

# Research and/or Development? Financial Frictions and Innovation Investment

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## Abstract

U.S. firms have reduced their investments in scientific research compared to product development. We use Census data to study how the composition of R&D responds to an increase in the cost of funds. Companies forced to refinance during the 2008 financial crisis made substantial cuts to R&D. These reductions were highly concentrated in basic and applied research, and their impact appears in citation-weighted patent output after three years. We explore several mechanisms and conclude that both differences in adjustment costs and strategic concerns play a role in determining the composition of firms' R&D investments.

**Keywords:** Research and Development, Financial Crisis, Technology Competition.

**JEL:** O32, O31, G30, L20.

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# 1 Introduction

The National Science Foundation (NSF) estimates that businesses were responsible for 75% of total U.S. domestic investment in Research and Development (R&D) in 2019.<sup>1</sup> While this share has grown in recent years, several scholars have voiced concerns about the composition of private R&D (Arora et al., 2018, Akcigit et al., 2021). In particular, there is evidence that firms have reduced their investment in scientific research relative to later stages of the technology commercialization process. In simple terms, U.S. firms seem to be doing less “R” for each dollar of “D.”

To date, most of the evidence that firms are shifting the composition of their R&D investments comes from either aggregate statistics or studies that use corporate publishing activity as a proxy for the output of basic research investments. While those two approaches can yield many insights, it remains difficult to study factors that shift the firm-level composition of R&D investments without observing them directly. In this study, we use Census data from two surveys that dis-aggregate basic research, applied research, and development expenditures to examine how a change in the cost of capital impacts each component of a firm’s R&D portfolio for a large set of public companies.

Our empirical context is the 2008 financial crisis. The research design is partially borrowed from earlier studies (e.g., Almeida et al., 2009; Benmelech et al., 2019; Costello, 2020; Granja and Moreira, 2022; Kalemli-Özcan et al., 2022; Duval et al., 2020) that exploit variation in firms’ refinancing needs during a financial crisis to construct a measure of short-run financial constraint. In particular, our main treatment variable measures a firm’s pre-determined amount of long-term debt coming due in 2008 relative to its cash holdings. The basic idea is that companies forced to access financial markets in 2008 found their funding options to be scarce and expensive (Santos, 2011), and are therefore more likely to reduce internal spending in order to minimize refinancing needs.

Our baseline estimates show that a one standard deviation increase in refinancing needs leads to an 8% decline in domestic R&D performed by a firm. This drop in R&D investment is explained almost entirely by a reduction in basic and applied research, as opposed to development. Furthermore, approximately two-thirds of the reduction in R&D can be attributed to R&D-specific labor costs. Using panel data, we show that exposure

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<sup>1</sup>The amount spent was estimated at \$498 billion. See <https://nces.nsf.gov/pubs/nsf22330>.

to the 2008 crisis is not correlated with pre-existing trends in R&D investment, and that firms exposed to the shock did not simply postpone their investment to the following year. Indeed, firms that experienced more financial constraint in 2008 exhibited a relative decline in citation-weighted cumulative patent counts over the next three to five years.

After establishing that firms cut research more than development in response to financial pressures, and that these cuts led to reductions in innovation output, we consider why development investments are “stickier.” The set of potential explanations includes differences in investment duration, risk, adjustment costs, and strategic incentives. In general, we find limited evidence that the larger cut in research simply reflects the need to mechanically reduce the duration or risk of the R&D portfolio. Adjustment costs are important for understanding the magnitude of the R&D decline and, to some extent, the distinction between research and development. However, our results also suggest that this mechanism alone is unlikely to explain the entire difference between research and development. In this context, we also find that strategic considerations were important: our evidence is consistent with the idea that development investments play a particularly important strategic role, as this investment allows the firm to profit from the current technology portfolio and keep up with rivals (Harris and Vickers, 1987). Altogether, our findings show that periods of crisis can alter the innovation trajectory of an economy by reducing overall R&D investment, and also by changing the types of projects that get financed.

Studying the relationship between financial constraints and R&D investments is important for several reasons. First, R&D investments are a key input to the knowledge production function. However, because research outputs are mostly intangible (Eisfeldt and Papanikolaou 2014), this activity is generally harder to finance externally, and there is still much uncertainty about the overall elasticity of R&D to the costs of finance (Hall and Lerner, 2010; Kerr and Nanda, 2015).<sup>2</sup> Second, previous studies have suggested that the allocation of resources between research and development can impact a firm’s growth dynamics and shape the overall pattern of innovation (e.g. Akcigit et al. 2021; Griliches 1988; Link et al. 1981; Mansfield 1980, 1981). There are very few other papers, however, that examine how the *composition* of R&D investment responds to changing

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<sup>2</sup>For instance, a few studies examined the impact of the Great Depression on innovation (Babina et al., 2023; Nanda and Nicholas, 2014), but they could only look at patenting outcomes, given the lack of data.

market conditions. And third, despite the large array of studies on the impact of the 2008 financial crisis on the real economy (e.g. Campello et al., 2010; Cingano et al., 2016; Chodorow-Reich, 2014; Bernstein et al., 2019), relatively little is known about how this event affected innovative efforts.<sup>3</sup>

This paper contributes to a large literature in economics that seeks to understand the determinants of innovative activity. Although many studies have examined how various economic forces influence the output of the innovation process (mostly focusing on patenting),<sup>4</sup> we have a more limited understanding of how inputs are selected.<sup>5</sup> This distinction between input and output is important for at least two reasons. First, if we are interested in understanding how changes in the economic environment alter firm-level innovation incentives, inputs provide a more direct measure of firms' actual choices. Second, output is typically measured using patents, and they are not always an ideal data source (Lerner and Seru, 2017). Some innovations are not patentable and a firm's propensity to patent can reflect various factors that are not directly related to the innovation itself (Mezzanotti et al., 2022; Hall and Ziedonis, 2001). Furthermore, there can be long lags between investment and patent application, making patent data poorly suited to study short-lived economic shocks. Lastly, as we show below, patenting is more strongly correlated with development than research, so patenting outcomes may be biased toward later stages of the innovation process.

Thanks to our detailed data on R&D expenditures, we contribute to the literature in two main ways. First, we show that negative financial shocks affect both the level and the composition of R&D investments. In particular, our companies respond to a negative financing shock by reducing research efforts much more than development, and this adjustment is achieved largely by cutting R&D workers. This evidence confirms

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<sup>3</sup>This question is particularly interesting in light of some divergent findings in the literature around the 2008 financial crisis. On the one hand, Brown and Petersen (2015) show that firms actively managed their liquidity, in large part to minimize the impact of the financial crisis on their R&D. On the other hand, the survey evidence in Campello et al. (2010) shows that CEO's listed technology investment as one of the most affected areas during the unfolding of the 2008 crisis.

<sup>4</sup>To cite just a few examples, the previous literature has studied how innovation output is influenced by government investments in R&D (e.g., Gross and Sampat, 2020; Moretti et al., 2019), laws on intellectual property (e.g., Moser, 2005; Mezzanotti, 2020; Mezzanotti and Simcoe, 2019), competition (e.g., Aghion et al., 2005), childhood exposure to innovation (e.g., Bell et al., 2019), and taxation (e.g., Akcigit et al. 2017), among other things.

<sup>5</sup>One notable exception is the recent work by Driver et al. (2020) that also uses Census data and studies how differences in ownership structure affect the composition of R&D investments by US firms.

that capital structure can affect the input decisions of firms (Kim and Maksimovic, 1990). Furthermore, the behavior of companies in our setting is qualitatively consistent with the evidence from Babina et al. (2020), which shows that corporate funding pushes university researchers to focus on more applied and less impactful work. In general, we believe that our results are important to better assess the economic cost of crises: given the time lag between when research is conducted and when it impacts productivity in the economy (Syverson, 2011), our evidence suggests that the short-run cost may under-estimate the full impact of a negative shock. In fact, the short-run impact may not internalize the impact that reducing research may have over the longer-run (Akcigit et al., 2021).

Second, while we do not aim to quantify the relative importance of various mechanisms, our paper highlights adjustment costs and strategic incentives as key forces shaping R&D investments. We find that adjustment costs significantly influence both the size and nature of adjustments. For instance, companies with established relationships with external R&D partners are more likely to cut research ex-ante. At the same time, our evidence highlights the different roles played by research and development in a firm’s strategy: specifically, investments in development are largely driven by the need to leverage existing technologies to fend off competition, while research appears to be less affected by short-run competitive forces and instead reflect firm-specific growth opportunities.<sup>6</sup>

Broadly, our paper also relates to the literature in finance focused on the connection between financial frictions and the real economy (e.g., Fazzari et al., 1988). Close to our setting, several papers have shown that the disruption of credit markets can significantly impair firms’ tangible investment and employment decisions (e.g., Peek and Rosengren, 1997; Almeida et al., 2009; Schnabl, 2012; Lin and Paravisini, 2013; Chodorow-Reich, 2014; Frydman et al., 2015; Cingano et al., 2016; Bottero et al., 2020). However, much less work has focused directly on R&D investment by large corporations.<sup>7</sup> Consistent with the

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<sup>6</sup>Our evidence is broadly consistent with the literature on the role of financial decisions as a strategic tool for firms (e.g. Campello, 2006; Chevalier, 1995; Cookson, 2017; Doraszelski et al., 2022; Fresard, 2010; Grieser and Liu, 2019; Phillips, 1995).

<sup>7</sup>Related to this question, other papers have examined using patent data how financial frictions affect the innovation by start-ups (i.e., Howell, 2017) or smaller firms (Hombert and Matray, 2017), or examined the connection between banking conditions and productivity (e.g., Bai et al., 2018; Huber, 2018), or product introduction (e.g., Granja and Moreira, 2022) or the role of banking crises more broadly (Nanda and Nicholas, 2014; Hardy and Sever, 2021; Babina et al., 2023). Outside the banking sector, other papers have established a relationship between the IPO market and innovation (e.g., Bernstein, 2015; Cong and Howell, 2018). The paper is also related to Aghion et al. (2012) that uses French data to study the cyclicity of R&D and

framework in Hall and Lerner (2010), our results confirm that R&D activity is indeed very sensitive to changes in financial conditions. In this area, the papers closer to us are Brown et al. (2009), Czarnitzki et al. (2012), Krieger et al. (2022), and Duval et al. (2020).

Brown et al. (2009) finds a large cash-flow sensitivity for R&D investments, consistent with the presence of frictions in the financing of R&D for large companies. Czarnitzki et al. (2012) are able to disaggregate research and development investments for a sample of Belgian firms, and find that research is more sensitive to internal liquidity, as measured by debt and working capital. Relative to these papers, we now provide direct evidence that shocks to financing will affect also the composition of the investments. Our results also complement that patent production function estimates in Czarnitzki et al. (2009). Krieger et al. (2022) studies the drug development industry and shows that companies experiencing positive cash-flow shocks are more likely to invest in more novel drugs. Our paper - on top of covering a broader set of companies than just the drug industry - provides evidence for a novel mechanism (i.e., the strategic interaction across companies) that may also contribute to determine the allocation of resources by firms. Duval et al. (2020) documents a significant decline in productivity for companies affected by a financing shock, also suggesting that this response may be connected to a reduction in intangible investments. Our analysis highlights that the reduction in the quantity of investments may underestimate the overall impact on innovation efforts, as firms may also reshuffle R&D activity towards more incremental projects, as shown in our analysis.

The rest of the paper is organized as follows. Section 2 provides a simple model of investment to frame our discussion of several factors that might influence the level and composition of R&D investment. Section 3 describes the dataset and research design used in the empirical analysis. Section 4 presents and discusses the empirical results, and Section 5 offers some concluding remarks.

## **2 Conceptual Framework**

The distinction between research and development rests on knowledge creation. The NSF, for example, defines research as “planned, systematic pursuit of new knowledge or understanding” whereas development means “systematic use of research and practical

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highlights the role of financial frictions at explaining aggregate R&D investments along the cycle.

experience to produce new and significantly improved goods, services, or process.”<sup>8</sup> In simple terms, research generates new knowledge and development applies existing knowledge to new problems. We study how these two types of investment respond to an increase in the cost of funds.

As a starting point, consider the canonical model of a single firm that maximizes the present value of a stream of dividends,  $\pi(A_t)$ , which are an increasing and convex function of the current knowledge stock, denoted by  $A_t$ . Knowledge depreciates at the rate  $\delta$  and is replenished by R&D investments (Hall and Jorgenson, 1967; Hall, 1996). Assuming a Cobb-Douglas knowledge production function, the law of motion for the firms’ knowledge stock is  $A_{t+1} = (1 - \delta)A_t + R_t^\alpha D_t^\gamma$ . Thus, if the real interest rate is  $r$  (with associated discount factor  $\beta = \frac{1}{1+r}$ ), the value of the firm can be expressed recursively:

$$V_t = \max_{R_t, D_t} \pi(A_t) - R_t - D_t + \beta V_{t+1}$$

Along a steady-state investment path, the Euler equations imply that  $\frac{\partial \pi(A^*)}{\partial D} = \frac{\partial \pi(A^*)}{\partial R} = r + \delta$ , so the financial return to the marginal dollar invested in research or development just equals the real interest rate.<sup>9</sup> Moreover, the Cobb-Douglas form of the knowledge production function implies that  $R^*/D^* = \alpha/\gamma$ , so the composition of R&D expenditures reflects the marginal productivity of each type of investment.

To model the impacts of an idiosyncratic shock to the cost of R&D, consider a one-period shift in total costs to  $\tau(R + D)$ . For that period, the first-order conditions become  $\frac{\partial \pi(A_{t+1})}{\partial I_t} = \tau(r + \delta)$  for  $I_t \in R_t, D_t$ . Thus, investment in both research and development declines as the cost of investing internal resources in new projects increases. The first part of our empirical analysis measures the size of this effect, where  $\tau$  corresponds to the marginal funding cost of R&D investments in 2008. A second prediction of this simple model is that a marginal cost shock has no impact on the composition of R&D, which remains fixed at  $R^*/D^* = \alpha/\gamma$ .

It is natural to assume that research investments take more time to bear fruit. We

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<sup>8</sup>It is also common to distinguish between Basic Research (“activity aimed at acquiring new knowledge or understanding without specific immediate commercial application or use.”) from Applied Research (“activity aimed at solving a specific problem or meeting a specific commercial objective.”)

<sup>9</sup>Derivations of any results mentioned in this section are provided in Appendix A. We ignore tax considerations that will generally complicate the model without altering any of the basic points we wish to make.

can incorporate that idea by assuming research is  $k$  periods slower than development, so the knowledge stock evolves according to  $A_{t+1} = (1 - \delta)A_t + R_{t-k}^\alpha D_t^\gamma$ . In this case, the steady-state composition of R&D investment is  $R^*/D^* = \beta^k \frac{\alpha}{\gamma}$ . Intuitively, longer lags increase the opportunity cost of research, and firms respond by investing relatively more in development. The long-run composition of R&D, moreover, does not depend on marginal costs. In other words, a permanent change in marginal cost (e.g., from 1 to  $\tau$ ) has no impact on their respective shares in total R&D.<sup>10</sup> At least within our simple framework, this suggests that changes in time-preference (i.e., the real interest rate) can shift the balance between research and development, but a symmetric cost shock will not.

