political factions within the firm (Cyert and March, 1963), and by allowing the firm to fulfil uncertain projects out of discretionary funds (Bourgeois, 1981). Financial slack makes the firm better able to alter its reaction to changing environmental conditions (Sharfman et al., 1988). On the other hand, excess free cash flow, or financial slack, is recognized as detrimental to a firm's performance and excess cash is evidence of managerial self-interest and complacency (Jensen and Meckling, 1976). Managers keep excess cash in order to maintain pet projects (Jensen, 1986, 1993). Yet Nohria and Gulati (1996) imply that an optimal level of financial slack exists - too little restricts exploration while too much fosters a lack of discipline and control. All in all, slack permits firms to fund R&D in a timely manner, even during periods of weak performance. Any financial shortfalls will lead to the cancellation of promising investments where firms do not have any slack (Bromiley, 1991). Research indicates that those innovative firms that aim to create sustainable competitive advantage through R&D have to support an internal environment that encourages valuable knowledge creation.

One view in the literature is that managers repeatedly manipulate R&D expenditures to smooth earnings or to meet earnings forecasts (Dechow and Sloan, 1991; Perry and Grinacker, 1994). Elliot et al., (1984) and Bushee (1998) find that managers can adjust their R&D budgets in order to smooth corporate earnings. According to Baber et al., (1991) managers decrease R&D expenses when earnings will be less than analysts' forecasts. In general, a prevalent approach in the literature is that managers make myopic decisions regarding R&D investments, concentrating on short-term earnings instead of focusing on value creation (Degeorge et al., 1999).

However, Schumpeter (1942) recognizes that VR&D may stem from a firm's ability to identify and terminate the least promising projects in order to consider new projects in the future, suggesting these fluctuations represent 'creative destruction' in R&D investments. Childs and Triantis (1999) find that firms often invest simultaneously in multiple projects along the same lines with the plan of selecting a lead project over a period of time and closing the others down. However, closing down R&D projects in the firm can be difficult because project managers can have personal incentives to continue their projects (Bernardo et al., 2001; and Stein, 2003). This suggests that persistent R&D investments appear from an inability to promote turnover among R&D projects in the firm. Henderson and Stern (2004) posit that firms are most likely to introduce more new products if they are able to exercise internal selection of R&D projects. In effect, creative destruction in the governance of R&D projects would lead to greater firm performance. Swift (2008) shows that fluctuations in R&D expenditure can be evidence of an effective R&D policy that enhances the firm performance. He provides empirical evidence showing how two forms of financial slack, available (highly liquid) and potential (low levels of debt) slack, enhance the positive relationship between VR&D and firm performance.

Volatile R&D investment is likely to reflect the volatile cash flows a firm experiences, therefore the firm is expected to implement some hedging tools in order to smooth their R&D investment.[3] Acharya et al., (2007) study both cash holdings and debt

[3] Han and Qiu (2007) claim that when future cash flow risk cannot be fully diversifiable, the intertemporal trade-off between current and future investments created by financial constraints gives constrained firms the incentives of precautionary savings: they increase their cash holdings in response to increases in cash flow volatility.

policies and they show that firms with “high hedging needs” will prefer to build cash stocks rather than debt capacity to hedge against cash flow shortfalls. We assume that constrained firms are most likely to hedge their R&D investment with cash holdings owing to the features of R&D investment, such as high risk, limited collateral value, severe information problems or high adjustment costs investment. This work directly explores the propensity with which firms invest their cash flows in precautionary cash stocks under the influence of VR&D. Volatile R&D investment firms facing severe financing constraints are most likely to save cash from cash flows in order to secure their R&D investment needs, while unconstrained firms can easily swap the sources of finances without any problems. Collectively, VR&D increases a firm’s motivation to save cash holdings out of cash flows, particularly when the firms face imperfect access to credit.

In this paper, the idea that firms with volatile R&D investment are more likely to save more cash out of cash flows to finance their investment, especially when they face more severe financing constraints, than firms with consistent R&D investment, is explored. We conjecture that cash holdings–cash flow sensitivities should be increasing with the volatility of a firms’ R&D investment, especially in the case of more financially constrained firms. Unconstrained firms’ cash holdings–cash flow sensitivities should not be systematically related to the volatility of a firms’ R&D investment. Put differently, we test empirically an implication for a firm's optimal cash holdings in response to a change in R&D volatility: cash – cash flow sensitivity of financially constrained firms increase in the presence of greater R&D volatility, while cash – cash flow sensitivity of financially unconstrained firms are not affected by R&D volatility. Thus, the hypothesis that the cash holdings-cash flow sensitivity increases with the volatility of R&D investment for financially constrained firms is tested.

