Three Essays on Innovation and Precautionary Cash Holdings

Inaugural dissertation submitted by Stefan Aebischer in fulfillment of the requirements for the degree of Doctor rerum oeconomicarum at the Faculty of Business, Economics and Social Sciences of the University of Bern.

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2016

The faculty accepted this work as dissertation on November 10th 2016 at the request of the two advisors Prof. Dr. Claudio Loderer and Prof. Dr. Dennis Sheehan, without wishing to take a position on the view presented therein.

Abstract

This thesis consists of three papers that investigate firms' management of innovation and precautionary cash holdings.

The first paper examines innovation efforts and abilities of firms at different stages in the lifecycle. The study exploits unique firm data on investments and sales related to innovation from six waves of the Swiss Innovation Survey between 1996 and 2011. Using firm age to identify established firms, I find that established firms, compared to young firms, invest less in innovation and are less efficient in producing innovation output within the firm. By contrast, established firms are more efficient in using knowledge from outside the firm (e.g., from suppliers, competitors, universities) to produce innovation output. These results largely do not depend on whether the innovation output is incremental or radical in nature. These findings suggest that young and established firms differ in the allocation and productivity of innovation resources.

The second paper examines the importance of the precautionary motive relative to other motives as a determinant of corporate cash holdings. According to the precautionary motive, firms facing future financing constraints hold cash to ensure that they can make investments or meet obligations. I develop an index that includes the precautionary information of six popular firm-level measures: cash flows, cash flow volatility, R&D intensity, market-to-book, net working capital and product market competition. The index explains 32% of the variation in corporate cash holdings and increases to 41% when using the debt and equity constraint indices of Hoberg and Maksimovic (2015) as additional precautionary measures. As the predominant cash determinant, the precautionary motive is particularly strong for firms that face greater opportunity costs of disclosing proprietary information. This finding is consistent with the notion that these firms are more reliant on precautionary cash to protect proprietary information that they otherwise have to disclose to investors to reduce equity constraints.

The third paper investigates whether the debt or equity capital supply shock of the recent financial crisis (2007-2009) caused firms to use precautionary cash holdings to mitigate underinvestment. I find that precautionary cash was used to substitute for the decline in net equity issuance but not net debt issuance. I also find that precautionary cash was used by equity- but not debt-constrained firms to mitigate underinvestment during the crisis. Consistently, precautionary cash was not used in the absence of the equity supply shock, i.e., during placebo crises or during the economy-wide demand shock following the financial crisis. This paper provides new evidence on the importance of corporate liquidity management for equity-constrained firms and identifies the crisis' equity capital supply shock as a dominant first-order effect on corporate financial policies.

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I. Firm innovation: a lifecycle perspective

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June 2016

This paper examines innovation efforts and abilities of firms at different stages in the lifecycle. The study exploits unique firm data on investments and sales related to innovation from six waves of the Swiss Innovation Survey between 1996 and 2011. Using firm age to identify established firms, I find that established firms, compared to young firms, invest less in innovation and are less efficient in producing innovation output within the firm. By contrast, established firms are more efficient in using knowledge from outside the firm (e.g., from suppliers, competitors, universities) to produce innovation output. These results largely do not depend on whether the innovation output is incremental or radical in nature. These findings suggest that young and established firms differ in the allocation and productivity of innovation resources.

Keywords: incremental and radical innovation, exploitation and exploration, innovation performance, absorptive capacity, firm age, firm size.

JEL codes: D83, L20, O31, O32

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1. Introduction

Innovation drives economic and productivity growth, and understanding the characteristics of firms that successfully conduct innovation activities is thus important. Moreover, innovation comes in many shapes and sizes (e.g., product versus process and radical versus incremental) and can originate inside or outside a firm's boundaries.

Although no recipe for successful innovation exists, a growing body of literature concludes that firms at different stages of their lifecycle show different efforts and abilities to generate innovations. In line with theoretical arguments, young and established firms differ in their efforts and abilities to pursue innovation primarily because, over time, firms accumulate knowledge and competences that enable them to efficiently manage existing assets (e.g., facilities, product lines, clients and relationships with additional stakeholders). In this process, firms increasingly organize themselves by establishing appropriate operational and organizational structures and routines. On the one hand, these structures (and routines) weaken established firms' efforts and abilities to undertake exploration activities aimed at producing radical innovation, i.e., innovation that results in new products that potentially disrupt existing markets. On the other hand, these structures increase their efforts and abilities to undertake exploitation activities aimed at producing incremental innovation, i.e., innovation activities that improve existing product lines or processes (Arrow (1962), Henderson and Clark (1990), March (1991), Henderson (1993), Stein (1997), Loderer, Stulz and Wälchli (2016)). Moreover, as they have accumulated knowledge, established firms have developed abilities that increase their efficiency in using knowledge from the outside to produce innovations (Cohen and Levinthal (1989)).

This paper seeks to empirically test these theoretical predictions that young and established firms differ in their efforts and abilities to engage in innovation. The paper thus examines inputs and outputs in the firm innovation process. Studying inputs such as innovation activity expenses enables me to test whether young and established firms differ in their efforts to pursue (incremental versus radical) innovations. Studying outputs relative to their inputs facilitates an investigation of whether young and established firms differ in their abilities to produce (incremental versus radical) innovations.

More specifically, the paper studies the innovation process of young and established firms from three perspectives. First, it analyzes the process from the *input* perspective and explores whether young firms engage more in exploration activities and whether established firms engage more in exploitation activities.[1] Second, this paper analyzes the process from the *performance* perspective and examines whether young firms are more efficient in producing radical innovation outputs and whether established firms are more efficient in producing incremental innovation outputs.[2] Third, this work analyzes the process from the *external knowledge* perspective and examines whether established firms are more efficient than young firms in using external knowledge to produce innovation outputs.

To study the innovation process from these three perspectives, I use unique data from six waves of the Swiss Innovation Survey between 1996 and 2011. The data source is a repeated cross-sectional sampling of listed and unlisted Swiss firms in the manufacturing and service sector. These data have distinct advantages relative to datasets used by other empirical studies that investigate innovation in the context of the firm lifecycle. First, the data facilitate the study of innovation in diverse firms and industries, whereas other datasets are limited to certain industries (e.g., Henderson (1993); Prusa and Schmitz (1994)), to industries with patentable

[1] Following the literature, the terms innovation inputs, innovation activities, and innovation efforts are used interchangeably, as are innovation performance, R&D productivity and innovativeness.

[2] On the side of innovation input, firms are asked to indicate the amount of CHF invested in R&D activities (exploration), refinement activities and implementation activities (the latter two are exploitation). Refinements describe significant adoptions of existing or newly developed products that extend beyond R&D activities. On the side of innovation output, firms are asked to indicate the proportion of sales attributed to remarkably improved products (incremental), products that are new to the firm and products that are new to the market (radical). See section 2.2 for a more detailed discussion and the appendix for a definition of these measures.

inventions (e.g., Akcigit and Kerr (2015); Balasubramanian and Lee (2008)), to the manufacturing sector (e.g., Foster, Grim and Zolas (2013); Kastl, Martimort and Piccolo (2013)) or to listed firms (e.g., Loderer et al. (2016)). Second, the dataset contains some unique information regarding innovation efforts and outputs that other datasets do not. For example, it contains quantitative and qualitative information on firm efforts associated with exploration versus exploitation activities.[3] Third, my output measures, i.e., sales related to innovations, are likely superior to patents in measuring the economic rents generated by an innovation. Acs and Audretsch (1987) note that patents are a "notoriously weak measure" of innovation because many never bear fruit and some are used simply to impede the innovations of others. This observation may be particularly relevant in a lifecycle study such as this one, as established firms have an incentive to patent to prevent other firms from entering the market, although these patents may never yield economic rents (see Etro (2004)). Fourth, the data allow me to control for many factors that could confound the relationships among my lifecycle measure, foundation age, and innovation. One prominent factor is firm size, as lifecycle dynamics of many innovation-related models are driven by the fact that older firms are typically larger and not necessarily by the fact that they have been active for a longer time period (see Akcigit and Kerr (2015); Klette and Kortum (2004)). Finally, using Swiss data is suitable for studying firm innovation because Switzerland is the world's leading country in innovation according to the Global Innovation Index of 2015.[4]

[3] Most similar information on firms' innovation efforts is used by Mansfield (1981) and Cohen and Klepper (1996). In a more general way, these studies distinguish expenses (patents) associated with product (treated as radical) versus process (treated as incremental) innovations.

[4] The popular Global Innovation Index is co-published by Cornell University, INSEAD, and the Word Intellectual Property Organization (WIPO). For further information on ranking details and methodology, see http://www.globalinnovationindex.org/content.aspx?page=GII-Home. Switzerland ranks among the top five countries (ranks in parentheses) in terms of gross expenditure on R&D performed by business enterprises as a percentage of GDP (5), innovation output (2), and university-industry research collaboration (3).

In line with the three innovation perspectives, the empirical analyses proceed in three parts. The first part examines innovation efforts (inputs) and investigates whether young and established firms differ in their exploration and exploitation activities. The results indicate that, relative to young firms, established firms invest significantly less in R&D (exploration) and refinement activities and invest equally in implementation activities (the latter two together constitute exploitation). The main differences emerge in the first 30 years of a firm's existence. The input results are partly inconsistent with the theoretical predictions, as established firms also engage less in exploitation activities that aim to produce incremental innovations, such as the improvement of existing products. A possible explanation is that routines and accumulated knowledge enable established firms to be more efficient in these exploitation activities. Among other things, this possibility will be investigated in the second part of the analysis.

The second part considers innovation performance and examines whether young and established firms differ in how efficiently they produce incremental and radical innovations. The results show that established firms produce both less incremental (significantly improved products) and radical (new-to-market products) innovation outputs for a given level of innovation inputs. On average, the main decline in innovation performance occurs between 20 and 40 years of a firm's existence, which occurs approximately 10 years after the decline in a firm's innovation efforts. Further analysis reveals that both R&D and refinement activities lead to lower innovation outputs in established firms than in young firms. Together, the results provide novel evidence that established firms are less innovative than young firms are in terms of both innovation inputs and innovation outputs. The reduction in innovativeness over the course of the firm's lifecycle occurs because established firms exist for a longer time, not because they are larger in size.

The third part examines whether young and established firms differ in terms of their efficiency in using external knowledge to produce innovations. To do so, I build a measure of how important innovation knowledge from external sources is (e.g., customers, suppliers, consultant, universities) to firm innovations. The results show that, as firms grow older, they become more efficient in using external knowledge to produce innovations. Thus, by using external knowledge, established firms can reduce the observed difference in innovativeness relative to young firms. This evidence is consistent with the theory from Cohen and Levinthal (1989) that firms accumulate innovation-related knowledge over time (absorptive capacities), which enables them to efficiently screen and exploit external knowledge to produce innovations.

Overall, the results show that, during the first 30 years of the lifecycle, firms' innovation efforts and abilities change significantly. More specifically, relative to its younger counterparts, firms that have been operating for more than 30 years invest less in innovations and are less efficient in producing innovations within the firm; however, they are more efficient in using external knowledge to produce innovations. These findings are consistent with the hypothesis that, as firms grow older, they establish organizational structures and routines that stifle innovation within the firm, on the one hand, and they build up absorptive capacities that foster the efficient use of external knowledge to produce innovations, on the other hand. Furthermore, the findings provide evidence that, in terms of innovation, firms undergo significant changes when they are young (fewer than 30 years in operation) and then enter into a sort of "innovation steady state" when they are established.

The findings of the paper contribute to several strands in the literature on innovation. First, this work contributes to a growing number of endogenous innovation and growth models of the innovativeness of young and established (incumbent) firms (Acemoglu and Cao (2015); Akcigit and Kerr (2015); Klette and Kortum (2004)). One key implication of these models is that differences in firm innovativeness emerge because of size differences between young and established firms rather than because of age differences. My results are inconsistent with these predictions because firm age rather than firm size is the main variable that drives firm innovativeness. These results are in line with theories that predict that older firms are organizationally more rigid and, hence, less innovative (e.g., Henderson (1993); Holmstrom (1989); March (1991)).

Second, this work relates to papers that test specific differences in the innovativeness of young and established firms. On the *input side*, Kastl et al. (2013) and Foster et al. (2013) find that R&D expenses decline as firm age increases. The present study adds to these studies by showing that both explorative R&D activities and exploitative refinement activities decline as firm age increases.

On the *output side*, Bernstein (2015) and Loderer et al. (2016) find that, as listed firms grow older, their effort and abilities to produce radical innovation decline. Furthermore, Kueng, Yang and Hong (2014) examine a representative sample of Canadian firms and find that the likelihood to produce process (incremental) and product (radical) innovation is decreasing with firm age. My paper extends these studies by showing that, in a sample of listed and unlisted firms, the efficiency in producing both incremental and radical product innovations is decreasing with firm age.

Third, more generally, I contribute to a better understanding of how firms use external knowledge to produce innovations. This study uses firm age as a measure of a firm’s ability to use external knowledge (absorptive capacities) and finds that a firm’s abilities to use external knowledge to produce innovation increase as firm age increases. This novel evidence is in line with the theory of absorptive capacities of Cohen and Levinthal (1989), who claim that firms need time to learn and build a stock of knowledge on how best to exploit external knowledge to produce innovation. Evidence from various case studies shows that firms increasingly recognize the importance of external knowledge in producing innovation, also referred to as "open innovation" (e.g., Chesbrough (2003); Cockburn and Henderson (1998)). An illustrative example is Holcim, one of the world's leading building material companies that recognizes open innovation as a key factor in its innovation success.[5]

The remainder of the paper is organized as follows. Section 2 describes the main data and testing strategies. Section 3 presents the empirical results, and Section 4 concludes the paper.

2. Data and Methods

This section describes the survey data and the sample construction. It also presents the main measures and regression frameworks to analyze the innovation process of young and established firms.

2.1. *Sample construction and survey method*

The firm-level data used in this paper are obtained from the 2nd to 7th Innovation Survey by the Swiss Economic Institute (KOF) at ETH Zurich. The surveys were conducted in 1996, 1999, 2002, 2005, 2008 and 2011 with a sample of Swiss manufacturing and service firms with at least five employees. The triennial panel ends in 2011 because the KOF conducted a subsequent

[5] Extract from the 2013 annual report of the Swiss corporation Holcim: "Open Innovation is an essential factor for innovation success, as innovation happens at intersections. This is why Holcim has always sought out innovative partners willing to challenge the status quo. Combining the knowledge of the materials manufacturing processes with other expertise of selected partners allows to constantly provide better solutions for the changing demands. Holcim works closely with research institutes and equipment and technology suppliers. A partner network of leading universities such as ETH Zurich and MIT Boston enables Holcim to stay at the pulse of new developments and to transfer basic research insights into practical offerings for customers. Solutions are increasingly demanded in a faster way – another reason for working jointly with customers and partners. Open Innovation is strengthening Holcim's ability to deliver fast and smart solutions."

survey in 2013 based on a different questionnaire that resembled the European Community Innovation Survey (CIS).

The sample is stratified by 27 three-digit (NACE) industries from the Swiss business census and, within each industry, by three firm-size classes. Within each of the 81 (27×3) industry-size strata, an equal number of firms is randomly chosen, except for the largest size class, which is surveyed in full. The sampling procedure leads firms from smaller industries and larger firms to be overrepresented relative to the population of firms from the Swiss business census. The surveys collect, among other data, information on firm innovation inputs and outputs, firm characteristics and the market environment.

Responses were received from 1,537 firms in 1996 (response rate of 33.5%), 1,470 firms in 1999 (33.8%), 1,938 firms in 2002 (39.6%), 2,555 firms in 2005 (38.7%), 2,172 firms in 2008 (33.8%), and 2,363 firms (35.9%) in 2011. The pooled dataset from 1996 to 2011 comprises 12,035 firm-year observations. I refine the sample by excluding the following firms: (i) those with missing data on sales, firm age and competition and (ii) those that are younger than three years old. The latter sample restriction helps alleviate concerns that start-up firms are driving the results. Furthermore, my investigation is restricted to innovation-active firms, which are identified by their answer to a question regarding whether they have been actively engaged in product or process innovations within the previous three years. The final sample consists of 4,657 firm-year observations of innovation-active firms; 2,648 observations are from firms that disclose their innovation expenditures, and 2,009 observations are from firms that do not disclose innovation expenditures. In some regression specifications, I control for possible sample selection biases using a Heckman selection model and missing information dummies (see section 3.2.3).

According to Weisberg (2005), empirical results from survey-based research might be biased for three prominent reasons: survey administration issues, measurement error, and non-representativeness. Below, I briefly discuss why these issues should not affect my results.

Survey administration: The KOF undertook remarkable efforts to reduce the possibility of data bias due to survey administration issues. For example, (1) the surveys are mailed during the same month in each survey year; (2) the questionnaire design is the same across survey waves and follows the established recommendations and definitions of the OECD Frascati (2002) and Oslo (2005) manuals; (3) the data are entered electronically, and all entries are double-checked manually; and (4) wrong or implausible answers to individual questions are treated as missing. Furthermore, both the survey administrators and external authors confirm the high methodological standards and strong validity of the data (see Keupp and Gassmann (2013) and the references therein).

Measurement errors: Using a survey of self-reported firm data might raise concerns that firms potentially over- or understate their innovation activities and success. According to Mairesse and Mohnen (2010), bias is likely in subjective answers and scarcely observable measures in which the respondent's judgment and knowledge matter. The authors state that innovation output measures from innovation surveys are more likely to suffer from such biases than innovation input measures are. For several reasons, I do not believe that measurement errors are systematically biasing my results. First, respondents are guaranteed anonymity, and they know that their answers will have no effect on them or their firms. Second, prior research shows that measures of innovation reported in the CIS are highly correlated with other observable measures of innovation outputs, such as patents in the same firms (e.g., Hall and Mairesse (2006)). Third, pure measurement error in the dependent variable would primarily bias the results if it were systematically related to the main variable of interest, namely, firm age. As a robustness check, the exclusion of start-up firms (<8 years of firm existence) from the sample does not alter the baseline results and, thus, alleviates concerns that young firms possibly overstating their innovation efforts or outputs bias the results.

Representativeness: As discussed above, the sample selection leads firms from smaller industries and larger firms to be overrepresented in my sample. For instance, the statistics for total employees (Table 2) shows that the firms in my sample are larger than those in the Swiss business census of 2008. While the average Swiss firm employs 11 employees, the average firm in my sample has an average of 234 employees. The firms in my sample are therefore larger and probably "more successful" than the representative Swiss firm. Determining the impact of this potential selection issue is difficult. Nevertheless, the baseline results are not altered by the exclusion of the top firm-size class (strata) or of firms from smaller industries. This alleviates concerns that the overrepresentation of larger firms or those from smaller industries could drive the results. Possible selection biases stemming from item non-responses in the questionnaire are addressed in the empirical section.

As in all survey-based research, this study cannot completely avoid all potential sources of bias. However, I believe that the careful survey administration and data analysis has helped limit potential problems.

2.2. *Variable definitions and measures*

By analyzing the innovation process from the three perspectives, I use measures that require some explanation, namely, those associated with innovation inputs, innovation outputs and the firm's use of external innovation knowledge.

2.2.1. Measures of innovation input

The traditional measures of innovation input (effort) are R&D expenses or patents. These measures have known limitations that may also bias the results of an empirical lifecycle analysis like mine. R&D measures only the initial input in the innovation process, capturing creative and explorative activities. However, it does not measure firms' innovative efforts that are devoted to more informal (occurring outside of R&D labs) or exploitative activities, such as the adaptation of existing products and technologies and their implementation in the marketplace (e.g., Lerner and Seru (2015); Mairesse and Mohnen (2010)). In that sense, Kleinknecht (1987) provides evidence that R&D from large archival data underestimates firms' innovation activities, and this underestimation is likely to be more pronounced for small (and presumably young) firms.

Patents are commonly used to measure an invention's degree of novelty. However, patents measure only successful inventions and neglect the efforts and resources needed to create an invention (Griliches (1990)). Moreover, because established firms are more incentivized to use patents for preemptive purposes, patents may overestimate innovation efforts of established firms relative to those of young firms (Etro (2004)).

Addressing the limitations of these traditional measures, this study analyzes firm expenses for both types of innovation activities: exploration and exploitation. Following March (1991), (1) R&D expenses are treated as explorative, whereas (2) expenses for the refinement of existing products and (3) expenses for the implementation of innovations are understood as exploitative. Refinement activities are adaptations of new and existing products beyond R&D activities. Implementation includes activities that are associated with the introduction of an innovation in the marketplace, such as pilot projects and market tests, licensing, the patenting of own inventions, the introduction of process innovations and the training of employees.

These activities also follow the logic of the innovation process, which typically begins with R&D activities, proceeds with refinement activities and ends with the implementation of the innovation in the marketplace. Relative to more incremental innovations, radical innovations are known to require more innovation expenses, especially for R&D activities.

Each of the three expense (effort) measures is defined as the sum of expenses over the past three years standardized by current sales, and it is thus defined as an intensity measure.

2.2.2. Measures of innovation output

To explore how efficient young and established firms are in producing innovation outputs that are associated with different degrees of novelty, I follow the literature and distinguish between three types of product innovation: incremental, mediocre, and radical (e.g., Mairesse and Mohnen (2002); Schneider and Veugelers (2010)). First, firms can innovate incrementally by introducing a significantly improved version of an existing product or service. Second, firms can imitate competitors' products or produce close substitutes that are still new from the firm's perspective. Third, firms can innovate more radically by introducing products that are new to the market, thereby enabling a market leadership role. In this study, the main focus will be on incremental and radical innovations.

Accordingly, this study uses three innovation output variables, which are defined as a firm's share of sales resulting from improved, new-to-firm, and new-to-market products. Because only questionnaires from 2005 onward distinguish between new-to-firm and new-to-market products, related investigations are based only on the 2005, 2008 and 2011 surveys.

2.2.3. *Measure of external knowledge*

To test whether established firms are more effective in using external knowledge to produce innovation, this study defines a measure of how important knowledge from external sources actually is for a firm's innovation process. In the questionnaire, firms rated the importance of knowledge from eight external sources for their innovations on a five-point scale, ranging from unimportant (1) to crucial (5). The external sources are clients, material suppliers, software suppliers, competitors, universities and other higher education institutions, government or private research institutions, consultants, and technology transfer offices. To generate a firm-specific measure of the importance of external knowledge, I aggregate these answers by summing the scores for each of these questions and rescale the total score to a number between 1 and 5. A value of 1 (5) means that external knowledge is not relevant (crucial) to a firm's innovation process (this approach is borrowed from Cassiman and Veugelers (2002)).

Figure 1 graphically summarizes the descriptions in the section 2.2.

2.3. *Model estimation*

To empirically investigate the innovation process of young and established firms from the three perspectives, I define two main regression specifications that are borrowed from the models developed by Cohen and Klepper (1996) and Mairesse and Mohnen (2002). In the first part of the analysis, I seek to document possible differences in the innovation efforts of young and established firms. To this end, I use the following econometric baseline specification:

$$Input_{it} = a + b \times Age_{it} + gX_{it} + \eta_j + \delta_t + u_{it}, \quad (1)$$

where i denotes the firm and t denotes time. $Input_{it}$ represents the different innovation effort measures introduced in section 2.2.1, and equation (1) is estimated separately for each effort measure. The main coefficient of interest (b) is for a measure that distinguishes young from established firms. For identification purposes, I use a firm's *foundation age*, defined as the difference in the current year and the year of a firm's foundation (e.g., Haltiwanger, Jarmin and Miranda (2013); Kastl et al. (2013)). Because I use age as a proxy for the inflexibility of a firm's organizational structures and routines, two situations speak in favor of using foundation age over incorporation age. First, a firm can run its operations and undergo organizational changes before its legal incorporation. Second, incorporation age can be reset to one if a firm changes its legal form, reincorporates in a different state, or undergoes corporate restructuring (e.g., a statutory consolidation), but organizational structures and routines are typically not reset in such events. In both situations, using incorporation age might lead to an underestimation of organizational structures and routines.[6]

Following the hypothesis that young firms engage more in exploration activities and established firms engage more in exploitation activities, the age coefficient should be positive when R&D expenses are the dependent variable and negative when refinement and implementation expenses are the dependent variables.

Following the literature, X_{it} is a vector of standard control variables (e.g., Cohen and Klepper (1996); Kastl et al. (2013); Mairesse and Mohnen (2002)), including firm size, five dummy variables that measure the strength of perceived competition, and two dummy variables that identify firms that have export activities and that are owned by a foreign company. Firm size, measured by the natural logarithm of sales, reflects access to finance, scale economies and the number of product lines (see also Akcigit and Kerr (2015)). I also include value added per employee, which is used as a proxy for the firm's productivity or distance from the technological

[6] An argument that speaks against the use of foundation age is that, before its legal incorporation, a firm might not be operatively active and thus is not building formal organizational structures and routines. Incorporation age is not available in the used dataset.

frontier in other studies (see Acemoglu and Cao (2015); Kastl et al. (2013)). Finally, all regressions include industry- (η_j) and time- (δ_t) fixed effects to capture the average effect in an industry and macro effects in a given year, respectively.[7]

In the second and third part of the analysis, I seek to document efficiency differences (abilities) between young and established firms in transforming innovation inputs into innovation outputs. This study relies on the regression framework of Mairesse and Mohnen (2002), in which the production of innovation follows the logic of a standard production function:

$$\text{Output}_{it} = a + b \times \text{Age}_{it} + c \times \text{Input}_{it} + d \times K_{it} + e \times \text{Age}_{it} \times K_{it} + f \times X_{it} + \delta_t + \eta_j + u_{it}, \quad (2)$$

where innovation outputs (Output_{it}) result from innovation inputs, such as innovation expenditures (Input_{it}), firm characteristics and other contextual variables. Again, the main variable of interest is firm age (Age_{it}), which is used to determine whether a firm's abilities to turn innovation inputs into innovation outputs is increasing or decreasing with age.[8] Equation (2) is estimated separately for the different innovation output measures, ranging from incremental to radical. Relative to other studies, this refers to a test of the innovativeness (e.g., Mairesse and Mohnen (2002)), innovation performance (e.g., Mairesse and Mohnen (2010)) or R&D productivity (e.g., Seru (2014)) of firms of different ages.

Output_{it} is the proportion of sales from innovative products that have been introduced within the last three years (see section 2.2.2), and Input_{it} represents innovation expenditures, i.e., the sum of expenses associated with exploration and exploitation activities (see section 2.2.1). Again, I include a vector of controls (X_{it}) that is also used in equation (1). The correction for size

[7] The baseline results are robust to the inclusion of a human capital index, which is defined as the fraction of employees with tertiary education (not shown). However, its inclusion may cause a mechanical relationship because innovation expenditures may largely consist of expenditures on wages of workers with tertiary education (see Kastl et al. (2013)).

[8] Please note that firm age is defined as the natural logarithm of a firm's foundation age. Similar results are obtained when age is defined alternatively as industry-adjusted age or standardized age (age minus the industry mean divided by the standard deviation).

also takes into account that young firms, which typically have a lower sales base, find it easier to obtain higher scores for innovative outcomes. The results are similar when the total number of employees is used as a measure of firm size. The estimations again control for industry- (η_j) and time- (δ_t) fixed effects.

To analyze the innovation process from the external knowledge perspective, I also include a variable (K_{it}) that measures the importance of external knowledge to a firm's innovation process, as introduced in section 2.2.3. The main coefficient estimate of interest is the interaction term between this variable and firm age ($Age_{it} \times K_{it}$). In line with the prediction that established firms are better able to use external knowledge to produce innovations, I expect to find a positive and significant coefficient estimate (e).

To accurately cope with the different scale levels and distributional characteristics of the dependent variables in the regression specifications, this study uses different econometric estimation techniques. Most of the innovation input measures are extremely left-skewed with a non-trivial fraction of zeros. Therefore, I use Poisson pseudo-maximum likelihood (PPML) estimation of regression 1 (Foster et al. (2013)), but the results are similar if ordinary least squares (OLS) or Tobit models are used. Furthermore, my innovation output variables are fraction data that take values between zero and one.[9] Therefore, I estimate a generalized linear model (GLM) with a logit link, a binomial distribution family and robust standard errors, following Papke and Wooldridge (1996).