Moving beyond this baseline model, the literature proposes several mechanisms that might influence the composition of R&D spending. As a starting point, models of R&D investment often assume adjustment costs (e.g., Hall and Van Reenen 2000).<sup>11</sup> If the adjustment costs for R and D are quite different, then the two types of investment will exhibit a different response to a symmetric increase in marginal cost. The presence of liquidity risk may generate more procyclicality in long-term investments in financially constrained firms (e.g., Aghion et al. 2010). Similarly, Stein (1989) shows how myopic managers may avoid cutting activities that impact short-run profits, like development, even when the present value of two projects is the same.<sup>12</sup> Changes in the composition of R&D could also reflect changing preferences for technology risk. For instance, Krieger et al. (2022) show that pharmaceutical firms take more technology risk (analogous here to increasing research) when their overall financial risk declines due to a positive cash-flow shock.

Changes in demand are another channel that could shift the composition of R&D investment. In particular, if cost shocks coincide with a demand contraction (as in the 2008 financial crisis), then long-term projects become more attractive. For example, suppose the firm in our simple model learns (by surprise) that next period dividends

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<sup>10</sup>When research and development investments mature at different rates, it is difficult to characterize firms' optimal response to a temporary cost shock, so we cannot rule out the possibility that there is a temporary change in the composition of R&D along the optimal adjustment path.

<sup>11</sup>In a model with adjustment costs, the prediction that firms will cut R&D is less obvious. In particular, if R&D investments are characterized by higher adjustment costs than other types of expenditures (e.g., marketing), firms may manage their internal liquidity and minimize the impact to R&D (Brown and Petersen, 2015).

<sup>12</sup>However, one could also assume rigidities in the firm's liability structure, or other short-run commitments that make short-term cash flows more valuable.



will be  $\pi(A_{t+1}) = 0$ , before reverting to normal. In that situation, it will clearly defer all development expenditures – since there is no benefit to increasing  $A_{t+1}$  – but may still invest in research that takes two periods to mature. A similar mechanism is proposed in Manso et al. (2019), where declining demand leads firms to shift from “exploitation” to “exploration.”<sup>13</sup> Indeed, versions of this argument can be found in Schumpeter (1939) as well as many later models of investment,<sup>14</sup> and appears consistent with some aggregate trends about R&D (Cohen, 2023).

Finally, the nature of strategic interactions among firms may influence how firms’ R&D investments respond to a change in the cost of funding. For example, Beath et al. (1989) illustrate how R&D can be motivated by “profit incentives” (i.e., direct benefits) or “competitive threats” (i.e., incentives to curb competition), and argue that the response of R&D to external factors will depend on which of the two forces is more important in a particular setting. When strategic forces predominate, the key question is how rival investment enters the firms’ best response functions. Changes in R&D will be amplified or dampened (relative to the single-firm baseline) according to whether those investments are strategic complements or substitutes (Bulow et al., 1985). The large empirical literature on knowledge spillovers (e.g. Jaffe 1986; Henderson et al. 1993) suggests that internal R&D productivity can benefit from external investments, which points in the direction of complementarity. On the other hand, when scale or learning effects are important, firms may expect their rivals to “compete for the market” instead of accommodating a reduction in investment – particularly in settings where R&D is motivated by a need to keep up with rivals (Harris and Vickers, 1987).<sup>15</sup>

It is not clear *a priori* whether strategic considerations are more salient for research or development, but several factors leads us to suspect the latter. First, because research is focused on developing new knowledge, it may be difficult to predict its competitive implications. Development tends to focus on incremental improvements with risks that

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<sup>13</sup>Manso et al. (2019) examines the effect of a demand and financing shock separately. However, their framework can be intuitively extend to a context where the two types of shock can interact, and therefore the nature of demand can alter how a firm respond to a supply shock. This framework is closer to our empirical exercise.

<sup>14</sup>See, for example, Aghion and Saint-Paul (1998); Caballero et al. (1994); Canton and Uhlig (1999); Cooper and Haltiwanger (1993); Kopytov et al. (2018)

<sup>15</sup>This idea is consistent with the evidence from the literature on predation (e.g. Campello, 2006; Chevalier, 1995; Cookson, 2017; Fresard, 2010; Grieser and Liu, 2019; Phillips, 1995), which shows how companies tend to exploit - not accommodate - competitors facing financial weakness.

are more commercial than technological in nature. Second, the value of research is more likely to reflect long-term opportunities that are less influenced by a competitor’s current actions.<sup>16</sup> Finally, the innovation literature suggests that the ability to learn from “upstream” knowledge producers, such as government labs and universities, that are not engaged in downstream competition, provides a significant motivation for research investments (Henderson and Cockburn, 1996; Cohen and Levinthal, 1989; Arora et al., 2021).

In summary, the impact of changes in financial conditions on the level and composition of R&D investment is not clear *a priori*. Broadly speaking, we expect total R&D to decline for firms facing a higher cost of funding. But the magnitude of this effect, and its implications for the composition of R&D, will depend on specific characteristics of the investments, the broader economic environment, and the actions of rival firms.

## 3 Data and Research Design

### 3.1 Data

Though public companies often provide information on aggregate R&D spending, there is no systematic disclosure of how that spending is allocated across different types of investments.<sup>17</sup> We therefore rely on data collected by the US Census that provides detailed information on the amount and nature of R&D investments for a large sample of US firms. Specifically, we combine information from two surveys: the Survey of Industry Research and Development (SIRD) for the period 2002-2007; and the Business R&D and Innovation Survey (BRDIS) for 2008-2012.<sup>18</sup> In addition to the distinction between

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<sup>16</sup>This hypothesis generates a similar prediction to the previous hypotheses based on cash-flow duration or technology risk, but the mechanisms are very different. In particular, if strategic interactions are economically important, investment will depend on what technology peers are expected to do, which in turn will depend on whether those firms are exposed to the same shock.

<sup>17</sup>Under IFRS accounting regulations, firms are allowed to capitalize Development (but not Research) expenditures. In principle, it may therefore be possible to gather data on R&D composition from public financial accounts. There is much discretion in the reporting of this information, however, and we leave the topic as an interesting avenue for future research.

<sup>18</sup>Similar to our paper, Foster et al. (2020) uses BRDIS combined with SIRD to understand how the type of firms investing in R&D has changed between 1992 and 2011. Instead, both Driver et al. (2020) and Mezzanotti et al. (2022) focus only on BRDIS in their analyses. Lastly, Cohen (2023) uses a combination of BRDIS and SIRD to measure how R&D evolves over time, but only exploits the aggregate, public version of the data.

research and development described above, the SIRD and BRDIS surveys ask firms to separate purely exploratory basic research from applied research that is directed towards a specific commercial objective.<sup>19</sup> In 2007, US corporations reported that 74.4% of total expenditures for internal R&D were spent on development, 21.4% on applied research, and 4.2% on basic research.<sup>20</sup>

We match the information from the two surveys to Compustat to track R&D investments around the 2008 financial crisis for a set of public firms. While SIRD and BRDIS are constructed as repeated cross-sections, both surveys oversample large firms and known R&D performers, which allows us to construct a panel dataset for roughly 1,100 U.S. public firms. Specifically, our main analyses focus on firms that: (a) responded to the survey in both 2007 and 2008; (b) were matched to Compustat; (c) are not financial firms or companies active in regulated sectors; and (d) reported all of the main variables used in the analysis. Appendix B contains a detailed discussion of the data and matching procedure.

Our primary outcome variables are based on domestic R&D performed by the firm. As a practical matter, this is the main measure of R&D activity that can be consistently observed across the two surveys, and several key variables - such as the breakdown between research and development - can be constructed only starting from this aggregate in the period of interest. Conceptually, domestic R&D performed by the firm also corresponds well to our model of the firm's knowledge production function. However, as we discuss in Section 4, we find similar results when using alternative definition of R&D, such as worldwide R&D performed by the firm, or R&D expenditures. As mentioned above, both surveys ask respondents to report annual investments in Basic Research, Applied Research, and Development, along with the type of expenditure (labor, materials, depreciation or other) and whether the R&D was performed internally or by a contractor. We performed a variety of consistency checks to ensure that all variables used in our analysis are measured consistently across the change in survey instruments.

Finally, there is the question of whether firms can accurately distinguish various types of R&D investment. While the Census does note that "differences in respondent

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<sup>19</sup>In particular, applied research is defined as an "activity aimed at solving a specific problem or meeting a specific commercial objective," while basic research is "activity aimed at acquiring new knowledge or understanding without specific immediate commercial application or use."

<sup>20</sup>The summary statistics reported come from NSF publicly available aggregate data.

interpretations of the definitions of R&D activities” are a source of measurement error, they also describe several efforts to address the issue, including “questionnaire pretesting, improvement of questionnaire wording and format, inclusion of more cues and examples in the questionnaire instructions, in-person and telephone interviews and consultations with respondents, and post-survey evaluations.”<sup>21</sup> Moreover, our research design has the potential to alleviate some measurement concerns. First, our sample is comprised of firms that (in most cases) have responded to the survey for many years, and should therefore have developed a set of processes to accurately collect and report the information requested by the Census. Second, our analyses will always exploit within-firm changes in behavior, therefore netting any systematic firm-specific bias in reporting. Though we cannot rule out heterogeneity in firms’ understanding of these concepts, we ultimately view the results presented below as providing some empirical validation of the survey measures.<sup>22</sup>

### 3.2 Research Design

The objective of our empirical analysis is to measure the impact of an increase in the cost of funding (i.e.,  $\tau$  in Section 2) on the level and composition of R&D investments. Our research design exploits firm-level variation in the demand for refinancing at the onset of the 2008 financial crisis. To be precise, our main specification measures refinancing risk with the firm’s ratio of long-term debt due within one year (as of 2007) to its cash and other liquid holdings.<sup>23</sup> Consistent with other studies that use a similar approach (e.g. Almeida et al. 2009; Benmelech et al. 2019; Costello 2020; Duval et al. 2020; Granja and Moreira 2022; Kalemli-Özcan et al. 2022), the validity of this model is generally predicated on two observations. First, firms entering a financial crisis with more extensive refinancing needs will face a stronger incentive to cut internal spending because they otherwise are compelled to access capital markets during periods of limited and costly funding options

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<sup>21</sup>See <https://www.nsf.gov/statistics/srvyberd/prior-descriptions/overview-brdis.cfm#collection>

<sup>22</sup>For instance, we believe that our analysis unpacking research activity between applied and basic can provide a useful validation to the data, since the risk of mis-categorize a basic research project is much less severe than for applied projects.

<sup>23</sup>The Compustat variable “dd1” in the 2007 report year is used to measure the debt due within one year, while the variable “che” (also in 2007) is used to measure the amount of cash and short-term investments available to the firm during the same time.

(Santos, 2011).<sup>24</sup> In this context, it is therefore plausible to expect a reduction in R&D investments, among other business activities. Second, the refinancing need is largely determined by the term-structure of a firm’s long-term debt, and therefore it should not be systematically correlated with a firm’s demand for technologies in 2008. Indeed, several tests discussed below appear consistent with this interpretation.

We implement this research design using a collapsed difference-in-difference specification (Bertrand et al. 2004):

$$GrowthR\&D_{i,2008} = \alpha_{ind(i)} + \beta Exposure_i + \gamma X_{i2007} + \epsilon_i \quad (1)$$

where  $GrowthR\&D_{i,2008}$  is the symmetric growth rate of R&D performed by firm  $i$  between 2007 and 2008 (e.g., Decker et al., 2014), and  $Exposure_i$  is the ratio of current portion of long-term debt to liquid assets in 2007 (winsorized at 5%). The specification includes narrowest industry fixed-effects available (e.g., 6-digit NAICS),  $\alpha_{ind(i)}$ , to control for changes in industry-level demand around the same time period. We also include a vector of firm-level controls,  $X_{i2007}$ , for size (log revenue), profitability (ROA), and R&D intensity (R&D scaled by revenue).<sup>25</sup>

We note that this first-differenced specification is conceptually equivalent to implementing the same approach using panel data, where we examine the level of R&D as a function of our treatment interacted with a crisis dummy and including firm and industry-by-year fixed effects (Wooldridge, 2010). Relative to this alternative, we believe that our approach has several advantages. First, our model estimated using the symmetric growth rate allows us to naturally accommodate companies with a zero outcome either before or after the shock (Davis and Haltiwanger, 1990), without taking a strong stance about the relative importance of the intensive and extensive margin (Chen and Roth, 2024). Second, this approach facilitates incorporating differences in firm expectations, as elaborated below. In any case, we show later how our estimates for R&D are qualitatively

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<sup>24</sup>To be clear, our empirical model does not require that firms use debt financing to fund innovation. Even if a company uses equity as the marginal source of funding for R&D (e.g., Brown et al., 2012), a refinancing shock may force the company to cut any type of internal activity if other sources of funding are not available at no cost. Indeed, the general economic environment in 2008 made it very hard to both refinance debt and issue new equity. This idea is consistent with the presence of imperfections in the firm’s internal capital market (e.g., Shin and Stulz, 1998; Campello, 2002).

<sup>25</sup>These variables are all measured at the same time as the treatment (2007). For further consistency with the treatment, we also winsorize the two ratios at the same level as the treatment.

identical across the two methodologies.

In order to place a causal interpretation on the estimates from this regression, one must assume that variation in exposure to the 2008 financial crisis is uncorrelated with potential R&D outcomes. The unexpected nature of the 2008 crisis lends some plausibility to this assumption. It is not likely that many firms had enough prior knowledge of how the crisis would unfold to systematically adjust their debt position *ex ante*. Nevertheless, one might still be concerned that a firm's balance sheet will reflect expectations of future R&D growth. We address this concern by using data on firms' forecasted R&D investment to control for (otherwise unobserved) differences in ex-ante expectations.

Both SIRD and BRDIS ask respondents to disclose a forecast of R&D investment for the upcoming year. For example, the 2007 survey contains data on both the actual amount of R&D performed in 2007, and the amount that each respondent expected to perform in 2008. We use these data to construct a projected one-year-ahead growth rate,  $ProjGrowth_{i,2008}$ , that allows us to control directly for the expectations at the start of 2007.<sup>26</sup> Controlling for growth leads to a our baseline specification:

$$GrowthR\&D_{i,2008} = \alpha_{ind(i)} + \beta Exposure_i + \theta ProjGrowth_{i,2008} + \gamma X_{i2007} + \epsilon_i \quad (2)$$

Interestingly, this information on projected R&D allows us to provide some evidence to reinforce the common view that the unfolding of the financial crisis in 2008 represented an unexpected shock for firms and had a meaningful impact on corporate investment. Figure (1), plots the average percentage difference between projected and (ex-post) actual R&D for all firms in our sample from 2006 through 2009. The difference is small and not statistically different from zero in all years except 2008, when actual R&D was 15% lower than projected. Figure (1) is consistent with the idea that firms' R&D projections are generally reliable, aside from the crisis period, when an unanticipated financial shock produced a systematic downward adjustment in actual spending.