3. Methodology

We use two alternative models to empirically examine the impact of VR&D on the cash flow sensitivity of cash. Both models focus on the question of whether VR&D influences cash – cash flow sensitivity. The first model, though, controls only for the basic firm-specific determinants, such as cash flows, and growth opportunities, while the second model is estimated using a specification in which a firm's long term decision about the level of its cash holdings is a function of a number of sources and the competing uses of funds.

3.1. An Empirical Model of Cash Holding, Cash Flow and VR&D

The parsimonious cash equation of Almeida et al., (2004), which includes cash flows and investment opportunities variables, is augmented with a proxy for VR&D and an interaction term that permits the effect of cash flow to vary with VR&D. Cash is defined as the ratio of cash and short term investment to total assets. Q is a traditional proxy for investment opportunities, calculated by the ratio of the book value of total assets minus the book value of equity plus the market value of equity to book value of assets. CF is the net income before extraordinary items and preferred dividends plus depreciation, depletion and amortization expense over total assets. There are two measures of R&D investment volatility. The first measure is taken from Han and Qiu (2007) or Swift (2008) and is a ratio of the standard deviation of R&D over the average of R&D, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. The second measure is a ratio of a standard deviation of the ratio of R&D over total assets over the average of the same ratio of R&D over total assets, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. These two measures are continuous. The baseline specification is as follows:

$$\Delta CASH_{i,t} = \alpha_1 CF_{i,t} + \alpha_2 Q_{i,t} + \alpha_3 VR\&D_{i,t} + \alpha_4 (CF \times VR\&D)_{i,t} + \Sigma\, firm_i + \Sigma\, year_t + \varepsilon_{i,t} \quad (1)$$

where firms are represented by subscript i=1,…,N, and time by t=1,…,T. $Firm_i$ and $year_t$ capture firm- and year-specific effects, respectively. In other words $firm_i$ represents time-constant firm-specific effects and $year_t$ represents firm-constant time effects. It is assumed that firm-specific effects $firm_i$ (firm-heterogeneity term) are unobservable but have a significant influence on cash holdings. They change across firms but are fixed for a given firm through time. In contrary $year_t$ changes over time but stays the same for all firms in a given year, capturing mainly economy-wide factors that are outside the control of firms such as prices. Our model estimation strategy allows the coefficient vector α to vary with the degree to which the firm faces financial constraints.

Growth opportunities are relevant in determining a firms' cash holding policies. Based on the view that external financing is more costly for firms with greater growth opportunities, it is predicted that there is a positive association between cash savings and the growth opportunities of firms. The current literature provides at least two explanations as to why there is a wedge between the costs of internal and external finance. First, agency costs are higher for growth firms because, risky debt firms are more likely to forego some of the valuable investment opportunities when the investment opportunity set of firms consists of growth opportunities (Myers, 1977). Second, for firms whose values are largely assessed by growth options, asymmetric information is more severe between insiders and outside investors (Myers and Majluf, 1984). As a result firms with greater growth opportunities generate more cash to lower their dependency on costly external financing and thus there is the possibility that they pass up valuable investment opportunities. Additionally, it is also argued that firms with greater growth opportunities are expected to incur higher bankruptcy costs (see, for example, Williamson, 1988; Harris and Raviv, 1990; and Shleifer and Vishny, 1992). The nature of growth opportunities is intangible and their value will decline significantly in financial distress and bankruptcy. To avoid financial distress and bankruptcy firms with greater growth opportunities hold larger cash holdings to offset the effect of larger expected costs.

Cash flow is another firm-specific characteristic that influences a firms' cash holding decisions. Kim et al., (1998) asserts that cash flow delivers a ready source of liquidity for investment and maturing liabilities. Firms with higher cash flows will have a lower risk of having to give up investment opportunities and facing financial distress, also such firms are not forced to keep high levels of cash holdings.[4]

In line with the main argument of this study, that higher VR&D will motivate firms to save cash out of cash flows, the extent to which internal funds matter for constrained cash should be an increasing function of VR&D. The primary variable of interest in this model is the interaction term between cash flow and VR&D, which tests if the impact of cash flow on cash holdings depends on the level of VR&D. The estimated coefficient of the interaction term is expected to be positive if VR&D provides incentives to make retained cash more sensitive to cash flow.

