Research and/or Development? Financial Frictions and Innovation Investment

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May 2023

Abstract

U.S. firms have reduced their investment in scientific research ("R") compared to product development ("D"), raising questions about the returns to each type of investment, and about the reasons for this shift. We use Census data that disaggregates "R" from "D" to study how US firms adjust their innovation investments in response to an external increase in funding cost. Companies with greater demand for refinancing during the 2008 financial crisis, made larger cuts to R&D investment. This reduction in R&D is achieved almost entirely by reducing investment in research. Development remains essentially unchanged. If other firms patenting similar technologies must refinance, however, then Development investment declines. We interpret the latter result as evidence of technological competition: firms are reluctant to cut Development expenditures when that could place them at a disadvantage compared to potential rivals.

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 74% of total U.S. investment in Research and Development (R&D) in 2019.[1] 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 be to 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.

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) that exploit variation in firms' refinancing needs during a financial crisis to construct a measure of short-run financial constraint. To be precise, 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 therefore should be more likely to cut down internal activity to minimize their 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 research – both basic and applied – as opposed to development. Furthermore, approximately two-thirds of the reduction in

[1]The amount spent was estimated at $493 billion. See links: https://ncses.nsf.gov/pubs/nsf22303#:~:text=In%202019%2C%20of%20the%20%24493,billion%20(78%25)%20on%20development and https://ncses.nsf.gov/pubs/nsf22330.

R&D can be attributed to a cut in R&D-specific labor costs. Using panel data, we show that exposure 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 had an impact on innovation output, we try to understand why development investments are "stickier." We argue that our findings cannot be easily explained by differences between research and development in investment duration, risk, or adjustment costs. Instead, our evidence suggests that the nature of technological competition may play a significant role in explaining our findings. In particular, we show that whereas research investment is sensitive to a firm's own refinancing needs, development investment declines when other technologically similar firms are exposed to an increase in the cost of refinancing. We interpret this finding as evidence that development investments are influenced by strategic interactions (e.g., Benoit, 1984; Bolton and Scharfstein, 1990; Fudenberg and Tirole, 1986), and specifically a desire to keep up with rivals (Harris and Vickers, 1987).

Altogether, our findings show that periods of crisis may affect the trajectory of innovation of an economy by altering both the amount of resources committed to R&D as well as the types of projects that are undertaken. Furthermore, we also highlight the importance of the strategic interactions to determine the investment allocation.

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).[2] 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;

[2]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.

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 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.[3]

This paper contributes to several areas in economics interested in understanding the determinants of innovative activity. While a large body of work has focused on how various economic forces influence the output of the innovation process (mostly focusing on patenting),[4] we have a much more limited understanding of how inputs are selected. As we discussed earlier, data availability likely explains the more limited number of studies focusing on this dimension. This distinction between input versus output is important for at least two reasons. First, if we are interested in understanding how changes in the economic environment will affect firms' incentives, studying the ex-post output will examine this question only indirectly. Second, innovation output is measured largely using patent data. Despite the importance of this data in the field, the use of patent data may be less than ideal in some contexts (Lerner and Seru, 2017). Differences in patenting among firms can be attributed to a variety of factors that may not directly relate to the innovation itself (Mezzanotti et al., 2022). As a result, patent data may not always fully capture the underlying change in investment, in particular when we study the response to relatively short-lived shocks, like in our case. Furthermore, patenting behavior should be affected by both the level of R&D and its composition. For example, we show that patenting is more responsive to changes in development than research. Therefore, studies that solely rely on patents may be more biased toward the later stages of the innovation process.

[3]This question is particularly interesting in light of some interesting results 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 companies' CEO listed technology investments as one of the most affected areas during the unfolding of the 2008 crisis.

[4]Just to cite a few, the previous literature has provided some evidence on how innovation output is affected 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), and exposure to innovation (e.g., Bell et al., 2019), taxation (e.g., Akcigit et al. 2017), among other things.

Thanks to our data, we contribute to this literature in two main ways. First, we show that negative shocks to the firm may 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 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 the corporations' funding pushes university researchers to focus on more applied and less impactful work.[5] 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).