Finally, we take advantage of the full panel to analyze dynamics of the treatment effects, both before and after 2008. This analysis allows us to examine whether any change in R&D in 2008 reflect a secular trend in R&D activity among affected firms. Specifically,

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<sup>26</sup>In other words, we estimate the symmetric growth rate where the base year is the actual realization for 2007 and the current year is the amount of R&D expected in the 2007 survey for 2008:  $\frac{(Expected_{2008} - Actual_{2007})}{(Expected_{2008} + Actual_{2007})}$ . The expectation regarding R&D is expressed on domestic R&D performed, like our main outcome variable.

we estimate the following model:

$$GrowthR\&D_{i,t} = \alpha_{ind(i),t} + \beta_t Exposure_i + \theta ProjGrowth_{i,t} + \gamma_t X_{i2007} + \epsilon_{i,t} \quad (3)$$

where  $t$  is equal to 2003-2012, and represents the post-year in the growth rate.<sup>27</sup> The coefficients  $\beta_t$  measure the correlation between financial exposure in 2007 and R&D growth in year  $t$ .<sup>28</sup> Plotting these dynamic treatment effects allows us to check for any pre-crisis correlation between financial exposure and R&D investment, and to evaluate whether any post-crisis response is permanent or transitory.

## 4 Results

### 4.1 Baseline

To begin, we ask whether the decline in R&D between 2007 and 2008 is associated with firm-specific refinancing needs. Table (1) presents estimates based on equation (1). The first column, which includes no firm-level controls, shows that firms entering 2008 with a higher level of debt to liquid assets experienced less R&D growth than peers within the same 6-digit industry. The relationship is economically significant: an 0.5 unit increase in the ratio (roughly one standard deviation) is associated with an 8% decline in R&D growth. In column 2, we add projected R&D growth as a control. Controlling for expectations produces only small changes in the coefficient on the debt to liquid assets ratio. In column 3, we add a full set of firm-level controls and find that the key coefficient remains statistically unchanged. As mentioned before, we note that these estimates are qualitatively identical to what you can obtain using the equivalent difference-in-difference approach in levels (Table A.1).

A causal interpretation of the estimates in Table (1) requires assuming that firms' financial position in early 2008 is uncorrelated with potential changes in R&D expenditure. It is not possible to test this assumption directly. We can potentially falsify the

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<sup>27</sup>In other words,  $GrowthR\&D_{i,2006}$  is the growth rate between 2006 and 2005. Since this analysis is now estimated with a panel of firms, we estimate our standard errors clustered at firm level.

<sup>28</sup>As we discuss when we present the result, one issue with using a longer panel is that the measure of expectation is not consistently measured throughout the sample. Therefore, we provide our results including  $ProjGrowth_{i,t}$  when using the short-panel (2006-2009) and excluding this measure when using the longer panel. Our main results are similar across the two approaches.

identification assumption, however, by checking for a correlation between the treatment variable and pre-treatment trends in R&D growth. Figure (A.2) plots estimates of dynamic treatment effects, based on estimating equation (3) with the years 2003-2012.<sup>29</sup> Since the outcome is measured as the rolling growth rate of R&D, this analysis is the first-differenced version of the typical pre-trend analysis that uses data in levels. The pre-crisis coefficients are small in comparison to our baseline estimates and statistically insignificant at standard levels. The same result is replicated in Figure (2): while this figure uses a shorter panel, this restriction allows us to focus on a sample for which we can consistently control for differences in R&D expectations, as in the baseline model. Thus, we fail to reject the hypothesis that companies entering the crisis with a high debt-to-liquid assets ratio had R&D growth patterns similar to “untreated” firms before the crisis.<sup>30</sup>

The key focus of the paper is on the immediate response to the shock. However, these tests also provide some insights regarding firms’ behavior after 2008. Across all specifications discussed above, we consistently find no statistically significant correlation between exposure to the crisis and R&D growth in 2009. In other words, companies that reduced R&D in 2008 did not compensate the cuts by growing R&D relatively more in the following year. This suggests that the reductions in 2008 were not simply a postponement of investment. While our empirical setting is not ideal for making strong statements about the persistence of the shock, evidence of a catch-up after 2009 appears—at best—mixed.<sup>31</sup> We offer additional evidence on this point when presenting the dynamic results for R&D composition.

The results in Table (1) are robust to various changes in measurement and model

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<sup>29</sup>We note that Figure (A.2) does not control for projected R&D growth, as this information is not consistently available for the full sample period (in particular post-2009). Furthermore, as we move away from 2008, the sample suffers from some attrition, as some companies may not be surveyed every year.

<sup>30</sup>In Figure A.1, we re-estimate equation (3) now including also firm fixed-effects to the specification. This specification allows firms to have differential growth rates over the estimation period, at the cost of having to normalize one period estimate. As before, we confirm no difference in R&D growth in the pre-period and a significant decline in R&D in 2008. We also note that Figure (A.4) reports the coefficients of the long-specification with controls.

<sup>31</sup>The results in Figure (A.2) suggests that companies more affected by the 2008 shock may have tried to catch up in R&D investment in 2010, but this year of relatively increased was followed by another reduction in R&D investments in 2011. As we discuss in Appendix (B), one of the issue in interpreting estimates far from the treatment year is that the sample is characterized by some attrition due to the survey structure of the underlying data. With this caveat in mind, we interpret this evidence as consistent with affected companies trying to limit the long-term impact of the 2008 financing shock.



specification. For example, Appendix Table (A.2) shows that winsorizing  $Exposure_i$  at the 1% level or applying a Box-Cox transformation does not alter the results. Similarly, Appendix Table (A.3) shows that results are also similar if we use the amount of debt due in 2008 scaled by 2007 total assets as an alternative treatment variable.<sup>32</sup> Lastly, Appendix Table (A.4) shows that results are not meaningfully changed by adopting a specification with 4-digit industry fixed-effects.

We also show that our results do not depend on the specific measure of R&D used: Appendix Table (A.5) shows that results are similar if we change the outcome variable from domestic R&D performed to either worldwide R&D performed or worldwide R&D expenditure.<sup>33</sup> Consistent with these findings, columns 1 and 2 in Appendix Table (A.6) show that the contraction in R&D performed by the firm do not simply reflect a consistent increase in the amount of R&D that is outsourced (i.e., paid by the firm, but performed by another entity). Furthermore, we also find that our effects do not mechanically reflect a decline in Federal Funding for R&D during the period in analysis (columns 3 and 4, Appendix Table A.6).

Importantly, we find that these estimates are mostly driven by companies that had a weaker financial profile in 2007. Our empirical model assumes that refinancing risk acts as a liquidity shock for the firms in our sample. If this interpretation is correct, we should expect our results to be driven by companies that are ex-ante more financially constrained, and therefore are more likely to have to cut internal activity to limit the impact of the shock. We examine this question in Table (A.7), by estimating our main equation separately for firms that are above or below the median of four common proxies of financial strengths: asset tangibility (e.g., Almeida and Campello, 2007), total leverage (i.e., long-term debt over asset), dividend over revenue, cash over EBITDA.<sup>34</sup> In general, we find that our estimates are mostly driven by companies that were ex-ante in a weaker financial position: these are firms with above median level of leverage, or lower than median levels of asset tangibility, low cash balances over EBITDA, and with low dividends. This

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<sup>32</sup>Scaling our treatment by book assets rather than cash allows us to assuage concerns about the importance of the denominator in constructing our treatment variable. In particular, it suggests that what drives our result is largely variation in the amount of long-term debt due in 2008, rather than the size of cash balances.

<sup>33</sup>As mentioned above, one caveat with this analysis is that - at best of our understanding - these variables cannot be perfectly reconstructed in a consistent way across the two surveys (Appendix B).

<sup>34</sup>Because of concerns with the Census disclosure, we only report the sign and statistical significance of these estimates.

evidence reinforces our key interpretation of the results, showing that firms with more financial slack were able to absorb the liquidity risk without reducing R&D investments. Table (A.8) confirms our finding when we add controls for asset tangibility and the firm's leverage ratio, to test for the possibility that short-term debt reflects a firm's balance sheet capacity during a crisis, rather than a short-term increase in funding needs.<sup>35</sup>

Lastly, financing concerns did not only affect R&D. In the first two columns of Table (A.10), we find that refinancing risk is also associated with larger cuts in capital investments (i.e., capx). This aligns with the idea that companies impacted by the 2008 financial crisis had a general incentive to scale back investments to mitigate potential liquidity problems. This observation is important in our context, as it clarifies that our focus on R&D does not imply that this type of investment is necessarily the only (or most critical) area of adjustment during times of financial stress. Instead, our emphasis on R&D is driven by a specific interest in this investment class, as discussed in Section (2), without suggesting it is the primary buffer for firms.

## 4.2 Types of Spending

According to data from the National Science Foundation, about 57% of total R&D costs in 2007 went to employee compensation and benefits, 12% were spent on materials, 4% on depreciation, and 28% on other items. If the decline in R&D expenditures measured above corresponds to a real operational change, we would therefore expect to find an impact on the wage bill. If the baseline estimates instead correspond to a short run cost adjustment, or a reduction in wasteful slack, we might find larger impacts for other types of expenditure.

Table (2) reports estimates from our baseline specification for each component of total R&D expenditure.<sup>36</sup> There is a strong negative association between exposure to the financial crisis and the growth in labor, material, and other costs. There is no evidence of a decline in capital investment. The coefficients for labor, materials and other costs are

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<sup>35</sup> Asset tangibility is measured as the share of fixed assets in the balance sheet, while the leverage ratio is calculated as the ratio between long-term debt (due over one year) to total assets. Notice that the measure of asset tangibility was missing for a very small subset of firms: to avoid issues with disclosure, we replace the missing values with zeros, but then also include in the regression a dummy variable that flags these replaced observations.

<sup>36</sup> We continue to use a symmetric growth rate in the outcome. By construction, these four variables used to construct the growth rate aggregate to total domestic R&D performed by the firm in the year.

similar to our baseline estimates for total R&D, which implies that labor costs account for roughly two-thirds of the total reduction.<sup>37</sup>

One natural question is whether the decline in the the labor cost reflects an actual employment cut or instead a reduction in compensation. In Appendix Table (A.12), we examine this question by estimating our baseline equation using the growth rate of R&D employment (scientists and engineers) between 2007 and 2008 as our outcome.<sup>38</sup> We find that the reduction in R&D costs is accompanied by a significant reduction in R&D workers: an 0.5 unit increase in the ratio (roughly one standard deviation) is associated with an 10% decline in R&D employment growth. This result confirms that – at least in part – the relative decline in labor costs also reflected a change in employment.

This evidence confirms how labor is a crucial margin of adjustment for R&D investments. Furthermore, the stickiness of employment relationships, and the substantial costs of replacing highly skilled workers, may help to explain the absence of a quick rebound in R&D among those firms most affected by the crisis.

### 4.3 Composition of R&D

We now examine the impacts of exposure to the financial crisis on the composition of a firm’s R&D spending. Specifically, Table (3) compares impacts for Research and Development expenditures, and Table (4) compares Basic to Applied Research.

The first two columns in Table (3) show that a 0.5 point increase in the debt-to-cash ratio is associated with a 14% drop in total (basic plus applied) Research expenditures, compared to a statistically insignificant 1.5% decline in Development spending. In columns 3 and 4 we add controls, producing a slight increase in the coefficient on Research but no change for Development. We find consistent results also when we use the alternative transformations of the treatment variable discussed earlier (Table A.13).

Thus, although we cannot reject the hypothesis that firms exposed to the crisis cut their Development spending – the coefficients for this type of investment are negative, and have modest standard errors – the key take-away from this analysis is that most

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<sup>37</sup>To estimate this back-of-the-envelope number, we combine our estimated coefficients with information of the breakdown of costs in 2007, as reported by the NSF aggregate data. Table (A.11) in Appendix confirms the same results when including controls.

<sup>38</sup>The employment variable contains some missing values in either 2007 and 2008. To avoid issues with disclosure (similar to the analyses with asset tangibility), we replace the missing values of the growth rate with zeros, but then also include in the regression a dummy variable that flags these replaced observations.

cost savings came from reductions in Research. In fact, even if we take the conservative assumption that Development declined by the estimated coefficient, we find that the dollar reduction in Research is about four times the decline in Development.<sup>39</sup> This is an important finding, we think, that reinforces the standard externality-based rationale for government research support.

If the differential response of research and development is based on differences in investment duration (i.e., cash flows from research take longer to arrive), then we might expect to find a similar pattern when comparing basic to applied research. By definition, basic research is conducted without a clear commercial application in mind, and thus, it is less likely to have an immediate impact on revenue. We also note that a similar argument can be used when thinking about idiosyncratic (technology) risk. In particular, development and applied research should be characterized by lower technology risk than basic research. Table (4) explores this hypothesis.

In models with and without controls, we find that the our treatment variable has a statistically significant negative association with both basic and applied research spending. The point estimates on applied research are around 50% larger than the coefficient on basic research. These results are inconsistent with the idea that managers' response to financial frictions during the 2008 crisis was to systematically cut high-duration investments. Section (4.5) will expand on this discussion. Furthermore, the results for basic research should also alleviate concerns that firms simply cannot distinguish between "R" and "D" given that basic research is has very different characteristics from development.

Consistent with the evidence for total R&D, we find no evidence that our results merely reflect systematic trends among affected firms (Figure A.3).<sup>40</sup> At the same time, we reject the notion that the 2008 cuts were followed by a significant rebound in 2009: in general, our estimates for 2009 are relatively small and statistically non-significant for all

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<sup>39</sup>This back-of-the-envelope estimate is obtained by combining information about the elasticity of Research and Development to the shock (Table 3) and the aggregate breakdown of Research and Development, as reported by the NSF aggregate data. With this information, we then convert our elasticities in dollar changes of Research and Development.

<sup>40</sup>As mentioned before, the longer-window of estimation implies that we cannot control for projected R&D in this sample. Therefore, this figure also controls that our differences between research and development is not affected by the expectation controls: in fact, the estimates for 2008 are qualitatively identical to those reported in the main table (i.e., 3). We also report the same figures with the firm level controls (ROA, R&D intensity, and size) in Figure (A.4).

R&D sub-components.<sup>41</sup> More broadly, we do not observe any systematic pattern in R&D growth in subsequent years. However, given the nature of our model and data, we also highlight that our results do not necessarily rule out a delayed rebound.