3.2. An Augmented Empirical Model of Cash Holdings, Cash Flow and VR&D

An alternative measure of the empirical VR&D impact on cash flow sensitivity of cash is estimated from a specification in which a firm's cash holding decision depends on

[4] However, firms have a preference for internal over external finance in the presence of asymmetric information and signaling problems associated with external funding, (Myers and Majluf, 1984). Thus a positive relation between cash and cash flow is expected. Also, to the extent that cash flows are a proxy for growth options the relationship between cash flow and cash holdings should be positive.

number of sources and competing uses of funds. This approach treats cash holdings as a firm's long run decisions; hence, it includes other long term decisions that a firm makes. Thus, we model that the firm's cash savings decision is a function of R&D expenses, capital expenditures (INV), leverage (LEV) and dividend payments (DIV), where all these additional variables are scaled by total assets. We also control for size proxied by the natural log of assets. Overall this analysis examines the relation between VR&D and cash flow sensitivity of cash after controlling for other firm-specific characteristics.

$$\Delta CASH_{i,t} = \alpha_1 CF_{i,t} + \alpha_2 Q_{i,t} + \alpha_3 R\&D_{i,t} + \alpha_4 SIZE_{i,t} + \alpha_5 INV_{i,t} + \alpha_6 LEV_{i,t} + \alpha_7 DIV_{i,t} + \alpha_8 VR\&D_{i,t} + \alpha_9 (CF \times VR\&D)_{i,t} + \Sigma firm_i + \Sigma year_t + \varepsilon_{i,t} \quad (2)$$

This empirical specification controls for R&D and capital expenditures because firms can draw down on cash savings in order to finance investment. Coefficient α_3 and α_5 are expected to be negative. We control for size because of standard arguments of economies of scale in cash management. The intuition for including a leverage variable is based on the argument that firms may employ substitutes for holding high levels of cash especially when they experience cash shortfalls. Specifically, firms can use borrowings as a substitute for cash savings because leverage can be perceived as a proxy for the ability of firms to issue debt (John, 1993). According to Baskin (1987) when the ratio of debt financing increases, the cost of funds used to invest in liquidity increases, which would suggest a decline in cash holdings with increased leverage. Hence, a negative relation between the firm's cash holdings and its leverage should be predicted. However, the likelihood of financial distress can rise with an increased debt in capital structure. In such a case one would expect a highly leveraged firm to raise its cash holdings to diminish the likelihood of financial distress. This would lead to a positive association between leverage and cash holdings. Leverage is measured by the ratio of total debt to total assets.

Finally, simply to control for the potential influence of the firm's dividend policy on its cash holdings we include the dividend payout ratio in the second model. To the extent that dividends paying firms can increase funds relatively easily by cutting their dividends, a negative relationship is expected between dividend and cash holdings (Opler et al., 1999). However, it is also possible that firms who pay dividends may retain more cash than firms that do not pay dividends in order to avoid a situation in which they are lacking cash to maintain their dividend payments. This would induce a positive relation.

Industry and year dummies are included in all specifications.

3.3. Ex Ante Constraint Selection

Equations (1) and (2) are estimated for constrained and unconstrained firms separately to compare the sign and the significance of the estimated coefficient of interaction term. Thus, the sample is divided into constrained and unconstrained firms in the spirit of Fazzari et al., (1988), who initiated the standard approach in the literature to use exogenous, *a priori* sorting conditions that are hypothesized to be associated with the extent of financing frictions that firms face (see Erickson and Whited, 2000; Almeida et al., 2004; and Hennessy and Whited, 2007 for recent examples of this strategy). Firms are sorted into constrained and unconstrained groups, on the basis of their dividend payouts, size and age. Previous research on the subject serves here in choosing variables for classification criteria. A brief discussion on each of these variables is now provided.

Dividend: Following Fazzari et al., (1988) firms are assigned to the financial constrained (unconstrained) group if they don't (do) pay dividend. It is argued that dividend paying firms, on the contrary to non-dividend paying ones, are less likely to be financially constrained because they can terminate dividends whenever their ability to acquire external funds is restricted. However, this variable should be considered carefully since cutting dividends for the sake of liquidity may also have adverse signalling effects for the firm's stock in the market (see Healy and Palepu, 1988).

Size: Firms are ranked on the basis of size (proxied by the logarithm of total assets) and assigned to the financially constrained (unconstrained) group if their size lies below (above) the 50th percentile size value in the sample. The rationale that smaller firms are more likely to be financially constrained as they are subject to greater asymmetric information and agency problems and, therefore, have difficulties in accessing external finance, follows the views of Gertler and Gilchrist (1994), Gilchrist and Himmelberg (1995), Kadapakkam et al., (1998), and Erickson and Whited (2000), among others.

Age: Firms are assigned to the financial constrained (unconstrained) group if their age lies below (above) the 50th percentile age value in the age distribution. The intuition, that older firms have an established reputation in the market, which facilitates their access to external finance, mainly because their relationships with creditors are settled within a longer time span, follows from work by Berger and Udell (1995).

In addition, in order to evaluate the research hypotheses offered above, firms are also divided according to the mean of their cash flows and the industry they belong to, that is high-tech firms versus non high-tech firms.