Given the sampling procedure and the long time lag between the surveys (three years), only 33% of the firms are present in more than one survey, which limits my ability to exploit the panel feature of the data.

[9] Previous studies have estimated Tobit-censored regression models (e.g., Cassiman and Veugelers (2006)) or have performed a logit transformation of the variable and used OLS (e.g., Mairesse and Mohnen (2002)). However, both approaches have well-known limitations (see Baum (2008); Ramalho, Ramalho and Murteira (2011)).

3. Empirical results

In these section, the following predictions from the theoretical literature (e.g., Cohen and Levinthal (1989); Henderson and Clark (1990); Henderson (1993); Loderer, Stulz and Wälchli (2016)) are tested: As firms grow older, organizational structures and routines associated with existing assets decrease (increase) their efforts and abilities to produce radical (incremental) innovation. Furthermore, by growing older, firms build up a stock of knowledge that increases the efficient use of external knowledge to produce innovations.

3.1. *Descriptive statistics*

Table 1 provides summary statistics for the variables from 1996 to 2011 that are also entered into the baseline regressions. Detailed variable definitions are presented in the appendix. Except for binary variables, all variables are winsorized at the 1^{st} and 99^{th} percentiles to prevent any influence of extreme outliers.

Panel A summarizes information about innovation *outputs*, which are measured as the proportion of sales attributed to different types of innovations that have been introduced within the last three years. On average, 15% and 18% of the firms' sales are attributed to significantly improved and new products, respectively. The 32% figure for average innovative sales (attributed to significantly improved or new products) suggests that the average sample firm renews its product lines every nine years, assuming uniform renewal across its product lines. The proportion of sales from new-to-market products is 13%, based on the short sample period from 2005 to 2011. A significant number of firms have introduced innovations but do not disclose innovation expenditures (N = 2009); consequently, they are not entered into the baseline regressions. The descriptive statistics suggest that innovation output is almost the same for firms that disclose innovation expenditures (32%) and those that do not disclose innovation expenditures (33%). The latter subsample is further analyzed in the section on robustness checks.

Panel B presents the distribution properties of the reported innovation *input* measures, which consist of expenses for exploration and exploitation activities within the last three years. On average, within the last three recent years, firms spent approximately 5% on innovation activities relative to their current revenues, consisting of equal parts of exploration (2.1%) and exploitation (2.6% = 1.2% + 1.4%) expenses. Dividing innovation expenditures by three years leads to annual innovation expenditures (relative to sales) of approximately 1.6%. The magnitude of the innovation input and output measures are comparable to the ones in Cassiman and Veugelers (2006), who use data from the Belgian Innovation Survey.

Finally, panel C summarizes the *firm characteristics* that typically covary with firms' innovation inputs and outputs. The main variable of interest, firm foundation age, shows a mean value of 57 years, and the distribution is right-skewed (see also Figure 2). Following previous discussions, in this study, young and established firms are identified by whether a firm was founded fewer or more than 30 years ago. Accordingly, approximately 30% of the observations consist of young firms, and approximately 70% consist of established firms. The mean value of foundation age in this study is greater than those in other studies, e.g., 36 years in Schneider and Veugelers (2010) and 31 years in Kastl et al. (2013). Another Swiss study based on a different set of survey data shows a comparable foundation age with a mean value of 51 years (Waelchli and Zeller (2013)). The authors further note that, in Switzerland, a firm's foundation age is, on average, 20 years greater than its incorporation age (see section 2.3 for a discussion of possible reasons). As noted above, because of the stratified sample selection, my sample is also tilted toward larger firms. The average firm has 236 employees and sales of CHF 78 million. As in this study, the sample in Kastl et al. (2013) is also selected based on size- and industry-strata, and their sample firms show comparable mean values in terms of size, i.e., 358 employees and sales of EUR 27.1 million.[10] Moreover, relative to the results of other studies, the value added per employee is high at CHF 145,900. Moreover, 16% of firms are owned by a foreign firm, and 75% of firms conduct export activities.

Table 2 reports correlation coefficients for innovation output and input measures and other important firm characteristics. Largely consistent with theoretical arguments and existing empirical evidence, innovation outputs are positively related to innovation inputs and exporting activities and negatively related to firm age (e.g., Aw, Roberts and Xu (2008); Mairesse and Mohnen (2002); Schneider and Veugelers (2010)). Furthermore, for innovation inputs, the negative age coefficients decrease in magnitude the more exploitative an innovation activity is (see the age coefficients in columns 6 to 8). The negative input-age coefficients reveal that established firms engage in fewer exploration and exploitation activities. The negative output-age coefficients indicate that older firms have lower innovation outputs. Finally, the two firm size measures, sales and the total number of employees, are unrelated to the innovation input and output measures. This notable finding indicates that neither the input nor the output results are driven by small (and presumably young) firms with lower sales or smaller employee bases. Because firm size is an important determinant of innovation in firm lifecycle models, the innovation–sales relationship will be addressed in the subsequent multivariate regression analysis.

[10] Their monetary variables are expressed in 2003 prices, and the exchange rate in 2003 was, on average, CHF/EUR 1.52.

3.2. *Multivariate regression results*

This section documents the empirical results from the multivariate analysis from the three perspectives of the innovation process. First, it investigates whether young firms differ from established firms in their exploration versus exploitation efforts. Second, the section analyzes whether these firms differ in their efficiency (performance) in producing incremental versus radical innovations. Third, this section examines whether these firms differ in their abilities to use external knowledge to produce innovations.

3.2.1. Innovation input results

The first set of empirical tests is used to investigate whether firms of different ages differ in their innovation efforts. Table 3 presents the results from regressions of innovation effort (expense) measures on firm age. The measures are standardized alternatively by firm sales and total number of employees. The latter standardization ensures that the results are not driven by young firms that have no or low sales. The inclusion of firm sales as a control variable and the exclusion of observations of firms younger than 3 years further alleviate this concern.

The results in column 1 and 2 show that established firms spend significantly less for innovation activities than their younger counterparts do. To explore the functional form of the relation between innovation expenditures and firm age, I estimate specification 1 by using age dummies that cover 10 years each (not shown) and using non-parametric kernel regressions (Figure 3). The results indicate that most of the differences in innovation expenditures occur at early lifecycle stages, i.e., in the first 30 years of a firm's existence. As an illustration of magnitudes, innovation expenditures (relative to sales) are 4.4%, 3.6% and 3.4% for firms that are 9 (5^{th} percentile), 27 (25^{th} percentile) and 49 (50^{th} percentile) years old. Thus, on average, a 9-

year-old firm invests approximately 20% more in innovation activities than a 27-year-old firm does. The results related to firm age are similar when innovation expenditures are standardized by the number of employees or are not standardized at all, following Kastl et al. (2013).[11]

The finding that established firms show relatively lower innovation expenditures raises the question of whether they spend less for exploration or exploitation activities. The results in column 3 to 8 shed light on this question. Established firms spend less for both R&D and refinement activities. Therefore, these firms seem to engage less in activities to explore new opportunities and activities to improve existing opportunities. As refinement activities are defined as the refinement of existing and new products, in regression 5 and 6, I also control for R&D expenditures that aim to generate new products. The negative age coefficient remains significant, which indicates that the refinement of existing products is actually declining with firm age (not shown). With regard to implementation expenditures, young and established firms do not differ. Hence, firms of different ages have a similar focus on activities associated with the implementation of innovations in the marketplace.

The coefficient estimates associated with the control variables provide further interesting insights into the determinants of innovation input intensity. The coefficient estimates associated with firm size provide rather inconclusive results. Larger firms seem to invest less in innovation activities per unit of sales, but they invest more per unit of employees. These results underscore the inconclusive evidence from studies on the relationship between firm size and R&D intensity (innovation inputs). The relationship is U-shaped in Bound, Cummins, Griliches, Hall and Jaffe (1984); not significant in Cohen, Levin and Mowery (1987); and negative in Acs and Audretsch (1988) and Akcigit and Kerr (2015). Furthermore, the positive and highly significant coefficients of the export dummy indicate that exporting firms invest more in innovation activities, which is

[11] Please note that R&D expenditures in the paper of Kastl et al. (2013) and the innovation expenditures in this paper are defined similarly.

in line with the evidence of Aw et al. (2008). This finding is consistent with arguments that larger export markets provide higher returns on R&D investments.

The negative R&D-age relationship raises an additional question on whether the lower R&D expenditures of established firms can be attributed to their lower engagement in research or development activities. The questionnaire does not distinguish between expenditures for research versus development activities, but it does include qualitative items related to this issue. In particular, firms rated how much of their innovation expenditures are allocated to either in-house research or development on five-point scales, ranging from none (1) to very much (5), separately.[12] Using this information, I create dummy variables that represent whether a firm has a strong (values of 4 and 5) or weak focus on research activities and development activities.

Table 4 shows the results from logit regressions of these measures of research versus development focus on firm age and the other determinants in equation (1). The coefficient estimates suggest that the previously documented lower R&D expenditures of established firms primarily stem from lower engagement in research activities but not in development activities. Accordingly, established firms are less focused on generating basic innovation knowledge from research activities. Consistent with this result, also the size of the R&D lab, measured as the proportion of R&D employees among all employees, significantly decreases with firm age (not tabulated). Furthermore, the results show that larger firms focus more on both research and development activities, which is consistent with the results in Table 3 that R&D expenditures (per employee) are increasing with firm size.

Overall, the results from the input analysis indicate that established firms spend less on exploration and exploitation activities than young firms do. Established firms' relatively lower

[12] In the survey, research activities are defined as basic and applied research activities with possible applications. Development activities are defined as the use of existing scientific knowledge to produce new or improved products and processes. See also the appendix for variable definitions.

expenditures on exploration primarily stem from their lower engagement in research rather than development activities. These results are only partly consistent with the theoretical predictions. The main inconsistency stems from the fact that established firms are also less involved in exploitation activities, such as refinement and implementation. A possible explanation is that established firms engage less in exploitation activities because they are more efficient in producing incremental innovations. This possibility will be investigated in the subsequent output analysis.

3.2.2. Innovation performance results

In this section, I test the predictions that young firms are more efficient in producing radical innovations and that established firms are more efficient in producing incremental innovations. To do so, I present regressions using the specification in equation (2). Additionally, an interaction term for firm age and innovation expenditures is included. In such a specification, the age coefficient is interpreted as the differences in innovation outputs for firms of different ages, holding firms' innovation inputs (including innovation expenditures) fixed. Moreover, the interaction term makes it possible to test whether one CHF of innovation expenditures leads to higher or lower CHFs in sales from innovations in firms of different ages.

Table 5 shows the performance results for innovation outputs with different degrees of novelty. The coefficient estimates associated with firm age suggest that young firms are more efficient in producing innovations. This finding holds for all innovation types, but the effect is stronger for radical innovations (i.e., new-to-market products) than for incremental innovation (i.e., significantly improved products). By analogy to the input analysis, I estimate non-parametric kernel regressions to illustrate the functional form of innovation performance and firm age. Figure 4 shows that most of the decline in innovation performance emerges from age 20 to age 40. In terms of the firm's lifecycle, this decline happens approximately 10 years after the decline in innovation efforts.

The coefficient estimates associated with "innovation expenditures" and the interaction term (Firm age × innovation expenditures) reveal further insights into possible efficiency differences in the innovation activities of firms of different ages. The estimates suggest that innovation expenditures significantly contribute to sales related to the different innovation types. Established firms, however, are less able to transform one CHF of innovation expenditures into sales related to new-to-market products (column 5). No such differences are observable for improved products or for new-to-firm products (see columns 1 and 4). The significant results in column 2 and 3 emerge because the innovation output measure includes new-to-market products.

The overall effect of firm age on innovation performance is economically meaningful. A change in firm age from 9 years (5^{th} percentile) to 49 years (50^{th} percentile) lowers the output from 18.6% to 16.1% for incremental innovations and from 15.0% to 10.5% for radical innovations, at means of all other variables.[13] This result corresponds to declines of 13 and 30 percentage points in firms' incremental and radical innovation outputs, respectively.

With regard to firm size, another key determinant of innovation throughout the firm lifecycle, the results are not significant. Neither incremental nor radical innovation outputs are significantly related firm size. This result is inconsistent with the theory and evidence of Akcigit and Kerr (2015), who find that larger (and presumably older) firms with a larger operative basis should be at a relative advantage in producing incremental innovations and at a relative disadvantage in producing radical innovations.

Additional checks show that the results are robust to the following changes (not tabulated). First, the main coefficient estimates remain significant when the dependent variables are

[13] Please note that, in GLM models, the economic effect cannot directly deduced from coefficient estimates. The economic effects of the age coefficients are calculated by using the margin command in STATA.

truncated at levels of 0.7 and 0.5, respectively. Thus, the results are not driven by “outliers” in the dependent variables. Second, the largest size strata, as defined by the KOF, is excluded because these firms are overrepresented. The documented effects are even stronger in the reduced sample. Third, following Mairesse and Mohnen (2002) and Cassiman and Veugelers (2006), the model is augmented with four additional determinants of innovation output, such as a dummy for continuous R&D, a dummy for collaborative R&D, and measures of financial and technical obstacles for innovations.[14] Although the number of observations is significantly reduced (N = 1,462 in specification 1), the main coefficient estimates remain statistically significant.

Finally, to obtain a better understanding of which innovation activities are performed less efficiently in established firms, this study regresses innovation outputs on the different expenses for exploration and exploitation activities. Table 6 shows the results. In columns 1 and 2, the interaction terms with firm age indicate that R&D and refinement activities lead to significantly lower innovation output in established firms. The results in columns 3 to 6 suggest that these inefficiencies stem from established firms’ lower efficiency in translating refinement activities into incremental innovations (columns 3 and 4) and in translating R&D activities into radical innovations (columns 5 and 6). No such differences can be documented for implementation activities (interaction term not shown). Finally, the highly significant coefficient estimates associated with R&D expenditures in all regressions indicates that R&D activities play a significant role for all types of innovation outputs. This does not apply to refinement and implementation activities.

Overall, the comparison of young and established firms’ innovation efforts and performance reveals the following results: Firms’ innovation efforts are declining with firm age,

[14] The dummies are equal to one if a firm does R&D on a continuous basis and collaborates in R&D with other firms, respectively; and zero otherwise. The measures on financial and technological obstacles (5-point Likert scale) indicate by how much a firm’s innovation is hampered by financial and technological constraints, respectively (see Mairesse and Mohnen (2002) and Cassiman and Veugelers (2006)).

primarily concentrated in the first 30 years of firm existence. The decline is primarily attributed to decreasing engagement in research activities and refinement activities. On the output side of innovation, a firm's innovation performance is declining with firm age for both incremental and radical innovations. The efficiency drop occurs from 20 to 40 years of firm existence and hence starts 10 years after the drop in innovation efforts. A possible explanation for these patterns is that decreasing innovation efforts in established firms reduce their capabilities to produce innovations. This parallel decline of efforts and efficiency in these activities makes it difficult to argue that the decline in innovation efforts is an inefficient decision by established firms.

The results support the notion that, as firms grow older, they establish organizational structures and routines that significantly stifle innovation efforts and abilities. To a great extent, the results are also consistent with those of other empirical studies that investigate innovation performance in the context of the firm's lifecycle (e.g., Akcigit and Kerr (2015); Sauermann (2013); Sørensen and Stuart (2000)). The main differences in the findings emerge in the area of incremental innovations. Using patents, these studies demonstrate that established firms are more engaged or more efficient in producing incremental innovations. By contrast, using investment and sales figures, I find that established firms invest less in incremental innovations and draw lower economic rents from incremental innovations. Extending these studies, I also assess different activities along the innovation process in terms of efficiency and find relative inefficiencies in established firms' exploration activities and in some of their exploitation activities.

3.2.3. Robustness checks: selection-corrected and industry analysis

In this section, I examine whether the construction of my sample may drive the baseline results. Two main issues are considered. First, I test whether the selection of innovation-active firms with non-missing innovation expenditure information produces biased results. Second, most empirical studies in the literature analyze innovation in manufacturing firms. Because my sample also includes service firms, I test whether age-related effects on innovation in service firms differ from the effects on innovation in manufacturing firms.

As noted, the baseline regression results are based on observations of innovation-active firms with non-missing information on innovation expenditures. This selection procedure may result in a non-random sample and cause bias in the coefficients in the baseline regressions. To assess whether selection produces biased results, I apply a two-stage Heckman (1979) selection procedure. The first stage in the procedure models a firm’s decision to engage in innovation (innovation: yes/no) with a probit model that regresses the indicator variable on the common innovation determinants and an instrument introduced by Cassiman and Veugelers (2002). The instrument is a three-digit industry average of a variable that measures the extent to which firms’ innovation activities are hampered by market regulations. The instrument should be valid because regulation-induced costs are expected to be fixed and should thus exclusively affect a firm’s decision to engage in innovation but not its decision regarding innovation intensity. The second stage in the procedure is the performance regression, which now includes a selection correction term, the Mills ratio.

Moreover, concerns about bias in the baseline results may arise because a non-random selection of firms with missing information on innovation expenditures is excluded from the analysis. To alleviate these concerns, I replace the missing innovation expenditures with zero and include an indicator variable that takes a value of one if innovation expenditures are missing for a firm and zero otherwise (see also Seru (2014)). If the main results are not biased by that type of selection, the inclusion of observations with missing innovation expenditures should not alter the age-related coefficients.

Panel A of Table 7 shows the results from the Heckman analyses accounting for possible sample selection bias. The results in columns 1–3 demonstrate that the regression results are not biased because of the selection of innovation-active firms. The first-stage selection equation indicates that the likelihood of engaging in innovation is significantly related to a firm's age, its size and the regulation of the market environment (column 1). Supporting the evidence of Criscuolo, Nicolaou and Salter (2012) and Kueng et al. (2014), the results show that younger and larger firms are more likely to engage in innovation. Because the inverse Mills ratio is statistically insignificant, there is no evidence of selection bias (column 2). Likewise, the age coefficients in the performance regression are not statistically and economically different from an OLS estimation that does not account for selection bias (column 3).

The results in columns 4 and 5 show that the selection resulting from the exclusion of firms with missing innovation expenditures does not bias the baseline results. The age coefficients in the sample of firms with missing innovation expenditures (column 4) and in the entire sample (column 5) are not statistically and economically different from those in Table 5, column 1.[15] In sum, the selection of innovation-active firms that disclose innovation expenditures does not cause the baseline results to be biased. This also applies to other regression specifications in which the dependent variables are related to other innovation types (e.g., improved products or new-to-market products).

A second area of interest is whether the documented age effects differ in service firms compared with manufacturing firms, as many empirical innovation studies solely focus on manufacturing firms. Following Criscuolo et al. (2012) (and the literature cited therein), the nature and conditions of innovation in services are substantially different from those in manufacturing. More specifically, service innovations are typically more difficult to protect via

[15] I obtain similar results in specification 5 when using the previously presented two-stage Heckman selection procedure.

intellectual property rights, require less capital, and require a higher degree of interactivity between producers and consumers. These conditions typically increase the relative advantage of young firms in producing innovation. For example, if a young bank wants to launch an innovative investment product, it does not have to fear that preemptive patenting by established competitors or financial constraints hamper the development and success of the innovation. Moreover, it can flexibly customize the product. Typically, these conditions do not apply to a young pharmaceutical firm that wants to launch a new drug.

Panel B of Table 7 presents the results from innovation performance regressions for subsamples of manufacturing versus service firms.[16] Consistent with the previous prediction, the negative age effects on firm innovation performance are significantly stronger in service firms than in manufacturing firms. This especially applies to radical innovations (columns 8 and 9). In economic terms, a change in firm age from 9 years (5^{th} percentile in the pooled distribution) to 49 years (50^{th} percentile in the pooled distribution) reduces the radical innovation output from 12.0% to 9.1% in manufacturing firms (column 8) and from 18.1% to 10.3% in service firms (column 9).

In contrast to the performance results, no differences in the age effect between manufacturing and service firms are observable in the innovation effort regressions (same as in Table 3). Nevertheless, a detailed analysis of the industry differences in the innovation-age relation is beyond the scope of this study and deserves further analysis.

Taken together, the results from robustness checks demonstrate that the selection of innovation-active firms that disclose their innovation expenditures does not bias the baseline results. The results further indicate that the decline in innovation performance over the firm

[16] The most important service industries in my sample are retail trade, wholesale trade, hotels and catering, finance and insurance, transportation, telecommunications, real estate, computer services, business services and personal services.

lifecycle is stronger in the service sector than in the manufacturing sector. In the subsequent section, firm innovation is examined from the third perspective: the external knowledge perspective.

3.2.4. Firm age, external knowledge and innovation performance

Thus far, my results show that established firms exhibit lower innovation performance than young firms. In particular, young firms' innovation outputs exceed those of established firms, holding their innovation inputs fixed. I have thus far disregarded the hypothesis that a firm can benefit from innovation inputs that come from outside the firm. In line with Cohen and Levinthal (1989), experience and knowledge from past innovation activities (absorptive capacities) increase a firm's efficiency in using external knowledge to generate further innovations. Because established firms have time to accumulate absorptive capacities, they should be more efficient in using external knowledge to produce further innovations.

In the subsequent analysis, I test this prediction and use firm age as a proxy for a firm's absorptive capacities. Existing studies use other proxies, such as a firm's current R&D intensity (Cohen and Levinthal (1989)), the existence of R&D departments (Cassiman and Veugelers 2002) or investments in scientific and technical training (Mowery and Oxley 1995). As an empirical proxy for a firm's absorptive capacity, firm age is superior to the other empirical measures for the following reasons. First, it is intuitively more in line with the logic of knowledge accumulation over time. Second, several observers argue that firm age is a key determinant of knowledge accumulation (e.g., Cohen and Levinthal (1990); Henderson (1993); Sørensen and Stuart (2000)). Third, because firm age is outside a firm's control, it is less likely to suffer from endogeneity.

Table 8 presents the corresponding regression results, focusing on the variable measuring the importance of external knowledge for a firm's innovation (see section 2.3) and also on its interaction with firm age. I measure firm age as a continuous variable (as before) and as a dummy variable equal to one if a firm is older than 25 years in the survey year and zero otherwise.[17] Additionally, it is worth noting that use of external innovation knowledge is not related to firm age; hence, established firms do not rely more on external knowledge than their younger counterparts do.

The results show that established firms are indeed more efficient in using external knowledge to produce innovations, independent of the novelty of those innovations. The interaction terms in columns 1 and 2 show that firm age fosters a firm's ability to use external knowledge to produce innovations. If the regression model in column 2 is used to predict the sales of young and established firms resulting from innovation depending on the importance of external knowledge (at the mean of all other controls), the results are as follows: Moving from the 25th to 75th percentile of the external knowledge distribution increases sales from innovation from 33.8% to 34.2% in young firms and from 28.0% to 32.0% in established firms (older than 25 years). Thus, established firms can significantly reduce the innovation gap of 6 percentage points (33.8% - 28.0%) to 2 percentage points (34.2% - 32.0%) when relying more heavily on external innovation knowledge.

The results in columns 3 to 6 indicate that established firms are more effective in using external knowledge to produce both incremental and radical innovations. Thus, in using external knowledge, established firms can reduce the performance gap to young firms with regard to incremental and radical innovations. For instance, in regression model 6, a move from the 25th to

[17] The most significant results are derived for a cutoff point of 25 years among alternative cutoff points within the first 40 years of firm existence. Thus, the cutoff point is motivated by an empirical search process rather than by a theoretical prediction.

75th percentile of the external knowledge distribution increases sales from radical innovation from 10.4% to 13.6% in established firms (older than 25 years) while they remain unchanged at 15.1% in young firms. This corresponds to a decline of the innovation gap from 4.7 percentage points (15.1% - 10.4%) to 1.5 percentage points (15.1% - 13.6%).

This evidence is consistent with the theory of Cohen and Levinthal (1989) and the arguments presented by Tushman and Anderson (1986) and Henderson (1993) that established firms possess information-processing routines that facilitate innovation. More generally, the evidence contributes to a growing literature and a number of case studies that emphasize the importance of external knowledge for successful firm innovation (e.g., Cassiman and Veugelers (2002); Cassiman and Veugelers (2006); Chesbrough (2003)).

4. Conclusion

This paper provides novel evidence of the differences between young and established firms in terms of their innovation efforts and abilities. The results are based on a unique dataset from the Swiss Innovation Survey and an investigation of the innovation process of young and established firms from the input, performance and external knowledge perspectives. Established firms, which are identified as firms that have existed for longer than 30 years, differ from their younger counterparts in terms of the following innovation perspectives: From the input perspective, established firms engage less in both exploration and exploitation activities. From the performance perspective, established firms are consistently less efficient in producing incremental and radical innovations. From the external knowledge perspective, established firms are more efficient in using external knowledge to produce incremental and radical innovations.

In general, the results support the hypothesis that, as firms grow older, they establish organization structures and routines that stifle the internal development of innovations. Moreover, the results are also in line with the hypothesis that firms accumulate knowledge over time (absorptive capacities), which helps them more efficiently use external knowledge to produce innovations. However, the results are at odds with arguments and evidence from other studies that established firms show greater efforts and abilities to produce incremental innovations. Possible explanations for the divergence in empirical results are that most comparable studies cannot distinguish inputs that aim to produce incremental versus radical innovations and that such studies use patents as innovation outputs. Following Acs and Audretsch (1987) and Etro (2004), patents are likely to overestimate the innovation success of established firms because they are more incentivized to produce patents for preemptive reasons that may never yield (directly observable) economic rents. Further research is needed to further elucidate this issue.

The paper provides a better understanding of the innovation efforts and abilities of firms at different lifecycle stages. Nevertheless, several interesting issues remain unresolved, thereby offering potentially fruitful avenues for further research. First, the data do not enable an examination of the dynamic effects of young and established firms' innovation behaviors. For example, this study could not investigate the effects of an innovation's introduction on the firm's or its competitors' economic profits. One could investigate these issues using a comparable dataset with a better panel structure. Second, I argue that differences in young and established firms' innovation abilities stem from differences in their organizational structures and routines. However, because of data limitations, I do not identify the actual underlying drivers of differences between young and established firms' innovation abilities (e.g., management practices, corporate governance, changes in ownership or organizational structure). Inquiring this information from Swiss firms in the Innovation Survey could reveal why young and established firms actually differ in their innovation abilities. Third, I provide evidence that established firms can close the innovation gap relative to their younger counterparts by using external innovation knowledge. It would be interesting to analyze whether young and established firms' innovations also benefit differently from other external innovation activities, such as R&D collaborations (Cassiman and Veugelers (2006)), R&D outsourcing or firm acquisitions. Finally, the results indicate that the negative effect of age on innovation performance is stronger in service than in manufacturing firms. Further analysis is necessary for a careful assessment of this difference.