Lastly, we examine whether our estimates differ across industries. For this analysis, we classify companies into three groups: (a) IT and Computers; (b) Science-based companies, such as Life Sciences and Chemicals; and (c) a residual group labeled Others (Appendix B). Table (5) reports the results of our baseline specification, where we estimate the effect of refinancing risk separately for the three groups. Overall, we find that the R&D activity of Science-based companies appears largely shielded from the effects of the financing shocks compared to the other two groups. While we cannot rule out some small impact for firms in Life Science or Chemicals, we find that the effect of refinancing for this group is small in size and statistically insignificant. Consistent with previous findings, we find that the reduction in R&D is almost entirely driven by cuts in research. Notably, these industry differences are not merely due to the fact that life sciences are generally more research-intensive. Indeed, we find that research intensity at the industry level does not generally mediate our effects (Table A.14).<sup>42</sup> In Section (4.5), we return to these results and discuss how these findings can help us better understand the mechanisms behind our results.

## 4.4 The Economic Impact

Given that firms exposed to the financial crisis responded by reducing R&D investments, it is natural to ask what is the broader economic impact of these findings for the firm.

The most natural starting point is to examine innovation output. To address this question, we analyze changes in the post-2008 patenting of firms with varying levels of short-term debt at the onset of the financial crisis. For several reasons, it is not obvious that we should find a sharp drop in patenting among firms most affected by the crisis.

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<sup>41</sup>If anything, we note that the largest elasticity in 2009 is estimated for development, which is the sub-component of R&D that is largely unaffected by the financing shock. While we are careful at interpreting a statistically noisy result, this result seems inconsistent with a rebound story. At the same time, this variable shows some negative effect in 2011. Given the nature of our exercise and data, we are careful at avoiding any strong claim about these results.

<sup>42</sup>This table estimates the heterogeneity of our main effects across research intensity at industry level. We define this measure by calculating the research performed over total R&D performed at the narrower industry level in 2007 data. The variable is z-scored to facilitate the interpretation of the coefficient.

First, the reduction in R&D may specifically target low-quality projects with minimal impact on future innovation output. Second, as we have already seen, spending reductions were concentrated in research, as opposed to development. We might expect research to produce fewer patents than development, given their relative proximity to commercial applications. Finally, even if the two types of investment are equally productive, the lag between research expenditures and patent applications may be longer. In Appendix Table (A.16), we report estimates from a descriptive panel regression that confirm the intuition that patents are responsive to development than to research expenditures. In particular, the elasticity of patenting with respect to lagged development is about twice the elasticity of patenting with respect to lagged research expenditures.

With those caveats in mind, Table (6) presents estimates based on the specification in equation (2) for six different measures of innovation output growth. The outcomes in columns (1) through (3) are constructed as the symmetric growth of the cumulative patent counts over a 1, 3 and 5-year post-crisis time window relative to 2007. The outcomes in columns (4) through (6) use instead cumulative citation counts over the same time period. For the one-year time horizon, we cannot reject the null hypothesis that there is no change in innovation output.<sup>43</sup> For patent counts, the point estimates suggest a 6 to 7% decline at the 3 or 5 year horizon, though again, we cannot reject the null. For citations, however, our estimates suggest that firms with greater exposure to the financial crisis exhibited a statistically significant 16 to 19% drop in innovation output over the 3 to 5 years following the crisis.

Though we remain cautious about interpreting null effects, the estimates in Table (6) do suggest the following natural interpretation. Although the financial crisis led to significant cuts in total R&D, its impact on patenting was more modest due to the stronger link between development and patenting.<sup>44</sup> Because research generates new knowledge, however, the crisis had a larger impact on forward citations. The latter results reinforce the idea that these are real effects, and raise the possibility that the composition of R&D is an important determinant of knowledge spillovers.

The reduction in R&D appears to have had a tangible impact on firms' innovation

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<sup>43</sup>We interpret this result as consistent with the validity of our experiment, since it would be hard to expect a change in R&D to have a contemporaneous effect on innovation output.

<sup>44</sup>This is also consistent with the idea that patenting behavior is also driven by firm-specific strategic considerations (e.g., Mezzanotti et al., 2022), that may attenuate the response of this metric to temporary shock.

pipeline. This interpretation is consistent with previous heterogeneity tests (e.g., Table A.7), showing that firms with greater financial slack aimed to limit the impact on R&D. However, mapping these results to welfare is challenging, as the economic costs of these decisions are hard to measure and must be weighed against the benefits of easing liquidity constraints. To start, the cost of these cuts depends on whether firms were overinvesting ex-ante; if so, the reduction may have had limited impact on the value of the firm despite its effect on innovation output. Additionally, reorganizing R&D could create efficiencies, potentially beneficial over time despite short-term costs. For instance, we find that affected firms reduced R&D spending per worker (Table A.10), suggesting increased focus on efficient spending. Overall, while the shock likely imposed costs, a precise cost-benefit analysis remains outside the scope of this paper.

## 4.5 Mechanisms

We conclude this section with some informed speculation about mechanisms that can best explain the full set of empirical results, building on the discussion in Section 2. As an initial matter, it is reassuring to find that total R&D declines for firms with greater exposure to the 2008 financial crisis. This straightforward prediction would emerge from most models of R&D investment and is consistent with the previous literature on the relevance of financing frictions for innovation (e.g., Brown et al., 2009; Hall and Lerner, 2010; Driver et al., 2020). When combined with the results showing a decline in labor costs and in 3- to 5-year cumulative patent citations, it provides some evidence that we are measuring real impacts of a change in the cost of R&D investment caused by the financial crisis.

The paper’s main result is arguably the finding that the overall decline in R&D was accomplished primarily through reductions in research. Thus, to the extent that a contemporaneous demand shock created incentives to engage in more “exploratory” research (Manso et al., 2019), that incentive was overshadowed in our setting by other factors. There are, however, several other plausible explanations for this result.

One set of factors that could lead firms to cut research by more than development are an increased preference for short-term investments (Aghion et al., 2010; Stein, 1989) or a desire to reduce technological risk as financial risk increases (Krieger et al., 2022). This interpretation is consistent with the intuitive idea that research tends to be characterized

by longer duration and higher technology risk than development. We find, however, that firms cut basic and applied research by similar amounts. At face value, this evidence cuts against the hypothesis that the financial crisis magnified a pre-existing preference for investments with a shorter duration or lower risk. On the other hand, respondents may find it relatively harder to distinguish between basic and applied research, especially if research activities are centrally managed and development takes place within business units.<sup>45</sup> However, we also note that the cross-industry evidence appears inconsistent with a mechanism tied to the need to cut duration or risk, assuming that R&D in science-based industries is, on average, of longer duration or greater uncertainty.<sup>46</sup>

Another possible explanation for our results is the difference in adjustment costs between research and development investments. In particular, our results are consistent with a model where development has greater adjustment costs than research. The key challenge is that adjustment costs can manifest in various forms. One possible idea is that differences in adjustment costs may arise from variations in cost structures. For example, labor or investments costs might be harder to adjust than material costs, and the prevalence of one type over the other could explain the heterogeneity in firm responses. While the Census data does not allow for measurement across both project type and cost category, we can use pre-crisis data to identify firms with a higher share of material and miscellaneous costs in R&D, as a possible proxy of operational flexibility. An alternative source of adjustment costs is that the ability to outsource part of the research process. External collaborations could represent a cheaper way to access knowledge (Bereskin and Hsu 2016; Bereskin et al. 2016) or may simplify R&D cuts by enabling firms to rely on external partners when rescaling up R&D. Though the exact impact on the composition of R&D is uncertain, it is reasonable to expect that research activities could be more easily outsourced, making strong external partnerships a facilitator for reducing R&D,

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<sup>45</sup>More broadly, failing to find a difference in the response of basic and applied research does not imply that risk and duration are unimportant in our setting. Instead, the test simply tries to examine whether firms systematically shifted away from activities with longer duration or higher risk. The difference in duration or risk can still play an indirect role in our findings: for instance, these features may explain why development investment is characterized by higher competitive pressure than research, as discussed below.

<sup>46</sup>For instance, if the need to cut duration was the major driving force behind companies' policies in 2008, it is reasonable to expect larger elasticities for companies with more high-duration projects. However, we approach this interpretation with caution, since R&D across industries will likely differ on a variety of dimensions that may be unrelated to duration and risk. Furthermore, we recognize that it is difficult to make strong statements about industry-level duration and risk, since these quantities are hard to measure.



particularly in research.

We explore these hypotheses in Table (A.17).<sup>47</sup> When examining cost structure (Panel A), the data show that companies with a higher proportion of flexible costs tend to reduce R&D more significantly. However, this cost structure does not seem to influence the allocation of cuts between research and development in a way that could explain our findings.<sup>48</sup> When we examine the strength of external collaborations (Panel B), our results indicate that companies with robust external partnerships are more likely to reduce research – rather than development – in response to the shock, consistent with our expectations. Despite this, our evidence suggests that external collaborations alone do not fully account for the differences in investment cuts: our estimates for firms without external collaborations (identified by the direct effect in the regression) are still negative and large in magnitude compared to the baseline results.

This evidence confirms that adjustment costs are important for understanding the magnitude of the R&D decline and, to some extent, the distinction between research and development. However, it also suggests that this mechanism alone is unlikely to fully explain the observed differences. An issue with this statement is that our analyses have so far examined only two possible channels that can generate differences in adjustment costs, while many other options may also be important. One way to generalize this hypothesis further is to investigate how firms adjust their R&D investments in response to a different shock. Adjustment costs do not depend on the specific nature of the shock studied. Therefore, if this mechanism plays a leading role in explaining our initial findings, development should always be less sensitive than research. Instead, if adjustment costs are only one of the important mechanisms at play, we may find different compositional changes depending on the shock examined.

We examine this hypothesis by studying the role of strategic incentives in explaining firms' R&D decisions in 2008 (e.g., Bloom et al. 2013; Vives 2008). In particular, we test

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<sup>47</sup>We measure the share of flexible cost as the share of material and miscellaneous costs of R&D over total R&D. We z-score this variable to facilitate the economic interpretation. Instead, we measure the intensity of external activity as the share of R&D activity paid by the firm but conducted by another entity over the total R&D expenses. In this case, the measure is not z-scored, because zero has a clear economic interpretation (i.e., companies without any external collaboration). Both measures are estimated using pre-crisis data (2007).

<sup>48</sup>Though we must be cautious with noisy estimates, the results suggest that cost structure primarily affects development rather than research, which would be inconsistent with this mechanism explaining the baseline finding..

whether a firm's investment in R&D is influenced by the refinancing need of its direct competitors' in the technology market. Companies' investments are generally influenced by the financial conditions of their peers (e.g., Campello, 2006; Chevalier, 1995; Cookson, 2017; Fresard, 2010; Grieser and Liu, 2019; Phillips, 1995). When focusing on R&D, it is reasonable to expect that a negative shock to technology peers would reduce the incentive to do R&D. In fact, both business-stealing incentives and technology spillovers—two of the leading sources of externalities identified in the literature—predict a negative relationship between a firm's R&D and its peers' exposure to a negative shock (i.e., positive externalities). However, the compositional change in R&D is less clear ex-ante.

To implement this idea, we follow Bloom et al. (2013) and use ten years of pre-2007 patent data to construct a measure of technological proximity between firms in our sample (see Appendix B for details).<sup>49</sup> This measure, denoted  $Closeness_{ij}$ , takes a value between zero (no overlap) and one (perfect overlap). Then, for each focal firm  $i$ , we compute a proximity-weighted average of other firms' exposure to the financial crisis:

$$CompShock_i = \frac{\sum_{j \in C_i} Closeness_{ij} Exposure_j}{\sum_{j \in C_i} Closeness_{ij}}$$

where  $Exposure_j$  measures firm  $j$ 's debt-to-cash ratio used in the earlier part of the paper, and the set  $C_i$  includes all patenting firms except for the focal firm  $i$ . Finally, we include  $CompShock_i$  as an additional explanatory variable in our baseline specification (equation 2).<sup>50</sup> The results are presented in Table (7).

In column 1, the outcome is total R&D performed, the direct effect is unchanged relative to baseline, and we also find evidence of peer effects, consistent with our expectation. In particular, the negative and statistically significant coefficient on  $CompShock_i$  indicates that a firm reduces R&D investment by a larger amount when technologically proximate peers also experience a negative shock. In terms of magnitude, a one standard deviation in our measure of peer exposure implies a 10 percent reduction in

<sup>49</sup>The focus of this paper is on the competitive dynamic in the creation of new technology. Consistent with this approach, we define the set of competitors using their past technological output (Bloom et al., 2013), rather than their product space (Hoberg and Phillips, 2016). In general, the set of competitors in the product and technology space may be different, and therefore we believe that our approach more accurately captures the type of competition that is relevant for our research question.

<sup>50</sup>We note that this approach does not suffer from the standard reflection problem (Manski, 1993) because it does not test for the presence of spillovers using directly the behavior of the peers, but instead exploit variation in the (pre-crisis) exposure to the financing shock.

total R&D performed. In column 2, we focus on research. For that outcome, we continue to find a statistically significant direct impact (consistent with Table 3), but the effect of peer exposure is a noisily estimated zero. Column 3 examines development, where the direct effect is statistically insignificant, but the peer exposure coefficient is negative and significant. The estimates imply that a one standard deviation change the exposure of technologically proximate firms is associated with a 16 percent decline in the growth rate of development investment by the focal firm. The results are robust to including firm-level controls (see Appendix Table A.15), and the large difference in our estimates for research and development eases concerns commonly associated with modeling peer effects in reduced form (Huber, 2022).<sup>51</sup>

Overall, the results in Table (7) indicate that peers' exposure to a financial shock matters for determining a firm's R&D investments, and that this mechanism mostly operates through development expenditures. Going back to our initial question, this evidence is inconsistent with the hypothesis that adjustment costs are the main cause of the different elasticities of research and development spending to the financial shock. If that were the case, peer effects for development should be smaller than for research. Instead, this result suggests that other mechanisms are also quantitatively important in explaining a firm's decision in allocating resources in R&D.