4. Data Description

Our sample selection approach is in line with similar prior work (see e.g., Almeida et al., 2004; Almeida and Campello, 2007). For our empirical analysis of corporate cash holdings we use a sample of US manufacturing (SICs 2000–3999) publicly traded firms from 1980 to 2014. Our initial sample is the set of all firms for which data are available on the

Worldscope database provided by the Thomson One Banker website. The panel data set for this study has been created as follows. We eliminate firm-years, for which the value of capital stock is less than $10 million, and those displaying real asset or sales growth exceeding 100%. The first selection rule eliminates very small firms from the sample, those for which linear cash models are likely inadequate (see Gilchrist and Himmelberg, 1995). The second rule eliminates those firm-years registering large jumps in business fundamentals (size and sales); these are typically indicative of mergers, reorganizations, and other major corporate events. Then, we trim all variables at their extreme 1 and 99 percentiles. Also all the missing firm-year observations for any variable in the model during the sample period were dropped. Lastly, from these firms, only those with at least seven continuous time series observations during the sample period have been chosen, given the definitions of the VR&D. These criteria have provided us with a total of 1,554 US firms, which represents 22,200 firm-year observations.

Table 1 provides variables' definitions while Table 2 presents descriptive statistics for all variables used in the analysis apart from the VR&D variables, which are reported separately in Table 3.

- Insert Table 1 and 2 here -

The findings of Table 2 reveal that the average values during the sample period of R&D/TA and CE/TA ratios are 0.066 and 0.05 respectively. Partly by construction, the average firm in the sample spends significantly more on R&D investment than on capital expenditures. The mean cash to assets ratio, the dependent variable in the regression analysis, is 19 percent for the firms' sample, whereas the mean value of cash flow is 6 percent. The average Tobin's Q is 1.949, suggesting that the firms sampled have relatively good growth prospects in the sample period. The average total debt by firms corresponds to 17.8 percent of total assets and the average dividend payout-to-assets ratio is only 0.13 percent. Finally, the average age of the firm in the sample is about 21 years.

- *Insert Table 3 here* -

Table 3 presents detailed summary statistics for each of the two measures of VR&D employed in this study. The first VR&D measure indicates that the average ratio of standard deviation to the mean of R&D investment is equal to 28.4% for the US firms. The second measure indicates that the average ratio of standard deviation to the mean of R&D investment-to-total assets is equal to 23.8% for the sample. The numbers in Table 3 imply that both measures show similar trends.

- *Insert Table 4 here* -

Table 4 reports summary statistics for a firm cash holdings, *Q*, and cash flows, separately for firms with high and low VR&D levels. The purpose of this table is to check whether there are distributional patterns in those two variables that are systematically related with VR&D. Both measures of VR&D are continuous variables and categorized according to the median value of the VR&D distribution. The numbers in Table 4 suggest the absence of any systematic patterns for investment opportunities, across the low- and high-VR&D firms. For example, while high-VR&D firms seem to retain more cash holdings and have lower cash flows according to the two VR&D proxies, the opposite is true when the investment opportunities proxy is considered. Namely, while high-VR&D firms have greater growth opportunities according to the first measure of VR&D, low-VR&D firms have greater growth opportunities according to the second measure of VR&D.

5. Results

- Insert Table 5 here -

Table 5 demonstrates the first set of pooled OLS-FE results according to the baseline model in equation (1) for a priori determined sample divisions into constrained and unconstrained subsamples and each of our two VR&D proxies. Equation (1) is estimated via OLS with firm- and year-fixed effects, and the error structure allows for residual heteroscedasticity and time clustering. In this table, each two out of the four columns reports the results associated with a particular measure of VR&D. Rows of this table present results from the constraints selection equations. We report a total of twelve cash holding equations (2 VR&D proxies × 3 constraints criteria x 2 constraints categories), yielding three constrained–unconstrained comparison pairs for each VR&D measure. Since we use interaction terms in all of our regressions and because the key variable used to gauge interaction effects (namely, VR&D) is defined differently across our estimations, the economic meaning of all of the estimates we report is carefully discussed.

Based on the results from three different selection regimes, we call the firms ‘‘constrained’’ (‘‘unconstrained’’) firms. Each and every one of the regression pairs in the table reveals the same key result: constrained firms’ cash–cash flow sensitivities are increasing in VR&D, while unconstrained firms’ sensitivities show no or little response (often in the opposite direction) to VR&D. Indeed, the interaction between cash flow and VR&D attracts positive, statistically significant coefficients in almost all of the constrained firm estimations. The exceptions appear for the first measure of VR&D when firms' ex ante constraints criteria is firms' dividend payout and age. Further, these coefficients are uniformly higher than those of the unconstrained samples, and statistically significant. Because higher VR&D makes it more likely that a firm will be unconstrained (Table 4 shows that high-VR&D firms have greater amounts of cash holdings, which will allow these firms to invest in more unconstrained way), the positive effect of VR&D on investment–cash flow sensitivities is most likely to obtain for low levels of VR&D. These findings are fully consistent with the main hypothesis of this paper.