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Appendix: Tables and Figures

Variable definitions

Variable	Definition
	Panel A: Innovation output variables (sales fraction attributed to…)
Improved products	Percentage of firms' sales generated by remarkably improved products that have been introduced over the previous three years.
New products	Percentage of firms' sales generated by *new* products that have been introduced over the previous three years.
New-to-firm products	Percentage of firms' sales generated by new-to-firm products that have been introduced over the previous three years.
New-to-market products	Percentage of firms' sales generated by new-to-market products (market novelties) that have been introduced over the previous three years.
	Panel B: Innovation input variables
Innovation expenditures	Innovation expenditures (sum of R&D, refinement and implementation expenditures) of the previous three years divided by sales at the time of the survey (Size).
R&D expenditures	Research and development expenditures (basic and applied research and development activities) of the previous three years divided by sales at the time of the survey (Size).
Refinement expenditures	Refinement expenditures (e.g., additional refinements of newly developed and existing products beyond R&D activities) of the previous three years divided by sales at the time of the survey (Size).
Implementation expenditures	Implementation expenditures (e.g., pilot project, market tests, implementation costs, certification, licensing costs, employee training) of the previous three years divided by sales at the time of the survey (Size).
High research focus	Binary variable based on an ordinal variable ranging from "none" (value 1) to "very high" (value 5) on a 5-point scale; firm's assessment of innovation expenditures devoted to research activities for product innovations. The binary variable equals 1 for values of 4 and 5 and equals 0 for values less than 4.
High development focus	Binary variable based on an ordinal variable ranging from "none" (value 1) to "very high" (value 5) on a 5-point scale; firm's assessment of innovation expenditures devoted to development activities for product innovations. The binary variable equals 1 for values of 4 and 5 and equals 0 for values less than 4.
External knowledge	Mean of eight ordinal variables ranging from "unimportant" (value 1) to "crucial" (value 5) on a 5-point scale; importance of 1) clients, 2) material suppliers, 3) software suppliers, 4) competitors, 5) universities or other higher education institutions, 6) government or private research institutions, 7) consultants, and 8) technology transfer offices as innovation knowledge providers.
	Panel D: Firm age and firm-level controls
Firm age	Natural logarithm of foundation age, computed as the difference between the survey year and the firm's foundation year plus one.
Firm size	Natural logarithm of firm sales in the last full year before the survey.
Value added per employee	Natural logarithm of value added, computed as sales less the cost of materials, expenditures on plant machinery and other fixed assets, and expenditures on buildings. Both this measure and employment refer to the last year-end before the survey.
Human capital index	Fraction of employees with tertiary-level education
Competition	Five dummy variables identifying the number of competitors declared by the firm (≤ 5, 6–10, 11–15, 16–50, < 50 competitors)
Foreign-owned firm	Binary variable equal to 1 if the firm is owned by a foreign conglomerate and equal to 0 otherwise
Exporting firm	Binary variable equal to 1 if the firm exhibits export activities in the survey year and equal to 0 otherwise
Market regulation	Average industry (three-digit level) score of the importance of Swiss market regulations to hamper firms' innovation activities. The original variable is an ordinary variable ranging from "very low" (value 1) to "very high" (value 5).

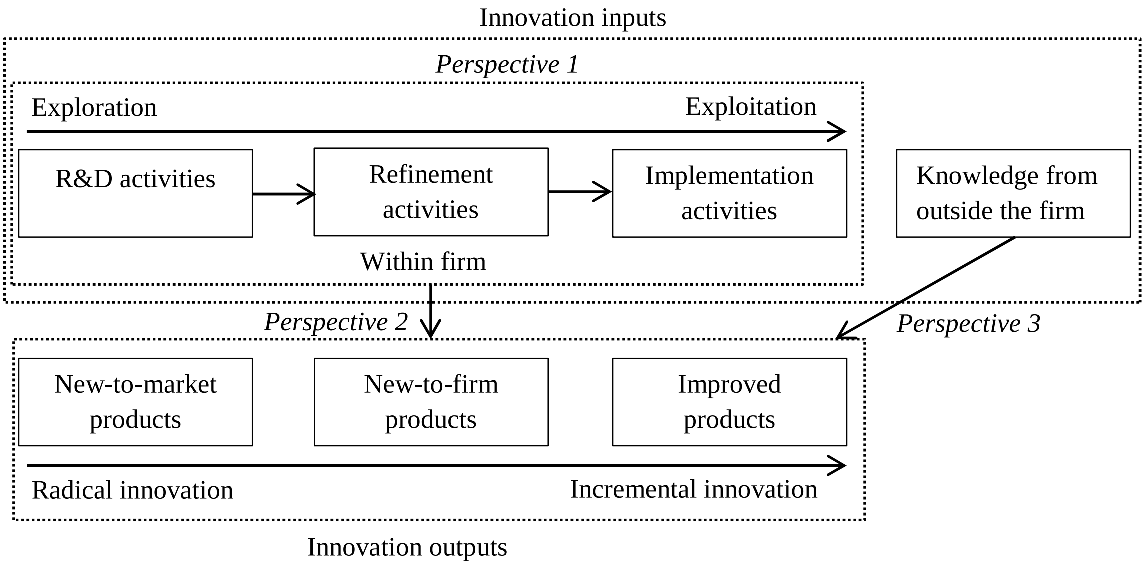

Figure 1: The innovation process. This figure summarizes the innovation process. Within a firm, the process starts with explorative R&D activities and ends with exploitative implementation activities (*Perspective 1*). Innovation outputs result from innovation inputs: Radical (incremental) innovation outputs require relatively more explorative (exploitative) innovation inputs (*Perspective 2*). Innovation outputs also result from external innovation knowledge (*Perspective 3*).

Table 1: Summary Statistics

The table presents summary statistics. Detailed information on the sample construction can be found in section 2.1. Variable definitions are in the appendix. The sample includes observations from the KOF surveys in 1996, 1999, 2002, 2005, 2008 and 2011. The "long" and "short" subscripts indicate whether the innovation output variable is based on data from 1996 to 2011 or 2005 to 2011, respectively.

Variable	Mean	Std.	Min	p25	p50	p75	Max	N
	Panel A: Innovation outputs (sales fraction attributed to...)							
Improved products (incremental) $_{long}$	0.18	0.19	0.00	0.03	0.10	0.25	0.90	2701
New products $_{long}$	0.15	0.18	0.00	0.03	0.10	0.20	0.90	2701
New-to-firm products (mediocre) $_{short}$	0.14	0.17	0.00	0.01	0.10	0.20	0.85	1394
New-to-market products (radical) $_{short}$	0.13	0.17	0.00	0.00	0.09	0.20	0.80	1394
Improved or new products $_{long}$	0.32	0.27	0.00	0.10	0.25	0.50	1.00	2879
Improved or new products (firms with missing innovation expenditures) $_{long}$	0.33	0.28	0.01	0.10	0.25	0.50	1.00	2009
	Panel B: Innovation inputs							
Innovation expenditures	0.049	0.074	0.000	0.007	0.022	0.060	0.520	2879
R&D expenditures	0.021	0.042	0.000	0.000	0.006	0.023	0.286	2879
Refinement expenditures	0.012	0.022	0.000	0.000	0.003	0.012	0.161	2879
Implementation expenditures	0.014	0.025	0.000	0.001	0.004	0.015	0.190	2879
External knowledge	2.57	0.62	1.00	2.10	2.55	3.00	4.85	2654
	Panel C: Firm characteristics							
Firm age	57	40	4	28	49	82	177	2879
Firm size (in millions of CHF)	78.1	210	0.4	6.5	20	56.7	1,800	2879
Total number of employees	232	1,154	5	28	75	183	39,899	2879
Value added per employee (in TCHF)	146	72	41	108	138	187	821	2879
Dummy foreign-owned	0.16	0.37	0.00	0.00	0.00	0.00	1.00	2879
Dummy export	0.73	0.45	0.00	0.00	1.00	1.00	1.00	2879

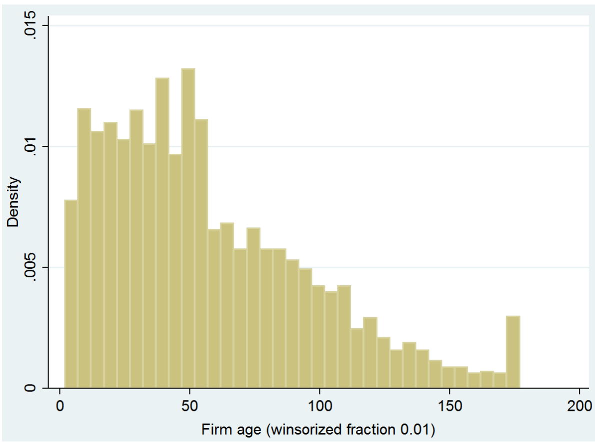

Figure 2: Firm age distribution

Table 2: Spearman partial rank order correlations

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Improved products	(1)	1.00														
New products	(2)	0.07	1.00													
New-to-market product	(3)	0.76*	0.70*	1.00												
Improved or new products (1) + (2)	(4)	0.72*	0.75*	0.66*	1.00											
Innovation expenditures (5) + (6) + (7)	(5)	0.17*	0.22*	0.26*	0.26*	1.00										
R&D expenditures	(6)	0.17*	0.20*	0.29*	0.25*	0.84*	1.00									
Refinement expenditures	(7)	0.15*	0.15*	0.17*	0.20*	0.64*	0.41*	1.00								
Implementation expenditures	(8)	0.09*	0.13*	0.08	0.14*	0.61*	0.24*	0.23*	1.00							
External knowledge	(9)	0.05	0.09*	0.11	0.09*	0.05	0.04	0.04	0.06	1.00						
Firm age	(10)	-0.10*	-0.10*	-0.13*	-0.14*	-0.14*	-0.15*	-0.10*	-0.04	0.09*	1.00					
Value added per employee	(11)	0.03	-0.01	0.02	0.01	-0.06	-0.01	-0.06	-0.07	0.04	0.05	1.00				
Firm size	(12)	0.00	-0.01	0.00	-0.01	-0.06	-0.03	-0.03	-0.07	0.29*	0.14*	0.16*	1.00			
Total number of employees	(13)	0.00	-0.01	0.00	-0.01	-0.02	-0.01	-0.01	-0.03	0.05	0.08*	0.06	0.55*	1.00		
Foreign-owned firm	(14)	0.03	0.04	0.08	0.05	0.02	0.07	0.01	-0.05	0.21*	0.13*	-0.08*	0.06	0.01	1.00	
Exporting firm	(15)	0.12*	0.13*	0.17*	0.17*	0.16*	0.18*	0.14*	0.06	0.07	0.15*	0.03	0.04	0.05	0.14*	1.00

Comment: The symbol * indicates statistical significance when testing against the null hypothesis that the correlation is zero with a confidence level of 0.95.

Table 3: Firm age and investments in innovation activities

The table presents the results from regressions that test the effect of firm age and size on various innovation expenditure components. The dependent variables are defined as ln(1+Innovation exp./Sales) in regression (1), as ln(1+R&D exp./Sales) in regression (3), as ln(1+Refinement exp./Sales) in regression (5) and as ln(1+Implementation exp./Sales) in regression (7). In even-numbered columns, the innovation expenditure components are standardized by the total number of employees. Regressions in odd-numbered columns are pseudo-maximum likelihood (PPML) estimations and include industry-year fixed effects, and standard errors are clustered at the firm level (see Foster et al. 2013). Regressions in even-numbered columns are ordinary least squares (OLS) estimations and include industry-year fixed effects with Newey-West standard errors that are robust to heteroscedasticity and autocorrelation at the firm level (see Kastl et al. 2013). The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

			Exploration		Exploitation			
Dependent variable:	Innovation exp./		R&D exp./		Refinement exp./		Implementation exp./	
	Sales	Employees	Sales	Employees	Sales	Employees	Sales	Employees
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm age	-0.111***	-0.127***	-0.125***	-0.149*	-0.169***	-0.144*	-0.045	-0.054
	(0.036)	(0.043)	(0.046)	(0.082)	(0.048)	(0.081)	(0.048)	(0.069)
Firm size	-0.091***	0.005	-0.087***	0.166***	-0.066**	0.107**	-0.112***	0.066
	(0.021)	(0.025)	(0.028)	(0.045)	(0.028)	(0.044)	(0.026)	(0.041)
ln(Value added per employee)	-0.077	0.736***	-0.151*	0.556***	-0.164**	0.340**	-0.050	0.703***
	(0.078)	(0.084)	(0.087)	(0.142)	(0.088)	(0.155)	(0.091)	(0.137)
Foreign-owned firm	-0.053	-0.228**	0.046	-0.164	-0.087	-0.473***	-0.227**	-0.533***
	(0.074)	(0.095)	(0.093)	(0.161)	(0.097)	(0.174)	(0.097)	(0.163)
Exporting firm	0.260***	0.533***	0.474***	1.005***	0.372***	0.713***	0.089	0.121
	(0.075)	(0.094)	(0.117)	(0.178)	(0.117)	(0.170)	(0.093)	(0.145)
Constant	-0.809	-0.261	-1.447	-3.197**	-1.516	-0.533	-1.611	-2.985**
	(0.895)	(0.928)	(1.105)	(1.631)	(1.040)	(1.765)	(1.055)	(1.555)
Competition dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	2826	2826	2826	2826	2826	2826	2826	2826
Adjusted R^2	0.220		0.258		0.162		0.098	

Table 4: Firm age and research vs. development focus

The table presents the results from regressions that test the effect of firm age on the focus on research and development activities. The dependent variables are dummy variables based on a firm's assessment (on a 5-point scale) of the magnitude of innovation expenditures devoted to research or development activities. The variables equal 1 for values of 4 (high) and 5 (very high) and equal 0 for values less than 4. All *logit* estimations include standard control variables (value added per employee, competition dummies and a foreign-owned firm dummy) and industry and year fixed effects, and standard errors are clustered at the firm level. The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

	High research focus	High development focus
	(1)	(2)
Firm age	-0.307***	-0.049
	(0.089)	(0.067)
Firm size	0.197***	0.257***
	(0.061)	(0.038)
ln(Value added per employee)	-0.056	0.012
	(0.191)	(0.124)
Exporting firm	0.413*	0.654***
	(0.221)	(0.138)
Constant	-4.058**	-4.888***
	(2.329)	(1.421)
Further controls	yes	yes
Industry FE	yes	yes
Year FE	yes	yes
Observations	2578	2578
Pseudo R^2	0.072	0.144

Table 5: Firm age and innovation performance

The table presents the results from regressions that test the effect of firm age on innovation performance for given innovation expenditures. The dependent variables of regression 1 to 5 are defined as follows: the proportion of sales from significantly improved products (1), from new products (2), from significantly improved or new product of products (3), from products that are new to the firm (4), and from products that are new to the market (5) that have been introduced within the last three years. Innovation expenditures are defined as demeaned Log(1+Innovation Exp./Sales). Firm age is also demeaned. All regressions are GLM estimations with a logit link and the binomial family. Furthermore, they include industry and year fixed effects, and standard errors are robust to heteroscedasticity. The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

Dependent variable: Proportion of sales from	Improved products	New products	Improved or new products	New-to-firm products	New-to-market products
Sample period		1996–2011		2005–2011	
	(1)	(2)	(3)	(4)	(5)
Firm age	-0.081***	-0.122***	-0.136***	-0.100**	-0.195***
	(0.034)	(0.036)	(0.033)	(0.046)	(0.054)
Innovation expenditures	1.674***	2.517***	2.948***	2.456***	1.465**
	(0.451)	(0.460)	(0.451)	(0.692)	(0.656)
Firm age × Innovation expenditures	-0.149	-0.706*	-1.134***	0.436	-1.305*
	(0.536)	(0.387)	(0.437)	(0.685)	(0.697)
Firm size	0.001	0.020	0.015	-0.017	0.033
	(0.020)	(0.020)	(0.018)	(0.029)	(0.029)
Value added per employee	0.266***	0.101*	0.240***	0.063	0.180**
	(0.070)	(0.063)	(0.063)	(0.084)	(0.106)
Constant	-4.996***	-3.294***	-3.956***	-2.768***	-5.115***
	-0.801	-0.71	-0.702	(0.936)	(1.147)
Further controls	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes
Observations	2701	2701	2701	1394	1394
p(chi^2)	0.00	0.00	0.00	0.00	0.00
Akaike IC	1965	1801	2578	926	900

Table 6: Firm age and the efficiency of innovation activities

The table presents the results from regressions that test the effect of firm age on the efficiency of different innovation activities. The dependent variables in columns 1–6 are defined as follows: the proportion of sales from significantly improved or new products in columns 1–2, from improved products in columns 3–4, and from new-to-market products in columns 5–6 that were introduced within the last three years. Innovation expenditures are defined as demeaned Log(1+Innovation Exp./Sales). Firm age is also demeaned. All regressions are GLM estimations with a logit link and the binomial family. Furthermore, they include industry and year fixed effects, and standard errors are robust to heteroscedasticity. The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

Dependent variable: Proportion of sales from	Improved or new products		Improved products		New-to-market products	
	(1)	(2)	(3)	(4)	(5)	(6)
Firm age	-0.135***	-0.134***	-0.097***	-0.096***	-0.151***	-0.151***
	(0.032)	(0.032)	(0.051)	(0.052)	(0.057)	(0.057)
R&D expenditures	3.339***	3.894***	3.817***	3.255***	3.701***	4.728***
	(0.811)	(0.782)	(1.514)	(1.285)	(1.286)	(1.259)
Firm age × R&D expenditures	-1.456**		0.540		-1.976*	
	(0.692)		(1.452)		(1.183)	
Refinement expenditures	2.635**	1.966*	2.599	0.756	-0.882	-1.113
	(1.274)	(1.159)	(2.236)	(2.234)	(2.316)	(2.376)
Firm age × Refinement expenditures		-1.941*		-4.290*		-0.906
		(1.083)		(2.230)		(2.534)
Implementation expenditures	2.981***	2.910***	2.327	2.215	-1.011	-0.881
	(1.071)	(1.072)	(1.873)	(1.875)	(1.679)	(1.670)
Constant	-4.072***	-4.019***	-3.485***	-3.449***	-5.209***	-5.153***
	(0.670)	(0.669)	(0.994)	(0.996)	(1.156)	(1.155)
Further controls	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Observations	2701	2701	2701	2701	1364	1364
p(chi^2)	0.000	0.000	0.000	0.000	0.000	0.000
Akaike IC	2725	2726	1962	1962	861	862

Table 7: Robustness checks: Selection biases and industry analysis

The table presents the results of tests to determine whether the results of the innovation performance regressions in Table 6 are driven by sample selection biases or by differences between service and manufacturing firms. Sample selection may bias the results because only innovation-active firms and firms disclosing innovation expenditures are included in the baseline regression. In panel A, selection biases resulting from the selection of innovation-active firms are investigated in columns 1–3, and those pertaining to the selection of firms disclosing innovation expenditures are investigated in columns 4–5. In column 4, the sample is restricted to firms that do not disclose innovation expenditures. The dependent variable is the proportion of sales from significantly improved or new products. In Panel B, firm innovation performance is investigated separately for manufacturing and service firms. Innovation expenditures are defined as demeaned Log(1+Innovation Exp./Sales). Firm age is also demeaned. Regressions in columns 4–9 are GLM estimations with a logit link and the binomial family. All regressions include standard control variables (firm size, value added per employee, competition dummies, an export dummy and a foreign-owned firm dummy). They also include industry and year fixed effects, and standard errors are robust to heteroscedasticity. The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

Panel A: Selection bias correction

Selection bias correction due to	Innovation-active firms			Firms with non-missing innovation expenditures	
	(1)	(2)	(3)	(4)	(5)
Firm age	-0.069***	-0.027**	-0.021***	-0.168***	-0.168***
	(0.019)	(0.011)	(0.007)	(0.035)	(0.024)
Innovation expenditures		0.610***	0.613***		3.171***
		(0.087)	(0.103)		(0.411)
Firm age × Innovation expenditures		-0.150**	-0.151*		
		(0.070)	(0.085)		
Market regulations	-0.417***				
	(0.104)				
Inverse Mills ratio		0.140			
		(0.209)			
Nondisclosure dummy					0.145***
					(0.042)
Firm size	0.125***	0.013	0.003	-0.006	0.000
	(0.012)	(0.016)	(0.004)	(0.019)	(0.013)
Constant	-1.511***	-0.694	-0.286**	-2.171***	-2.513***
	(0.415)	(0.534)	(0.136)	(0.742)	(0.530)
Equation	Selection	Performance			
Observations	6491		2701	2415	4859
Censored observations	3790				
Model estimation	Heckman correction		OLS	GLM	GLM
Model	Wald $\chi2$ (46) = 543.0***		Adj. R2 = 0.186	Akaike = 2266	Akaike = 4594

Panel B: Industry analysis

Dependent variable: Proportion of sales from	Improved or new products		New-to-market products	
Industries	Manufacturing	Service	Manufacturing	Service
	(6)	(7)	(8)	(9)
Firm age	-0.089**	-0.215***	-0.097	-0.451***
	(0.035)	(0.066)	(0.062)	(0.128)
Innovation expenditures	2.841***	2.861***	1.352*	1.664
	(0.457)	(1.076)	(0.733)	(1.428)
Firm age × Innovation expenditures	-1.196***	-0.769	-1.307*	-3.328
	(0.468)	(0.761)	(0.779)	(2.057)
Observations	2221	762	1027	347
p(chi^2)	0.000	0.000	0.000	0.000
Akaike	2115	680	676	225

Table 8: Firm age, external knowledge and innovation performance

The table presents the results from regressions that test the effect of firm age on the effectiveness of using external innovation knowledge for innovation. The dependent variable is the proportion of sales from significantly improved or new products in columns (1) and (2), from significantly improved products in columns (3) and (4), and from new-to-market products in columns (5) and (6). The age measure in odd-numbered columns is the demeaned natural logarithm of the firm's foundation age, and, in even-numbered columns, it is a dummy equal to one if the firm exists for longer than 25 years and zero otherwise. External knowledge is a demeaned index that measures how important external knowledge sources are for a firm's innovation (see the appendix for variable definitions). All regressions are GLM estimations with a logit link and the binomial family. Furthermore, they include industry and year fixed effects, and standard errors are robust to heteroscedasticity. The symbols ***, **, and * indicate statistical significance in two-sided tests with confidence levels of 0.99, 0.95, and 0.90, respectively. The sample includes observations from surveys in 1996, 1999, 2002, 2005, 2008 and 2011.

Dependent variable: Proportion of sales from	Improved or new products		Improved products		New-to-market produces	
Age measure	Firm age	Old dummy	Firm age	Old dummy	Firm age	Old dummy
	(1)	(2)	(3)	(4)	(5)	(6)
Age measure	-0.128***	-0.197***	-0.092***	-0.140***	-0.201***	-0.214***
	(0.034)	(0.051)	(0.035)	(0.056)	(0.056)	(0.084)
External knowledge	**0.128*** **	**0.012**	**0.061**	**-0.036**	**0.130***	**-0.072**
	(0.042)	**(0.058)**	**(0.045)**	**(0.062)**	**(0.074)**	**(0.103)**
Age measure × External knowledge	**0.142*** **	**0.231*** **	**0.139*** **	**0.191** **	**0.253*** **	**0.426*** **
	(0.046)	**(0.078)**	**(0.051)**	**(0.085)**	**(0.083)**	**(0.130)**
Innovation expenditures	2.835***	3.705***	1.567***	1.898***	1.297**	2.847***
	(0.457)	(0.547)	(0.458)	(0.551)	(0.686)	(0.809)
Age measure × Innovation expenditures	-1.169***	-1.425*	-0.135	-0.739	-1.330**	-2.973***
	(0.443)	(0.832)	(0.533)	(0.870)	(0.756)	(1.196)
Firm size	-0.000	-0.009	-0.005	-0.007	0.025	0.020
	(0.019)	(0.019)	(0.021)	(0.020)	(0.032)	(0.032)
Constant	-3.797***	-3.627***	-4.985***	-4.911***	-5.025***	-4.922***
	(0.712)	(0.714)	(0.812)	(0.816)	(1.181)	(1.192)
Further controls	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Observations	2654	2654	2654	2654	1300	1300
p(chi^2)	0.000	0.000	0.000	0.000	0.000	0.000
Akaike IC	2535	2539	1936	1937	849	850

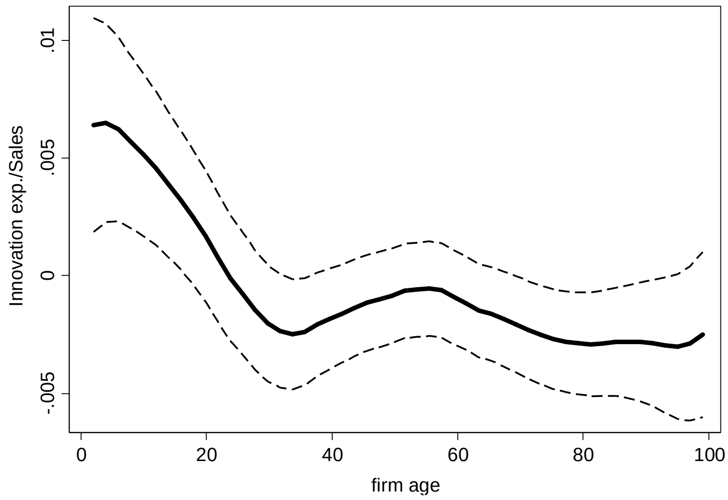

Figure 3: Non-parametric regressions for innovation expenditures. The figure shows the results of kernel-weighted local polynomial regressions to investigate the functional relationship between innovation input measures and firm age. As the dependent variable, the graph uses residuals from OLS regressions of innovation expenditures on the control variables in equation (1), except for firm age. The independent variable is firm age, winsorized at the 1^{st} and 99^{th} percentiles. The values are obtained using an Epanechnikov kernel function with a rule-of-thumb bandwidth estimator and local-mean smoothing. The dashed lines plot the 90% confidence band.

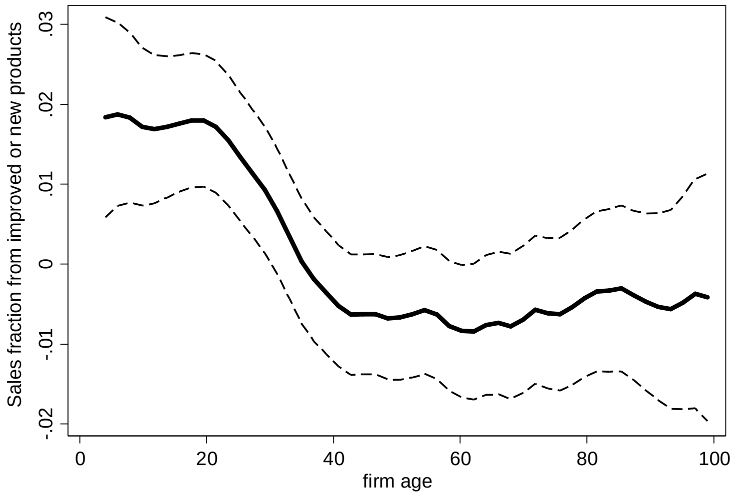

Figure 4: Non-parametric regressions for innovation performance. The figure shows the results of kernel-weighted local polynomial regressions to investigate the functional relationship between innovation performance and firm age. As the dependent variable, the graph uses residuals from OLS regressions of innovative sales (improved and new products) on the control variables in equation (2), except for firm age. The independent variable is firm age, winsorized at the 1^{st} and 99^{th} percentiles. The values are obtained using an Epanechnikov kernel function with a rule-of-thumb bandwidth estimator and local-mean smoothing. The dashed lines plot the 90% confidence band.

II. Precautionary cash holdings

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March 2016

According to the precautionary motive, firms facing future financing constraints hold cash to ensure that they can make investments or meet obligations. This paper examines the importance of the precautionary motive relative to other motives as a determinant of corporate cash holdings. I develop an index that includes the precautionary information of six popular firm-level measures: cash flows, cash flow volatility, R&D intensity, market-to-book, net working capital and product market competition. The index explains 32% of the variation in corporate cash holdings and increases to 41% when using the debt and equity constraint indices of Hoberg and Maksimovic (2015) as additional precautionary measures. As the predominant cash determinant, the precautionary motive is particularly strong for firms that face greater opportunity costs of disclosing proprietary information. This finding is consistent with the notion that these firms are more reliant on precautionary cash to protect proprietary information that they otherwise have to disclose to investors to reduce equity constraints.

Keywords: Cash holdings; precautionary motive; financial constraints; high-tech firms; firm age; proprietary information.

JEL codes: G30, G31, G32

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1. Introduction

When observing cash holdings of U.S. industrial firms, stark patterns emerge. On one hand, over time, the average cash-to-assets ratio has more than doubled, from 10.5% in 1980 to 23.2% in 2006 (Bates, Kahle and Stulz (2009)). On the other hand, in 2005, 25% of the firms have a cash-to-assets ratio of less than 3.6% and another 25% of the firms have one that is more than 32.4%.