Lastly, the differential response between research and development could also arise from differences in the downstream impact of these investments. Net of the other mechanisms discussed, firms may prefer to cut more research than development because the nature of this investment better fits their strategic landscape. In our context, development investments may be favored because they allow firms to maintain their competitive position, preserving their ability to monetize existing technology or core products. This interpretation is consistent with the spillover result discussed above (i.e., Table 7). In particular, if development is motivated by the incentive to keep up with rivals (Harris and Vickers, 1987), whereas research is focused on adapting to long-run

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<sup>51</sup>We note that our approach is qualitatively equivalent to estimating the across firms spillover effects research and development in reduced form, as discussed in Huber (2022). As noted in this paper, this approach may be biased by the presence of measurement errors or multiple spillover dimensions. However, following the argument in Huber (2022), this concern is likely to be second-order in our context, given the large difference in estimate between the effect for research and development. In fact, the main sources of bias in our context are likely to affect similarly both the estimates for research and development, and therefore they would generally induce the two effects to be similar.

technological change (Henderson and Cockburn, 1996; Cohen and Levinthal, 1989), we would expect the former to be more responsive to expectations of rival investment and the latter to be more sensitive to changes in cost. In the extreme case, if a company's investment primarily mirrors strategic incentives, its investment may not respond to idiosyncratic firm shocks but instead adjust only based on the expected behavior of the rivals. That is what we observe. The direct impact of exposure to the financial crisis is larger for research. At the same time, development spending is correlated with the exposure of technologically similar firms (and research spending is not).<sup>52</sup> Taken together, these results suggest that the competitive salience of development may have in part explained the shift towards “D” in our setting.

The strategic benefit of preserving development investments is closely linked to a firm's success in monetizing existing products and technology. In firms already successful, the incentive to cut research and focus on development is stronger, as incremental improvements are more likely to generate high returns (Manso et al., 2019). To test this, we assess whether companies with higher pre-crisis mark-ups—as in Gutiérrez and Philippon (2017)—show differing responses to the shock (panel C of Table A.17).<sup>53</sup> Consistent with our hypothesis, companies with higher pre-crisis mark-ups show a stronger trade-off between research and development, cutting research more sharply while increasing development. This evidence supports our hypothesis that these firms are more aggressive in safeguarding their existing assets. More broadly, this test highlights how the differing roles of research and development in shaping a firm's strategy may influence the overall effect of the shock.

While we recognize the difficulty in identifying the exact mechanisms at play, we believe that these tests can provide some insights into what is driving our results. In particular, our findings can be summarized by three main takeaways. First, there is

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<sup>52</sup>We want to reiterate how the presence of a direct response for Development is not a necessary condition to rationalize the presence of a competitors' effect for the same variable. As argued, firms may decide to coordinate towards low investment if they expect that their rivals will do the same. However, the presence of this coordination mechanism does not tell us anything about the presence of a direct effect, because the firm-specific shock and the rivals' exposure are uncorrelated (i.e., a firm may experience a negative shock when competitors are not, and vice-versa). Therefore, the two mechanisms operate in a separable way.

<sup>53</sup>Following Gutiérrez and Philippon (2017), we estimate firm mark-ups (Lerner index) as operating cash flow before depreciation, minus depreciation, divided by sales. To smooth fluctuations, we use the firm's longest available pre-shock sample (2003-2007). For clarity, we winsorize this measure at 1% and convert it to a z-score.

evidence suggesting that the cut in research does not simply reflect this investment being of longer duration or higher risk. Second, while adjustment costs are important, the differences between research and development cannot be fully explained by these costs alone. Finally, pressures from the downstream market also play a crucial role, as fears of weakening the firm’s strategic position led to a more cautious approach in reducing development.

## 5 Conclusions

The paper investigates the impact of an external funding shock on R&D activity of US firms. Our identification strategy exploits variation in exposure to the 2008 financial crisis based on the amount of short-term debt (relative to liquid assets) held by a firm in 2007. A key contribution of the paper is to construct data that separately measures the various components of R&D (i.e., basic research, applied research, and development) from surveys conducted by the U.S. Census. We use these data to estimate the impact of a financial shock on the overall level R&D expenditure, and also the allocation of R&D investment across different spending categories.

Companies that entered 2008 with a higher short term debt-to-cash ratio responded to the financial crisis by cutting R&D. The effect is robust to a variety of tests, including controlling directly for firms’ *ex ante* forecasts of R&D expenditure. The majority of the reduction in R&D activity is linked to cuts in research rather than development. Firms do reduce development, however, if technologically similar peers are strongly exposed to the same crisis-induced financial shock. Finally, firms with greater exposure to the shock experienced larger declines in citation-weighted patenting within 3 to 5 years of the crisis.

This research could be extended in several directions. One natural extension is to use similar data on R&D spending, but seek alternative sources of variation in the cost of investment.<sup>54</sup> For instance, Hoberg and Maksimovic (2022) show that different types of negative shock to R&D (e.g., financial crisis vs. technology bust) may affect different stages of product development. Similarly, although the mechanisms we identify could

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<sup>54</sup>One example is Gu (2024) that examines the allocation of resources between drug research and clinical trials in response to a positive shock to the drug market in China. Consistent with our finding, the paper shows that firms have a strong preference for the later stage of R&D (i.e., clinical trials), in some cases even at the expense of reducing research. Cong et al. (2024) examines the impact of automation on innovation, finding results that are also consistent with the presence of a compositional change in R&D.

have contributed to the long-run decline in “R” documented by Arora et al. (2018), the 2008 financial crisis is not an ideal experiment for assessing the relative importance of factors that drove this longer term phenomenon. A second possible extension is to seek project-level data that allows direct measurement of R&D inputs and outputs, along with decisions to continue or abandon a given project. A third option is to find particular settings or natural experiments that can isolate the effect of particular mechanisms, such as a model of R&D competition that differentiates between research and development.

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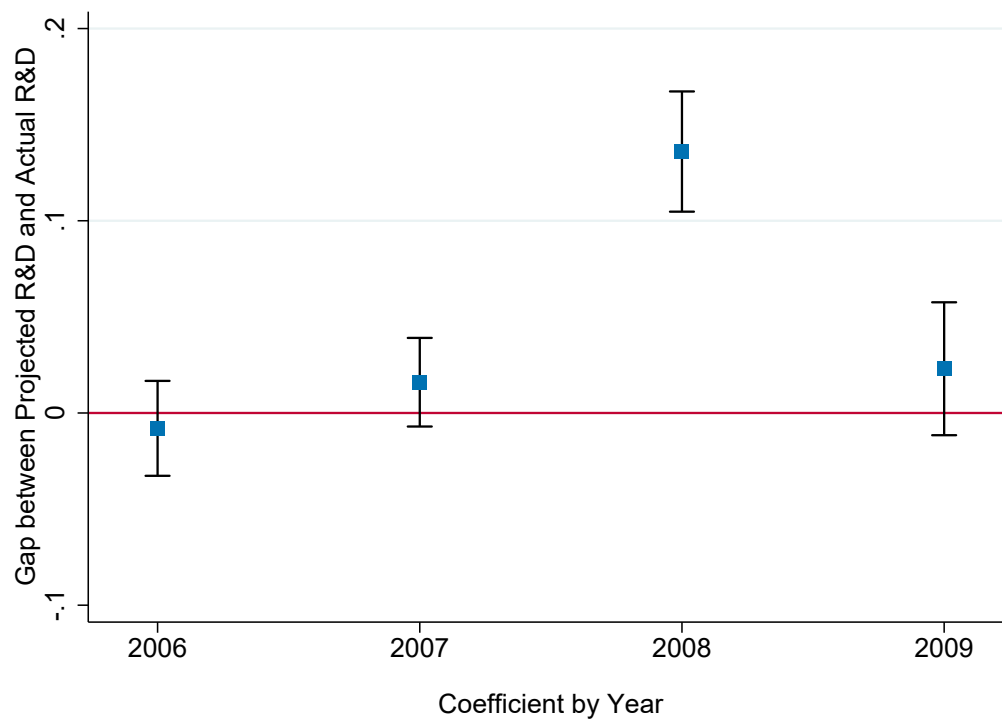
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## Figures and Tables

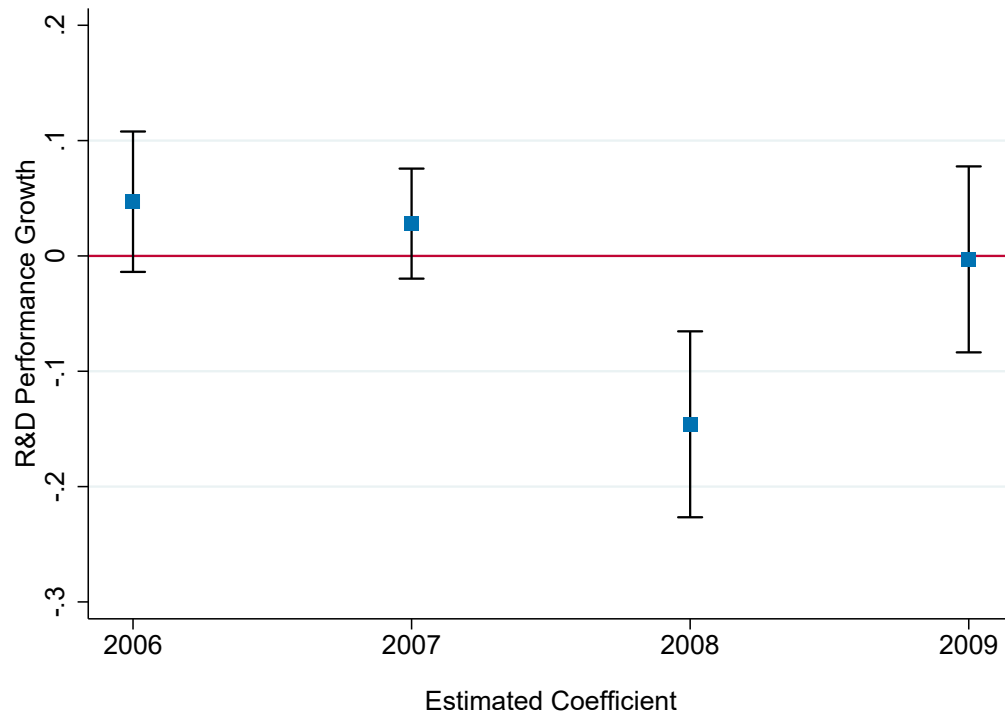
**Figure 1:** Percentage Gap: Actual vs. Expected R&D



This figure plots the average percentage difference between actual domestic R&D performed by a firm and its prediction.



**Figure 2:** R&D and Financing Need in 2008: dynamics



This Figure reports the coefficient from the estimation of equation (3). The outcome is yearly R&D growth, considered over the period between 2006 and 2009. To be clear, the growth rate is calculated between the year reported in the y-axis (post) and the year before. The coefficient reports the year-by-year effect of our main treatment variable on the outcome, with the corresponding 95% confidence interval. Industry-by-year fixed effects are included as well as the contemporaneous control for projected R&D. Standard errors are clustered at firm-level.

**Table 1: R&D and Financing Need in 2008**

	(1)	(2)	(3)
Debt/Cash	-0.165*** (0.051)	-0.141*** (0.049)	-0.150*** (0.048)
Proj R&D		X	X
Log(Revenue)			X
ROA			X
R&D/Asset			X
Industry Effects	Yes	Yes	Yes

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

This Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for domestic R&D performed between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. In column (1), we provide the baseline analysis where the only other control is the set of narrow industry fixed-effects. In column (2), we include our measure of projected R&D growth as of 2007, as described in the main text. In column (3), we augment the specification in column (2) with the listed set of firm level controls. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 2: R&D Adjustment Across Types of Costs**

	(1)	(2)	(3)	(4)
Debt/Cash	-0.162*** (0.051)	.016 (0.083)	-0.149* (0.084)	-0.216** (0.104)
Firm Controls	Yes	Yes	Yes	Yes
Projected Growth	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Wages	Inv.Depr.	Mat. Costs	Oth. Costs
Obs	1100	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider four different outcomes, which measure a specific component of R&D along the cost dimension. In particular, in column 1 we measure R&D performed used to cover labor costs; in column 2 we focus on the R&D that covers investment depreciation; in column 3, we consider R&D covering material costs; in column 4, we consider R&D covering other costs, which is a residual category. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 3: Research versus Development**

	(1)	(2)	(3)	(4)
Debt/Cash	-0.274** (0.113)	-.03 (0.079)	-0.322*** (0.112)	-.028 (0.080)
Firm Controls			Yes	Yes
Projected Growth	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Research	Development	Research	Development
Obs	1100	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider separately R&D performed that focuses on actual Research (columns 1 and 3) and Development (columns 2 and 4). The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. Columns 3 and 4 also include firm-level controls, as in the baseline model. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 4: Applied versus Basic Research**

	(1)	(2)	(3)	(4)
Debt/Cash	-0.203** (0.098)	-0.291*** (0.112)	-0.217** (0.099)	-0.339*** (0.112)
Firm Controls			Yes	Yes
Projected Growth	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Basic Res.	Applied Res.	Basic Res.	Applied Res.
Obs	1100	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider separately R&D performed that focuses on actual Basic Research (columns 1 and 3) and Applied Research (columns 2 and 4). The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. Columns 3 and 4 also include firm-level controls, as in the baseline model. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 5: Industry-level Effects**

	(1)	(2)	(3)	(4)	(5)	(6)
Debt/Cash X IT	-0.206** (0.083)	-0.354* (0.187)	-.02 (0.144)	-0.205*** (0.077)	-0.390** (0.184)	-.014 (0.143)
Debt/Cash X Science	-.041 (0.097)	-.027 (0.245)	-.053 (0.161)	-.087 (0.095)	-.132 (0.240)	-.06 (0.160)
Debt/Cash X Other	-0.143* (0.079)	-0.339** (0.166)	-.025 (0.115)	-0.141* (0.078)	-0.361** (0.167)	-.022 (0.116)
Projected Growth	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls				Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes	Yes	Yes
Outcome	Full	Res.	Devel.	Full	Res.	Devel.
Obs	1100	1100	1100	1100	1100	1100

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

This Table reports the estimate a variation of equation (2), where we interact the treatment variable with three dummy variables identifying three industry groups in the data: (1) IT and Computers; (2) Science-based; (3) Other (residual groups). The outcome is the symmetric growth rate for the various measures of R&D considered between 2007 and 2008. The specific outcome considered is reported at the bottom of the table. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. Results are presented both with and without standard controls, as reported in the table. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 6: Innovation Outputs: Patents and Citations**

	(1)	(2)	(3)	(4)	(5)	(6)
Debt/Cash	0.014 (0.071)	-0.060 (0.064)	-0.066 (0.058)	-0.081 (0.084)	-0.185** (0.076)	-0.159** (0.070)
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Projected Growth	Yes	Yes	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes	Yes	Yes
Outcome	1yr Pats	3yr Pats	5yr Pats	1yr Cits	3yr Cits	5yr Cits
Obs	1100	1100	1100	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2). The outcome is a 1, 3, or 5 year cumulative count of patents or patent citations, based on patent filing dates with 2007 as the base year. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table 7:** R&D and Financing Need in 2008: Direct and Indirect Effects

	(1)	(2)	(3)
Debt/Cash	-0.152*** (0.048)	-0.328*** (0.112)	-.026 (0.080)
CompShock	-0.779** (0.365)	.245 (0.769)	-1.182** (0.538)
Unconnected Dummy	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Projected Growth	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes
Outcome	Overall	Research	Development
Obs	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2) augmented by the average financing need of competitors, as discussed in the paper. The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider total R&D performed (column 1), only Research (column 2) and only Development (column 3). The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. e also include the variable capturing the weighted-average of the financing need for all competitors, where the weights are measured based on the technological proximity between the firm and all possible competitor. Each specification includes narrow industry fixed-effects as in the baseline. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