It is important to illustrate the impact of VR&D on the sensitivity of cash to cash flows when the firm is financially constrained. To do so, we consider the estimates associated with our baseline measure of VR&D (first row in Table 3). When calculated at the first quartile of US VR&D (i.e., at 0.138, see Table 3), the partial effect of a one standard-deviation cash flow innovation (which is equal to 0.144), see Table 2) on cash per dollar of total assets is around 0.010. In contrary, at the third quartile of the same measure (i.e., at 0.357), that partial effect equals approximately 0.014.[5] Likewise calculations for unconstrained firms generate mostly economically and statistically insignificant effects regarding the effect of VR&D. Because we are not strictly estimating structural cash equations, these economic magnitudes should be interpreted with some caution. Yet, they clearly ascribe an important role to VR&D in shaping the cash decisions of constrained firms.

The remaining estimates in Table 5 display patterns that are also consistent with our story and with previous research. The coefficients returned for *cash flow and Tobin's Q* are positive in all models. Cash flow coefficients tend to be somewhat larger and statistically

[5] Following Almeida and Campello (2007) the partial effects are equal to the standard deviation of cash flows times the coefficient on Cash Flow, plus that same standard deviation times the coefficient on the interaction term times the level of R&DIV (first or third quartiles).

significant for small and young firms, a pattern also seen in some of the estimations in Almeida et al., (2004) or Han and Qui (2007). The coefficients returned for *VR&D* are mainly positive in our estimations, although statistically insignificant.

- Insert Table 6 here -

Table 6 presents the results for the alternative cash holdings model described by the equation (2). The results in Table 6 resemble the previous results obtained from the estimation of the regression model in equation (1). All new variables included in the model show negative and in most cases statistically significant impact on cash holdings for our sample regardless of the VR&D measure. This suggests that both R&D and physical investments, next leverage and dividend payments, all play a substitutive role with cash holdings. The coefficients for interaction between cash flows and VR&D are similar to the corresponding coefficients estimated with the equation (1), however, they are greater in size. As in our previous estimations, each one of the regression pairs in the table shows that constrained firms' cash–cash flow sensitivities are increasing in VR&D, while unconstrained firms' sensitivities show little or no response to VR&D. Once again, the interaction between cash flow and VR&D attracts positive, statistically significant coefficients in all of the constrained firm estimations (except for one subsample of young firms for the first measure of VR&D). And these coefficients are uniformly higher than those of the unconstrained samples. The results we obtain through this estimation approach are of special interest in that they are very closely related to the types of tests implemented in the vast literature on financial constraints.

Also, the estimated coefficients of the remaining variables in our models are as expected. For example, Tobin's Q is positive in all models and statistically significant in majority of estimations, which supports the view that high-growth firms prefer to retain more cash to be able to finance future growth opportunities. Furthermore, profitability enters positively the cash equation, whilst the coefficients of remaining variables show negative signs.

Overall, the results in this paper show the same pattern that constrained firms do increase their cash savings out of cash flows under the influence of higher R&D expenditure volatility. Indeed, the interaction between cash flow and VR&D attracts positive, statistically significant coefficients in almost all of the constrained firm estimations for US sample. Because higher volatility of R&D expenditures makes it more likely that a firm will be unconstrained, the positive effect of VR&D on cash–cash flow sensitivities is most likely to be obtained for low levels of VR&D. These findings are similar to the tangibility effect on investment cash flow sensitivity where there is a presence of a credit multiplier effect for constrained firm investment that works for Almeida and Campello (2007) model.

6. Robustness

We carry out a number of robustness checks in order to address potential concerns with empirical biases in our estimations. These additional checks involve, among others, changes to our baseline specification (including the use of alternative lagging schemes), changes to proxy construction, various subsampling checks, additional constraints categories (e.g., low- versus high-sales growth firms), additional divisions (e.g., low- versus high- long term debt firms) and outlier treatment (e.g., winsorizing at extreme quantiles). These tests produce no qualitative changes to our empirical findings and are omitted from the article for space considerations.

Importantly, our estimations stem from the Almeida et al., (2004) model and before we augmented their model with the VR&D and interaction of VR&D and cash flow, we checked whether the sample would provide results in agreement with their results, which was the case.

So far our analysis presented the results for VR&D only, however, in this section we also consider the capital investment volatility (CIV hereafter) with similar reasoning to VR&D. Namely we collect new data set that it is not scaled down by the R&D investment and experiment with the same analysis as for the VR&D. We also rerun our results with this paper's data set with CIV proxies instead of VR&D ones. All these tests prove that the CIV lacks the power to influence the cash flow sensitivity of cash holdings. We find no significant results for any CIV proxies, sample, methodology or firms' divisions. This finding supports finding of Brown and Petersen (2011) that firms smooth their R&D investment with cash holdings. This result also confirms previous findings in the literature that R&D investment is most likely to be financed with cash reserves.