BKS demonstrate that the dramatic increase of cash holdings over time was a response mainly to firms' increasing business and financing risk. Accordingly, firms facing the increasing risk that adverse cash flow shocks coupled with costly external financing can lead to underinvestment or default hold more cash for precautionary reasons. While these results allow for the conclusion that precautionary considerations for holding cash must have become more important over time, little is known about their actual importance. One exception is the international survey evidence of Lins, Servaes and Tufano (2010), who indicate that precautionary considerations are key when CFOs assess a firm's cash situation.[18] Nevertheless, these findings are qualitative in nature, are restricted to a small sample of (responding) firms and depict the situation at the point in time when the survey was conducted.

In this paper, by addressing these limitations, I assess whether the precautionary motive is actually the predominant driver of corporate cash holdings in a large sample of U.S. industrial firms. I exploit the previously presented, substantial variation in cash holdings across firms to figure out whether the precautionary motive dominates other popular motives for holding cash (i.e., tax, agency and transactional). To do so, based on multivariate cash holding regressions developed by Opler, Pinkowitz, Stulz and Williamson (1999) and BKS, I

[18] Among the top reasons why firms hold non-operating cash, the following ones relate to precautionary considerations: 1) preparation for possible shortfalls in future cash flows, 2) excessive time and cost to raise money when funds are needed, and 3) uncertainty about future investment opportunities.

decompose the cash holding variation attributed to empirical measures for the various motives.

The economics and finance literatures have identified four motives for firms to hold cash; they are grounded on the following ideas (and measures): First, firms hold *precautionary* cash to prevent themselves from the possibility that an adverse cash flow shock, coupled with costly external financing, leads to underinvestment or default. Therefore, firms' precautionary cash holdings are increasing in the *need* for external funds (due to shocks to their cash flows or investment opportunities) and in the *costs* of external funds (see, among others, Denis (2011)). Second, firms require cash to support their day-to-day operations, as suggested by the *transaction cost* motive of Keynes (1936). The idea is that firms hold cash to reduce recurring transaction costs of converting non-cash assets to cash. Since transaction costs are subject to scale economies, cash holdings are decreasing in firm size. Third, U.S. firms may incur *tax* consequences from repatriating foreign earnings; therefore, multinational firms are likely to hold more cash (see Foley, Hartzell, Titman and Twite (2007)). Fourth, the *agency* motive predicts that managers of badly governed firms are more likely to retain excessive cash to realize projects that maximize their own but not the shareholders' value (Dittmar and Mahrt-Smith (2007)).[19]

In the existing cash holding literature, the four motives, but not the precautionary motive, are typically approximated by a single measure (e.g., firm size, governance indices, and foreign income information). In the case of the precautionary motive, numerous firm-level measures are used to approximate a firm's need and cost of external finance, such as R&D intensity, cash flow level, cash flow volatility, growth opportunities (market-to-book), net working capital and competitive threats (see Opler et al. (1999), BKS and Hoberg, Phillips and Prabhala (2014)). In principle, these measures are good proxies for a firm's precautionary

[19] For an overview of theoretical contributions related to the different cash holding motives, see BKS or Almeida, Campello, Cunha and Weisbach (2014).

motives. Yet they are likely to contain information both related and unrelated to precautionary motives. Thus, based on a principal component analysis (PCA), I develop an index that captures the precautionary information in the six proxies mentioned above. The index represents a novel unidimensional measure of precautionary motives at the firm level and allows for a better and more realistic comparison of precautionary motives across firms than the use of the six proxies separately. A further major advantage of the index is that it can be easily replicated, modified and used in other samples. Finally, the PCA approach does not require a fixed weighting of the various proxies and is thus more flexible than comparable indices, such as the constraint indices of Kaplan and Zingales (1997) or Whited and Wu (2006).

Using a sample of 78,378 firm-quarter observations between 1998 and 2005, basic regression analysis provides evidence of the central role precautionary motives play in explaining firms' cash holdings. The regression results from the BKS cash holding model show that the precaution index is significantly and positively related to corporate cash holdings. For instance, a one-interquartile range (1-IQR) increase in the index is associated with an increase in the cash-to-assets ratio of 14.2 percentage points, which is economically meaningful, given that the mean (median) value of the ratio is 18.8% (8.8%). More importantly, results from the variance decompositions reveal that 32% of the cash holding variation is attributed to the precaution index, which represents approximately 70% of the cross-sectional and longitudinal variation explained by the regression model. Empirical measures associated with other motives for holding cash do not come close to explaining the same level of variation in cash holdings as the precaution index, i.e., the transactional motive (firm size: 5.3%), the agency motive (entrenchment index of Bebchuk, Cohen and Ferrell (2009): 2.2%), and the tax motive (foreign income: 0.2%).

In a next step, I include the financial constraint indices of Hoberg and Maksimovic (2015) (henceforth, HM) as additional explanatory variables associated to the precautionary motive. Following Kaplan and Zingales (1997), HM obtain information on constraints directly from firm disclosures by analyzing the MD&A section in firm 10-Ks. Based on this information, they create four continuous measures of financial constraints, indicating whether a firm faces potential underinvestment due to broad liquidity challenges or due to specific liquidity challenges related to costly financing from debt, equity and private placements.[20] I consider these measures as suitable complementary precautionary variables for my index since they may contain additional and more detailed information about the cost/supply-side of external financing. Including these measures of financial constraints in the regression model increases the variation in cash holdings explained by precautionary measures to 41%. Although the precaution index loses some explanatory power (23%), it nonetheless explains more cash holding variation than the HM constraint indices (18%). From these results, I conclude that the precautionary motive is by far the predominant driver of corporate cash holdings.

Finally, I examine subsamples to understand whether the baseline results are driven by certain types of firms. According to BKS, the new listing wave of high-tech firms in the 1980s to the early 2000s has led the precautionary motive for holding cash to become more important. Thus, it is expected that the precautionary motive is more important for young and high-tech firms than for their mature and manufacturing counterparts. I test this by examining the effect of the precautionary measures on cash holdings in subsamples of young versus mature firms and of high-tech versus manufacturing firms. I find that precautionary considerations are significantly more important for cash holdings among young and high-tech firms. Most significant differences between the groups result from the HM private placement-constrained index. Accordingly, young and high-tech firms are relatively more reliant on

[20] HM demonstrate that private placement is primarily associated with the private placement of equity (private SEOs). Further, they show that private placement constraints are a more extreme version of equity constraints. Consequently, firms facing high constraints in private equity markets are also facing high constraints in public equity markets.

precautionary cash if they are concerned about insufficient equity financing in the future. The most plausible explanation why equity constraints result in relatively higher cash holdings in young and high-tech firms is the following: Young and high-tech firms engage more in innovation and, thus, face higher opportunity costs of disclosing proprietary information (see Brown, Fazzari and Petersen (2009), HM and Loderer, Stulz and Wälchli (2016)). Proprietary information, in turn, is typically disclosed by firms to reduce information asymmetry with investors and, thus, to reduce equity constraints. Consequently, young and high-tech firms are more reliant on precautionary cash to reduce the reliance on equity capital, which may cause them to disclose proprietary information (see also Farre-Mensa (2015)). To verify this explanation, I split the sample based on an indicator variable introduced by HM for whether or not a firm explicitly mentions a need to protect proprietary information in its 10-Ks. I find that firms mentioning a need for the protection of proprietary information tend to be young and high-tech and consistently have a significantly higher motive for holding cash, which is again driven by equity constraints.

In this paper, I provide novel evidence on the relative importance of alternative determinants of corporate cash holdings. I demonstrate that concerns about the insufficient funding of future growth opportunities are key determinants of corporate cash holdings. Understanding what determines corporate cash holdings is interesting for both practitioners and academics. *For practitioners*: Not least because U.S. corporations are holding record-high amounts of cash, corporate cash holdings are currently under close scrutiny, especially by activist investors (e.g., Brav, Jiang, Partnoy and Thomas (2008)). Corporations are increasingly criticized for their excessive cash holding at the cost of shareholders. To objectively assess whether a firm actually holds cash in excess of an “optimal” level as justified by its business model, assessors such as inside managers or outside analysts and shareholders need to know the key determinants of cash holding. Knowing that precautionary considerations are key, assessors can use a measure such as my precaution index to build a peer group of firms with similar precautionary motives that allows for an assessment of a firm's cash holding level.

For academics: My paper contributes to various strands of the academic literature. First, it is most closely related to empirical papers studying the determinants of firm cash holdings, including Kim, Mauer and Sherman (1998), Opler et al. (1999), BKS, Lins et al. (2010) and Graham and Leary (2015). It also relates to empirical studies that focus on specific cash holding determinants, such as taxes (Foley et al. (2007)), agency issues (Harford, Mansi and Maxwell (2008)) and product market competition (Fresard (2010) and Hoberg et al. (2014)). It also connects to studies demonstrating that firms with higher financial constraints and precautionary motives save more cash out of operating cash flows and stock issues, respectively (Almeida, Campello and Weisbach (2004) and McLean (2011)).[21]

Second, it contributes to a strand of literature that investigates the connections among financial constraints, cash holdings and the value of these cash holdings. Acharya, Davydenko and Strebulaev (2012) and Hadlock and Pierce (2010) show that cash holdings are positively related to firm credit risk and financial constraints. Denis and Sibilkov (2010) and Harford, Klasa and Maxwell (2014) find that firms facing higher financial constraints and refinancing risks have higher cash reserves and that these cash reserves have higher value. Using HM's financial constraint measure, I show that both debt and equity constraints are relevant cash determinants. The distinction between debt and equity constraints is important in that debt constraints (indicating distress) are negatively related and equity constraints are positively related to corporate cash holdings. Thus, firms hold cash primarily for precautionary reasons because they are concerned about the risk of insufficient equity financing in the future.

Finally, my evidence contributes to studies that emphasize the importance of proprietary information in shaping firms' cash holdings. For instance, Farre-Mensa (2015)

[21] Recent theoretical contributions based on the precautionary notion are provided by Acharya, Almeida and Campello (2007), Gamba and Triantis (2008), Han and Qiu (2007), Denis (2011), and Almeida et al. (2014).

show that, relative to private firms, public firms hold more precautionary cash to avoid having to publicly disclose proprietary information when issuing equity that is otherwise misvalued. While similar, my setting is different from the one of Farre-Mensa (2015) in two main regards. First, Farre-Mensa (2015) uses the listing status (listed vs. unlisted) to identify firms with different opportunity costs of disclosing proprietary information.[22] In contrast, among listed firms, I use age, technology and firms' statements to identify firms with different opportunity costs of disclosing proprietary information. Second, Farre-Mensa (2015) uses proxies at the industry level to identify firms with high and low potential for equity misvaluation (resulting in equity constraints). In contrast, I use a direct measure of equity constraints at the firm level.

The remainder of this paper is organized as follows. Section 2 details the construction of the precaution index and the econometric approach to measure the importance of the various motives in explaining corporate cash holdings. Section 3 describes the sample and data. Section 4 presents the empirical results. Finally, Section 5 concludes.

2. Measurement of precautionary motives and cash holdings

In this study, I am interested in measuring the relevance of the different motives of holding cash, especially the relevance of the precautionary motive. In this section, I first present the established empirical proxies for a firm's precautionary cash holding motives. Second, I explain why and how I create a one-dimensional precaution index based on these precautionary proxies. Third, I introduce the financial constraint indices from HM as complementary measures to the precaution index. Finally, I present a regression framework

[22] According to Farre-Mensa (2015), public firms face higher costs of disclosing proprietary information than private firms do. The SEC Regulation "Fair Disclosure" only prohibits public firms from disclosing material information selectively. If a public firm wants to reduce information asymmetry with investors it has to disclose the information publicly. This comes at higher costs because the information may be exploited by product-market competitors.

that allows me to empirically measure how important the four motives are as drivers of cash holdings.

2.1. *Precautionary proxies and index*

Based on the precautionary savings motive for corporate cash holdings, firms facing financial friction hold cash to ensure that they can realize future investment projects. Therefore, as their needs (i.e., growth opportunities and cash flow variability) and the costs of external finance increase, firms should hold more cash. The recent empirical literature has identified several proxies for a firm's needs and costs of external finance, both of which significantly relate to cash holdings. The following list captures the most commonly used precautionary proxies in the recent empirical cash holding literature.

- *Cash flow levels*: Firms with lower operating cash flows require more external funds, all else equal. To avoid having to rely on costly external financing in the future, firms with weaker operating cash flows should hold more cash (Dittmar and Duchin (2011)).
- *Cash flow volatility*: Firms in industries with high cash flow volatility tend to have less reliable internal cash flows and a greater need for external capital. These firms are more likely to suffer from a negative liquidity shock and should therefore hold more cash (Opler et al. (1999) and McLean (2011)).
- *R&D intensity*: Firms with high R&D spending tend to have more valuable investment opportunities and are more likely to experience financial distress, so these firms should hold more cash (McLean (2011)). Further, R&D expenses are a form of investment in which information asymmetries are particularly prevalent and, therefore, are costly to finance with external capital. Consequently, R&D-intensive firms require a greater buffer against future shocks to internally generated cash flows (see Opler and Titman (1994)).

- *Market-to-book*: Firms with better investment opportunities value cash more because it is costly for these firms to be financially constrained (BKS).
- *Net working capital* (without cash): Net working capital can be converted into cash relatively quickly and is a close substitute for cash. Further, it is also treated as a tangible and pledgeable asset that may reduce the cost of external financing. Net working capital reduces the need and cost of external finance and, therefore, reduces the need for holding cash.
- *Product market competition*: Firms operating in more competitive product markets face more competitive threats to the stability of their future cash flows. Firms hold cash as a hedge against future cash flow shocks due to competitive threats (Haushalter, Klasa and Maxwell (2007), Fresard (2010), Hoberg et al. (2014)).

Taken together, firms with lower and more volatile cash flows, lower net working capital, higher R&D spending, growth opportunities and competitive threats should have a higher precautionary demand for cash. In their cash holding regressions, Opler et al. (1999), BKS and Hoberg et al. (2014) show that individual precautionary measures are related to cash holdings in the predicted way. However, these precautionary proxies are correlated with one another, and each measure also contains information unrelated to precautionary motives. I will use principal component analysis to extract the factor, if there is one, that represents firm-level motives to hold precautionary cash. The possibly resulting factor can be interpreted as an index that measures the precautionary motives of firm *i* at time *t* (for more detail, see section 3.1).

2.2. *Financial constraint measures as determinants of precautionary cash*

As discussed above, precautionary motives are positively associated with needs and costs of external finance. Therefore, financially constrained firms, facing costly and limited access to external finance, should have higher precautionary motives for holding cash. Not surprisingly, certain firm characteristics are used to measure both financial constraints and precautionary motives. For example, cash flows, Tobin's Q and cash holdings are part of established constraint indices, namely, the indices of Kaplan and Zingales (1997) and Whited and Wu (2006).

Following the recent constraint literature, additional firm characteristics may be good proxies for financial constraints and, thus, for precautionary motives. For instance, it has been shown that younger, smaller and non-dividend paying firms are relatively more financially constrained (DeAngelo, DeAngelo and Stulz (2006) and Hadlock and Pierce (2010)). However, I do not consider age, size and dividends as additional precautionary proxies for the following reasons. Firm age and size are not considered as precautionary measures by the literature. Instead, firm size is understood as a primary measure associated to the transaction motive of cash holdings (BKS). Furthermore, the relation between dividends and cash holdings may be mechanical because, all else equal, if a firm pays dividends, it has less cash. In untabulated robustness tests, I define an augmented version of the precaution index, including size, age and dividends. As theory predicts, the three additional measures negatively load on the precaution index when they are included in the PCA (see section 3.2). However, the baseline results do not change substantially when I use the extended index version.[23]

Instead of augmenting the precaution index with further precaution or constraint proxies based on common firm characteristics, I use the recently developed constraint indices from HM as additional explanatory variables for firm cash holdings. As mentioned above, using information from the MD&A section in firm 10-Ks, HM create four constraint indices

[23] I do not consider capex as a precautionary measure in my precaution index. All else equal, capex increases the need for external finance but reduces the costs of external finance (since investment in tangible assets) at the same time (see also the discussion in BKS). In additional tests, I find that capex does not significantly contribute to my index.

that allow for distinguishing constraints stemming from alternative funding sources, such as debt and equity.[24]

I derive two important advantages by using the four text-based constraint indices to complement the precaution index as an explanatory variable for corporate cash holdings. First, my precaution index captures both the need (demand) and costs (supply) of external finance. The HM constraint indices are more likely to specifically capture the supply side of external finance. Second, using the HM constraint indices allows me to distinguish between precautionary cash attributed to debt and equity constraints, respectively. In the next subsection, I present the empirical test strategy.

2.3. *Measuring the importance of cash holding motives*

To empirically examine the importance of the different motives of holding cash, I use the standard empirical model of cash holdings introduced by Opler et al. (1999) and BKS. The cross-sectional regression model is specified as follows:

$$\text{Cash}_{it} = \alpha + \beta \times \text{Precaution index}_{it} + \gamma \times \text{X}_{it} + \sigma \times \text{HM}_{it} + \delta_t + \varepsilon_{it}, \qquad (1)$$

where Cash_{it} denotes the cash holdings of firm *i* at time *t*. The main explanatory variable is the precaution index, which is the first principal component of the six precautionary proxies from the PCA. This simple *precautionary cash holding model* allows for a first test of the importance of precautionary motives for holding cash. I then augment this model by measures associated to the other cash holding motives and further control variables (X_{it}), such as dividend dummy, capital expenditures, acquisition activities, firm age, firm size, a foreign income dummy and governance indices. Following the literature, I use the following measures to approximate the other three cash holding motives: firm size for the transactional

[24] Please see Hoberg and Maksimovic (2015) for a detailed description of the employed methods to build the different financial constraint measures.

motive (BKS), a foreign income dummy for the tax motive (Foley et al. (2007)) and the popular governance indices, i.e., GIM-index (Gompers, Ishii and Metrick (2003)) and e-index (Bebchuk et al. (2009)) for the agency motive. Finding novel empirical proxies for these motives is beyond the scope of this paper. This *augmented cash holding model* allows measuring the relative importance of the different motives as determinants of cash holdings. Finally, I extend the model with the constraint indices from HM (HM_{it}), which results in the *comprehensive cash model*.

To control for time trends in cash holdings and macroeconomic shocks, I include time fixed effects (δ_t) in all the models. Further, to account for serial correlation in the error term, I cluster standard errors at the firm level throughout the investigation (Petersen (2009)). It should be noted that this regression framework does not allow clean causal inferences to be drawn.

Thus far, the cash holding literature has focused mainly on the statistical and economic significance of the various cash determinants presented above. The main interest of my study is different because I aim to determine the relative importance of the different motives as determinants of corporate cash holdings. Thus, I am interested primarily in the cross-sectional and longitudinal variation in cash holdings explained by the various determinants. To obtain this information from the cash holding regressions presented above, I employ the variance decomposition procedure suggested by Lindeman, Merenda and Gold (1980), which averages the marginal contribution that each variable makes to the R^2 of the regression (Kruskal (1987)). Specifically, the procedure averages the increase in explained variance obtained when adding the precautionary variable(s) to all possible variations of the cash holding model.

3. Sample selection and data description

3.1. *Sample description and variable definition*

I construct my sample of observations from the WRDS merged CRSP/Compustat quarterly files for the 1998–2005 period. The sample period is limited because of data availability at the beginning and by the onset of the financial crisis at the end. Specifically, the (lack of) availability of product market fluidity and financial constraints data from Hoberg et al. (2014) and HM restricts my sample period at the beginning. Further, in a follow-up and out-of-sample study, I examine whether the equity or debt supply shock of the recent financial crisis caused firms to *use* precautionary cash (Aebischer (2016)). However, I obtain almost identical results when I extend my sample period to 2011.

I exclude financial firms (SIC codes 6000-6999) and utilities (SIC 4000-4999) and require that firms have positive assets and positive sales to be included in a given quarter. I restrict the sample to firms incorporated in the U.S. Finally, for the relatively few firms that changed their fiscal year during the sample period, I maintain the most recent fiscal year convention. The final sample consists of 3,995 firms and 78,378 firm-quarters.

The main variables of interest are a firm's cash holdings and its precautionary motives for holding cash. *Cash holdings* are defined as the cash-to-asset ratio, namely, cash and marketable securities divided by book assets. I also employ alternative definitions of the cash ratio, including the log of cash to net assets (where net assets equal book assets minus cash) and cash to sales (results not shown). The signs of the coefficient estimates associated with the main variables remain, as does their relative importance within the model. However, the variation in cash holdings explained by these models drops by approximately 50% to 0.24.

Following the empirical literature on precautionary cash holdings (e.g., Opler et al. (1999), BKS, Dittmar and Duchin (2011), McLean (2011), and Hoberg et al. (2014)) and the discussion in section 2.1, I use the following variables in the precautionary motive index: (1)

operating cash flows, (2) industry cash flow volatility, (3) R&D intensity, (4) market-to-book ratio, (5) net working capital (without cash) and (6) product market threat. Variables (1) to (5) are normalized by total assets. To measure product market threats, I utilize the fluidity measure from Hoberg et al. (2014).[25] Higher fluidity indicates higher potential threats to the firm's own product success due to changes in the competitors' product offerings.

Furthermore, I use the HM constraint indices as additional precautionary measures. To build these indices, HM use information from the MD&A section in firm 10-Ks, in which managers implicitly or explicitly state to what extent liquidity challenges in general (investment delay) and due to insufficient financing from debt (debt delay), equity (equity delay) and private placements of equity (private placement delay) may lead to potential underinvestment in the future.

To investigate whether the precautionary saving motive is stronger in younger and high-tech firms, I split the sample based on firm age and a firm's affiliation to either the high-tech or the manufacturing sector. *Firm age* is the number of years since the firm's initial appearance on the CRSP/Compustat quarterly tapes (e.g., Loderer et al. (2016)). The *high-tech industries* are defined as in Brown et al. (2009) and special industry machinery firms are included as well: drugs (SIC 283), special industry machinery (SIC 355), office and computing equipment (SIC 357), communications equipment (SIC 366), electronic components (SIC 367), scientific instruments (SIC 382), medical instruments (SIC 384), and software (SIC 737). These two sorting criteria are relatively exogenous because age is outside the firm's control and because industry affiliation is difficult to alter in a short period of time.

Table 1 presents summary statistics for the entire sample. To reduce the influence of outliers, I winsorize all variables at the 1st and 99th percentiles of their pooled distribution. Detailed variable definitions are in the Appendix. Mean cash holdings have a pooled mean of

[25] I thank Gerard Hoberg, Gordon Phillips and Nagpurnanand Prabhala for making these data available online at http://cwis.usc.edu/projects/industrydata/.

18.8% and a pooled standard deviation of 22.1%. The median is 8.8%, indicating that the distribution of cash is right-skewed. The precautionary measures, consisting of the precaution index and the HM constraint measures, have similar distributional properties, means close to zero and standard deviations between 0.57 and 1.36. The average values of the other variables are in line with previous studies. In particular, the average firm is 17 years old, has quarterly R&D and capital expenditure ratios of 1.66% and 1.63%, a market-to-book ratio of 1.8, and a net working capital-to-asset ratio of 7.8%. Further, 37% of the firm-quarter observations have positive dividends, 39% have non-zero foreign income and 35% are from high-tech industries.

3.2. *Construction and properties of the precaution index*

As discussed in section 2.1, the six precautionary proxies are likely to contain components related and unrelated to precautionary motives. With this in mind, I use PCA to isolate the common component of the cross section of the six proxies for firm-level precautionary motives. Table 2 shows the first three orthogonal components resulting from the analysis. The first component seems to fulfill the requirements of being a good precaution index. Each precautionary proxy enters the index with the right sign, meaning that the index is highest for firms with low but volatile cash flows, high R&D intensity, growth opportunities, competitive pressures and low net working capital. The index explains 36% of the corresponding cross-sectional sample variation, and its eigenvalue is significantly larger than one. Notably, as the index increases, the precautionary motives of firm i in fiscal quarter t increase. The properties of the second and third components are less appealing in this context. The individual measures do not enter the components with the expected and economically meaningful signs, the components explain remarkably less of the proxies' variance, and the eigenvalues are not significantly greater than one (for a discussion of PCA outcomes, see Bharath, Pasquariello and Wu (2009)).

Next, I investigate whether firms with different levels of precautionary motives exhibit distinguishing characteristics. Based on the precaution index, I group firms into five quintiles. Table 3 shows several basic characteristics of firms across the five quintiles. Firms with higher precautionary motives actually hold more cash. Firms in the lowest quintile hold 6% cash as a percentage of assets, whereas firms in the highest quintile hold 44%. Although there seems not to be any clear size pattern across the precaution ranking groups, there is a negative one for firm age, meaning that younger firms show higher precautionary needs for cash holdings. Further, the industry composition within each precaution group is remarkably different: 79% of the observations in the high-precaution group are in high-tech industries, whereas only 4% of the observations in the low-precaution group are in high-tech. Finally, I examine financing policies across the different quintile groups. I observe no differences in net debt issuance across the groups but find remarkable differences in equity issuance activities. Firms in high-precaution groups issue substantially more equity than firms in low-precaution groups. Firms with high precautionary motives seem to rely more heavily on external equity capital, which is known to be a volatile financing source over time in terms of availability and cost (see Brown et al. (2009) and McLean (2011)). This suggests that precautionary cash is increasingly held by young and high-tech firms whose predominant external financing source is equity. I will resume this discussion in the subsequent section in which multivariate results are presented.

4. Importance of cash holding motives

In this section, I present the results of the multivariate analysis, in which I empirically investigate the importance of precautionary motives relative to other motives in explaining corporate cash holdings. I begin with the results of the basic cash holding model from BKS. I then extend this model and consider the financial constraint indices of HM as additional precautionary variables. Finally, in subsample tests, I investigate whether the precautionary motive of holding cash is of greater importance for some firms than for others.

4.1. *Results from basic cash holding models*

I start the multivariate analysis by documenting basic associations between cash holdings and their determinants in the precautionary and augmented cash holding models (see Panel A of Table 4). Consistent with the precautionary savings motive and the univariate results, the precaution index is positively associated with firm cash holdings (column 1). The R^2 indicates that the index can explain 40% of the variation in cash holdings, which is a substantial fraction. This should be interpreted as an upper boundary because the index may correlate with other explanatory variables of the cash holding models. Replacing the index with the six proxies yields similar explanatory power, and the proxies enter the regression with the expected signs (not shown).

Next, columns 2 and 3 show the results from the augmented cash holding models without and with industry fixed effects, respectively. Including additional cash determinants in the model leads to a slightly lower coefficient of the precaution index and slightly higher R^2 of 0.47. Similar cash holding variation is explained by the empirical models of Haushalter et al. (2007), BKS and Dittmar and Duchin (2011). The signs of the additional cash determinants are in line with the theoretical predictions and the empirical results of these empirical studies. For instance, dividend-paying firms hold less cash. Firms with higher capital and acquisition expenditures hold less cash because these investments are likely to generate pledgeable assets and are thus easier to finance. Further, larger and more mature firms hold less cash, and firms with non-zero foreign income hold more cash. The foreign income dummy is not significant when industry fixed effects are included.

Panel B of Table 4 illustrates the economic significance of the results of specification 2 in Panel A and shows the predicted cash holdings at the 10th, 25th, 50th, 75th, and 90th percentiles of the precaution index, holding the other variables at their mean values. Thus, an increase of 1-IQR in the precaution index is associated with an increase of 14.2 percentage points in firm cash holdings. Cash holdings seem to have an economically meaningful sensitivity to precautionary motives, given that the mean (median) value of cash holdings (as of assets) is 18.8% (8.8%). Moreover, the 14.2 percentage points amounts to 50% of the initially presented IQR-range in corporate cash holdings in 2005.