# Research and/or Development? Financial Frictions and Innovation Investment

Filippo Mezzanotti and Timothy Simcoe

## Appendix

### A Derivation of Analytical Results

**Model Setup** A single firm maximizes the present value of a stream of dividends,  $\pi(A_t)$ , that are an increasing and convex function of its knowledge stock, denoted by  $A_t$ . Knowledge depreciates at the rate  $\delta$  and is replenished by R&D investments. Development investments pay in the next time period, whereas research investments take an additional  $k$  periods to mature. The firms' knowledge stock therefore evolves according to  $A_{t+1} = (1 - \delta)A_t + R_{t+k}^\alpha D_t^\gamma$ . The marginal cost of investment is  $\tau$ . (Note that we can initially set the marginal cost of research and development equal to one another without loss of generality, because the parameters  $\alpha$  and  $\gamma$  will adjust to capture the rate of exchange between nominal expenditures and the real stock of knowledge.) The real interest rate is  $r$ , with associated discount factor  $\beta = \frac{1}{1+r}$ . The firm's objective can be written recursively as:

$$V_t = \max_{R_t, D_t} \pi(A_t) - \tau(R_t + D_t) + \beta V_{t+1}$$

Along any optimal investment path, the Euler equations state that a firm cannot realize a net benefit by investing an extra dollar in research (or development) in period  $t$ , and reducing investment by  $1 - \delta$  in period  $t + 1$ . In formal terms, the Euler equations for Research and Development respectively are:

$$dV_t = -\tau + \beta\tau(1 - \delta) + \beta^{k+1} \frac{\partial \pi(A_{t+k+1})}{\partial R_t} = 0 \quad (\text{A.1})$$

$$dV_t = -\tau + \beta\tau(1 - \delta) + \beta \frac{\partial \pi(A_{t+1})}{\partial D_t} = 0 \quad (\text{A.2})$$

#### Steady State Comparative Statics

For a steady-state investment path, we have  $A_{t+1} = A_{t+k+1} \equiv A^*$ . Substituting into the Euler equations and using the fact that  $\frac{1-\beta}{\beta} = r$ , we can derive a set of first-order conditions:  $\frac{\partial \pi(A^*)}{\partial D_t} = \beta^k \frac{\partial \pi(A^*)}{\partial R_t} = \tau(r+\delta)$ . Because of the convexity of  $\pi(A)$ , the equilibrium knowledge stock declines with the cost of R&D investment,  $\tau$ . Moreover, taking the ratio of these two Euler equations, and exploiting the Cobb-Douglas form of the knowledge production function, we have  $R_t/D_t = R^*/D^* = \beta^k \alpha/\gamma$ . (Note that the discussion in the text starts from case where  $k = 0$ , before moving to the more general case of  $k \geq 0$ .)

**Idiosyncratic Cost Shock** Now consider an idiosyncratic shock that raises the costs of R&D for a single period. The Euler equations will continue to hold for any optimal plan of investment. Setting A.1 equal to A.2 and rearranging terms, we can derive the following expression that characterizes R&D investment in period  $t$ :

$$\frac{R_t}{D_t} = \beta^k \frac{\alpha}{\gamma} \frac{\pi'(A_{t+k+1}) dA_{t+k+1}}{\pi'(A_{t+1}) dA_{t+1}}$$

When  $k = 0$ , this expression simplifies to  $\beta^k \frac{\alpha}{\gamma}$ , so an idiosyncratic cost shock will reduce the total amount of R&D but have no impact on its composition, as claimed in the text. (Note that this result uses only optimality, and no assumption about the steady state investment path.) When  $k > 0$ , it is harder to make analytic predictions about the short-run composition of R&D, though in the long-run it will return to the steady-state of  $\beta^k \frac{\alpha}{\gamma}$ .

## B Data Appendix

This Appendix provides additional details related to data construction.

### B.1 R&D Survey Data

The core data used in our empirical exercise is constructed by combining the output of the Survey of Industrial Research and Development (SIRD) and Business Research & Development and Innovation Survey (BRDIS). These surveys aim to provide a representative picture of the R&D activities of surveys tend for the population of for-profit non-farm businesses above five employees. As we mentioned in the paper, SIRD is a

survey of R&D that was run from 1953 to 2007, and was replaced by BRDIS starting from the 2008 data release. In terms of data construction, there are two key features of these surveys that are important to highlight. First, while the original survey output is as a repeated cross-section, large companies - in particular when active in R&D - are surveyed with high probability. Public documentations provide a more complete description of the sampling procedure, however we provide here a short description. In general, firms are classified into three strata: known positive R&D, known zero R&D, and unknown R&D. The largest firms from each strata are sampled with high probability or certainty.<sup>55</sup> This is either done by an R&D threshold, by a revenue threshold, or by being a large firm across each state. While the exact procedure changes year-by-year, this process implies that most large companies should be consistently sampled. At best of our understanding, the Census will generally follow up with sampled firms that do not respond to the survey. However, we cannot exclude that some firms may not comply with the request. As we discuss below, our final sample will focus on companies that answered the survey in both 2007 and 2008, and we follow their R&D activity between 2002 and 2012.

Second, despite the switch between BRDIS and SIRD, the core questions from SIRD are maintained also in BRDIS. As it is discussed more extensively in Mezzanotti et al. (2022), BRDIS can be considered as an extension of SIRD, which explores more in depth dimensions of the innovation activity that were missed in the early survey. For instance, among the other things, BRDIS contains a wider set of questions that cover issues like the use of intellectual property. For our study, a key aspect is that the data allows us to measure consistently the domestic R&D performed by the firm over time.<sup>56</sup> While there are also conceptual reasons to focus on this specific measure of R&D inputs, our choice is also motivated by practical reasons. In fact, this aggregate is the only measure of total R&D inputs that can be consistently measured over the period considered. More importantly, several relevant other measures used in the paper can be only constructed relative to this quantity. In particular, domestic R&D performed can be split based on the type of project that is covered by the investment: applied research, basic research,

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<sup>55</sup>The actual final sampling happens at the establishment level, rather than firm level. As a result, there are a few cases in the data of the same company having more than one establishment sampled. In this project, this is not an issue because we will match the data at Compustat data, therefore allowing us to preserve the firm-level structure of the sample. Furthermore, also among the full sample, the number of cases is quite limited.

<sup>56</sup>The question is asked with a slightly different format over time: however, the actual content should actually be perfectly consistent over time.



and development.<sup>57</sup> Similarly, we can also reconstruct how the investment was used to cover specific type of costs. We specifically divide costs across four categories: labor costs, investment depreciation, material costs, and others. Labor cost is a combination of both wages and benefits, which are measured separately in both SIRD and BRDIS.<sup>58</sup> The variable “other costs” is a residual category: this is measured directly in SIRD, and it is created by us in BRDIS by aggregating all costs that were not covered in the other categories.<sup>59</sup> Another advantage of domestic R&D performed is that for this quantity we can also measure the company’s projections for the following year. In other words, a company in year  $t$  is asked about how much R&D is expecting to perform in  $t + 1$ . This variable is available in SIRD and in BRDIS up to 2009 (i.e. the 2010 projection).

We also replicate our main results using two alternative measures of a firm’s R&D inputs: worldwide R&D performed and worldwide R&D expenditure. One limitation of these variables is that we are not able to undertake all the breakdown analysis discussed. Furthermore, it is not clear that these variables can be constructed in a perfectly consistent way across SIRD and BRDIS. For instance, when we look at worldwide R&D performed, this variable is directly measured in BRDIS. In SIRD, we can proxy it by summing domestic R&D performed and a variable measuring the R&D performed outside the US by subsidiaries for which the firm owns more than 50%. At best of our understanding, this second component may not be exactly consistent with the definition in BRDIS of what was undertaken abroad. For worldwide R&D expenditure, we face the same issue: while this quantity is measured directly in BRDIS, it is not clear that our data allows us to measure the amount of R&D that the company paid abroad when performed by firms that are not subsidiaries. Despite the differences, we are able to show that the total R&D effects are similar when using these alternatives.

We undertake an extensive data management process to confirm the quality and improve the coverage of our data set.<sup>60</sup> Given that the structure of the exact questions and the variable labels may change across surveys, we manually re-code all variables

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<sup>57</sup>While these quantities can be constructed consistently across the years, some work is necessary to achieve this goal because the structure of the underlying question changes from year-to-year. For instance, in 2008, the question asks to breakdown across the categories as a percentage of the total R&D performed, while in the other years it asks the same question in dollar.

<sup>58</sup>BRDIS 2008 actually provides a more detailed breakdown of this quantity.

<sup>59</sup>We note that the breakdown is not available for our full sample. However, both samples are approximately made up by 1,100 (following the rounding guidelines of the Census).

<sup>60</sup>Our starting point we use the edited version of each reported variable.

and construct aggregate that are consistent across years. Furthermore, while not very frequent, we also impute some missing variable, when we are confident that this information should actually be present. For instance, there are some cases where detailed R&D questions are missing but the firm reports null but non-missing total worldwide R&D. In these cases, we make sure that the variables that breakdown R&D across categories are set to zero if the firm reports the total to be zero. A special note has to be made for the 2008 survey: the survey had a check box at the very beginning asking if a company has done or paid any R&D activity. If the answer is no, the respondent skips most of the survey and only answers the second part about intellectual property. As a result, we need to set to zero all measures of R&D investments as well as R&D employment when a firm has checked the box and then responded to the questions about intellectual property.

Furthermore, to guarantee consistency in terms of sample size across outcomes, we replace missing at breakdown variables when we have the total and all but one component. We make an example to clarify this point: assume we have information on both applied and basic research and total R&D performed, but for some reason development is missing. By the definition of these variables, we can replace the missing with the difference between total R&D and research. The same logic can apply to other combination of variables. To be clear, we generally do these adjustments at the level of the full combined SIRD/BRDIS panel: already within that large sample, these changes are relatively uncommon, and they are likely to be even more uncommon (if present at all) once we consider the final sample used in this paper. We also refer to the data Appendix in Mezzanotti et al. (2022) for more information.

## **B.2 Final Sample**

The construction of final sample starts from the R&D panel described above and then only keep firms that respect the following criteria: (a) the company responded to the survey in both 2007 and 2008; (b) the company was successfully matched to Compustat during the same years (more discussion below); (c) the company is located in US and does not belong to the financial or regulated sector;<sup>61</sup> (d) reported all the main variables used in the analysis. This last filter has been imposed to make sure we satisfy the disclosure

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<sup>61</sup>We exclude firms with Compustat NAICS within 52, 92, and 813/814. We also only consider companies with positive asset and revenue in Compustat.

requirements for the Census: specifically, we want to make sure that our sample size does not change across different specifications and outcomes, therefore potentially identifying small implicit samples. Lastly, while the rounded sample size is the same as the main sample, the paper uses a slightly different sample when conducting the analysis splitting between research and development. In fact, for a small number of companies in our final sample, we do not have the split at project type.<sup>62</sup>

On top of the R&D sample, the final sample is made up of two other external data sets. First, to incorporate measures of financial conditions, we match our survey data to Compustat in order. To be clear, we are conducting the matching using the full R&D survey, before zooming on the financial crisis period. After a preliminary cleaning of Compustat,<sup>63</sup> we have first matched this data set to the Standard Statistical Establishment List (SSEL) (Miranda et al., 2006), combining together the SU, MU, and MA datasets. We conduct this procedure in different steps, and each step we remove all matched firms from the sample.<sup>64</sup> In the first step, we match based on the year and the EIN, which is reported in both samples. This step successfully matches more than half of the data. Subsequently, we proceed at matching based on the exact name after cleaning and standardizing the name, which also leads to a significant increase in coverage.<sup>65</sup> On the remaining sample, we perform a fuzzy matching followed by a manual review of all plausible matches. At the end of the matching procedure, we perform a variety of quality checks, comparing information that should be available across the two data sets, like industry and location. While we cannot exclude the presence of errors throughout the matching procedure, we are generally confident of the high-quality of our approach.

At the end, we are able to match a very large share of Compustat firms to our survey data. Once matched to SSEL, we can easily extend the matching to our combined sample of SIRD and BRDIS, and import all relevant variables. However, there are two aspects to

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<sup>62</sup>Specifically, these are cases where the firm reports total R&D but leaves applied research, basic research, and development missing. We also classify cases as missing when total R&D is positive but all sub-components are zero (which is technically impossible) or when research or development is negative.

<sup>63</sup>In particular, we remove from Compustat 2002-2016 duplicates information, ADRs and other non-standard firms, financial vehicle and royalty trusts (firms within NAICS 5221, 5239, 5259, 5311, 5331 with zero or missing employment), firms without revenue and assets. We also removed firms without NAICS or reported with fewer than 4-digit.

<sup>64</sup>To be precise, we drop from SSEL all establishment within the same firm when one establishment matches.

<sup>65</sup>Before performing the match, we clean the names before stripping away endings (e.g. inc, corp, llc, -old), standardizing abbreviations (e.g. technology and tech), and removing special characters and spaces.

discuss. First, it is important to note that - while the survey asks about the overall R&D at firm level - the actual sampling for the surveys is done at the level of the establishment. The Census aims to only sample one establishment per firm but, in a small number of cases we have more than one establishment within the same firm ID within the Census. This raises the question of which establishment to use. We observe that in most cases - when more than one establishment is sampled - only one answers the survey, consistent with the idea that a company has to provide only one response. We also note that in most cases, one establishment is sampled consistent across the years, and the second one is only sample once. We therefore deal with this issue by keeping the modal establishment within a firm over the sample period. To solve any possible tie at this point, we then keep the establishment that report firm level revenue that are closer to the Compustat number for the year. . Second, there are few cases where one Compustat firms is matched to more than one firm ID from the Census. When this happens, we recursively keep the firm that has reported sales in the survey, reported non-missing and positive R&D. If a tie still arises, we keep the largest R&D performer. To be clear, both types of issues are generally uncommon in the overall R&D panel, and they are even more uncommon when we focus on the 2002-2012 sample used in this analysis.