7. Conclusions

This study provides an empirical analysis to investigate the interaction between financing fractions and R&D investment in determining corporate cash holdings. The main hypothesis that the paper explores is that firms, in particular financially constrained ones, increase their cash holdings with the volatility of R&D investment expenditures (VR&D). The analysis is carried out by conducting an OLS-FE panel data analysis for a sample of 1,554 non-financial US firms during the period from 1980 to 2014.

By investigating the role of VR&D in determining cash savings for financially constrained and unconstrained firms, we are able to emphasize an important aspect of VR&D, which has been explored partially in the literature. It seems that VR&D can play an effective role in firms' hedging policy against the fluctuations in cash flow and financial constraints, which restrict the ability of firms to undertake profitable R&D investment opportunities. The evidence uncovered in this article is strongly consistent with the significant relation between financing frictions and cash. As we hypothesize, we find that while VR&D increases cash–cash flow sensitivities for financially constrained firms, no such effects are observed for unconstrained firms. This possibly suggests that higher R&D volatility leads to higher cash holdings due to precautionary motives. Based on our findings we conclude that one way that VR&D smooths flow of R&D spending in the face of shocks to the availability of external finance is by allowing constrained firms to maintain a hedging policy through higher cash reserves. Cash flow increases have especially large effects for constrained firms with high VR&D, because these firms are most likely to have highly pro-cyclical cash reserves. This insight can have interesting implications for asset pricing and macroeconomics, which could be explored by future researchers and policymakers.

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Table 1

Variables Definitions

Variable	Definition
ΔCASH	The annual change in a ratio of total cash and short term investment to total assets
CE	The ratio of capital expenditures to total assets
R&D	The ratio of research and development expenditures to total assets
CF	The ratio of net income before extraordinary items and preferred dividends plus depreciation, depletion and amortization to total assets
Q	The ratio of book value of total assets minus the book value of equity plus the market value of equity to book value of total asset
LEV	The ratio of total debt to total assets
SIZE	The logarithm of total assets
AGE	Number of years firm is publicly listed since 1980
DIV	The ratio of total cash dividend to total assets
VR&D	Volatility of research and development expenditures = standard deviation of research and development expenditures over six years starting from t-1/ average of research and development expenditures over six years starting from t-1,
VR&D/TA	Volatility of R&D/TA = standard deviation of R&D/TA over six years starting from t-1/ average of R&D/TA over six years starting from t-1,

Notes: This table provides the definitions of the main variables used in our analysis.

Table 2

Descriptive statistics for the whole sample for R&D

	Mean	Median	St. Dev.	Min	Max
R&D	0.066	0.040	0.079	0	0.810
CASH	0.190	0.119	0.196	0.002	0.964
CE	0.050	0.042	0.036	0	0.257
CF	0.060	0.092	0.144	-1.237	0.302
Q	1.949	1.556	1.244	0.249	9.998
LTD	0.135	0.107	0.135	0	0.918
LEV	0.178	0.160	0.154	0	0.963
SIZE	6.294	6.007	2.150	0.703	13.528
AGE	21.215	20	8.636	7	35
DIV	0.013	0.003	0.027	0	1.367

Notes: This table presents descriptive statistics of the variables used in the empirical tests for the whole sample of 1,554 US firms. The number of observations is 22,200. All data are from the annual Worldscope data base. The sampled firms include only manufacturers (SICs 2000–3999) and the sample period is 1980 through 2014. Analytical definitions for all the variables are provided in table 1.

Table 3

Summary statistics for R&D investment volatility

	Mean	St. Dev.	Pct.10	Pct.25	Pct.50	Pct.75	Pct.90	Obs.
Investment volatility measures								
1. VR&D	0.284	0.236	0.090	0.138	0.223	0.357	0.534	12776
2. VR&D/TA	0.238	0.223	0.072	0.111	0.178	0.291	0.462	12776

Notes: This table displays summary statistics for research and development investment volatility. Two different measures of investment volatility are considered. The first measure is taken from Han and Qiu (2007) or Swift (2008) and is a ratio of the standard deviation of R&D over the average of R&D, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. The second measure is a ratio of a standard deviation of the ratio of R&D over total assets over the average of the same ratio of R&D over total assets, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. These two measures are continuous. The sampled firms include only manufacturers (SICs 2000–3999) and the sample period is 1980 through 2014. The definitions of the variables used in the analysis are provided in Table 1.