4.2. *Importance of cash holding motives*

Next, I assess the importance of the cash holding motives and conduct two tests. First, I re-estimate the augmented cash model by using standardized explanatory variables. Standardizing consists of subtracting the mean and dividing by the standard deviation. This allows for a simple comparison of the variables with different units and for the interpretation of what effect a one-standard-deviation change in a certain variable has on firm cash holdings. Second, I decompose the explained variation in cash holdings from the various explanatory variables.

Table 5 reports the results from these tests. The coefficient estimates of standardized variables indicate that the precaution index is by far the most important explanatory variable for firm cash holdings (see specification 1). For instance, a standard deviation change in the precaution index results in a cash-holding change that is 3.5 times (12.38/3.47) larger than that caused by a standard deviation change in firm size, the second most important variable in the model.

Even more distinct differences are found in the variance decomposition in specification 2, which shows the explained variation from each variable: 32% of the cross-sectional variation in cash holding is explained by the precaution index, which corresponds to nearly 70% of the variation explained by the model. The next most important explanatory variables are firm size and firm age, which explain 5% and 4% of the cash holding variation, respectively.

In specification 3, I show results when considering the entrenchment index of Bebchuk et al. (2009) as a proxy for possible agency problems in firms. The general idea is that entrenched managers and poorly governed firms pursue cash policies that are not in shareholders' interest. Regression results show that agency issues are not substantial drivers of corporate cash holdings: The cash holding variation explained by the precaution index is 29.6%, whereas the variation explained by the E-index is only 2.2%. The coefficient index associated to the E-index indicates that firms with weaker governance hold less cash, which may result because these firms spend cash quickly on acquisitions and capital expenditures rather than hoarding it (Harford et al. (2008)). Alternatively, I include the GIM index of Gompers et al. (2003), which explains 1.2% of the cash-holding variation (not shown). I do not consider these governance indices in further analyses because they substantially reduce the sample size and have no economically significant effect on firm cash holdings.

Together, the results indicate that the precautionary motive is the predominant cash holding determinant, explaining 31.9% of corporate cash holding variation. In that regard, the empirical measures associated with the other motives, such as taxes (foreign income dummy: 0.2%), transaction costs (firm size: 5.3%) and agency costs (E index: 2.2%), are of second-order importance.

These results are consistent with the evidence of other empirical studies on the importance of cash holding motives. BKS show that the secular increase in the average cash-to-asset ratio for U.S. industrial firms from 1980 to 2006 can be explained partly by the increasing demand for precautionary cash over time. Their precautionary proxies jointly explain 53% of the aggregated increase in cash holdings over this period (12.7 percentage points). However, it should be noted that their results from time trend analyses are driven by changes in the composition of the sample over time, namely, by the influx of newly listed technology firms. This allows for the conclusion that the precautionary motive has become more important for the sample firms in 2006 relative to those in 1980. Going beyond BKS, my results show that the precautionary motive actually is the predominant corporate cash holding motive. In a more general way, my results also confirm the survey evidence of Lins et al. (2010) that the precautionary motive is key when firms consider their cash holding levels.

4.3. *Results from the comprehensive cash holding model*

In a next step, I extend the cash holding model by the constraint indices of HM. As already mentioned, these are good precautionary proxies because they measure firms' concerns about underinvestment due to either insufficient debt or equity financing.

Before I examine the contribution of the HM constraint measures in the cash-holding model, I explore their relation to the precaution index. Table 6 reports Pearson correlation coefficients between the precaution index and the HM constraint measures. Not surprisingly, the correlations among the constraint measures are almost identical to the ones displayed by HM. Following HM, the positive correlations among the investment delay, equity delay and private placement delay measures, and their negative correlations with the debt delay measure suggest that constraints are most severe for firms that are focused on the equity markets relative to those focused on debt markets. HM also show that private placement constraints are a more extreme version of equity constraints and that equity constraints, in turn, are a more extreme version of the general investment constraint measure. The correlations with the precautionary index suggest that the precaution index is most closely related to equity-related constraint measures. Therefore, the index seems to identify equity-constrained rather than debt-constrained firms, which is in line with my univariate evidence (Table 3) that the primary financing source of firms with high precautionary motives is equity.

In Table 7, I investigate how the HM constraint measures are related to cash holdings. With the exception of debt market constraints, more financially constrained firms show higher cash holdings, as predicted by the precautionary savings motive (see columns 1 to 4). Inconsistent with the precautionary savings motive is that debt constraints are negatively related with corporate cash holdings. According to HM, debt-constrained firms resemble distressed firms because they have high leverage and low Q's but invest more than their industry peers. Borrowing from this information, distressed firms seem to have limited opportunities to maintain financial flexibility and, thus, hold systematically less cash.

The R^2 in columns 1 to 4 indicate that the debt (distress) and private placement-focused measure can explain remarkably more variation in cash holdings than the other two constraint measures. In the analysis in column 5, in which the precaution index is also included as an explanatory variable, the coefficient of the investment delay index becomes insignificant, and the coefficient of the equity delay-focused reverses its sign and now disagrees with the precautionary logic. Thus, I exclude these two measures from subsequent analyses, which leads to a marginal reduction in the model's R2 of only 0.005. Because the private placement delay measure deals with firms' constraints in public and private equity market, following HM, I will refer to it as equity constraints.[26] Together, the precaution, the debt and equity constraint indices explain 47.2% of the cross-sectional variation in cash holdings. This analysis assumes that the measures are orthogonal to the other firm characteristics. Next, the three measures are stepwise integrated in the augmented cash holding model.

[26] In the subsequent analyses, I find similar results when using an equity constraint index based on the first principal component of the equity-focused and private placement delay measures (not shown).

Table 8 presents the regression results and corresponding variance decompositions based on the comprehensive cash-holding model. Similar to the previous analysis, debt-related constraints are negatively related to cash holdings, and their inclusion in the model leaves the explanatory power of the precaution index mostly unaffected, which indicates that these two measures explain different dimensions of firm cash holdings (see specification 1). The situation is different for equity constraints. The inclusion of the private placement index lowers the coefficient estimates and the explained variance associated with the precaution index (see specification 2). Consequently, the two measures seem to capture a common precautionary dimension in cash holdings, namely, the ones pertaining to costly equity financing in the future. Beyond this, each measure independently explains a significant share of a firm's cash holdings; the precautionary index most likely the share pertaining to the need for external financing (because the HM measures control for costs/constraints) and the private placement index most likely the share pertaining to costly equity financing.

When including the three measures together, they can jointly explain 40.6% of the variation in firm cash holdings, which is 20 percent higher than that explained solely by the precaution index (see specification 3). Interestingly, the precaution index can explain more variation (22.8%) in cash holdings than the two HM measures together (17.7%). Overall, the results suggest that the three measures explain specific dimensions in corporate cash holdings, namely, the ones pertaining to external financial needs (precaution index), financial distress (debt constraints), and financial constraints in equity markets.[27]

Table 9 presents a second set of results to illustrate the economic significance of the results in Table 8. Panel A shows how much each of the three measures contributes to cash holdings when taking on a value equal to its respective unconditional mean (at the means of

[27] The three precautionary measures are fairly robust to the inclusion of additional financing control variables, such as net debt issuance, equity issuance and leverage and industry fixed effects measured at the 2- or 3-digit SIC level (not shown). These variables are also included in some of the specifications in BKS.

all other variables). Given that the relevant mean cash-to-asset ratio is 19.11%, the measures play an important role in explaining this figure. The precaution, debt and private placement indices justify values of 15.1%, -7.5% and 6.5%, respectively. Similarly, Panel B illustrates predicted cash holdings at specific quantiles of the precautionary variables, when the other variables are held at their mean values. A 1-IQR increase in the precaution and private placement index is associated with an increase in cash holdings of 11.4 and 4.5 percentage points, respectively. An increase of the same magnitude in debt constraints is associated with a decrease in cash holdings of 5.2 percentage points.

4.4. *Subsample analysis*

The previous results show that the precautionary motive is the predominant determinant of U.S. industrial cash holdings. By estimating the cash holding model for the entire sample, it is assumed that the precautionary motive is of equal importance for all firms. However, BKS find evidence that technology and newly listed firms decisively contribute to the increasing importance of precautionary cash over time. This leads me to assume that the precautionary motive is likely more important for young firms than for mature firms and for high-tech firms than for manufacturing firms. I therefore examine the importance of the precautionary measures in explaining cash holdings in subsamples of young versus mature firms and high-tech versus manufacturing firms. I will first present the results and then explain why possible differences between the subsamples are likely to emerge.

Table 10 presents the regression results by differentiating between young firms and mature firms. Columns 1 and 2 show the results from the augmented cash holding model. The coefficient estimates and the explained variation in cash holdings attributed to the precautionary index indicate that the precautionary motive of holding cash is almost twice as important for young firms than for mature firms. For instance, the index explains 33.5% of the cash holding variation in young firms and 19.5% in mature firms. In economic terms, a 1-IQR increase in the precaution index leads cash holdings to increase by 16.9 percentage points in young firms and by only 7.9 percentage points in mature firms.

When augmenting the model by the HM constraint indices, the previously documented differences in the importance of the cash holding motive among young and mature firms remain the same (see columns 3 and 4). The jointly explained variation in cash holdings determined using the three precaution measures is 43.2% (22.2% + 9.2% + 11.8%) for young firms and 25.4% (16.0% + 5.9% + 3.5%) for mature firms. A substantial part of these differences can be attributed to the different importance of equity constraints in explaining cash holdings of young firms (11.8%) versus mature firms (3.5%). To emphasize the difference in economic terms, a 1-IQR increase in equity constraints leads cash holdings to increase by 6.0 percentage points in young firms and only by 1.9 percentage points in mature firms. These results suggest that young firms are more reliant on precautionary cash if they are concerned about equity constraints in the future. Next, I investigate whether the same is also true for high-tech and manufacturing firms.

By analogy to the previous analysis, Table 11 presents the regression results by separating high-tech from manufacturing firms. In the augmented model, the coefficient estimates, the economic significance and the explained variation associated with the precaution index are substantially higher in high-tech than in manufacturing firms (see columns 1 and 2). For instance, the variation in cash holdings explained by the precaution index indicates that the precautionary motive is again almost twice as important for high-tech firms (26.9%) than for manufacturing firms (14.9%).

The comprehensive model shows a similar picture as the case of young firms versus mature firms (columns 3 and 4): substantial differences in the documented importance of the precautionary motive between high-tech and manufacturing firms stem from different effects of equity constraints on cash holdings. The cash holding variation (and economic effects) explained by variation in equity constraints is substantially higher for high-tech firms, with 10.4% (1-IQR: 6.3%), than it is for manufacturing firms, with 4.4% (1-IQR: 2.1%). Similar to the age-related results, this suggests that concerns about equity constraints in the future lead to higher precautionary cash holdings in high-tech than in manufacturing firms.

The question that arises from these results is why young and high-tech firms are relatively more reliant on precautionary cash when facing equity constraints. The most plausible explanation is the following: One important difference between these firm groups is that young and high-tech firms engage relatively more in innovation in order to be at the competitive edge. These firms therefore have higher levels of undisclosed proprietary information and face higher opportunity costs from publicly disclosing such information (Brown et al. (2009), HM and Loderer et al. (2016)). Proprietary information, in turn, is typically disclosed by firms to reduce information asymmetry with investors in order to reduce equity constraints (see Farre-Mensa (2015)). Consequently, young and high-tech firms are more reliant on precautionary cash to reduce the reliance on external equity capital which may cause them to costly disclosure of proprietary information.

To verify this explanation, I perform the same subsample tests based on a more direct split criterion (than age and high-tech) on whether or not a firm faces high opportunity costs from disclosing proprietary information. To do so, I use an indicator variable created by HM for whether or not a firm explicitly mentions the need to protect proprietary information in its 10-K. Firms that mention the need to protect proprietary information tend to be young and high-tech firms.[28] Consistently, the subsample results based on this split criterion are almost identical to the previous subsample results (see Table 12). It shows that the precautionary motive of holding cash is almost twice as important for firms with a high need to protect proprietary information than for firms with low needs. Again, important differences emerge

[28] The proprietary information indicator is positively correlated with a young firm indicator (0.38) and with a high-tech firm indicator (0.57).

due to equity constraints (see columns 3 and 4). This is consistent with the notion that firms with a higher need to protect proprietary information hold relatively more precautionary cash. In doing so, they reduce the reliance on external equity financing because restrictions in equity markets (information asymmetries) may force them to disclose valuable proprietary information.

Overall, the subsample results show that the precautionary motive of holding cash is significantly stronger among firms with a higher need to protect proprietary information, such as young and high-tech firms and firms that explicitly state these needs.

5. Conclusion

Using a large sample of listed U.S. industrial firms, this paper studies whether precautionary motives predominantly determine the substantial differences in the cash-to-asset ratio across firms. To do so, based on multivariate regressions, I investigate how much variation in firm cash holdings can be attributed to empirical measures associated to alternative cash holding motives, such as the precautionary, transactional, tax and agency motive. Furthermore, to properly measure precautionary motives at the firm level, I create a novel unidimensional precaution index, which is the first principal component of six popular proxies for firm precautionary motives, such as the level and volatility of operating cash flows, R&D intensity, market-to-book ratio, product market threats, and net working capital.

My evidence shows that the substantial variation in cash holdings across firms is explained predominantly by differences in firms' precautionary motives. For instance, the precaution index can explain 32% of the cross-sectional and longitudinal variation in corporate cash holdings, corresponding to 70% of the variation explained by the cash holding model. Empirical measures associated with other motives for holding cash do not come close to explaining the same level of variation in cash holdings as the precaution index. Further tests reveal that the debt and equity financial constraint indices from Hoberg and Maksimovic (2015) are also relevant precautionary measures in explaining corporate cash holdings. It shows that the precaution, debt-focused delay and private placement delay indices tend to explain specific dimensions in corporate cash holdings, namely, those pertaining to the need for external financing, to financial distress and to costly equity financing. Together, the measures explain 41% of the corporate cash holding variation. Finally, I document that as the predominant cash holding determinant, the precautionary motive is particularly strong for firms with a higher need to protect proprietary information, such as young and high-tech firms and firms that explicitly state these needs. This finding is consistent with the notion that these firms are more reliant on precautionary cash to reduce the reliance on equity capital because restriction in equity markets may force them to costly disclosure of proprietary information.

Although the comprehensive cash model does a good job of describing firm cash holdings, a substantial cross-sectional variation in cash holdings (39%) remains unexplained by the model. Future research efforts aiming at identifying further cash determinants might provide a better understanding of firm liquidity management. Further, I have examined the importance of the precautionary savings motive for cash holdings of listed U.S. industrial firms, a sample that has experienced dramatic changes in its composition in the past three decades. According to Fama and French (2004), the increasing supply in equity capital has enabled listings of technology firms that are characterized by unprecedentedly low cash flows and high R&D intensities and growth opportunities. My analysis and the one by BKS provide evidence that the listing of technology firms has increased the importance of the precautionary motive in explaining corporate cash holdings. It would be interesting to investigate whether the importance of the precautionary motive for holding cash systematically varies across countries with different industry compositions and different development of equity markets. Finally, the precautionary savings motive suggests that firms hoard cash to finance their activities and investments when other sources of funding are not available or are excessively costly. Therefore, it would be interesting to test whether firms with high amounts of precautionary cash really use more cash to sustain investment in the presence of an exogenous cash flow shock. Duchin, Ozbas and Sensoy (2010), Brown and Petersen (2014) and Aebischer (2016) use the exogenous capital supply shock of the recent financial crisis in 2007-2009 to test this prediction.

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Appendix: Tables

Variable definitions

Variable	Definition (Compustat item name)
Cash	Cash and short-term investments (cheq)/total assets (atq).
	Panel A: Precaution variables
Cash flow	Operating income before depreciation (oibdq)/total assets (atq).
Industry sigma	The mean of the standard deviations of cash flow/assets over 20 quarters (minimum of 8 consecutive quarters) for firms in the same industry, as defined by the two-digit SIC code.
R&D	R&D expenses (xrdq)/total assets (atq).
Market-to-book	The market value of assets (total assets (atq) + market value of common equity (cshoq × prccq) – common equity (ceqq))/(0.9 × book value of assets(atq) + 0.1×market value of assets). This definition follows Kaplan and Zingales (1997).
NWC	Net working capital without cash (current assets (actq) – current liabilities (lctq) – cash (cheq))/total assets (atq).
Product market fluidity	Text-based fluidity measure (product market threats) according to Hoberg, Phillips, and Prabhala (2014).
	Panel B: Precaution and constraint indices
Precaution index	First principal component from principal component analysis (PCA) of cash flow, industry sigma, R&D, Tobin's Q and product market fluidity.
Investment delay	Text-based constraint measure indicating potential underinvestment due to liquidity challenges, according to Hoberg and Maksimovic (2015).
Debt-focused delay	Text-based constraint measure indicating potential underinvestment due to debt financing constraints, according to Hoberg and Maksimovic (2015).
Equity-focused delay	Text-based constraint measure indicating potential underinvestment due to equity financing constraints, according to Hoberg and Maksimovic (2015).
Private placement delay	Text-based constraint measure indicating potential underinvestment due to private placement financing constraints, according to Hoberg and Maksimovic (2015).
	Panel C: Further control variables
Leverage	Short-term debt (dlcq) plus long-term debt (dlttq)/total assets (atq).
Dividend dummy	A quarterly dummy variable equal to one if the firm paid dividends ((dvp+dvc) > 0) in the fiscal year and equal to zero if it did not.
Capex	Quarterly capital expenditure/total assets (atq). Because capital expenditure is reported on a year-to-date basis in quarterly financial statements, I subtract the previous quarter's capital expenditure from the current quarter's capital expenditure (capxy) for fiscal quarters 2, 3, and 4.
Acquisitions	Quarterly acquisitions (aqcq)/total assets (atq).
Net debt issuance	(Long-term debt (dlttq) at t + short-term debt (dlcq) at t – long-term debt (dlttq) at t-1 – short-term debt (dlcq) at t-1)/total assets (atq).
Equity issuance	Quarterly sale of common and preferred stock (sstky)/total assets (atq). Because the sale of common and preferred stock (sstky) is reported on a year-to-date basis in quarterly financial statements, I subtract the previous quarter's sstky from the current quarter's sstky for fiscal quarters 2, 3, and 4.
Foreign income dummy	A quarterly dummy variable equal to one if the firm reported non-missing pretax foreign income in the fiscal year and equal to zero if it did not.
Age	Natural logarithm of listing age, computed as one plus the difference between the year under investigation and the firm's birth year. The birth year is computed as the minimum value of: (a) the first year the firm appears on the CRSP tapes; (b) the first year the firm appears on the COMPUSTAT tapes; or (c) the first year in which I find a link between the CRSP and the COMPUSTAT tapes.
Size	Natural logarithm of the book value of total assets.
High-tech	Dummy variable for firms in high-tech industries with SICs 283 (Drugs), 355 (Special Industry Machinery), 357 (Computer and Office Equipment), 366 (Communications Equipment), 367 (Electronic Components and Accessories), 382 (Measuring and Controlling Devices), 384 (Medical Instruments & Supplies), and 737 (Computer and Data Processing Services).

Table 1: Summary statistics

This table presents summary statistics. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	Mean	Median	SD	Min	Max	Observations
Cash	19.11	9.18	22.28	0.01	90.50	78,378
Precautionary variables						
Cash flow	2.64	3.19	4.76	-18.82	13.65	78,378
Industry sigma	4.14	4.26	1.26	0.64	8.35	78,378
R&D	1.69	0.15	3.08	0.00	19.06	78,378
Market-to-book	1.84	1.51	1.05	0.16	9.88	78,378
NWC	7.76	6.12	17.23	-42.40	52.41	78,378
Product market fluidity	6.91	6.39	3.39	1.42	17.46	78,378
Precaution and constraint indices						
Precaution index	-0.01	-0.29	1.42	-2.23	5.33	78,378
Investment delay	-0.13	-0.24	0.94	-1.90	2.34	67,018
Debt-focused delay	0.01	-0.03	0.58	-1.11	1.54	67,018
Equity-focused delay	-0.18	-0.28	0.87	-1.80	2.34	67,018
Private placement delay	-0.07	-0.14	0.79	-1.62	2.03	67,018
Further financial policies and firm characteristics						
Capex	1.64	1.00	1.98	-0.04	12.19	77,416
Acquisitions	0.79	0.00	3.08	-0.28	21.97	75,463
Size	2,108	347	6,218	9	55,574	78,378
Age	16.79	11.00	16.20	1.00	79.00	78,378
Dividend dummy	0.37	0.00	0.48	0.00	1.00	77,555
Foreign income dummy	0.39	0.00	0.49	0.00	1.00	78,378
High-tech dummy	0.35	0.00	0.48	0.00	1.00	78,378

Table 2: Precaution index with principal component analysis (PCA)

The table reports results from a principal component analysis (PCA) of six precautionary measures. Columns 1 to 3 show factor loadings of the six precautionary measures on the first three principal components. The loadings in column 1 indicate the weight by which each of the six standardized original variables should be multiplied to compute the first component. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	Component 1 ($Prec_1$)	Component 2 ($Prec_2$)	Component 3 ($Prec_3$)
	(1)	(2)	(3)
Cash flow	-0.408***	0.603***	-0.347***
	(0.003)	(0.016)	(0.027)
Industry sigma	0.328***	0.421***	0.251***
	(0.004)	(0.017)	(0.028)
R&D	0.492***	-0.021	0.426***
	(0.003)	(0.020)	(0.010)
Market-to-book	0.359***	0.643***	-0.083***
	(0.004)	(0.032)	(0.031)
NWC	-0.356***	0.187***	0.734***
	(0.004)	(0.032)	(0.010)
Product market fluidity	0.477***	-0.097***	-0.298***
	(0.003)	(0.014)	(0.009)
Eigenvalues	2.16	1.02	0.94
Proportion of explained variance	0.36	0.17	0.16
Observations		78,378	

Table 3: Firm characteristics across precaution quintiles

The table reports average firm characteristics and financial policies within each quintile of the precaution index. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

Quintile	1	2	3	4	5	Means
Precaution index	-1.56	-0.85	-0.28	0.43	2.23	-0.01
Cash	6.44	8.88	14.20	22.28	43.74	19.11
Size	1,456	2,334	2,667	2,888	1,193	2,108
Age	21.99	20.37	17.85	15.03	8.72	16.79
High-tech firms	0.04	0.15	0.31	0.49	0.79	0.36
Net debt issuance	0.52	0.63	0.64	0.59	0.68	0.61
Equity issuance	0.36	0.54	0.91	1.22	3.56	1.32

Table 4: Precaution index and cash holdings

The table examines the effects of the precautionary index on firm cash holdings. In Panel A, the panel regressions are estimated based on the cash holding model of Bates, Kahle and Stulz (2009). The dependent variable is equal to firm cash and cash equivalents divided by firm assets. All specifications include year fixed effects, and specification 3 includes industry (SIC 3-digit) fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. Panel B displays the economic effects of the precaution index on cash holdings based on specification 2 in Panel A. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

Panel A: Regressions

	(1)	(2)	(3)
Precaution index	9.874***	8.631***	7.452***
	(0.176)	(0.183)	(0.252)
Dividend dummy		-2.660**	-0.886**
		(0.437)	(0.429)
Capex		-1.424***	-0.773***
		(0.083)	(0.079)
Acquisitions		-0.450***	-0.417***
		(0.020)	(0.020)
Size		-1.988***	-1.685***
		(0.143)	(0.159)
Age		-1.890***	-1.949***
		(0.266)	(0.269)
Foreign income dummy		1.531***	-0.051
		(0.455)	(0.487)
Constant	19.428***	38.591***	35.699***
	(0.345)	(0.883)	(0.937)
Time FE	yes	yes	yes
Industry FE (SIC 3 digit)	no	no	yes
Observations	78,378	73,920	73,920
Adjusted R2	0.400	0.466	0.528

Panel B: Economic significance (Specification 2)

Percentile	10th	25th	50th	75th	90th
Precaution index	6.26%	10.70%	16.81%	24.93%	35.18%

Table 5: Importance of cash holding determinants

The table examines the importance of firm policies and characteristics in determining cash holdings. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. In specification 1, all independent variables are standardized prior to fitting regressions to permit more intuitive comparisons across variables. From specifications 2 and 3, OLS coefficient estimates and the percentage of the variation coming from each variable are displayed. The method used in the variance decomposition takes the average of all R-squared from all possible orderings of all regressors (see Lindeman, Merenda, and Gold (1980) and Kruskal (1987)). All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	(1)	(2)		(3)	
	Coeff. (se)	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained
Precaution index	12.382***	8.631***	31.9%	9.372***	28.9%
	(0.262)	(0.183)		(0.437)	
Dividend dummy	-2.660***	-2.660***	2.7%	-2.902***	5.1%
	(0.437)	(0.437)		(0.859)	
Capex	-2.831***	-1.424***	2.0%	-1.598***	2.9%
	(0.166)	(0.083)		(0.170)	
Acquisitions	-1.391***	-0.450***	0.6%	-0.469***	0.5%
	(0.062)	(0.020)		(0.047)	
Size	-3.468***	-1.988***	5.3%	-3.096***	5.6%
	(0.249)	(0.143)		(0.313)	
Age	-1.764***	-1.890***	4.1%	0.307	2.6%
	(0.249)	(0.266)		(0.510)	
Foreign income dummy	1.531***	1.531***	0.2%	0.119	0.1%
	(0.455)	(0.455)		(0.770)	
E-index				-1.583***	2.2%
				(0.302)	
Constant	19.512***	38.591***		46.574***	
	(0.435)	(0.883)		(2.209)	
Time FE	yes	yes		yes	
Observations	73,920	73,920		10,059	
Adjusted R2	0.466	0.466		0.501	

Table 6: Pearson correlation coefficients

The table displays Pearson correlation coefficients between the precaution index and the financial constraint indices of Hoberg and Maksimovic (2015). Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

		(1)	(2)	(3)	(4)	(5)
Precaution index	(1)	1				
Investment delay	(2)	0.317	1			
Debt-focused delay	(3)	-0.304	-0.037	1		
Equity-focused delay	(4)	0.420	0.926	-0.127	1	
Private placement delay	(5)	0.501	0.460	-0.497	0.642	1

Table 7: Constraint/precautionary measures and cash holdings

The table examines the effect of the financial constraint measures from Hoberg and Maksimovic (2015) on firm cash holdings. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	(1)	(2)	(3)	(4)	(5)
Investment delay	5.439***				0.725
	(0.373)				(0.631)
Debt-focused delay		-16.818***			-6.970***
		(0.390)			(0.372)
Equity-focused delay			8.355***		-1.589**
			(0.392)		(0.807)
Private placement delay				14.539***	5.354***
				(0.342)	(0.427)
Precaution index					7.845***
					(0.185)
Constant	18.722***	18.464***	19.264***	18.710***	19.649***
	(0.432)	(0.406)	(0.416)	(0.377)	(0.368)
Time FE	yes	yes	yes	yes	yes
Observations	76,802	76,802	76,802	76,802	67,018
Adjusted R2	0.053	0.180	0.104	0.254	0.473

Table 8: Importance of cash holding determinants in the comprehensive cash model

The table examines the effect of the precautionary measures on cash holdings. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	(1)		(2)		(3)	
	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained
Precaution index	7.600***	27.6%	7.022***	25.1%	6.801***	22.8%
	(0.192)		(0.194)		(0.193)	
Debt-focused delay	-8.932***	10.4%			-6.694***	7.7%
	(0.332)				(0.361)	
Private placement delay			6.505***	13.1%	4.213***	10.1%
			(0.288)		(0.308)	
Dividend dummy	-2.870***	2.4%	-2.965***	2.4%	-2.977***	2.3%
	(0.424)		(0.441)		(0.422)	
Capex	-1.314***	1.8%	-1.401***	2.0%	-1.309***	1.7%
	(0.080)		(0.082)		(0.079)	
Acquisitions	-0.431***	0.5%	-0.457***	0.6%	-0.437***	0.5%
	(0.021)		(0.021)		(0.021)	
Size	-1.698***	4.7%	-2.038***	4.9%	-1.782***	4.4%
	(0.146)		(0.149)		(0.145)	
Age	-2.271***	3.8%	-1.274***	3.2%	-1.712***	3.1%
	(0.262)		(0.265)		(0.258)	
Foreign income dummy	0.753*	0.1%	1.665***	0.2%	1.035**	0.1%
	(0.447)		(0.455)		(0.440)	
Constant	37.770***		37.486***		36.977***	
	(0.894)		(0.907)		(0.881)	
Time FE	yes		yes		yes	
Observations	63,450		63,450		63,450	
Adjusted R2	0.514		0.506		0.527	
Variance from precaution		38.0%		38.2%		40.5%