Our second key contribution is to emphasize the critical role of strategic interactions between companies in determining firms' investment choices. Companies try to exploit the financial weakness of their peers, for instance by cutting prices or increasing investments (e.g. Campello, 2006; Chevalier, 1995; Cookson, 2017; Fresard, 2010; Grieser and Liu, 2019; Phillips, 1995). Our findings indicate that a firm may anticipate its competitors' reactions and ex-ante avoid cutting investments in areas where the cost of strategic response from peers is high. Specifically, our results align with a model in which competition from technology peers has a greater impact on determining investments in development rather than research. As a result, companies are less likely to make changes to their development plans following an unexpected negative shock. This evidence is consistent with the theoretical framework in Doraszelski et al. (2022), that shows how higher financial frictions may not necessarily lead to lower investments when taking into account strategic interactions.

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

[5] This result is also consistent with the descriptive evidence in Driver et al. (2020), which shows that companies with less financing issues (i.e., public companies in their study) tend to invest relatively more in research relative to development.

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.[6] Consistent with the 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) and Krieger et al. (2022). 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. Relative to this paper, we now also provide direct evidence that shocks to financing will affect also the composition of the investments. 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.

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 experience to produce new and significantly improved goods, services, or process."[7]

[6]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). From an historical perspective, this contribution also relates at the literature focused on the effect of the unfolding of the Great Depression on innovation output (Babina et al., 2023; Nanda and Nicholas, 2014).

[7]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.")

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 byA_t. Knowledge depreciates at the rate δ and is replenished by R&D investments. Assuming a Cobb-Douglas knowledge production function, the law of motion for the firms' knowledge stock is $A_{t+1} = \delta A_t + R_t^{\alpha} D_t^{\gamma}$. 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:

$$V_t = \max_{R,D} \pi(A_{t-1}) - R - D + \beta V_{t+1}$$

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.[8] 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 instance, in the context of the paper's empirical exercise, you can interpret τ as the marginal funding cost faced by R&D investments this year. For that period, the Euler equations become $\frac{\partial \pi(A_{t+1})}{\partial I_t} = r + \delta + \kappa$, where $\kappa = (\tau - 1)/\beta$ and $I_t \in R_t, D_t$. Not surprisingly, investment in both research and development declines when the cost of investing internal resources in new projects increases. The first part of our empirical analysis measures the size of this effect. A more interesting prediction of this simple model is that the size of the shock, τ, has no impact on the share of total spending devoted to research or development (which remains fixed at $R^*/D^* = \alpha/\gamma$).

However, this prediction may change if we modify our assumptions slightly. First, suppose research investments take more time to bear fruit, so the knowledge stock evolves according to $A_{t+1} = \delta A_t + R_{t-1}^{\alpha} D_t^{\gamma}$. For this knowledge production function, if firms expect

[8] Derivations of any results mentioned in this section are provided in Appendix A.

the costs of R&D to remain at τ, then the composition of R&D investment will converge to $R^*/D^* = \frac{\alpha}{\gamma}\frac{\tau r+\delta}{\tau(2r+r^2)+\delta} < \frac{\alpha}{\gamma}$.[9] Intuitively, longer lags between research investments and associated dividends (compared to development) increase the opportunity cost of research. It is easy to verify that increasing τ will amplify this affect, producing a larger shift towards development. While this shift is purely a function of investment duration within our framework, the literature describes several closely related mechanisms that could generate a similar prediction. Stein (1989), for example, shows how myopic managers may avoid cutting activities that impact short-run profits even when the present value of two projects is the same.[10] Alternatively, one can tie a change in the composition of R&D with differences in technology risk between R and D. For instance, Krieger et al. (2022) show that pharmaceutical firms take more technology risk (analogous here to increasing research) when financial risk declines due to a positive cash-flow shock.

Changes in demand are a second channel that could shift the composition of R&D investment. In particular, if higher interest rates coincide with demand contractions (as in the 2008 financial crisis), then long-term projects to become more attractive. For example, suppose the firm in our simple model learns (by surprise) that next period dividends 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."[11] Indeed, versions of this argument can be found in Schumpeter (1939) as well as many later models of investment.[12]

Considering adjustment costs is another crucial dimension in understanding the response of firms to shocks (e.g., Hall and Van Reenen 2000). If firms are characterized by comparable adjustment costs across both research and development, then these costs

[9]We focus on steady-state comparative statics because characterizing the dynamic response to an idiosyncratic shock is complex, and adds little to our discussion of the underlying mechanisms.

[10]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.