The second non-Census data set used in the paper is the patent data. The procedure to import this data is much easier, since we can leverage on the pre-existing linkage file developed by Dreisigmeyer et al. (2018). This file provides a direct linkage between patents and firms' identifiers available within the Census for the sample of patents granted during the period 2000 and 2015. Given the typical delay between application and grant time, this implies that our sample has a good coverage of patenting since 1997. Using this file, we import patent data from PatentsView, downloaded at the end of 2018.<sup>66</sup>

We use the patent data for two tasks. First, we construct measures of innovation outputs. In particular, we measure total patenting activity and citation-weighted patents. For both measures, we count patents based on the application year and we only considered granted patents. To avoid issues with truncation in the citation distribution (Lerner and Seru 2017), we use citations received in the first three years from the patent grant. Second, we use patent data to construct our measure of technology similarity (Bloom et al., 2013), which requires us to know both the amount of patenting activity and its distribution across

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<sup>66</sup><https://patentsview.org/>

technology classes. We estimate similarity across all the firms in our final data set (i.e. the sample of firms used in the main analyses). We follow the approach in Bloom et al. (2013), which effectively measures similarity by constructing the level of overlapping in patenting activity across firms. In other words, our measure takes value between zero and one, where zero characterizes a pair of firms with no technological overlapping and one identifies companies that operate exactly in the same technological space.

We then construct a firm-specific proxy for the exposure of technology peers; this measure is simply the weighted-average of our baseline treatment measure across all firms in the sample but the firm itself, where the weights are the proxy of the technological proximity estimated above. In other words, the measure is:  $TreatComp_i = \frac{\sum_{j \in C_i} Closeness_{ij} Treat_j}{\sum_{j \in C_i} Closeness_{ij}}$ . To measure the treatment  $Treat_j$ , we use the same variable as the baseline. For each firm, the set  $C_i$  is defined as all other firms in the data but the firm itself.

An important note is that the measure of indirect treatment can only be constructed following this procedure for firms that have done some patenting during the period considered. Given the type of firm considered in this paper, almost every company in our data had applied to at least one patent, and most of them have patented extensively. For those firms that did not patent, we replace  $TreatComp_i$  to be zero. However, we also create a dummy variable in our data that flags this small subset of firms, and always include this as a control when the variable  $TreatComp_i$ . We have followed this approach because it allows us to keep the sample consistent across analyses, therefore avoiding disclosure concerns about the presence of small implicit samples.

The final sample used in the paper is made up of about 1,100 firms that respect the criteria discussed above. While most of the analyses in the paper focus on the period 2007 and 2008, we also examine the dynamics of the effects, using data between 2002 and 2012. When interpreting these analyses, it is important to recognize that our sample is not necessarily fully balanced with the exception of the period 2007 and 2008.<sup>67</sup> Having said that, we also want to clarify two aspects. First, this issue does not affect in any way the core of our analysis, which focuses on the immediate impact of the crisis (i.e., 2007-2008).

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<sup>67</sup> A company presents in our main sample may have missing years over the period 2002 and 2012 for a variety of reasons. In particular, a firm may not be sample in our year - for either economic reasons or sampling variability -, may not be always matched, or may decided not to respond to the survey in one or more years.

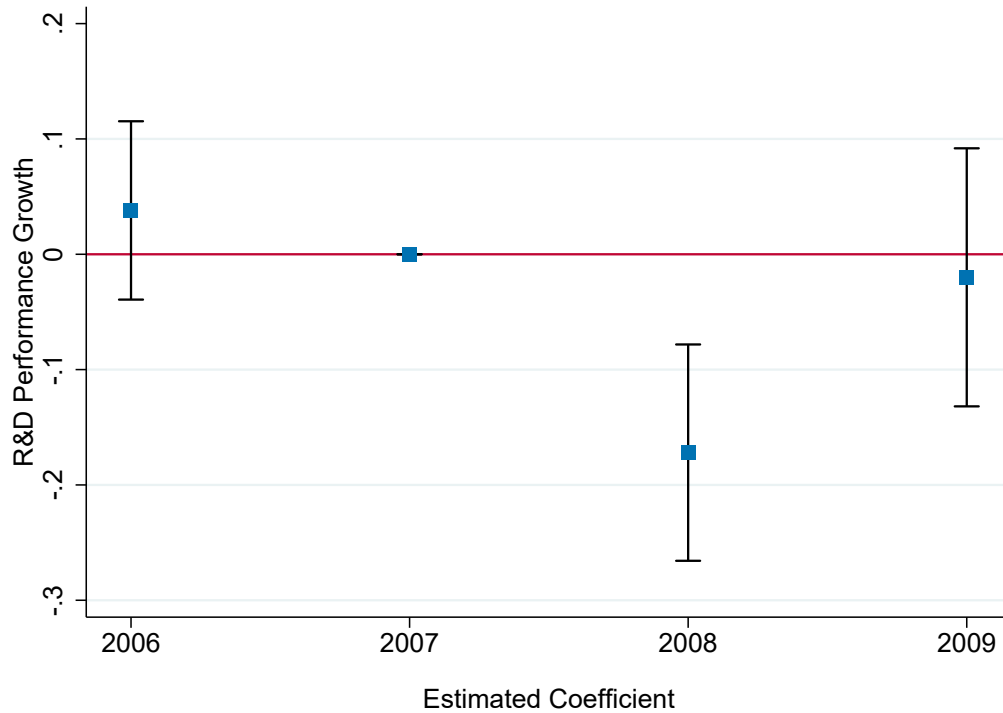
Second, this issue is also unlikely to have a first order impact on our estimates of the dynamic effects in the years around the crisis. Intuitively, survey eligibility remained stable over time, and large public firms—the focus of our study—typically experience limited churning or exit. Thus, firms reporting in 2007 and 2008 are likely to continue reporting in the years surrounding the crisis.

Data supports this intuition. While the Census restricts our ability to report exact firm count, we can infer the relevant information by comparing the rounded sample size across the different models estimated in different sample periods. For instance, the paper examines a set of figures using a short panel (e.g., Figure 2) estimated using growth rates defined over the period 2006 and 2009. The sample used in this analysis is made up by 4,000 rounded observations. If we take these rounded values at face value, this implies about 9% attrition, defined as missing firm-by-year observations. However, given the rounding, the actual attrition could be much lower. Clearly, this issue might become more significant as we move further from the crisis. Nevertheless, even when considering the longer panel analysis (e.g., Figure A.2 in the paper) over ten years of growth rates, the rounded sample count is 8,500, only about 22% lower than expected based on a simple projection.

We also examine the heterogeneity of our results by industry, using a broad industry classification that divides the sample into three groups: (a) IT and Computers; (b) Science-based industries; (c) Others. The first two groups can generally be considered as firms in the high-tech sector, while the third group comprises companies in more traditional industries. We define the industry groups based on the 4-digit NAICS codes from Compustat. Specifically, IT and Computers includes industries such as 3341, 3342, 3344, 3345, 3346, 3353, 5112, 5141, 5171, 5172, 5179, 5182, 5191, 5413, 5414, 5415, 5416, 5412, 5187, 5133, 5177. Meanwhile, science-based industries combine typical life-science firms (3254, 3391, and 5417) with companies operating in the chemical industry (i.e., 3241, 3251, 3252, 3253, 3255, 3256, and 3259). We combine these two categories to ensure our sub-sample is large enough and avoid potential disclosure issues regarding sensitive information. Lastly, the third group consists of any company not belonging to the previous two categories.

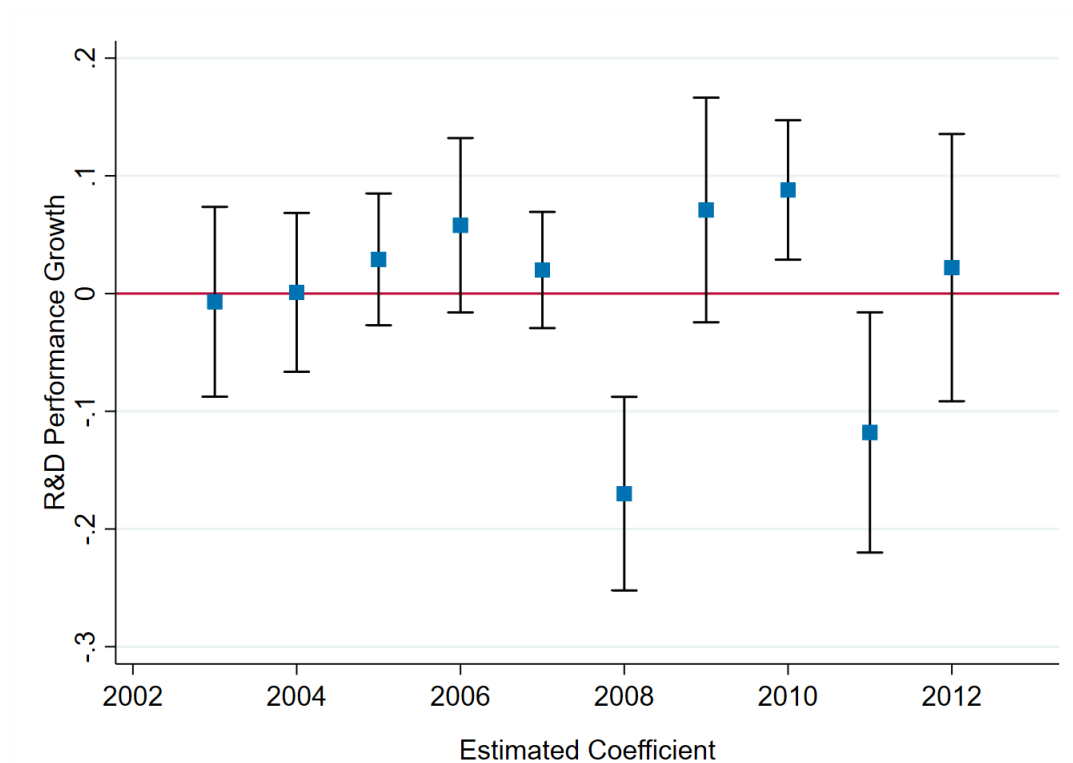
## C Supplemental Figures

**Figure A.1:** R&D and Financing Need in 2008: dynamics with firm fixed-effects



This Figure reports the coefficient from the estimation of equation (3), where we also include a firm fixed-effects. The outcome is yearly R&D growth, considers over the period between 2006 and 2009. To be clear, the growth rate is calculated between the year reported in the y-axis (post) and the year before. The coefficient reports the year-by-year effect of our main treatment variable on the outcome, with the corresponding 95% confidence interval. Industry-by-year fixed effects are included as well as the contemporaneous control for projected R&D. Because of the inclusion of the extra firm-fixed effect, we normalize the 2007 coefficient to zero. Standard errors are clustered at firm-level.

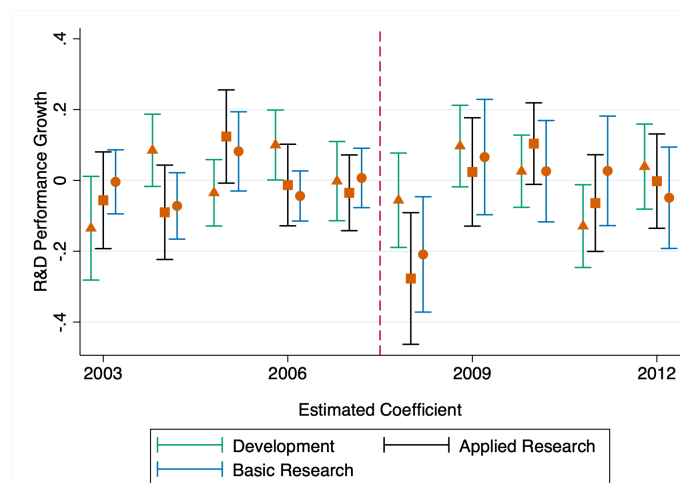
**Figure A.2:** R&D and Financing Need in 2008: longer time period



This Figure reports the coefficient from the estimation of equation (3). The outcome is yearly R&D growth, considers over the period between 2003 and 2012. To be clear, the growth rate is calculated between the year reported in the y-axis (post) and the year before. The coefficient reports the year-by-year effect of our main treatment variable on the outcome, with the corresponding 95% confidence interval. Industry-by-year fixed effects are included. Relative to Figure (2), we cannot control in this specification for the firm expected growth, since this information is not available for the full period. Standard errors are clustered at firm-level.

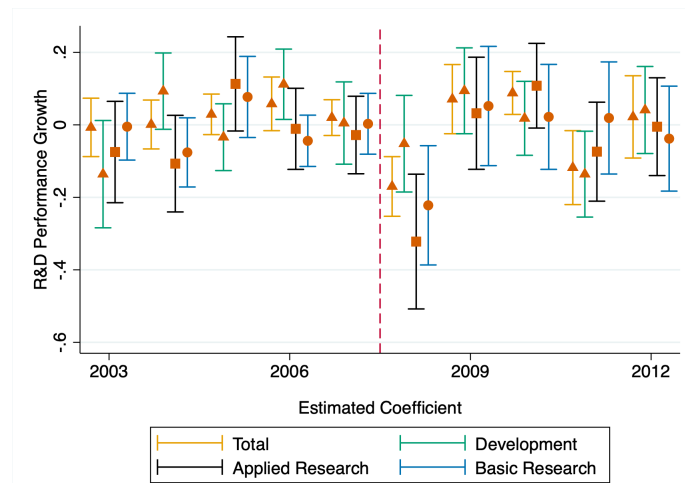


**Figure A.3:** R&D Breakdown and Financing Need in 2008: longer time period



This Figure reports the coefficient from the estimation of equation (3). The outcome is yearly three measures of R&D growth, considers over the period between 2003 and 2012. In particular, we consider development, applied research and basic research. To be clear, the growth rate is calculated between the year reported in the y-axis (post) and the year before. The coefficient reports the year-by-year effect of our main treatment variable on the outcome, with the corresponding 95% confidence interval. Industry-by-year fixed effects are included. Relative to Figure (2), we cannot control in this specification for the firm expected growth, since this information is not available for the full period. Standard errors are clustered at firm-level.

**Figure A.4:** R&D and Financing Need in 2008: longer time period with controls



This Figure reports the coefficient from the estimation of equation (3). The outcome is yearly four measures of R&D growth, considers over the period between 2003 and 2012. In particular, we consider total R&D, development, applied research and basic research. To be clear, the growth rate is calculated between the year reported in the y-axis (post) and the year before. The coefficient reports the year-by-year effect of our main treatment variable on the outcome, with the corresponding 95% confidence interval. Industry-by-year fixed effects are included. Relative to the two figures before with the long panel, this figures also includes firm control (ROA, size, and R&D intensity) measured like in the baseline analysis (Table 2) interacted with time dummies. Standard errors are clustered at firm-level.

## D Supplemental Tables

**Table A.1:** R&D and Financing Need in 2008: Alternative Specification

	(1)	(2)
Post Debt/Cash	-0.351** (0.174)	-0.354** (0.174)
Firm FE	Yes	Yes
Industry by Year Effects	Yes	Yes
Controls-by-time		Yes
Obs	2300	2300
*** p<0.01, ** p<0.05, * p<0.1		

This Table reports the estimation of the effect of refinancing needs on R&D by using the panel specification that is equivalent to equation (2). The model is estimated using the usual sample and data from 2007 and 2008. The outcome in this analysis is the (inverse hyperbolic sine transformation) of domestic R&D performed in the year. The main variable of interest is the interaction between a dummy variable identifying 2008 interacted with our usual treatment variable. Each specification includes firm fixed-effects and industry-by-year fixed effects. The second column also includes the usual firm controls (size, R&D intensity, ROA) as in Table (1), interacted with time dummies. Standard Errors are clustered at firm-level and reported in parenthesis.