Table 9: Economic Significance

The table displays the economic effects of the precaution and constraint indices on cash holdings using on the estimates from Table 8, specification (3). Panel A presents the effect of a variable (at its mean) on cash holdings. Panel B shows predicted cash holdings at the 10th, 25th, 50th, 75th, and 90th percentile of a variable, holding the other variables at their mean values. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	Precaution index	Debt-focused delay	Private placement delay
Panel A: Effects at mean of variable			
Effect at mean	15.1%	-7.5%	6.5%
Panel B: Predicted cash holdings			
Percentile			
10	9.7%	25.0%	15.9%
25	13.2%	22.8%	17.7%
50	18.1%	20.3%	19.8%
75	24.6%	17.6%	22.2%
90	32.8%	14.9%	24.6%

Table 10: Precautionary determinants of cash holdings: Young vs. mature firms

The table examines the effect of the precautionary measures on firm cash holdings by young versus mature firms. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. A firm is classified as young if it is less than 12 years after the year it first appears in the Compustat/CRSP tapes, and as mature otherwise. All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	Young		Mature		Young		Mature	
	(1)		(2)		(3)		(4)	
	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained
Precaution index	9.278***	33.5%	5.611***	19.3%	7.044***	22.2%	4.726***	16.0%
	(0.241)		(0.318)		(0.263)		(0.323)	
Debt-focused delay					-7.232***	9.2%	-5.453***	5.9%
					(0.507)		(0.591)	
Private placement delay					5.061***	11.8%	2.189***	3.5%
					(0.437)		(0.499)	
Constant	51.108***		31.957***		45.440***		33.489***	
	(1.405)		(2.431)		(1.384)		(2.543)	
Precaution index (25th to 75th)	16.7%		7.9%		12.7%		6.9%	
Debt-focused delay (25th to 75th)					-6.0%		-3.9%	
Private placement delay (25th to 75th)					6.0%		1.9%	
Further controls	yes		yes		yes		yes	
Time FE	yes		yes		yes		yes	
Observations	36,080		37,840		30,434		33,016	
Adjusted R2	0.477		0.299		0.537		0.364	
Variance from precaution		33.5%		19.3%		43.2%		25.4%

Table 11: Precaution determinants of cash holdings: High-tech vs. manufacturing firms

The table examines the effects of the precautionary measures on cash holdings by high-tech versus manufacturing firms. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. High-tech firms operate in industries with SIC codes 283, 355, 357, 366, 367, 382, 384, and 737. All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

	High-tech		Manufacturing		High-tech		Manufacturing	
	(1)		(2)		(3)		(4)	
	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained
Precaution index	7.579***	26.9%	4.783***	14.8%	6.079***	16.5%	4.041***	11.9%
	(0.313)		(0.250)		(0.325)		(0.226)	
Debt-focused delay					-7.236***	5.4%	-5.384***	6.2%
					(0.679)		(0.408)	
Private placement delay					5.569***	10.4%	2.277***	4.4%
					(0.558)		(0.338)	
Constant	51.454***		27.967***		46.756***		28.548***	
	(1.687)		(1.058)		(1.694)		(1.064)	
Precaution index (25th to 75th)	14.1%		6.7%		11.4%		5.8%	
Debt-focused delay (25th to 75th)					-4.9%		-4.1%	
Private placement delay (25th to 75th)					6.3%		2.1%	
Further controls	yes		yes		yes		yes	
Time FE	yes		yes		yes		yes	
Observations	26,369		47,551		23,430		40,020	
Adjusted R2	0.345		0.251		0.424		0.316	
Variance from precaution		26.9%		14.8%		32.2%		22.5%

Table 12: Precaution determinants of cash holdings: low vs. high need to protect proprietary information

The table examines the effects of the precautionary measures on cash holdings by firms low versus high needs to protect proprietary information. The dependent variable is equal to firm cash and cash equivalents divided by firm assets. Firms with needs to proprietary information are firms that mention concerns about the risk of losing proprietary information in their 10-Ks. All specifications include time fixed effects. Standard errors are clustered by firm and corrected for heteroskedasticity. ***, **, and * indicate statistical significance in two-sided tests at confidence levels of 0.99, 0.95, and 0.90, respectively. Variable definitions are in the Appendix. The sample period is 1998 – 2005. Data are taken from the quarterly Compustat/CRSP data files and from the 10-K database of Hoberg et al. (2014) and Hoberg and Maksimovic (2015).

Needs to protect proprietary information	Yes		No		Yes		No	
	(1)		(2)		(3)		(4)	
	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained	Coeff. (se)	Variance explained
Precaution index	8.250***	25.0%	4.734***	12.1%	6.535***	18.1%	4.045***	9.8%
	(0.281)		(0.270)		(0.297)		(0.259)	
Debt-focused delay					-7.797***	6.9%	-5.145***	6.2%
					(0.613)		(0.411)	
Private placement delay					5.081***	10.3%	2.026***	3.1%
					(0.509)		(0.332)	
Constant	52.359***		25.474***		48.061***		26.601***	
	(1.563)		(1.082)		(1.585)		(1.104)	
Precaution index (25th to 75th)	14.9%		7.5%		11.9%		6.0%	
Debt-focused delay (25th to 75th)					-5.7%		-3.9%	
Private placement delay (25th to 75th)					6.2%		1.8%	
Further controls	yes		yes		yes		yes	
Time FE	yes		yes		yes		yes	
Observations	29,006		43,707		26,253		36,460	
Adjusted R2	0.392		0.210		0.463		0.277	
Variance from precaution		25.0%		12.1%		35.3%		19.1%

III. Costly equity and the use of precautionary cash holdings: Evidence from the financial crisis

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April 2016

In this paper, I investigate whether the debt or equity capital supply shock of the recent financial crisis (2007-2009) caused firms to use precautionary cash holdings to mitigate underinvestment. I find that precautionary cash was used to substitute for the decline in net equity issuance but not net debt issuance. I also find that precautionary cash was used by equity- but not debt-constrained firms to mitigate underinvestment during the crisis. Consistently, precautionary cash was not used in the absence of the equity supply shock, i.e., during placebo crises or during the economy-wide demand shock following the financial crisis. This paper provides new evidence on the importance of corporate liquidity management for equity-constrained firms and identifies the crisis' equity capital supply shock as a dominant first-order effect on corporate financial policies.

Keywords: Precautionary cash holdings, financing constraints, corporate financing, corporate investment, financial crisis.

JEL codes: G01, G31, G32, E51

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1. Introduction

This paper investigates whether costly debt or equity financing caused firms to use precautionary cash holdings to mitigate underinvestment during the recent financial crisis of 2007-2009. Following the precautionary motive, firms *hold* cash to protect against cash flow shocks, which would force firms to underinvest or default in the future when coupled with costly external financing. The financial crisis is well-suited to analyzing the *use* of corporate precautionary cash because there was a large exogenous shock to the supplies and costs of debt and equity capital (Kahle and Stulz (2013) and Bliss, Cheng and Denis (2015)). The central insight of this paper is that only costly equity financing caused firms to use precautionary cash.

The majority of the existing literature on the crisis uses the (subprime mortgage) credit crisis of 2007-2009 as an experimental setting to investigate the impact of the crisis' external finance shock on corporate policies, such as liquidity management and investment (e.g., Duchin, Ozbas and Sensoy (2010), Campello, Giambona, Graham and Harvey (2011), Brown and Petersen (2014)). Consistent with a capital supply shock affecting the real sector, these studies show that more financially constrained firms experienced greater declines in investment and drew more on alternative funding sources, such as credit lines or cash. Strikingly, Kahle and Stulz (2013) show that bank- and credit-dependent firms did not experience changes in their cash positions or investment that differed from the changes of matched firms that did not depend on banks or credit. They highlight one additional important fact: relative to the pre-crisis period, corporate borrowing was not systematically reduced during the period from August 2007 to September 2008 when the Lehman Brothers investment bank declared bankruptcy. This is the crisis period during which a presumably major capital supply shock took place. Given these results, the authors cast doubt that a bank lending shock or a credit supply shock were first-order determinants of corporate financial policies during the crisis (referred to as credit rationing). This raises the question of which alternative capital shortage had a first-order effect on corporate cash and investment policies during the crisis.

One possible answer to that question is equity. The hypothesis is as follows: The uncertainty associated with the emerging crisis, starting in late 2007, induced a "flight to quality" leading investors to shift capital away from risky investments and toward safer investments.[29] The perception of increasing risk led investors to require higher risk premiums, especially for risky investments, i.e., bonds of lower credit quality and especially equities (Brunnermeier (2009), Gorton (2009); Gorton (2010), and Kahle and Stulz (2013)). Such episodes of high investor uncertainty primarily lead to shortage of equity capital and cause "equity rationing" among firms in the real economy (Krasker (1986)).

In this paper, I seek to solve the puzzle of whether credit or equity rationing during the financial crisis caused firms to use precautionary cash to mitigate possible underinvestment. To solve this puzzle, I employ a difference-in-differences (diff.-in-diff.) approach in which I compare the financing (i.e., net equity issuance, net debt issuance, and cash savings) and investment policies of firms before and after the onset of the crisis as a function of their precautionary cash holdings, controlling for firm fixed effects and time-varying firm characteristics, such as market-to-book, cash flows, and leverage (see Duchin et al. (2010) and Bliss et al. (2015) for similar model specifications). Thus, the empirical analysis proceeds in two main steps. First, by analyzing financing policies, I seek to determine whether firms used precautionary cash holdings to substitute for a decline in net debt or net equity issuance. Second, by analyzing investment policies, I seek to determine whether firms actually used precautionary cash to mitigate underinvestment induced by costly debt or equity financing.

[29] Caballero and Krishnamurthy (2008) build a model in which investors' flight to quality results from capital/liquidity shortages and Knightian uncertainty (Knight (1921)). Knightian uncertainty is triggered by unusual events and financial innovations that lead agents to question their worldviews.

Most of my analysis focuses on the five consecutive quarters from January 1, 2008 to March 30, 2009 (2008Q1-2009Q1), which define the crisis period in this paper. This definition of the crisis period closely follows Kahle and Stulz (2013) but starts two quarters later. My definition is derived from changes in macroeconomic indices and aggregate corporate financial policies indicating that the corporate sector was most likely affected by a capital supply shock during these quarters (see the discussion in Section 2). Following the literature, I define a *pre-crisis* period of equal length to the crisis period, extending from July 1, 2006 to September 30, 2007 (2006Q3-2007Q3).[30]

The variable of primary interest in my regression framework is precautionary cash holdings. Because firms also hold cash for other reasons than precaution, I define precautionary cash following Aebischer (2016) instead of using observed cash as in Duchin et al. (2010).[31] Accordingly, precautionary cash is based on a prediction from a cash-holding model in which a precaution index constitutes the main explanatory variable. The precaution index itself is the first principal component of the following popular precautionary proxies: R&D intensity, cash flow level and volatility, market-to-book ratio (growth opportunities), net working capital, and competitive threats.[32] To address endogeneity concerns, precautionary cash is measured six quarters before the start of the crisis, namely, at the end of the last fiscal quarter ending before July 1, 2006. The estimator of main interest, the "diff.-in-diff." estimator, includes an interaction between a crisis indicator and pre-crisis precautionary cash holdings.

[30] My crisis definition covers a similar period as studies that use annual data and define 2008 as the crisis year (e.g., Campello et al. (2011), Brown and Petersen (2014), Bliss et al. (2015)). Moreover, my baseline results are not sensitive to alternative (pre-)crisis definitions. To show robustness, I will also discuss the results in certain sub-periods of the crisis.

[31] I obtain similar results when using observed instead of precautionary cash. Exceptions will be discussed in the context of the investment results in Tables 7 and 10.

[32] For a more detailed discussion of the established precautionary proxies and the creation of the precaution index, see Aebischer (2016) and the literature cited therein.

As an additional test of whether costly debt or equity financing drove corporate cash and investment policies, I estimate the same regressions using subsamples of firms facing different degrees of financial constraint. In doing so, I utilize the firm-level measures of debt and equity financial constraints recently developed by Hoberg and Maksimovic (2015). Based on text-based analysis, they score Management's Discussion and Analysis (MD&A) sections in 10-Ks to obtain measures of debt and equity constraints, which capture a firm's inability to obtain debt or equity financing for planned investment. Among others, a main advantage of these constraint measures over other existing measures (e.g., firm size, firm age, dividends, KZ index, SA index) is that they enable better identification of the source of a firm's financing constraints. Similar to precautionary cash, I build the subsamples based on firms' financial constraints, as measured at the end of the last fiscal quarter ending before July 1, 2006.

Based on a sample of 2,322 listed U.S. industrial firms, univariate statistics of financial policies over time and across terciles of firms with different pre-crisis precautionary cash holdings yield interesting results. As the crisis started, cash was used and net equity issues plunged. This applies to a greater extent to firms with more pre-crisis precautionary cash. After the crisis, net equity issuance rebounded to pre-crisis levels and firms started to save cash again. In contrast, net debt issuance plunged later, i.e., immediately after the bankruptcy of Lehman Brothers in 2008Q4, and recovered later, i.e., in early 2010. More importantly, the magnitude of the decline in net debt issuance was not sensitive to firms' precautionary cash holdings. Taken together, this evidence suggests that firms use precautionary cash holdings to offset declines in equity issuance but not debt issuance.

The results of multivariate regressions, accounting for time-varying observable firm characteristics and unobservable firm fixed effects, confirm this conclusion. Firms with more precautionary cash used more of this cash and experienced greater declines in net equity issuance during the financial crisis. The results are economically meaningful; a one-interquartile range (IQR) increase in pre-crisis precautionary cash holdings reduced quarterly cash savings and net equity issuance by 1.14% and 0.49% (as a percentage of assets), respectively. These figures correspond to declines of 305% and 57%, respectively, relative to the levels of these financial policies during the last five quarters of the boom. In contrast, I find no statistically significant effect of precautionary cash holdings on changes in net issuance of debt. Furthermore, estimating cash saving regressions in subsamples of firms facing different degrees of debt and equity constraints reveal consistent results with firms using precautionary cash in reaction to costly equity but not costly debt financing during the crisis.

To complete the precautionary analysis, I estimate investment regressions to ascertain whether costly debt or costly equity financing caused firms to use precautionary cash to alleviate underinvestment. Consistent with equity rationing altering cash and investment policies during the crisis, I find that only equity-constrained firms reduced investment and used precautionary cash to counteract the negative consequences of insufficient equity funding on investment. To illustrate the magnitudes, firms with high equity constraints and zero precautionary cash holdings experience a decline in quarterly investment of 0.367% (as a percentage of assets); a decline of 9.2 percentage points relative to average pre-crisis investment. A one-IQR increase in precautionary cash mitigates the decline by 0.525 percentage, which corresponds to 143% of the decline for a firm with zero precautionary cash. In contrast, firms with low equity constraints show neither a significant decline in investment nor significant use of precautionary cash.

I perform several robustness checks to address concerns that the results may be driven by confounding effects. First, I test whether the diff.-in-diff. estimator is 0 in the absence of the treatment (i.e., the equity capital supply shock), which constitutes the key identifying assumption of the diff.-in-diff. strategy. To do so, I estimate the financing and investment regressions using placebo (nonexistent) crises occurring on January 1, 2005 and 2006. During these placebo crises, none of the diff.-in-diff. estimators is significantly different from 0, and thus, the parallel trend assumption regarding the various financial policies is satisfied. Second, to validate the claim that cash was only used to counteract the negative consequence of the (equity) capital supply shock on investment, I extend the crisis period by another five quarters (2009Q2-2010Q2). During these quarters, an economy-wide demand shock is considered to dominate a capital supply shock (e.g., Kahle and Stulz (2013)); therefore, financial constraints should be less binding, and precautionary cash should no longer be used. Consistent with this prediction, the results show that compared to the crisis period, firms experience a more pronounced decline in investment and issuance of net debt and precautionary cash was no longer used to counteract these trends.Finally, I test the validity of my instrument, precautionary cash, by comparing its explanatory power with that of the non-precautionary component of cash holdings, defined as the difference between observed and precautionary cash. Non-precautionary cash is held for other than precautionary reasons, most likely to support day-to-day operations or held in excess of an optimal cash level.[33] Surprisingly, I find that the non-precautionary component can also explain significant changes in cash savings and investment during the crisis. However, the explained effects are significantly smaller in the cash regression, and the magnitude of those effects is independent of financial constraints in the investment regression.

The remainder of this article is organized as follows. Section 2 outlines the financial crisis and possible financing channels through which the corporate sector was affected. Section 3 discusses the related literature. Section 4 introduces the data and the basic empirical strategy. Section 5 presents the results. Section 6 concludes.

[33] Following Bates, Kahle and Stulz (2009), firms hold cash for other than precautionary reasons, namely, for transactional (supporting day-to-day operations), tax and agency (inefficient management) reasons.

2. The capital supply shock of the financial crisis

In this section, I describe the timeline of the financial crisis and the dynamics of U.S. capital markets that might cause an exogenous capital supply shock to firms in the real sector. Understanding the dynamics of debt and equity markets helps determine whether and when the real sector was affected by shocks to the supplies of debt and equity. In doing so, I continue the existing literature and provide additional evidence of whether and when the original panic in the financial sector spilled over into debt markets or into capital markets in general. Upheavals that are limited to debt markets imply that risky borrowers in the corporate sector are most negatively affected by a debt supply shock. General upheavals in capital markets imply that risky firms are most negatively affected by a capital supply shock, in particular, by a shock to the availability of equity capital.

2.1. *Was there a debt supply shock before the Lehman Brothers bankruptcy?*

The onset of the credit and financial crisis is dated to August 2007, as financial institutions became concerned about their "toxic" asset holdings, which was mainly caused by write-downs of bad loans and plummeting values of collateralized debt obligations (CDOs). The continuing meltdown of these bank assets resulted in increased counterparty risk in the interbank market, which in turn led to an increased interest in risk management and stricter lending standards on the part of financial institutions (see Brunnermeier (2009) and Gorton (2010)). Consequently, the TED spread, which is a popular indicator of the perceived counterparty risk in the interbank market, spiked in August/September 2007.[34] Around the same time, uncertainty in the financial sector spilled over into credit markets, which led to increases in corporate bond

[34] The TED spread is defined as the difference between the 3-month LIBOR rate and the 3-month T-bill rate.

spreads across the credit quality spectrum until they spiked after the Lehman Brothers bankruptcy in September 2008 (see Figure 1). Based on this evidence, several authors argue that the phase before the Lehman's bankruptcy represents a dramatic negative shock to the supply of credit (e.g., Duchin et al. (2010), Campello, Graham and Harvey (2010) and Bliss et al. (2015)).

There is, however, evidence that casts doubts on this view. Although credit spreads and yields were increasing before Lehman, their levels during the pre-Lehman period were not so high that they would suggest a credit crisis (see Figures 1 and 2). For example, yields and spreads were lower before the Lehman bankruptcy than they were in 2002, a year that is not typically associated with a credit crisis (see also Kahle and Stulz (2013)). The yields of corporate bonds did not change remarkably from August 2007 to August 2008 (Aaa: -0.09%, Baa: +0.24%). Furthermore, Ivashina and Scharfstein (2010) show that syndicated lending fell by 22% before Lehman, but most of the decline is attributed to corporate restructuring loans (for LBOs, M&As, and stock repurchases) rather than to real investment loans. They also show that commercial and industrial loans increased, mainly due to drawdowns by corporate borrowers on existing credit lines. The described conditions in credit markets cast serious doubt on whether a shock to the supply of debt capital really occurred before bankruptcy of Lehman.

2.2. *The investors' flight to quality and an equity supply shock*

There exists an alternative view and channel through which a capital supply shock may have predominantly affected the corporate sector during the financial crisis: investors' discovery of the financial system's fragility and realization that some investments that they had thought were safe (e.g., highly rated CDOs and bonds) had become risky and illiquid led to general panic and upheaval in capital markets (Gorton (2009), Gorton (2010) and Kahle and Stulz (2013)). The emerging and profound uncertainty about the environment led to a flight to quality among riskaverse investors. Investors fled from risky investments, such as equities or lower quality debt, to safer investments, such as US Treasuries. Consequently, for the corporate sector, equity capital became increasingly costly and unattractive relative to other sources of capital.

Flight-to-quality episodes are typically characterized by the joint occurrence of higher economic uncertainty, lower equity prices and higher prices of safer investment (e.g., US Treasuries) (see, e.g., Beber, Brandt and Kavajecz (2009)). Such episodes in the US in the twenty-first century included events that followed the attacks of 9/11, the bankruptcy of Worldcom, the later phases of the dot-com bubble, the financial crisis and the events of the European sovereign debt crisis (Baele, Bekaert, Inghelbrecht and Wei (2013)).

Figures 1 to 3 provide evidence that is consistent with the description above. During these flight-to-quality episodes, uncertainty among investors (measured by the S&P 500 volatility index VIX) was high, equity prices dropped and yields of US Treasuries decreased in absolute terms and relative to riskier corporate bonds. The most interesting period is the financial crisis. This flight-to-quality episode likely began in October/November 2007, which is when equity markets prices began to fall and volatility increased dramatically. By the time of Lehman Brothers declared bankruptcy, the S&P 500 index had lost 20% of its value, and the VIX stayed well above the 20% level. In the same period, yields of safe US Treasuries decreased (-1.49%), and corporate bond spreads increased (Baa: +1.73%). These documented events intensified when Lehman declared bankruptcy in September 2008 and abruptly ended in March 2009.

Together, these patterns suggest that before the Lehman bankruptcy, investors’ flight to quality led to a disproportionate increase in the cost of risky capital, especially of equity capital. The panic in capital markets following the Lehman collapse led to a more general increase in the cost of firms’ external capital.

2.3. *The demand shock of the economy-wide crisis*

As the financial crisis spilled over into the real economy in 2009, demand-side effects are assumed to dominate supply-side effects in corporate financing policies. Specifically, the economic crisis led to a shift away from consumption toward saving and led firms to reassess the value of their investment opportunities, which in turn led to lower corporate investment and lower demand for external financing (e.g., Duchin et al. (2010) and Bliss et al. (2015)). As a result, costly external financing should have become less restricting for non-financial firms.

Overall, the documented dynamics in U.S. debt and equity markets give rise to doubts about whether a credit supply shock to the corporate sector took place before the Lehman Brothers bankruptcy in September 2008. Instead, they suggest that investors' flight to quality led to increasing costs of raising equity capital and rationing in investment of firms with more abundant and risky projects. The ensuing panic in financial markets, mainly due to Lehman's failure in September 2008, led to a serious shock to the availability of all forms of finance. The crisis and uncertainty in financial markets increasingly spilled over into the real economy, which led to lower consumption, corporate investment and demand for corporate financing. Table 1 summarizes the shocks to the financial markets and the real economy, and when they were most likely to affect the corporate sector. This table will be referenced when describing the development of the financial policies in my sample (Section 5.1).

3. Related literature

This paper contributes to several strands of the extant literature. First, it most closely relates to papers studying the effects of the recent financial crisis on corporate financing, liquidity management, and investment in financially constrained and unconstrained firms. Consistent with a first-order effect of a finance supply shock on corporate investment, Duchin et al. (2010) demonstrate that financially constrained firms had to decrease investment by a greater degree, and cash holdings played a more important role in sustaining investment in these firms. Similarly, Brown and Petersen (2014) show that cash holdings were primarily used by financially constrained firms to protect R&D instead of fixed investment (capital expenditures). Although these studies claim that the crisis period they analyze is particularly well suited to examining the impact of a credit supply shock, they do not explicitly compare the development of financing policies of constrained and unconstrained firms during the crisis. In addition, they use constraint measures (e.g., firm size, firm age, dividends, Withed-Wu index, KZ index) that are general in nature. Thus, their empirical approaches do not identify the critical capital supply channel causing capital rationing in non-financial firms.

Studies that focus on proper identification of the critical capital supply channel provide mixed evidence on whether credit rationing had a systematic effect on corporate outcomes during the crisis. In support of a first-order effect of the credit supply shock on corporate policies, international survey evidence presented by Campello et al. (2010) indicates that credit-constrained firms made deeper cuts in technology, employment and capital spending relative to unconstrained firms during the crisis (2007Q3-2008Q4).[35] Moreover, Almeida, Campello, Laranjeira and Weisbenner (2012) show that firms with a substantial fraction of long-term debt (more than 20%) maturing within the crisis period (i.e., 2008) reduced their investments compared with other firms. In these studies, the number of observations related to U.S. firms is limited, and the samples are skewed toward larger and "better quality" firms than the representative Compustat firm, which may explain why other studies find conflicting evidence.

[35] See Kahle and Stulz (2013) for a critical assessment of the survey approach to identifying a credit supply shock. They note that similar results could have emerged from a demand shock leading to a reduction in the net worth of a firm after which credit becomes too expensive from CFOs' perspectives.

For instance, Kahle and Stulz (2013) find no evidence for a bank lending or credit supply shock as a first-order determinant of firm financing and investment policies during the crisis. They show that bank-dependent firms do not adapt financing and investment policies that differ from those of matching firms. Finally, based on their newly developed and more detailed financial constraint indices, Hoberg and Maksimovic (2015) reveal that equity-constrained, but not debt-constrained, firms experienced a significant decline in capital expenditures and R&D spending during the crisis. This paper contributes to these studies by showing that the crisis' equity supply shock caused firms to use precautionary cash to sustain investment.

Second, it adds to the literature on corporate cash holdings that points to the importance and origins of the precautionary motive. In general, the motive is grounded in Keynes' (1936) initial contention that if a firm can always access external capital markets at no cost, then it has no reason to save cash internally. Recent studies (Bates et al. (2009), Lins, Servaes and Tufano (2010), Aebischer (2016)) demonstrate that over the last three decades, increasing concerns about accessing external capital markets have made the precautionary motive the primary consideration in firm decisions about how much cash to hold. McLean (2011) further demonstrates that due to the growing importance of the precautionary motive, firms increasingly save cash from share issuance during times of low issuance costs (during economic expansions) to avoid issuing shares when costs are high (during economic contractions). Additionally, Hoberg and Maksimovic (2015) and Aebischer (2016) find that corporate cash holdings are negatively related to debt constraints and positively related to equity constraints, indicating that firms hold more precautionary cash when they are concerned that equity financing will be insufficient in the future. Consistent with this evidence, this paper demonstrates that in the presence of a debt and equity capital supply shock, firms actually use their precautionary cash holdings to substitute for a decrease in the issuance of equity.[36] This patterns is consistent with evidence presented by Farre-Mensa (2015) that precautionary cash is held primarily by public firms to time their equity issues optimally.

Finally, this paper is closely related to one of my previous papers that develops a precaution index to explain cash holdings (Aebischer (2016)). In cross-sectional cash-holding regressions, the index is by far the predominant variable in explaining corporate cash holding variation. In this paper, I use the index to determine firms' precautionary cash at the onset of the financial crisis and find that it is a good predictor of firms' use of cash in the presence of the capital supply shock of the financial crisis – the type of situation for which precautionary cash positions are built.