[11]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.

[12]See, for example, Aghion and Saint-Paul (1998); Caballero et al. (1994); Canton and Uhlig (1999); Cooper and Haltiwanger (1993); Kopytov et al. (2018)

will primarily affect the magnitude of the response, rather than the composition of investments.[13] However, if there is heterogeneity in the adjustment costs associated with different types of investments, this could result in varying degrees of sensitivity to shocks. While the exact response will depend on how this mechanism is modeled, intuitively investments that are easier to modify will be characterized by higher elasticity.

Finally, competition may influence how firms' R&D investments respond to changes 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).[14]

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 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.[15] Finally, the innovation literature suggests that the ability to learn from

[13]This is why it is trivial to expect firms to cut R&D. If R&D investments are characterized by higher adjustment cots 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).

[14]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.

[15]Note that this hypothesis will produce a similar prediction than the one based on cash-flow duration

"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-cut. 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 strategic interactions between 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.[16] 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.[17] In addition to the distinction between 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.[18] In 2007 (the relevant pre-period for our study) the

or risk. However, the mechanism would be totally different. If this hypothesis is economically important, firms' investments should also depend on what technology peers are expected to do, which in turn will depend on whether these companies are exposed to the same shock.

[16]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.

[17]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.

[18]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

aggregate corporate sector in US 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.[19]

There are a few features of the survey data that are worth highlighting. First, although SIRD and BRDIS are structured as repeated cross-sections, both surveys over-sample large firms and known R&D performers. In particular, large companies - especially when active in R&D - are generally always sampled.[20] Therefore, for this subset of firms, it is possible to construct a panel data set. Second, while the Census replaced SIRD with BRDIS around 2007, the core R&D-related questions in SIRD were kept in BRDIS. In particular, 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.

Our primary outcome variables are based on domestic R&D performed by the firm.[21] As a practical matter, this is the main measure of R&D activity that can be consistently measured across the two surveys, and several key variables can be easily constructed starting from this aggregate.[22] 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 also conduct some robustness tests using worldwide R&D performed by the firm or R&D expenditure.

We match the survey data to Compustat to obtain firm-specific measures of the scale of the 2008 financial crisis, and are left with an estimation sample containing roughly 1,100 large U.S. firms. To be precise, our analyses focus on those firms that: (a) were sampled in both 2007 and 2008; (b) were matched to Compustat; (c) are not financial firms or companies active in regulated sectors; (d) reported all of the main variables used in the analysis. Appendix (B) contains a detailed discussion of the data and matching procedure,

understanding without specific immediate commercial application or use."

[19]The summary statistics reported come from NSF publicly available aggregate data.

[20]While the exact sampling rules change year-by-year, both surveys tend to target the population of for-profit non-farm businesses above five employees.

[21]Supplemental analyses show that we obtain qualitatively similar results if worldwide R&D performed or total R&D spending are used as outcomes.

[22]For instance, the breakdown between applied research, basic research, and development is constructed relative to this quantity.

while the balance of this Section discusses several key issues.

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 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."[23] Moreover, our research design has the potential to alleviate some of the concerns related to measurement. First, our sample is made up by firms that (in most cases) have been responding to the survey for many years, and should 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.[24]

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., τ 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.[25] Consistent with other studies that use a similar approach (e.g. Almeida et al. 2009; Benmelech et al. 2019; Costello 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

[23] See https://www.nsf.gov/statistics/srvyberd/prior-descriptions/overview-brdis.cfm#collection

[24] 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.

[25] 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.

incentive to cut internal spending because they otherwise are compelled to access capital markets during periods of limited and costly funding options (Santos, 2011).[26] 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 during the crisis. 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):

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

where $GrowthR\&D_{i,2008}$ is the symmetric growth rate of R&D performed by firm i between 2007 and 2008, and $Exposure_i$ is the ratio of current debt to liquid assets in 2007 (winsorized at 5%).[27] The specification includes narrow (6-digit NAICS) industry fixed-effects, $\alpha_{ind(i)}$, 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).[28]

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

[26] 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).

[27] We use the symmetric growth rate to flexibly accommodate changes in R&D at both the intensive and extensive margin (Decker et al., 2014).

[28] 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.