**Table A.2:** R&D and Financing Need in 2008: Robustness Alternative Treatments

	(1)	(2)	(3)	(4)
Debt/Cash W1	-0.092*** (0.030)		-0.090*** (0.029)	
Debt/Cash BP		-0.083*** (0.028)		-0.080*** (0.028)
Controls	Proj R&D	Proj R&D	All	All
Industry Effects	Yes	Yes	Yes	Yes
Obs	1100	1100	1100	1100
*** p<0.01, ** p<0.05, * p<0.1				

This Table reports the estimate of equation (2), both without (columns 1 and 3) and with (columns 2 and 4) firm controls. The outcome is the symmetric growth rate for domestic R&D performed between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007. However, in columns 1 and 2, we winsorize this variable at 1%, while in columns 3 and 4 we apply a Box-Cox transformation, as described in the paper. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.3: R&D and Financing Need in 2008: Robustness Alternative Treatments**

	(1)	(2)	(3)	(4)
Short/Asset (W5)	-2.581*** (0.857)	-2.598*** (0.857)		
Short/Asset (W1)			-1.312*** (0.457)	-1.185*** (0.453)
Projected Growth	Yes	Yes	Yes	Yes
Firm Controls		Yes		Yes
Industry Effects	Yes	Yes	Yes	Yes
Obs	1100	1100	1100	1100
*** p<0.01, ** p<0.05, * p<0.1				

This Table reports the estimate of equation (2), both without (columns 1 and 3) and with (columns 2 and 4) firm controls. The outcome is the symmetric growth rate for domestic R&D performed between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the total assets in 2007. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.4: R&D and Financing Need in 2008: Robustness Alternative Outcomes**

VARIABLES	(1)	(2)	(3)	(4)
Debt/Cash	-0.133*** (0.050)	-0.089* (0.049)	-0.146*** (0.049)	-0.103** (0.048)
Projected Growth			Yes	Yes
Firm Controls			Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	World Performed	World Exp.	World Performed	World Exp.
Obs	1100	1100	1100	1100
*** p<0.01, ** p<0.05, * p<0.1				

This Table reports the estimate of equation (2), both without (columns 1 and 2) and with (columns 3 and 4) firm controls. The outcome is the symmetric growth rate for a measure of R&D between 2007 and 2008. In particular, in columns 1 and 3, we consider worldwide performed R&D while in columns 2 and 4 we consider worldwide R&D expenditure. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.5:** R&D and Financing Need in 2008: Robustness Alternative Industry Adjustment

	(1)	(2)	(3)
Debt/Cash	-0.145*** (0.041)		
Debt/Cash (W1)		-0.078*** (0.024)	
Debt/Cash (BP)			-0.052*** (0.018)
Projected Growth	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Industry Effects (4 digit)	Yes	Yes	Yes
Obs	1100	1100	1100

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

This Table reports the estimate of the full version of equation (2). The outcome is the symmetric growth rate for domestic R&D performed between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, across the three transformations considered: 5% winsorize (column 1), 1% winsorize (column 2), and Box-Cox transformation (column 3). Relative to the other analyses, we now consider fixed-effects at 4-digit NAICS, which are therefore broader than the one considered before. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.6:** R&D and Financing Need in 2008: Federal Support and Outsourcing

	(1)	(2)	(3)	(4)
Debt/Cash	.076 (0.092)	.068 (0.093)	-.013 (0.052)	-.019 (0.052)
Projected Growth	Yes	Yes	Yes	Yes
Firm Controls		Yes		Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Outsourced	Outsourced	Federally Funded	Federally Funded
Obs	1100	1100	1100	1100

This Table reports the estimate of the full version of equation (2), with alternative outcomes. In particular, in columns 1 and 2, the outcome is the symmetric growth rate for domestic R&D that was paid by the firm but performed by another entity (i.e. the amount of outsourced R&D) between 2007 and 2008. In columns 3 and 4, the outcome is the symmetric growth rate for the amount of domestic R&D performed by the firm but supported by Federal Funding between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. We also include always the standard controls in columns 2 and 4. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.7:** R&D and Financing Need in 2008: Split by Ex-Ante Financial Strength

VARIABLES	High	Low
Tangible Capital	NEGATIVE	NEGATIVE***
Leverage	NEGATIVE*	NEGATIVE
Dividend/Revenue	NEGATIVE	NEGATIVE***
Cash/EBITDA	NEGATIVE	NEGATIVE***

This Table reports the estimate of the full version of equation (2) across different sub-samples defined based on measures of ex-ante financial strength of the firm. For minimizing Census disclosure issues, we simply report the size and significance of the estimate of our main treatment variable in each subsample. The variables used to measure ex-ante financial strengths are tangible capital (i.e., fixed asset divided by total asset), leverage, Dividend divided by firm sales, cash over EBITDA, all measured in 2007. The split between high and low in these measures is done at the median of the variable distribution within the regression sample. The significance level is constructed using Heteroskedasticity Robust Standard Errors, as usual.

**Table A.8:** Funding Gap vs. Balance Sheet Strength

	(1)	(2)	(3)
Debt/Cash	-0.139*** (0.048)	-0.149*** (0.048)	-0.139*** (0.049)
Leverage	Yes		Yes
Tangibility		Yes	Yes
Projected Growth	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes
Obs	1100	1100	1100

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

This Table reports the estimate of the full version of equation (2). The outcome is the symmetric growth rate for domestic R&D performed between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. We also include always the standard controls. On top of this, we now include a measure of total leverage in 2007 (column 1), measured as total long-term debt over asset; a measure of asset tangibility in 2007 (column 2), measured as the share of fixed assets and total assets; and both variables (column 3). Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.9:** R&D across Age and R&D intensity

	(1)	(2)
Debt/Cash	-0.151*** (0.045)	-0.158*** (0.047)
Debt/Cash X Age	.011 (0.053)	
Debt/Cash X R&D Intensity		-.04 (0.046)
Age (norm.)	-.03 (0.023)	
R&D/Asset (norm.)		-0.164*** (0.035)
Controls	Yes	Yes
Industry Effects	Yes	Yes
Obs	1100	1100

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

This Table reports the estimate of a variation of (2), where we interact our main effects with firm age and R&D intensity. The outcome is the symmetric growth rate for R&D between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%, which is interacted with the z-score of: (1) Firm Age; (2) R&D intensity (measured as the control in the baseline model). Each specification includes narrow industry fixed-effects as in the baseline. In odd columns, we also include the standard controls. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.10:** Tangible Investments and R&D per worker

	(1)	(2)	(3)	(4)
Debt/Cash	-0.082** (0.039)	-0.073* (0.037)	-0.210** (0.092)	-0.189** (0.092)
Firm Controls		Yes		Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	CAPX	CAPX	R&D per worker	R&D per worker
Obs	1100	1100	1100	1100
*** p<0.01, ** p<0.05, * p<0.1				

This Table reports the estimate of the full version of equation (2). The outcome is the symmetric growth rate for CAPX and R&D per R&D worker between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. In odd columns, we also include the controls for R&D intensity, size, and ROA, measured in 2007. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.11:** R&D Adjustment Across Types of Costs: Robustness with firm controls

	(1)	(2)	(3)	(4)
Debt/Cash	-0.157*** (0.051)	.028 (0.084)	-.141 (0.085)	-0.203* (0.104)
Firm Controls				
Projected Growth	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Wages	Inv.Depr.	Mat. Costs	Oth. Costs
Obs	1100	1100	1100	1100
*** p<0.01, ** p<0.05, * p<0.1				

This Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider four different outcomes, which measure a specific component of R&D along the cost dimension. In particular, in column 1 we measure R&D performed used to cover labor costs; in column 2 we focus on the R&D that covers investment depreciation; in column 3, we consider R&D covering material costs; in column 4, we consider R&D covering other costs, which is a residual category. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects and firm controls as in the baseline. Heteroskedasticity Robust Standard Errors are reported in parenthesis.



**Table A.12:** R&D Employment and Financing Need in 2008

	(1)	(2)
Debt/Cash	−0.229*** (0.073)	−0.215*** (0.073)
Projected Growth	Yes	Yes
Firm Controls		Yes
Industry Effects	Yes	Yes
Outcome	# Scientist	# Scientist
Obs	1100	1100

This Table reports the estimate of the full version of equation (2). The outcome is the symmetric growth rate for the number of R&D employees in the firm between 2007 and 2008. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. Each specification includes narrow industry fixed-effects as in the baseline. We also include always the standard controls in column 2. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.13:** Research versus Development: Alternative Treatment

	(1)	(2)	(3)	(4)
Debt/Cash W1	-0.143*** (0.043)	-.025 (0.031)	-0.151*** (0.042)	-.023 (0.031)
Controls	Projected Growth	Projected Growth	All	All
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Research	Development	Research	Development
Obs	1100	1100	1100	1100

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

Panel (a)

	(1)	(2)	(3)	(4)
Debt/Cash BP	-0.143*** (0.044)	-.038 (0.031)	-0.151*** (0.044)	-.031 (0.031)
Controls	Projected Growth	Projected Growth	All	All
Industry Effects	Yes	Yes	Yes	Yes
Outcome	Research	Development	Research	Development
Obs	1100	1100	1100	1100

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

Panel (b)

The two panels in Table reports the estimate of different versions of equation (2). The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider separately R&D performed that focuses on actual Research (columns 1 and 3) and Development (columns 2 and 4). The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007: however, this treatment is transformed differently across panels. In particular, this is winsorized at 1% in panel (a), and it is transformed using a Box-Cox transformation as in the main analysis in panel (b). Each specification includes narrow industry fixed-effects as in the baseline. Columns 3 and 4 also include firm-level controls, as in the baseline model. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.14: Heterogeneity Across Research Intensity**

	(1)	(2)	(3)
Debt/Cash	-0.150*** (0.048)	-0.317*** (0.111)	-.029 (0.080)
Debt/Cash X Research Int	.022 (0.045)	.056 (0.115)	-.04 (0.087)
Proj R&D	Yes	Yes	Yes
ROA	Yes	Yes	Yes
Log(Revenue)	Yes	Yes	Yes
R&D/Asset	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes
Outcome	Full	Research	Development
Obs	1100	1100	1100

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

This Table reports the estimate of a variation of (2), where we interact our main effects with Research Intensity. The outcome is the symmetric growth rate for a measure of R&D between 2007 and 2008. The exact outcome is reported in each column. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%, which is interacted with the z-score of industry research intensity. This measure is calculated as the average share of research over total R&D in the narrow industry in which the firm belongs in 2007. Each specification includes narrow industry fixed-effects and the standard controls. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.15:** R&D and Financing Need in 2008: Direct and Indirect Effects, with controls

	(1)	(2)	(3)
Debt/Cash	-0.143*** (0.049)	-0.274** (0.113)	-.031 (0.079)
CompShock	-0.626* (0.360)	.356 (0.766)	-1.159** (0.538)
Unconnected Dummy	Yes	Yes	Yes
Firm Controls			
Projected Growth	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes
Outcome	Overall	Research	Development
Obs	1100	1100	1100

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

This Table reports the estimate of different versions of equation (2) augmented by the average financing need of competitors, as discussed in the paper. The outcome is the symmetric growth rate for the measure R&D considered between 2007 and 2008. In particular we consider total R&D performed (column 1), only Research (column 2) and only Development (column 3). The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%. We also include the variable capturing the weighted-average of the financing need for all competitors, where the weights are measured based on the technological proximity between the firm and all possible competitor. Each specification includes narrow industry fixed-effects and firm controls as in the baseline. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.16:** Elasticity of Patenting: Research versus Development

	(1)	(2)	(3)
Lag IHS(Research)	0.014*** (0.002)		0.020*** (0.003)
Lag IHS(Development)		0.033*** (0.004)	0.039*** (0.004)
Lagged Outcome	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Outcome	Patents	Patents	Patents
Obs	7800	7800	7800

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

This Table reports results from a descriptive panel regression of patent applications on lagged Research (R) and/or Development (D) expenditures, as discussed in the paper. Specifically, we estimate the elasticity of patenting with respect Research (column 1), Development (column 2) or both (column 3). Both R and D are lagged by one-year and transformed using the inverse hyperbolic sine function. The 1-year lagged of the outcome is included as a control. Heteroskedasticity Robust Standard Errors are reported in parenthesis.

**Table A.17**

	(1)	(2)	(3)
Panel a: Operational Rigidity			
Debt/Cash	-0.152*** (0.047)	-0.319*** (0.112)	-.03 (0.080)
Debt/Cash X Share Easy Cut	-0.075* (0.044)	.057 (0.091)	-.049 (0.065)
Share Easy Cut (z-scored)	-0.053* (0.031)	-.046 (0.069)	-.018 (0.053)
Panel b: R&D Outsourcing			
Debt/Cash	-0.167*** (0.050)	-0.255** (0.117)	-.05 (0.084)
Debt/Cash X Share External	.318 (0.387)	-0.780* (0.432)	.238 (0.377)
Share External	.328 (0.226)	.629 (0.406)	-.517 (0.375)
Panel c: Firm Mark-up			
Debt/Cash	-0.149*** (0.047)	-0.296*** (0.109)	-.047 (0.078)
Debt/Cash X Markup	-.006 (0.025)	-0.156** (0.068)	0.132** (0.065)
Markup (z-scored)	-.025 (0.020)	.041 (0.050)	-.073 (0.048)
Firm Controls	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes
Outcome	Full	Research	Development
Obs	1100	1100	1100

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

This Table reports the estimate of a variation of (2), where we interact our main effects with different firm-level variables. The outcome is the symmetric growth rate for a measure of R&D between 2007 and 2008. The exact outcome is reported in each column. The main treatment variable is the ratio between debt due in 2008 relative to the liquid assets in 2007, winsorized at 5%, which is interacted with three measures across the panels. In the first panel, we exploit heterogeneity across firms in their operational rigidity, measured as the share of total R&D performed made up of labor and investment costs in 2007, z-scored. In the second panel, we compare firms based on the extent to which they outsourced R&D: we measure this dimension by calculating the share of the worldwide expenditure in R&D in 2007 that is made up R&D paid by the firm but conducted by others. This measure is not z-scored, and therefore the coefficient for the treatment variable can be interpreted as the effect for those firms with zero outsourcing. The third panel exploits variation in the mark-ups across firms, measured using the Lerner index as in Gutiérrez and Philippon (2017). This measure is z-scored. Each specification includes narrow industry fixed-effects and the standard controls. Each specification includes the narrow industry fixed-effects and the usual controls. Heteroskedasticity Robust Standard Errors are reported in parenthesis.