4. Data and empirical strategy

4.1. *Sample description*

My sample consists of quarterly data collected from the CRSP/CompustatMerge (CCM) Fundamentals Quarterly database for 2005–2011. This particular sample horizon is utilized to obtain a balanced timeframe around the crisis period. The utilization of quarterly data is well suited to the analysis of the financial crisis because, as discussed in Section 2 and as will be shown later, capital market conditions and financial policies exhibit dramatic changes from one quarter to the next. As also shown in Section 2, the real sector was likely affected by a dominant capital supply shock starting in November 2007 and lasting to March 2009. The five quarters covering the period from January 2008 to March 2009 (2008Q1-2009Q1) are therefore defined as

[36] This paper also adds to recent theoretical contributions based on the precautionary notion, such as Acharya, Almeida and Campello (2007), Gamba and Triantis (2008), Han and Qiu (2007), Denis (2011), and Almeida, Campello, Cunha and Weisbach (2014). It also provides an example-based rationalization for why the marginal value of cash holdings is greater for financially constrained firms, as found by Faulkender and Wang (2006).

the *crisis* period.[37] They represent the early phase of the crisis, and according to the literature, they are well suited to analyzing the capital supply shock to the financing and investment policies of non-financial firms. In the later phase of the crisis, capital supply- and demand-side effects become difficult to disentangle. I define this as the *later crisis* period, extending from 2009Q to 2010Q2. To divide the main sample into equal pre-crisis and crisis periods, the *pre-crisis* period is defined as extending from 2006Q3 to 2007Q3. The pre-crisis and crisis periods do not cover quarters equally, but additional checks reveal that the baseline results are not driven by seasonality.

I eliminate financial firms and utilities (SIC codes 4900-4949 and 6000-6999, respectively) because of their statutory capital requirements and other regulatory restrictions. For the relatively few firms that changed their fiscal year during the sample period, I preserve the most recent fiscal year convention. I delete observations with negative total assets (atq) and cash holdings (cheq), cash holdings greater than total assets, and firms that are not incorporated in the U.S. Following Duchin et al. (2010), I also exclude firms that experienced quarterly asset or sales growth greater than 100% at any point during the sample period, as these firms might have experienced mergers or major restructurings that might skew the results.

I examine multiple financial policies, including cash savings, net equity issuance, net debt issuance, and investment. Cash savings is defined as the difference between cash at the end of the quarter and cash at the beginning of the quarter divided by assets at the beginning of the quarter (lagged assets). Net equity issuance is defined as aggregate equity issuance (sstky) minus aggregate equity repurchase (prstkcy) divided by lagged assets. Net debt issuance is calculated from balance sheet data and includes changes in current liabilities (dlcq) and long-term debt

[37] Because the crisis started in the middle of 2007Q4, I exclude this quarter from the analysis. The results are not sensitive to this choice.

during the quarter divided by lagged assets. Following Bliss et al. (2015), investment is defined as capital expenditures (capxy) plus R&D expenses (xrdq) divided by lagged assets.

The main explanatory variable is precautionary cash holdings, measured at the end of the last fiscal quarter ending before July 1, 2006. Following Aebischer (2016), I estimate the cash level for each firm, which is attributed to its precautionary motives. Precautionary motives are measured based on a precaution index that is the first principal component of six established precautionary proxies discussed in the literature: cash flows, cash flow volatility, R&D intensity, market-to-book ratio (growth opportunities), net working capital, and product market fluidity (product market competition). The index thus aims to capture the precautionary component of these variables.

To analyze whether costly debt or equity financing drove corporate cash and investment policies, I estimate the baseline regressions subsamples of firms facing different degrees of debt and equity constraints. To do so, I utilize the debt and equity constraint measures of Hoberg and Maksimovic (2015), which are based on text analysis of 10-K MD&A sections. Debt constraints are measured by their debt-focused constraint variable. Equity constraints are measured by their private-placement constraint variable because it approximates a firm's constraints in private and public equity markets.[38] As in the case of precautionary cash, equity and debt constraints are measured six quarters before the onset of the crisis. Empirically, the measures are distinctly and negatively correlated (-0.597), suggesting that firms with high debt constraints face low equity constraints, and vice versa.

Table 2 provides summary statistics for the main variables for the July 1, 2006 – March 30, 2009 sample period. On average, no cash was burned during the sample period because cash savings before the crisis equated to cash burning during the crisis. The average quarterly levels of

[38] For a detailed description of the constraint measures and methodology, see Hoberg and Maksimovic (2015).

the other financial policies are consistent with previous studies of the financial crisis (i.e., Duchin et al. (2010) and Kahle and Stulz (2013)): net equity issuance is 0.64%, net debt issuance is 0.53%, and investment is 2.6% of total assets. Precautionary and observed cash (relative to assets) have a mean value of 19.5%, which correspond to the mean cash-to-asset ratios in other studies (e.g., Bates et al. (2009)). The other control variables are also comparable with those in other studies.

4.2. *Empirical Strategy*

To determine whether the debt or equity supply shock caused firms to use precautionary cash to mitigate underinvestment during the financial crisis, the following diff.-in-diff. regression models are estimated:

$$\begin{aligned}\text{Financial policy}_{it} = \beta_1 + \beta_2 \times \text{after}_{it} + \beta_3 \times \text{after}_{it} \times \text{Precautionary cash}_{i} + \beta_4 \times \text{Tobin's Q}_{it} + \\ \beta_5 \times \text{Cash flow}_{it} + \beta_6 \times \text{Leverage}_{it} + \text{Firm FE} + \mu_{it},\end{aligned}$$

where "Financial policy_{it}" depicts the set of financial policy variables (cash savings, net equity issuance, net debt issuance, and investment) for firm *i* at quarter *t*. I regress the firm-level quarterly variables over July 1, 2006–March 30, 2009 on an indicator variable for whether the quarter in question is after the onset of the crisis ("after") and on the interaction between this indicator variable and firm precautionary cash measured once six quarters before the start of the crisis, controlling for market-to-book, cash flows, leverage, and firm fixed effects. The firm fixed effect captures the precautionary cash and time-invariant characteristics of individual firms (see also Duchin et al. (2010)). The approach tests whether firms with different pre-crisis precautionary cash adapted their financial policies differently in the presence of the exogenous capital supply shock. If equity rather than debt was the main restricting financing channel for non-financial firms, the diff.-in-diff. estimator is negative for the cash and equity regression, zero for the debt regression, positive for the investment regression, and highest for the investment of firms with high equity constraints.

The key identifying assumption behind the diff.-in-diff. strategy is that precautionary cash holdings are not correlated with unobserved within-firm changes in financing conditions or investment opportunities (e.g., demand shocks). This implies that in the absence of the treatment (i.e., the capital supply shock), the diff.-in-diff. estimators should be 0, an assumption that is often referred to as the parallel trend assumption (Lemmon and Roberts (2010)). Technically, the assumption requires similar trends in the financial variables during non-crisis periods for firms with different precautionary cash holdings. Economically, this means that firms with different precautionary cash should not experience different changes in financial policies in the absence of the capital supply shock. I will formally test this assumption by estimating the regression models during nonexistent (placebo) crises before the financial crisis and during the late financial crisis, when an economy-wide demand shock is likely to be at work.

5. Results

5.1. *Nonparametric results*

I begin the empirical analysis by showing the development of the main financing policies during the defined sample horizon for terciles based on their precautionary cash (motives) at the end of the last fiscal quarter ending before July 1, 2006.[39] Figure 1 shows that firms saved cash during normal times, whereas they used cash during the crisis period from 2008Q1 to 2009Q1. Moreover, consistent with the precautionary notion, firms with higher pre-crisis precautionary

[39] Because precautionary cash is a linear prediction based on precautionary motives (index) both measures lead to the same grouping of firms and conclusions. In splitting the sample into terciles, I follow Duchin et al. (2010) and Hoberg and Maksimovic (2015).

cash used more cash during the crisis. For instance, firms with high precautionary cash reduced their cash holdings (as a percentage of assets) by 6.5 percentage points, measured cumulatively over the five crisis quarters (see Figure 2). This corresponds to a reduction in cash holdings of 20% relative to their pre-crisis cash holdings (as a percentage of assets) of 32%. In contrast, firms with low precautionary cash did not use cash at all. Beginning in 2009Q2, firms started to hoard cash again, possibly to prepare for further shocks.

I perform a more formal test to examine whether the use of cash during the crisis and the subsequent hoarding of cash can be explained by precautionary motives: The precautionary cash-holding model is estimated cross-sectionally at different points in time. If cash is first used and then hoarded for precautionary reasons, the model's explanatory power and the coefficient estimate associated to the precaution index should be low during the crisis period and higher before and after the crisis. The results in Table 3 are consistent with this prediction; the R2 substantially decreases from 0.41 before the crisis (2006Q1) to 0.23, after which cash was used on an aggregated basis (2009Q1) and steadily rebounded to 0.34 after the crisis (2011Q1). The same applies to the coefficient estimates of the precaution index. These results indicate that because firms use precautionary cash during the financial crisis, observed cash holdings can be less explained by precautionary motives.

To provide preliminary evidence of whether the equity or debt supply shock caused firms to use precautionary cash, the development of net equity and debt issuance are plotted. The issuance of equity declined in the wake of plummeting and volatile stock markets during the same five crisis quarters (see Figure 6). The lowest issuance levels can be observed two quarters after the Lehman bankruptcy (2008Q4-2009Q1) when uncertainty in capital markets peaked (see Figure 3). The group of firms with high precautionary cash (motives) was most affected because it showed the highest issuance levels before the crisis. After the crisis, the issuance levels rebounded quickly. This development is consistent with the evidence presented by Dittmar and Dittmar (2008) and McLean (2011), according to whom phases of low uncertainty (economic expansions) are associated with low cost of equity relative to the cost of debt, which drives equity issues, especially by firms with high precautionary motives.

Net debt issues seem to have followed a different logic. Although some forms of credit (i.e., syndicated loans) had already experienced initial declines in late 2007 and early 2008 (Ivashina and Scharfstein (2010)), corporate net debt issuance started to fall post-Lehman and continued to decrease in 2009 when corporate bond yields peaked (see Figure 7).[40] Additionally, in contrast with cash savings and net equity issuance, the development of net debt issuance during the sample period was identical for the different precautionary terciles.

The fact that the use of cash and the decline in net debt issuance started at different times and that the latter decline was identical across the precautionary tertiles, raises doubts about whether a credit supply shock was a first-order determinant of firms' use of precautionary cash. Finally, I note that financial policies exhibited different levels across the precautionary terticles before (and after) the crisis, but they did not follow different trends during these periods, which is consistent with the parallel trend assumption (see Section 5.4 for more formal tests).

Next, Table 4 shows the pre-crisis and crisis levels of the main financing and investment policies and tests whether crisis-induced changes are significantly different from zero. Panels A-C, showing the three financing policies, confirm the evidence presented in Figures 4-7. The declines in cash savings and net equity issuance were driven by firms with higher precautionary cash, whereas the decline in net debt issuance was not.

Instead of an external equity supply shock causing firms to use precautionary cash, the following alternative scenario could have led to the same results: firms with high precautionary

[40] These trends fit the descriptions in Section 2.1, which are summarized in Table 1.

cash may be more affected by a negative demand shock (e.g., demand in their product markets). The ensuing lower investment opportunities lead to lower demand for external capital, and cash was used to substitute for a greater decline in operating cash flows. However, the results in Panels D-E are discordant with such a scenario because the group of high precautionary firms was the only one that did not experience a significant decline in operating cash flows and investment during the crisis. Instead, the results are consistent with firms using cash as a substitute source of equity to finance investment.

In the following analyses, I investigate these relations in more detail using multivariate regressions.

5.2. *Precautionary cash and crisis financing policies*

In Table 5, I use the baseline specification described in Section 3.2 to analyze the association between precautionary cash holdings and within-firm changes in financing policies around the financial crisis, controlling for simultaneous demand-side effects (i.e., cash flows and investment opportunities) and changes in leverage. Consistent with the precautionary motive of holding cash, columns 1 and 2 show that firms with more precautionary cash at the onset of the crisis used more cash during the financial crisis. The coefficient estimate of the "after" dummy variable in column 1 indicates a decline in average quarterly cash savings of 1.09 percentage points (as a share of assets) during the crisis.

When the main variable of interest (i.e., the "after × precautionary cash" interaction term) is included, the coefficient estimate for "after" should be interpreted as the change in cash savings following the crisis in a firm with zero precautionary cash. Thus, a firm with zero precautionary cash before the crisis actually increased its quarterly cash savings by 0.79 percentage points during the crisis (column 2). More importantly, the coefficient estimate of the interaction term implies that a one-IQR increase in precautionary cash induced a decrease in quarterly cash savings of 1.14 (0.115×-9.647) percentage points. Overall, the results show that firms made use of precautionary cash during the financial crisis.

The question of whether precautionary cash was used to substitute for an involuntary decrease in equity or debt issuance is considered next. The results in columns 3 and 4 provide evidence that firms used precautionary cash to substitute for the decrease in equity issuance during the crisis. Firms, on average, showed a significant decrease in net equity issuance during the crisis (column 3). Similar to the cash saving results, firms with zero precautionary cash actually increased net equity issuance, and increasing precautionary cash led to decreasing net equity issuance during the crisis (column 4). For instance, a one-IQR increase in precautionary cash is associated with a quarterly decrease in net equity issuance of 0.49 percentage points. In contrast to net equity issuance, firms decreased their net debt issuance by 0.76 percentage points, regardless of pre-crisis precautionary cash (see column 5 and 6).

The documented decrease in net debt issuance mainly occurred in 2008Q4 and 2009Q1 because of post-Lehman turbulence in credit markets (see Figure 7 and the discussion in Section 2). Hence, firms might have used precautionary cash to offset the decline in net debt issuance during these two quarters. If changes in policies, relative to before the crisis, are analyzed only for these two crisis quarters, the results are identical to the baseline results for all five crisis quarters.[41] These sub-period results affirm that the use of precautionary cash is associated to the decline in equity funding but not debt funding.

Overall, the results provide evidence that the use of precautionary cash is associated with a decline in equity funding but not debt funding during the financial crisis. This finding is consistent with the evidence presented by McLean (2011) of a dominant association between

[41] Precautionary cash tends to be even more important in explaining changes in cash savings and net equity issuance during these two quarters given that coefficient estimates for the interactions are -11.86 and -4.70, respectively.

cash savings and share issuance, which is significantly stronger for firms with high precautionary motives.

To provide additional evidence on whether insufficient debt or equity financing caused firms to use precautionary cash, model (1) and (2) in Table 5 are estimated separately for firms with different degrees of *ex ante* debt and equity constraints. Table 6 presents cash saving regressions for terciles of firms with different degrees of debt and equity constraints at the onset of the crisis. Columns 1 to 6 show that firms with low debt and high equity constraints experienced the greatest decreases in cash savings. The differences in the point estimates between firms with low and high financial constraints are statistically significant in two-tailed tests.[42] When precautionary cash is added to the regression model, the term absorbs the previously documented differences in cash saving changes between the different constraint groups after the crisis ("after") (see columns 7 to 12). Instead of the "after" coefficient, most other coefficients of the interaction terms become statistically significant. One notable exception is the interaction term in column 10, indicating that firms with low equity constraints did not make significant use of precautionary cash. In contrast, highly equity-constrained firms significantly relied on precautionary cash. To illustrate the magnitudes, the coefficient estimate in column 12 implies that a one-IQR increase in precautionary cash holdings relative to assets (14.6%) led to a decrease in quarterly (cumulative) cash savings of 1.54% (7.7% = 1.54%×5) relative to assets in firms with high equity constraints during the crisis. The coefficient estimates of the interaction terms are also significantly different between firms with low and high constraints. Similar results are obtained when cash levels (relative to assets) is used as the dependent variable instead of cash savings following the specification in Bliss et al. (2015).

[42] For this and further subsample tests, I compute the significance of the difference by interacting every independent variable with the constraint group variable in the full (pooled) regression sample.

A possible explanation for the high use of precautionary cash in the low debt-constrained subsample is that approximately 90% of these firms have medium and high equity constraints. Accordingly, the highly significant results in the less debt-constrained sample may be driven by firms with medium and high equity constraints. The negative coefficient is lower in magnitude but remains significant if firms with medium and high equity constraints are excluded. Thus, firms with lower constraints to external capital also made use of precautionary cash during the financial crisis, which is somehow inconsistent with the notion of precautionary cash holding.[43] Whether they used it for investment purposes will be tested, among other things, in the subsequent section in which corporate investment is analyzed.

Taken together, the results in Tables 5 and 6 indicate that insufficient equity financing but not insufficient debt financing caused firms to *use* precautionary cash. These findings are consistent with the discussion in Section 2 that a shock to the supply of equity but not debt most likely affected the corporate sector before the Lehman bankruptcy. Furthermore, these results are consistent with evidence from Hoberg and Maksimovic (2015) and Aebischer (2016), who find that firms stating concerns about possible underinvestment due to insufficient equity financing in the future *hold* more precautionary cash today.

5.3. *Precautionary cash and crisis investment*

In the previous section, it was demonstrated that precautionary cash is primarily used to substitute for declines in net equity issuance during the crisis. In other words, when equity constraints became binding in the wake of financial market turbulence, cash was utilized as a substituting financing source. Thus far, I have not examined whether firms actually used

[43] It should be noted that this remaining firm group is rather small, with 49 firms and 477 quarterly observations.

precautionary cash to mitigate possible underinvestment due to insufficient equity financing during the crisis. The subsequent analysis addresses this issue.

Other studies provide some evidence on this issue. Hoberg and Maksimovic (2015) show that primarily equity-constrained firms were forced to curtail investment in capital expenditures and R&D during the crisis, and Duchin et al. (2010) demonstrate that (financially constrained) firms used their cash reserves to mitigate declines in investment. Extending these studies, I test whether precautionary cash is used to mitigate underinvestment by equity-constrained firms.

Table 7 shows the results from investment regressions following Duchin et al. (2010). The regressions are estimated for the full sample and for subsamples of firms with varying degrees of ex ante debt and equity constraints. Columns 1 and 2 present the results based on the full sample. Quarterly investment by the average firm decreased by 0.112 percentage points during the crisis, a decrease of 4.3% relative to an unconditional pre-crisis mean of 2.589% as a share of assets (see column 1). The estimates in column 2 imply that firms with no precautionary cash were forced to reduce investment during the crisis and that precautionary cash was used to counteract the reduction in investment. In economic terms, investment declined by 0.237% of assets for a firm with zero precautionary cash, and 15.5% (0.237/1.531) precautionary cash (as a share of assets) is needed to eliminate this decline.

In columns 3-8, the investment model is estimated separately for firms with different degrees of debt and equity constraints. The results show that the previously presented full sample results are driven by firms facing equity constraints. For instance, the "after" coefficient in column 8 indicates that firms with high equity constraints and zero precautionary cash experienced a decline in investment by 0.361 percentage points, a decrease of 9.2% relative to the high pre-crisis quarterly mean investment of 4.005% of that tercile. Additionally, the coefficient associated with the interaction term implies that a one-IQR increase in precautionary cash (21.9%

of assets) mitigates the investment decline by 0.525 percentage points, which corresponds to 143% of the investment decline of a firm with no precautionary cash.

The coefficient estimates for the “after” indicator and the interaction term differ significantly across firms with low and high equity constraints. The results indicate that firms facing high equity constraints had to undertake relatively greater cuts in investment during the crisis and that precautionary cash was relatively more important for mitigating these cuts.

Finally, the results for the low debt constraint group are driven by firms with medium and high equity constraints. If these firms are excluded from the subsample, the coefficient estimates become insignificant. Together with the results presented in Table 6, this suggests that these low constrained firms systematically used precautionary cash during the crisis but for other purposes than investment. Further financial policies (e.g., dividends) should be investigated to shed light on this issue, which is beyond the scope of this study.

Together with the financing results in Section 4.2, the results in Table 7 provide evidence that equity rationing during the crisis caused firms to underinvest and to use precautionary cash to mitigate underinvestment.

5.4. *Robustness tests*

In this section, I perform two tests to ensure that the baseline results are not driven by confounding effects. Specifically, I seek to show that precautionary cash is not related to financial policies during placebo (non-existent) crises or during the dominant demand shocks of the later crisis in 2009 and 2010.

First, tests during placebo crises are used to examine whether the financial policies of firms with different levels of precautionary cash followed different trends before the financial crisis. If policies followed different trends, this could be an indication that precautionary cash was correlated with unobserved within-firm changes in investment or financing opportunities. I test for placebo crises starting on January 1 of 2005 and 2006 because these periods are unlikely to be influenced by other economic crises, periods of flight to quality or recuperation (e.g., rebound from the dot-com crisis).

Table 8 presents the results of the placebo crises analysis. For both crises, no significant coefficients for the interaction term are observed. This confirms the insights from Figures 4-7 that the main outcome variables do not follow different trends before the onset of the financial crisis among firms with varying pre-crisis precautionary cash. Insignificant results are also found for net debt issuance during these nonexistent crises (not shown). These results confirm that the parallel trends assumption is satisfied in my setting.

Second, analyzing the later crisis from 2009Q2 to 2010Q2 reveals further interesting insights on the use of precautionary cash holdings. As mentioned in Section 2.1, the uncertainty in the financial markets extended to the real economy, which led to decreasing consumer demand and caused firms to reconsider the values of their investment opportunities. This, in turn, led to a decrease in firms' demand for external financing, and supply-side frictions became less binding. In such a state, firms are expected to use less (no) precautionary cash to mitigate declines in investment.

Table 9 displays the results of the analysis of the later crisis period, which differ significantly from those of the crisis analysis. During the later crisis, quarterly net equity issuance and cash savings rebounded to levels that exceeded their pre-crisis levels (see columns 1 and 2).[44] The insignificant interaction terms in these two specifications indicate that firms with more precautionary cash did not experience different changes from before the crisis to the later crisis. Nevertheless, because these firms experienced significantly greater decreases in these policies

[44] Similar trends are also documented by Kahle and Stulz (2013). The simultaneous increase in net equity issuance and cash savings suggests that firms again start hoarding cash from equity proceeds.

during the crisis, their rebound after the crisis was consequently significantly larger (Figures 4 to 6 also illustrate this idea). Firms experienced further declines in investment and net debt issuance, which were however the same for firms with different precautionary cash holdings (see columns 3 and 4). This indicates that precautionary cash was used neither to substitute for declines in net debt issuance nor to sustain investment. These results are consistent with a dominant demand shock during which firms generally reduce their investment and demand for external capital.

Overall, the results in Tables 8 and 9 show that in the absence of a capital supply shock (treatment), precautionary cash was not used. These results confirm the key identifying assumption behind my diff.-in-diff. strategy that, in the absence of treatment, the observed diff.-in-diff. estimator is 0.

5.5. *Non-precautionary cash and crisis financial policies*

All of the previous analyses used the precautionary component of cash based on the precaution index of Aebischer (2016) to explain differences in financial policy reactions to the financial crisis. In this section, I validate this instrument by testing whether the non-precautionary component of a firm's cash reserves is able to explain the financial policy adoptions. In doing so, non-precautionary cash is defined as the difference between observed cash and precautionary cash, again measured six quarters before the onset of the financial crisis. As previously mentioned, this component of cash should be held for non-precautionary reasons, such as to support day-to-day operations, or held in excess of an optimal cash level.

The results of this analysis are displayed in Table 10. Non-precautionary cash has a significant effect on the crisis-induced reduction in cash savings (see column 1). However, the coefficient estimates of the interaction terms imply that changes in cash savings during the crisis are roughly four times more sensitive to precautionary cash than to non-precautionary cash.

Column 2 shows that only precautionary cash can explain significant changes in net equity issuance, which is consistent with the precautionary notion. In the investment regression, non-precautionary cash is significant, and the coefficient estimate ascribes a similar role to this cash component in sustaining investment during the crisis as that ascribed to precautionary cash (see column 3). An important difference between the two components, however, emerges when investment regressions are estimated separately for firms with different degrees of equity constraints (see columns 4 to 6). While the importance of precautionary cash to sustain investment is significantly increasing in equity constraints, this is not the case for non-precautionary cash.

Overall, the results in Table 10 suggest that precautionary cash, as defined by Aebischer (2016), is a good instrument to explain firm cash savings, net equity issuance, and investment during the capital supply shock of the financial crisis. The residual, non-precautionary cash component also explains some, but generally less, variation in these policies. The results reveal that firms also used non-precautionary cash to fund some investment; however, this was observed mostly independent of financial constraints.

6. Conclusion

The present study uses the capital supply shock of the recent financial crisis to examine the use of precautionary cash holdings among U.S. industrial firms. If precautionary cash is really held to protect the firm and its investment against adverse economic changes, precautionary cash is expected to be used in reaction to the capital supply shock of the financial crisis. The specificity and exogenous nature of the crisis' capital supply shock enables me to employ a difference-in-differences research design aimed at identifying whether insufficient debt or equity financing predominantly caused firms to use precautionary cash to mitigate underinvestment.

I utilize a novel instrument, precautionary cash defined as in Aebischer (2016), and find that firms with high precautionary cash at the onset of the crisis used more cash and experienced a greater decline in net equity issuance but no greater decline in net debt issuance during the crisis. Furthermore, I find that equity constraints rather than debt constraints caused firms to use precautionary cash. This evidence is consistent with the hypothesis that equity rationing was the predominant driver of firms' use of precautionary cash during the financial crisis. In addition, in line with this hypothesis, I demonstrate that equity-constrained firms showed the greatest decline in investment and made relatively more use of precautionary cash to sustain investment.

In a series of additional tests, concerns that the baseline results may be due to confounding effects are alleviated. Namely, the financial policies of firms with different precautionary cash holdings followed parallel trends during placebo (nonexistent) crises and during the later economy-wide crisis in 2009-2010 when capital demand effects were likely to dominate capital supply effects. I also demonstrate that the precautionary component of cash does a significantly better job at explaining changes in financing and investment policies during the financial crisis than the non-precautionary component of cash does.

These findings raise several questions for future research. First, although the financial crisis is an event during which simultaneous credit and equity rationing were likely to be relevant for non-financial firms (especially from 2008Q4 to 2009Q1), evidence is found that only equity rationing caused U.S. industrial firms to use precautionary cash to mitigate underinvestment. This raises the question of whether credit rationing played an economically subordinate role among these corporate policies only during this specific event or whether this is true in general. Studying other capital supply shocks and flight-to-quality periods would shed light on this question. Second, the current results demonstrate that equity-constrained firms used precautionary cash as a tool to hedge the risk of an unexpected capital supply shock. It would be interesting to investigate whether firms use additional tools, such as credit lines or derivatives, to hedge such risk. The first evidence on this issue is provided by Lins et al. (2010) and Campello et al. (2011). Third, there is evidence that precautionary cash is an important funding source for investment in the presence of a capital supply shock. However, precautionary cash is not only held to sustain investment but also to protect the firm from default (Keynes (1936)). Thus, it would be interesting to investigate whether precautionary cash systematically helped firms survive the financial crisis.