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, $ProjGrowt_{i,2008}$, that allows us to control directly for the expectations at the start of 2007.[29] Controlling for growth leads to a our baseline specification:

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

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 represents an unexpected shock for firms and had a meaningful impact on corporate investment.[30] 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, we estimate the following model:

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

where t is equal to 2003-2012, and represents the post-year in the growth rate.[31] The coefficients β_t measure the correlation between financial exposure in 2007 and R&D growth in year t.[32] Plotting these dynamic treatment effects allows us to check for any

[29]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.

[30]Almeida et al. (2009) suggest that credit markets began to deteriorate in late 2007, prior to the arrival of a full-blown crisis in 2008.

[31]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.

[32]As we discuss when we present the result, one issue with using a longer panel is that the measure

pre-crisis correlation between financial exposure and R&D investment, and to evaluate whether any post-crisis response is permanent or transitory.[33]

4 Results

4.1 Baseline

We now 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.

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 identification assumption, however, by checking for a correlation between the treatment variable and pre-treatment trends in R&D growth. Figure (2) plots estimates of dynamic treatment effects, based on estimating equation (3) with the years 2006-2009. 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.[34] 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 (A.2), which uses

of expectation is not consistently measured throughout the sample. Therefore, we provide our results including $ProjGrowt_{i,t}$ 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.

[33]When we use the full panel data set, we cluster our standard errors at the firm level.

[34]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.

data going back to 2002.[35] 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.

These tests also allow us to gain some insights on firms' R&D adjustment post 2008. Across all the different specifications, we consistently find no statistically significant correlation between exposure to the crisis and R&D expenditure growth in 2009. In particular, firms that reduced R&D in 2008 did not have a "rebound" (i.e. positive coefficient) the following year. This indicates that R&D reductions in 2008 were not simply a postponement of investment. Instead, the reduction in R&D investments persisted longer than the financial crisis.[36] Evidence on the composition of R&D costs will provide some explanation for the persistence.

The results in Table (1) are robust to various changes in measurement and model specification. For example, Appendix Table (A.1) shows that winsorizing $Exposure_i$ at the 1% level or applying a Box-Cox transformation does not alter the results. Similarly, Appendix Table (A.2) 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.[37] Lastly, Appendix Table (A.3) shows that results are not meaningfully changed by adopting a specification with 4-digit rather than 6-digit NAICS industry effects.

We also show that our results do not depend on the specific measure of R&D used. In fact, Appendix Table (A.4) 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.[38] 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

[35]It is useful to point out that Figure (A.2) does not control for projected R&D growth, as this information is not consistently available for the full sample period. Furthermore, as we move away from 2008, the sample suffers from some attrition, as some companies may not be surveyed every year.

[36]Figure (A.2) also reports the estimates post-2009. The results 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. While we recognize the difficulty of interpreting the effect of the 2008 shock as we move far from the treatment year, we interpret this evidence as consistent with affected companies trying to limit the long-term impact of the 2008 financing shock.

[37]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.

[38]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).

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).

Finally, Table (A.5) adds controls for asset tangibility (e.g., Almeida and Campello, 2007) and the firm's leverage ratio, to control 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.[39] Adding these extra controls, individually or in combination, does not significantly change our main coefficient estimates.

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.[40] 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 similar to our baseline estimates for total R&D, which implies that labor costs account for roughly two-thirds of the total reduction.[41]

One natural question is whether the decline in the the labor cost reflects an actual

[39]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.

[40]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.

[41]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.7) in Appendix confirms the same results when including controls.

employment cut or instead a reduction in compensation. In Appendix Table (A.8), 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.[42] 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 workers 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. Thus, although we cannot reject the hypothesis that firms exposed to the crisis cut their Development spending – the coefficients in columns 2 and 4 are negative, and have modest standard errors – the key take-away from Table (3) is that most cost savings came from reductions in Research. 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,

[42]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.

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. 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.

4.4 Innovation Output

Given that firms exposed to the financial crisis responded by reducing R&D investments, it is natural to ask whether we also observe a drop in innovation output. Specifically, we analyze changes in the post-2008 patenting of firms with varying levels of short-term debt at the onset of the financial crisis. It is not obvious that we should find a sharp drop in patenting among firms most affected by the crisis. Firstly, 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. Moreover, 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.10), we report estimates from a descriptive panel regression that seem to confirm this intuition. 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 (5) 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.[43] 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 (5) do suggest the following natural interpretation. Although the financial crisis led to significant cuts in total R&D, impact on patenting were modest likely due to the stronger link between development and patenting.[44] Because research generates new knowledge, however, we observe 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.