Table 4

Summary statistics of CASH, Q and CF across low- and high- R&D investment volatility firms

	CASH			Q			CF			
Investment volatility measures	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Mean	Median	St. Dev.	Obs.
Low-VR&D	0.149	0.096	0.153	1.792	1.539	0.943	0.080	0.097	0.106	6388
High-VR&D	0.190	0.128	0.187	1.941	1.564	1.216	0.056	0.089	0.149	6388
Low-VR&D/TA	0.142	0.098	0.137	1.895	1.609	1.018	0.096	0.104	0.084	6388
High-VR&D/TA	0.197	0.129	0.197	1.838	1.485	1.158	0.040	0.081	0.159	6388

This table displays summary statistics for cash, Q, and cash flows across groups of low- and high-investment volatility firms for the whole sample of 1,554 US firms. There are two measures of investment volatility. The first measure is taken from Han and Qiu (2007) or Swift (2008) and is a ratio of the standard deviation of R&D over the average of R&D, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. The second measure is a ratio of a standard deviation of the ratio of R&D over total assets over the average of the same ratio of R&D over total assets, where both nominator and denominator of the ratio are calculated over six consecutive years starting with the lagged value of R&D for a given year. These two measures are continuous and we define as low (high) - investment volatility firms those ranked in the bottom (top) five deciles of the investment volatility distribution. The sampled firms include only manufacturers (SICs 2000–3999) and the sample period is 1980 through 2014. The definitions of the variables used in the analysis are provided in Table 1.

Table 5

Cash–cash flow sensitivity and investment volatility: Ex ante constraint selection

Dependent Variable: ΔCASH

	Volatility proxied by VOL_R&D				Volatility proxied by VOL_R&D/TA			
1. Payout Policy								
	Constrained Firms		Unconstrained Firms		Constrained Firms		Unconstrained Firms	
CF	0.052*	(1.71)	0.063**	(2.33)	0.048	(1.39)	0.059**	(2.27)
Q	0.004	(1.32)	0.002	(1.45)	0.004	(1.29)	0.002	(1.53)
Volatility	-0.001	(-0.04)	0.007	(0.78)	0.006	(0.37)	0.001	(0.08)
CF x Volatility	0.123	(1.64)	0.007	(0.09)	0.143*	(1.87)	0.021	(0.31)
R2	0.034		0.033		0.034		0.033	
Obs.	3507		9269		3507		9269	
Firms	656		897		656		897	
2. Firm Size								
	Constrained Firms		Unconstrained Firms		Constrained Firms		Unconstrained Firms	
CF	0.077**	(2.44)	0.044*	(1.70)	0.079**	(2.43)	0.045	(1.29)
Q	0.002	(0.56)	0.005***	(3.03)	0.002	(0.55)	0.004***	(2.98)
Volatility	-0.005	(-0.47)	0.012	(1.29)	0	(-0.03)	0.009	(0.82)
CF x Volatility	0.126*	(1.77)	-0.035	(-0.42)	0.122*	(1.71)	-0.047	(-0.49)

R2	0.046		0.028		0.046		0.028	
Obs.	3322		9454		3322		9454	
Firms	603		950		603		950	

3. Firm Age

	Constrained Firms		Unconstrained Firms		Constrained Firms		Unconstrained Firms	
CF	0.057**	(2.00)	0.037	(1.23)	0.045	(1.43)	0.065**	(2.37)
Q	0.003	(1.18)	0.003*	(1.71)	0.003	(1.18)	0.003*	(1.72)
Volatility	0.007	(0.64)	-0.006	(-0.70)	-0.006	(-0.57)	0.006	(0.74)
CF x Volatility	0.096	(1.36)	0.096	(1.11)	0.139*	(1.90)	-0.001	(-0.01)
R2	0.029		0.036		0.029		0.036	
Obs.	6287		6389		6287		6389	
Firms	1150		403		1150		403	

Notes: This table displays OLS-FE (firm and year effects) estimation results of the parsimonious cash model (Eqution (1) in the text), for the research and development sample of 1,554 US firms. The estimations use pre-determined firms election into ‘‘financially constrained’’ and ‘‘financially unconstrained’’ categories. Constraint category assignments use ex ante criteria based on firm dividend payout, size, and age (see text for details). All data are from the annual Worldscope data base. The sampled firms include only manufacturers (SICs 2000–3999) and the sample period is 1980 through 2014. The estimations correct the error structure for heteroskedasticity and clustering effects. All regressions include time dummies. t-statistics values are reported in parentheses.***, ** and * indicate statistical significance at the 1- 5- and 10-percent (two-tail) test levels, respectively. Analytical definitions for all the variables are provided in table 1.