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Appendix: Tables and Figures

Variable definitions

Variable	Definition (Compustat item name)
	Panel A: Financial policy variables
Cash savings	(Cash and short-term investments (cheq) at t – cash and short-term investments (cheq) at t-1) / total assets (atq) at t-1.
Net debt issuance	(Long-term debt (dlttq) at t + short-term debt (dlcq) at t – long-term debt (dlttq) at t-1 – short-term debt (dlcq) at t-1)/total assets (atq).
Net equity issuance	Sale of common and preferred stock (sstky)/total assets (atq). Because sale of common and preferred stock (sstky) is reported on a year-to-date basis in quarterly financial statements, we subtract the previous quarter's sstky from the current quarter's sstky for fiscal quarters 2, 3, and 4.
Investment	(CAPEX(capxy) + R&D(xrdq))/total assets (atq). Because CAPEX is reported on a year-to-date basis in quarterly financial statements, we subtract the previous quarter's CAPEX from the current quarter's CAPEX.
	Panel B: Precautionary and constraint variables
Observed cash	Cash and short-term investment (cheq)/total assets (atq).
Precaution index	First principal component from principal component analysis (PCA) of operating cash flow, industry sigma, R&D intensity, market-to-book ratio, net working capital (without cash), and product market fluidity (see Aebischer (2016) and Hoberg, Phillips and Prabhala (2014)).
Precautionary cash	Predicted cash values derived from the following cross-sectional regression from Bates, Kahle and Stulz (2009): $Cash_{it} = \beta_0 + \beta_1 \times Precaution\ index_{it} + \eta_t + \varepsilon_{it}$, where $Cash_{it}$ denotes cash of firm i at quarter t, and η_t are quarter fixed effects.
Debt constraint	Text-based constraint measure indicating potential underinvestment due to debt financing constraints, following Hoberg and Maksimovic (2015).
Equity constraint	Text-based constraint measure indicating potential underinvestment due to equity financing constraints, following Hoberg and Maksimovic (2015).
	Panel C: Firm characteristics and crisis indicators
Operating CF	Operating income before depreciation (oibdq)/total assets (atq).
Tobin's Q	Market value of assets (total assets (atq) + market value of common equity (cshoq×prccq) – common equity (ceqq))/(0.9×book value of assets(atq) + 0.1×market value of assets). The definition follows Kaplan and Zingales (1997).
Book leverage	(Short-term debt (dlcq) + long-term debt (dlttq))/total assets (atq).
Assets	Book value of total assets.
After	Indicator variable equals one if the observation's calendar time is between January 1, 2008 and March 31, 2009 and zero otherwise.
Late after	Indicator variable equals one if the observation's calendar time is between July 1, 2008 and June 30, 2009 and zero otherwise.

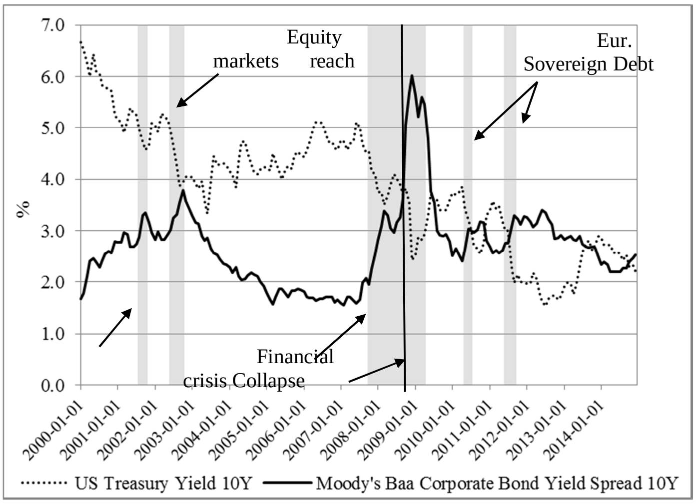

Figure 1: US Treasury Yields and Baa Corporate Bond Yield Spreads

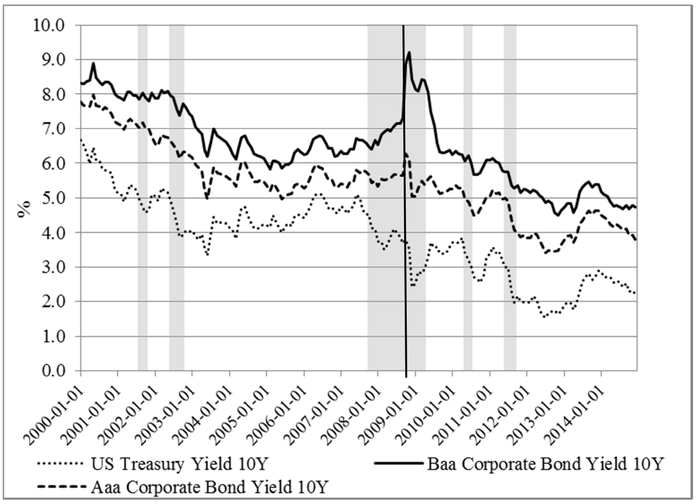

Figure 2: US Treasury and Corporate Bond Yields (10 years)

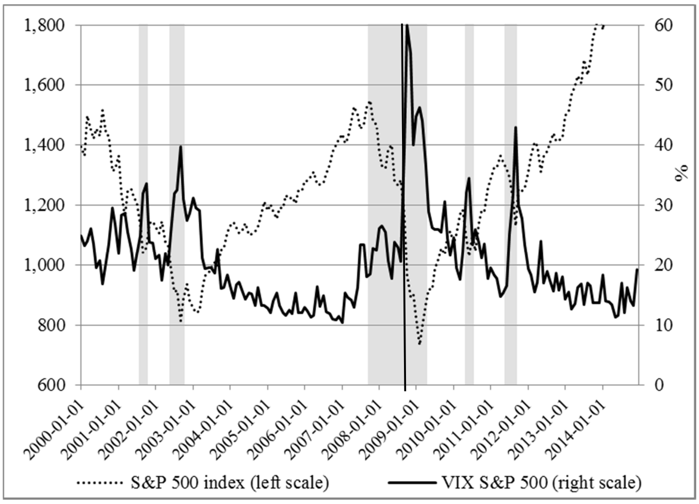

Figure 3: S&P 500 index and S&P volatility index

Comments on Figures 1-3: The data series are based on monthly averages, and the period from January 2000 to December 2014 is covered. Treasuries and corporate bonds have a time to maturity of 10 years. The Baa bond spread is calculated as the yield of Moody's Baa bonds with respect to the 10-year Treasury rate. Gray areas depict flight-to-quality episodes consistent with Baele et al. (2013). The data are obtained from the Federal Reserve (https://research.stlouisfed.org/) and the Compustat/CRSP database.

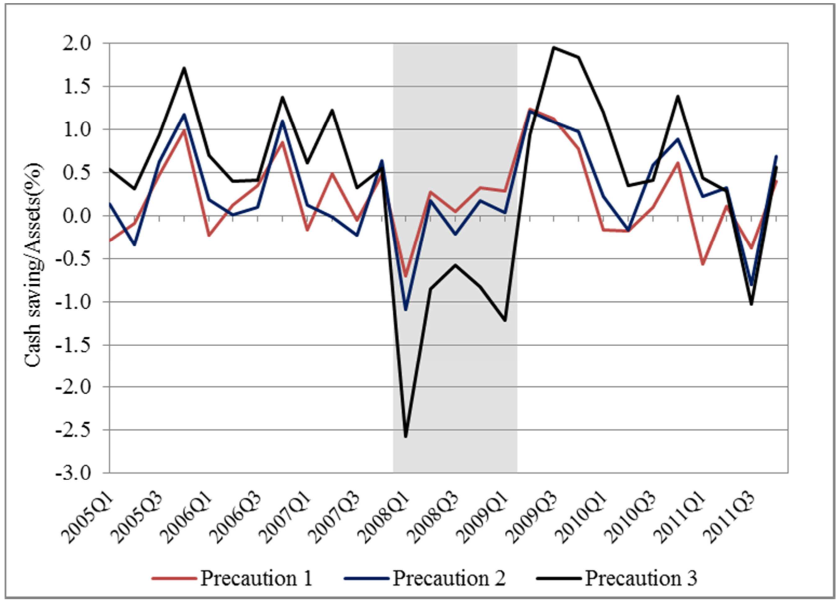

Figure 4: Quarterly cash saving for precaution subgroups

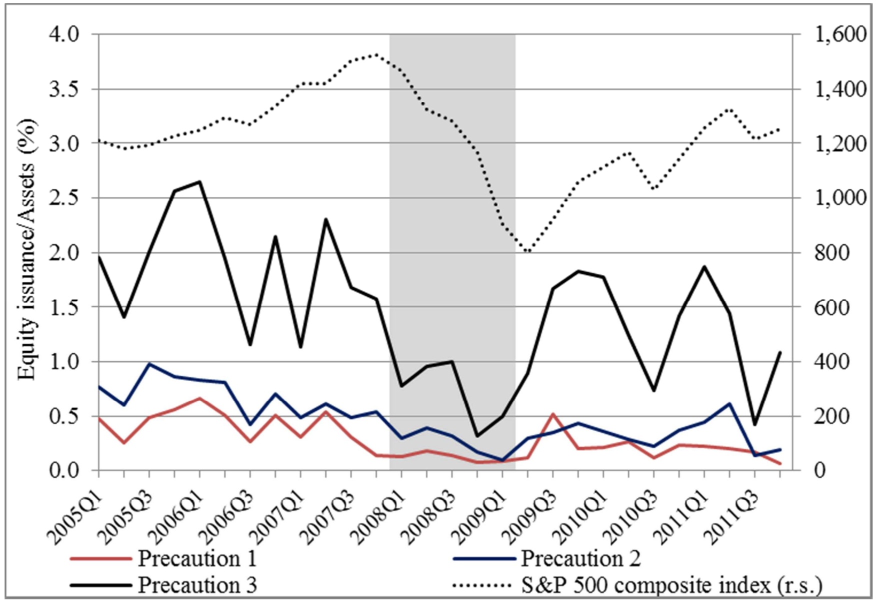

Figure 6: Quarterly issuance of equity for precaution subgroups

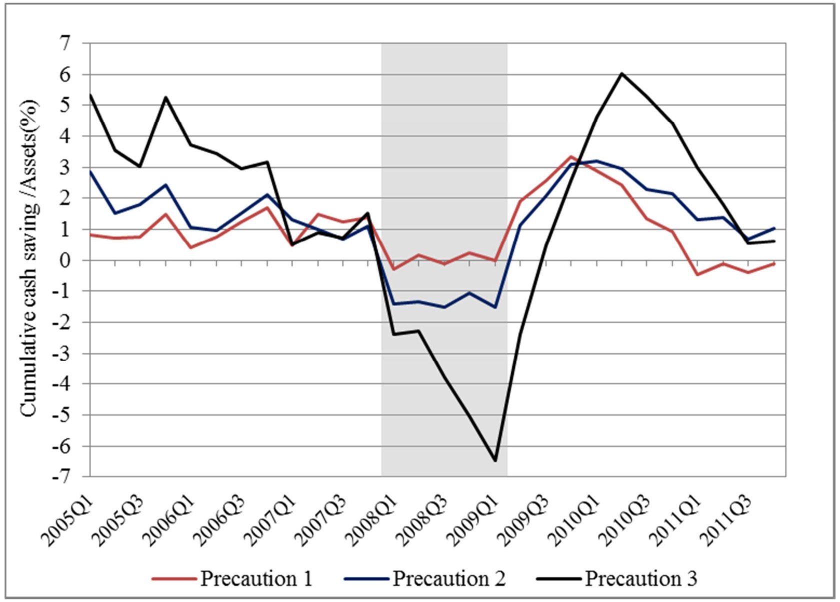

Figure 5: Cumulative cash saving (five quarters) for precaution subgroups

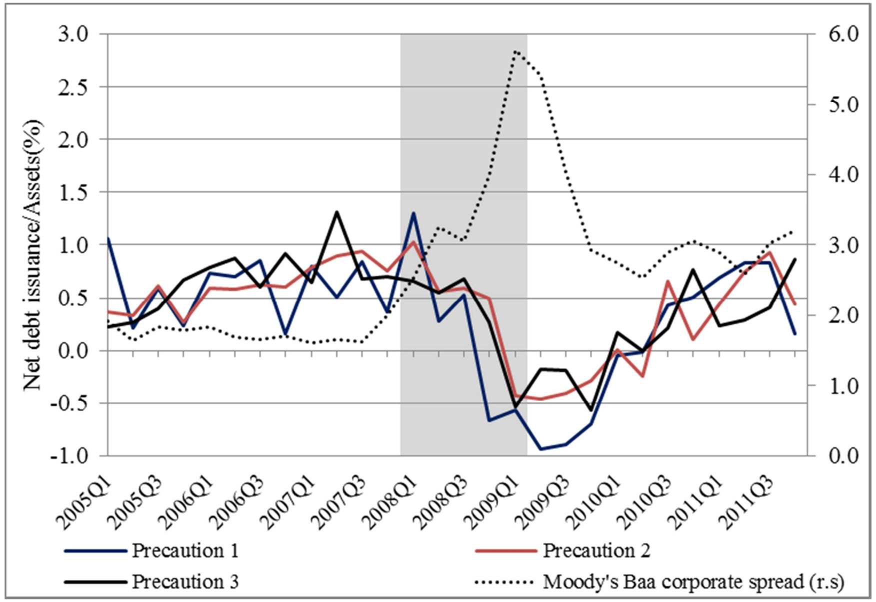

Figure 7: Quarterly net debt issuance for precaution subgroups

Table 1: Timeline of the financial crisis: Shocks to financial and real markets

This table outlines when shocks in the financial and real markets were most likely to affect the U.S. corporate sector during the financial crisis, following the discussion in Section 2. "Crisis I" and "Crisis II" refer to the crisis periods defined in this study; the distinction between these sub-periods is relevant for the investigation associated with financing policies in Table 5.

Shock to corporate	Before 2006Q3-2007Q3	Crisis I 2008Q1-2008Q3	Crisis II 2008Q4-2009Q1	Later crisis 2009Q2-2010Q2
equity market	no	likely	likely	no
debt market	no	less likely	likely	likely
product market (demand)	no	less likely	less likely	likely

Table 2: Summary statistics

This table reports summary statistics for the main sample of firm-quarter observations from July 1, 2006 to March 30, 2009. Precautionary cash holdings are predicted values from the following cross-sectional cash holding regression following Bates, Kahle and Stulz (2009):

$Cash_{it} = \beta_0 + \beta_1 \times \text{Precaution index}_{it} + \eta_t + \varepsilon_{it}$,

where $Cash_{it}$ denotes the observed cash of firm i at quarter t, and η_t are quarter fixed effects. Cash is defined as cash and short-term investments as a percentage of assets. The precaution index is the first principal component of the following firm characteristics: operating CF, industry CF volatility, R&D intensity, market-to-book ratio, net working capital (without cash), and product market fluidity (see Aebischer (2016) for a more detailed description of the index construction). Precautionary and observed cash holdings are measured at the end of the latest fiscal quarter ending before July 1, 2006. All other variables are defined in the Appendix. "(%)" indicates that a variable is expressed as a percentage of assets.

	Mean	St. dev.	Observations
Cash savings (%)	-0.052	5.946	22,284
Net equity issuance (%)	0.635	3.506	20,335
Net debt issuance (%)	0.528	4.788	21,443
Investment (%)	2.598	2.703	22,292
Precautionary cash	0.195	0.113	1,934
Observed cash	0.195	0.214	2,322
Operating CF (%)	2.705	4.272	22,292
Tobin's Q	1.688	0.798	22,292
Book leverage (%)	20.513	20.402	22,292
Assets ($ millions)	3,889	9,249	22,292

Table 3: The precautionary cash-holding model over time

The table presents the explanatory power of the precautionary cash-holding model over time. The precautionary cash-holding model, following Bates, Kahle and Stulz (2009), is estimated separately for the first quarter of each fiscal year and takes the following form:

$Cash_i = \beta_0 + \beta_1 \times \text{Precaution index}_i + \varepsilon_i$.

$Cash_i$ is defined as cash and short-term investments as a percentage of the assets of firm i. The precaution index is the first principal component of the following firm characteristics: operating CF, industry CF volatility, R&D intensity, market-to-book ratio, net working capital (without cash), and product market fluidity (see Aebischer (2016) for a more detailed description of the index construction).

Quarter	Coeff.	St. Error	R2
2004Q1	11.141***	(0.352)	0.405
2005Q1	10.499***	(0.310)	0.375
2006Q1	10.869***	(0.302)	0.410
2007Q1	10.472***	(0.321)	0.365
2008Q1	10.509***	(0.322)	0.360
2009Q1	6.247***	(0.373)	0.229
2010Q1	8.290***	(0.360)	0.266
2011Q1	9.043***	(0.316)	0.343
2012Q1	8.948***	(0.316)	0.350

Table 4: Precautionary cash and financial policies during the financial crisis

This table presents quarterly financial policies as a percentage of assets before and after the onset of the financial crisis for subgroups of firms based on their precautionary cash holdings at the latest fiscal quarter ending before July 1, 2006. Before covers fiscal quarters with an end date between July 1, 2006 and September 30, 2007 (2006Q3-2007Q3). After covers fiscal quarters with an end date between January 1, 2008 and March 30, 2009 (2008Q1-2009Q1). Change is the mean change of the financial variables from before to after the onset of the financial crisis. The financial policy variables are defined in the Appendix. ***, **, and * indicate statistical significance in two-sided difference-in-means tests with confidence levels of 0.99, 0.95, and 0.90, respectively.

Precautionary cash group	Before	After	Change (sign.)	Change/Before
Panel A: Cash savings				
Low	0.310	0.046	-0.264*	-85.0%
Medium	0.240	-0.179	-0.420***	-174.6%
High	0.576	-1.149	-1.725***	-299.3%
Panel B: Net equity issuance				
Low	0.398	0.122	-0.276***	-69.4%
Medium	0.580	0.251	-0.329***	-56.7%
High	1.620	0.721	-0.899***	-55.5%
Panel C: Net debt issuance				
Low	0.626	0.183	-0.443***	-70.8%
Medium	0.744	0.479	-0.265*	-35.7%
High	0.824	0.340	-0.483***	-58.7%
Panel D: Operating CF				
Low	4.008	3.095	-0.913***	-22.8%
Medium	4.076	3.351	-0.724***	-17.8%
High	1.368	1.105	-0.263	-19.2%
Panel E: Investment				
Low	1.960	1.842	-0.119*	-6.1%
Medium	2.352	2.140	-0.212***	-9.0%
High	4.005	4.054	0.049	1.2%

Table 5: Precautionary cash and financing policies during the financial crisis

This table presents estimates from panel regressions explaining firm-level quarterly financing policies for quarters with an end date between July 1, 2006 and March 30, 2009. The dependent variable in regressions (1) and (2) is quarterly cash savings as a percentage of assets. The dependent variable in regressions (3) and (4) is quarterly net equity issuance as a percentage of assets. The dependent variable in regressions (5) and (6) is quarterly net debt issuance as a percentage of assets. After is an indicator variable equal to one for fiscal quarters with an end date between January 1, 2008 and March 30, 2009 and zero for fiscal quarters with an end date between July 1, 2006 and September 30, 2007. Precautionary cash is measured at the end of the last fiscal quarter ending before July 1, 2006. All other variables are defined in previous tables and in the Appendix. All regressions include firm fixed effects. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively.

Dependent variable	Cash savings		Net equity issuance		Net debt issuance	
	(1)	(2)	(3)	(4)	(5)	(6)
After	-1.089***	0.797***	-0.141**	0.627***	-0.875***	-0.700***
	(0.118)	(0.222)	(0.061)	(0.131)	(0.095)	(0.170)
After × Precautionary cash		-9.935***		-4.128***		-0.924
		(1.303)		(0.805)		(0.799)
Operating CF	0.267***	0.297***	-0.050***	-0.039**	0.063***	0.066***
	(0.033)	(0.033)	(0.016)	(0.016)	(0.024)	(0.024)
Tobin's Q	-0.796***	-1.009***	0.227**	0.139	-0.056	-0.075
	(0.214)	(0.210)	(0.108)	(0.109)	(0.121)	(0.123)
Book leverage	0.022**	0.026***	-0.018***	-0.017***	0.198***	0.198***
	(0.009)	(0.009)	(0.006)	(0.006)	(0.012)	(0.012)
Constant	0.638	0.879*	-0.046	0.069	-3.210***	-3.189***
	(0.466)	(0.453)	(0.244)	(0.244)	(0.363)	(0.366)
Firm FE	yes	yes	yes	yes	yes	yes
Observations	20,992	20,992	19,100	19,100	20,403	20,403
R2	0.118	0.126	0.251	0.256	0.179	0.179

Table 6: Financial constraints, precautionary cash, and cash savings around the financial crisis

This table presents estimates from panel regressions explaining firm-level quarterly cash savings for quarters with an end date between July 1, 2006 and March 30, 2009. The regressions are estimated separately for subsamples of firms formed on the basis of their financial constraint status (according to Hoberg and Maksimovic (2015)) at the latest fiscal quarter ending before July 1, 2006. The dependent variable in all regressions is quarterly cash savings as a percentage of assets. All regressions include the same control variables as in Table 4 and firm fixed effects. All other variables are defined in previous tables and in the Appendix. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively. p-values are reported at the bottom for the stated null hypotheses for the estimated coefficients A (After) and AxP (After x Precautionary cash) using subsamples of firms with low and high financial constraints.

	Debt constraints			Equity constraints		
	low	medium	high	low	medium	high
	(1)	(2)	(3)	(4)	(5)	(6)
After	-1.861***	-0.842***	-0.367**	-0.531***	-0.626***	-2.027***
	(0.307)	(0.173)	(0.164)	(0.147)	(0.188)	(0.315)
Observations	5,310	5,302	5,213	5,320	5,296	5,209
R2	0.111	0.094	0.084	0.085	0.112	0.104
After H_0: low=high		0.000			0.000	
	(7)	(8)	(9)	(10)	(11)	(12)
After	0.872	0.364	0.406	-0.129	1.024***	0.437
	(0.551)	(0.359)	(0.272)	(0.319)	(0.370)	(0.497)
After × Precautionary cash	-11.420***	-6.853***	-5.373***	-2.709	-9.169***	-10.572***
	(2.571)	(2.229)	(1.740)	(2.130)	(2.351)	(2.332)
Observations	5,310	5,302	5,213	5,320	5,296	5,209
R2	0.120	0.097	0.086	0.086	0.118	0.113
After H_0: low=high		0.424			0.312	
After×Prec. H_0: low=high		0.040			0.009	

Table 7: Financial constraints, precautionary cash, and investment around the financial crisis

This table presents estimates from panel regressions explaining firm-level quarterly investment activities for quarters with an end date between July 1, 2006 and March 30, 2009. The regressions are estimated separately for subsamples of firms formed on the basis of their financial constraint status (following Hoberg and Maksimovic (2015)) at the latest fiscal quarter ending before July 1, 2006. The dependent variable in all regressions is quarterly investment (CAPEX + R&D) as a percentage of assets. All other variables are defined in previous tables and in the Appendix. All regressions include firm fixed effects. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively. p-values are reported at the bottom for stated null hypotheses on the estimated coefficients A (After) and AxP (After x Precautionary cash) for subsamples of firms with low and high financial constraints.

	Full sample		Debt constraints			Equity constraints		
Subsamples			Low	Medium	High	Low	Medium	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
After	-0.119*	-0.237***	-0.431***	-0.009	-0.107	-0.023	-0.255*	-0.368***
	(0.062)	(0.077)	(0.153)	(0.137)	(0.105)	(0.086)	(0.151)	(0.118)
After × Precautionary cash		1.531***	2.712***	0.318	0.273	-0.024	1.559*	2.396***
		(0.439)	(0.556)	(0.644)	(0.725)	(0.658)	(0.895)	(0.721)
Operating CF		-0.056**	-0.074**	-0.026***	-0.007	-0.021*	-0.029*	-0.056
		(0.027)	(0.036)	(0.009)	(0.010)	(0.012)	(0.015)	(0.044)
Tobin's Q		0.477***	0.555***	0.394***	0.382***	0.330***	0.359***	0.610***
		(0.134)	(0.186)	(0.130)	(0.092)	(0.106)	(0.108)	(0.209)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	20,994	20,994	5,310	5,302	5,215	5,322	5,296	5,209
R2	0.772	0.776	0.786	0.720	0.718	0.724	0.664	0.797
A H_0: low=high				0.092			0.021	
A×P H_0: low=high				0.010			0.011	

Table 8: Precautionary cash and financial policies during placebo crises

This table presents estimates from panel regressions explaining firm-level quarterly financial policies for two years around placebo crises. The placebo crises occur on January 1, 2005 and 2006. After is an indicator variable equal to one for fiscal quarters with an end date after the placebo crisis, and precautionary is measured at the end of the last fiscal quarter ending one year before the placebo crisis. All variables are defined in previous tables and in the Appendix. All regressions include firm fixed effects. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively.

Dependent variable	Cash savings		Net equity issuance		Investment	
Placebo crises	2005	2006	2005	2006	2005	2006
	(1)	(2)	(3)	(4)	(5)	(6)
After	0.178	-0.055	-0.048	-0.221	-0.040	0.004
	(0.407)	(0.381)	(0.234)	(0.222)	(0.090)	(0.086)
After × Precautionary cash	-1.453	-0.982	-1.123	-0.365	0.520	0.497
	(2.172)	(2.088)	(1.276)	(1.239)	(0.463)	(0.473)
Further controls	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
Observations	9,334	9,271	8,202	8,253	9,334	9,271
Adjusted R2	0.015	0.021	0.189	0.200	0.782	0.809

Table 9: Precautionary cash and financial policies during and after the financial crisis

This table presents estimates from panel regressions explaining firm-level quarterly financial policies for quarters with an end date between July 1, 2006 and June 30, 2010. After is an indicator variable equal to one for fiscal quarters with an end date between January 1, 2008 and March 30, 2009. Late after is an indicator variable equal to one for fiscal quarters with an end date between April 1, 2009 and June 30, 2010. All other variables are defined in previous tables. All regressions include firm fixed effects. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively.

Dependent variable	Cash savings	Net equity issuance	Net debt issuance	Investment
	(1)	(2)	(3)	(4)
After	-0.948***	-0.108*	-0.684***	-0.187**
	(0.116)	(0.057)	(0.091)	(0.082)
After × Precautionary cash	-9.519***	-3.983***	-0.604	1.566***
	(1.316)	(0.616)	(0.751)	(0.468)
Late after	0.275**	0.504***	-1.230***	-0.375***
	(0.110)	(0.059)	(0.095)	(0.087)
Late after × Precautionary cash	-0.263	1.129	-0.401	0.049
	(1.358)	(0.898)	(0.977)	(0.494)
constant	0.384	-0.397	-2.293***	1.649***
	(0.413)	(0.346)	(0.350)	(0.094)
Further controls	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Observations	28,070	25,631	27,183	30,137
Adjusted R2	0.027	0.155	0.055	0.756

Table 10: Precautionary and non-precautionary cash and financial policies around the financial crisis

This table presents estimates from panel regressions explaining firm-level quarterly financial policies with precautionary and non-precautionary cash holdings for quarters with an end date between July 1, 2006 and March 30, 2009. Non-precautionary cash is the difference between observed cash and precautionary cash as a percentage of total assets, measured at the end of the last fiscal quarter ending before July 1, 2006. In columns 4 to 6, the regressions are estimated separately for subsamples of firms formed on the basis of their equity financial constraint status (following Hoberg and Maksimovic (2015)) at the latest fiscal quarter ending before July 1, 2006. All other variables are defined in previous tables and in the Appendix. All regressions include firm fixed effects. Standard errors (in parentheses) are heteroskedasticity consistent and clustered at the firm level. ***, **, or * indicates that the coefficient estimate is significant at the 1%, 5%, or 10% level, respectively.

	Cash savings	Net equity issuance	Investment			
	Full sample	Full sample	Full sample	Low	Medium	High
	(1)	(2)	(3)	(4)	(5)	(6)
After	0.697***	0.644***	-0.182**	-0.023	-0.207*	-0.348**
	(0.230)	(0.136)	(0.081)	(0.106)	(0.118)	(0.171)
After × Precautionary cash	-9.297***	-4.165***	1.343***	0.195	1.395**	2.099***
	(1.345)	(0.841)	(0.467)	(0.754)	(0.652)	(0.788)
After × Non-precautionary cash	-2.612***	-0.360	1.123***	0.777*	1.163***	1.355***
	(0.609)	(0.350)	(0.201)	(0.426)	(0.353)	(0.369)
Firm FE	yes	yes	yes	yes	yes	yes
Observations	18,945	17,265	20,994	5,322	5,296	5,209
Adjusted R	0.107	0.244	0.803	0.753	0.700	0.820

Statement of authorship

I hereby declare that I have written this thesis without any help from others and without the use of documents and aids other than those stated above. I have mentioned all used sources and cited them correctly according to established academic citation rules. I am aware that otherwise the Senat is entitled to revoke the degree awarded on the basis of this thesis, according to article 36 paragraph 1 letter o of the University Act from 5 September 1996.

Stefan Aebischer