Table 6

Cash–cash flow sensitivity and investment volatility with various controlling variables: Ex ante constraint selection

Dependent Variable: ΔCASH								
	Volatility proxied by VOL_R&D				Volatility proxied by VOL_R&D/TA			
1. Payout Policy								
	Constrained Firms		Unconstrained Firms		Constrained Firms		Unconstrained Firms	
CF	0.026	(0.79)	0.074***	(2.69)	0.024	(0.67)	0.069**	(2.54)
Q	0.005*	(1.68)	0.005***	(2.92)	0.005*	(1.65)	0.005***	(2.98)
R&D	-0.230***	(-3.80)	-0.174***	(-2.72)	-0.222***	(-3.69)	-0.168***	(-2.63)
SIZE	-0.019***	(-3.15)	-0.002	(-1.12)	-0.018***	(-3.08)	-0.002	(-1.06)
CE	-0.742***	(-8.90)	-0.455***	(-11.75)	-0.740***	(-8.92)	-0.456***	(-11.79)
LEV	-0.041*	(-1.71)	-0.037***	(-3.33)	-0.041*	(-1.69)	-0.037***	(-3.33)
DIV	0.000	(.)	-0.233***	(-2.92)	0.000	(.)	-0.234***	(-2.93)
Volatility	0.012	(0.83)	0.008	(0.94)	0.001	(0.05)	-0.001	(-0.14)
CF x Volatility	0.135*	(1.74)	-0.005	(-0.07)	0.149*	(1.91)	0.012	(0.18)
R2	0.065		0.065		0.065		0.065	
Obs.	3507		9269		3507		9269	
Firms	656		897		656		897	

2. Firm Size

	Constrained Firms		Unconstrained Firms		Constrained Firms		Unconstrained Firms	
CF	0.035	(1.05)	0.058**	(2.23)	0.037	(1.10)	0.06	(1.64)
Q	0.004	(1.33)	0.006***	(3.98)	0.004	(1.32)	0.006***	(3.89)
R&D	-0.231***	(-3.95)	-0.082	(-1.05)	-0.229***	(-3.87)	-0.078	(-0.99)
SIZE	0	(0.01)	-0.007***	(-3.12)	0	(-0.01)	-0.007***	(-3.05)
CE	-0.722***	(-8.75)	-0.478***	(-11.72)	-0.724***	(-8.80)	-0.478***	(-11.78)
LEV	-0.085***	(-2.74)	-0.026**	(-2.56)	-0.086***	(-2.77)	-0.025**	(-2.46)
DIV	-0.424***	(-4.42)	-0.165**	(-2.06)	-0.419***	(-4.41)	-0.166**	(-2.08)
Volatility	-0.003	(-0.27)	0.014	(1.57)	-0.004	(-0.33)	0.008	(0.77)
CF x Volatility	0.133*	(1.78)	-0.053	(-0.64)	0.130*	(1.82)	-0.073	(-0.77)
R2	0.090		0.051		0.089		0.051	
Obs.	3322		9454		3322		9454	
Firms	603		950		603		950	

3. Firm Age

	Constrained Firms		Unconstrained Firms			Constrained Firms		Unconstrained Firms	
CF	0.027	(0.91)	0.050*	(1.65)		0.018	(0.55)	0.077***	(2.83)
Q	0.005*	(1.80)	0.004***	(2.70)		0.005*	(1.80)	0.004***	(2.68)
R&D	-0.249***	(-4.16)	-0.055	(-0.90)		-0.240***	(-4.01)	-0.053	(-0.84)
SIZE	-0.010**	(-2.02)	-0.002	(-1.08)		-0.010**	(-2.00)	-0.002	(-1.06)
CE	-0.737***	(-12.02)	-0.389***	(-8.90)		-0.739***	(-12.09)	-0.389***	(-8.89)
LEV	-0.042**	(-2.14)	-0.040***	(-3.69)		-0.042**	(-2.15)	-0.040***	(-3.70)
DIV	-0.255***	(-3.67)	-0.220*	(-1.91)		-0.256***	(-3.68)	-0.220*	(-1.91)
Volatility	0.010	(0.96)	-0.005	(-0.53)		-0.009	(-0.82)	0.004	(0.57)
CF x Volatility	0.104	(1.40)	0.085	(0.98)		0.143*	(1.89)	-0.008	(-0.13)
R2	0.066		0.059			0.067		0.059	
Obs.	6387		6389			6387		6389	
Firms	1150		403			1150		403	

Notes: This table displays OLS-FE (firm and year effects) estimation results of the augmented cash model (Eqution (2) in the text). The estimations use pre-determined firms election into ‘‘financially constrained’’ and ‘‘financially unconstrained’’ categories. Constraint category assignments use ex ante criteria based on firm dividend payout, size, and age (see text for details). All data are from the annual Worldscope data base. The sampled firms include only manufacturers (SICs 2000–3999) and the sample period is 1980 through 2014. The estimations correct the error structure for heteroskedasticity and clustering effects. All regressions include time dummies. t-statistics values are reported in parentheses.***, ** and * indicate statistical significance at the 1- 5- and 10-percent (two-tail) test levels, respectively. Analytical definitions for all the variables are provided in table 1.