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. 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 R&D costs created 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.

[43]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.

[44]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.

One set of factors that could lead firms to cut research by more than development are an increased preference for short-term cash flows (Stein, 1989) or a desire to reduce technological risk as financial risk increases (Krieger et al., 2022). We find, however, that firms cut basic and applied research by similar amounts. This evidence goes against the hypothesis that the financial crisis magnified a pre-existing preference for investments with a shorter duration or lower risk.[45]

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 in which development is characterized by larger adjustment costs than research. To assess the plausibility of this hypothesis, we can investigate how our firms adjust their R&D investment in response to a shock distinct from the one previously studied. In fact, the importance of adjustment costs does 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.

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 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). Therefore, we expect that a firm's investment in R&D should be also affected by the degree to which its technology competitors are exposed to large refinancing risk during the 2008 financial crisis. However, both the direction of this response and (more importantly) the compositional change in R&D are 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).[46] This measure, denoted $Closeness_{ij}$, takes a value between

[45]To be clear, we are not implying that risk and duration are unimportant in our setting. Instead, we simply want to highlight that firms did not simply reduce R&D by shifting 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 the development may be characterized by higher competitive pressure than research, as discussed below.

[46]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.,

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). The results are presented in Table (6).

In column 1, the outcome is total R&D performed, the direct effect (i.e., the coefficient on $Exposure_i$) is unchanged relative to baseline, and we also find evidence of the peer effects. In particular, the negative and statistically significant coefficient on $CompShock_i$ indicates that a firm cuts R&D more extensively 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 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. Finally, column 3 reports estimates for development. The direct effect is small and statistically insignificant. The coefficient on peer exposure, however, 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 development by the focal firm. The results in Table (6) are robust to including firm-level controls (see Appendix Table A.9), and the large difference in our estimates for research and development eases concerns commonly associated with modeling peer effects in reduced form (Huber, 2022).[47]

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.

[47] 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.

Overall, the results in Table (6) indicate that peers' exposure to a financial shock matters for determining R&D investments, and this mechanism mostly operates through an adjustment in development. Going back to our initial question, this evidence is inconsistent with our hypothesis that adjustment costs explain the difference in sensitivity between research and development. If that were the case, we should have found also in this case that development had adjusted less than research.

The alternative mechanism that we think best fits the data is related to strategic interactions. 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 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 the cost.[48] 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). In simple terms, the evidence suggests that financial frictions cause R&D investments to shift towards "D" because of its competitive salience.

These results suggest that the differential response between research and development is unlikely to simply reflect differences in duration, risk, and adjustment costs between the two types of investment. At the same time, our evidence suggests that strategic considerations may have played a role in determining a firm's allocation.

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 that separately measures the various

[48]For example, consider a simple model where a firm's investment D_i depends on both a firm-specific parameter (s_i) and rival behavior (D_{-i}), such that $D_i = \alpha s_i + (1-\alpha)D_{-i}$. In this context, a firm's investment in equilibrium is given by $D_i = \alpha s_i + (1-\alpha)s_{AVE}$, where s_{AVE} is the average of the firm-specific parameter in the sample. An important underlying assumption in this framework is that companies cannot easily coordinate towards "low investment." They can, however, observe one another's *ex ante* financial conditions, and use this information to understand how costly it would be for competitors to invest. In other words, the average shock experienced by peer companies can act as a public signal and aid in coordination among firms within the same technology sector (Morris and Shin, 2001).

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 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.

We consider several mechanisms that could explain our findings, and argue that the best explanation highlights the role of competition in determining the composition of private R&D investments. In particular, the fact that development is less sensitive to direct cost shock than research (but more sensitive to the cost shock at technically proximate firms), is consistent with the idea that competitive pressure is relatively more important for development. Thus, although investment-specific characteristics are important to determine a firm's decision during the business cycle, our evidence suggests that the nature of interaction between peers may also significantly affect the investment dynamics.

Finally, 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. For instance, Hoberg and Maksimovic (2022) show that different types of negative shock to R&D (e.g., financial crisis vs. tech bust) may affect different stages of product development. Another possibility 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 settings where it is possible to estimate a more explicit model of competitive interactions in R&D investment.

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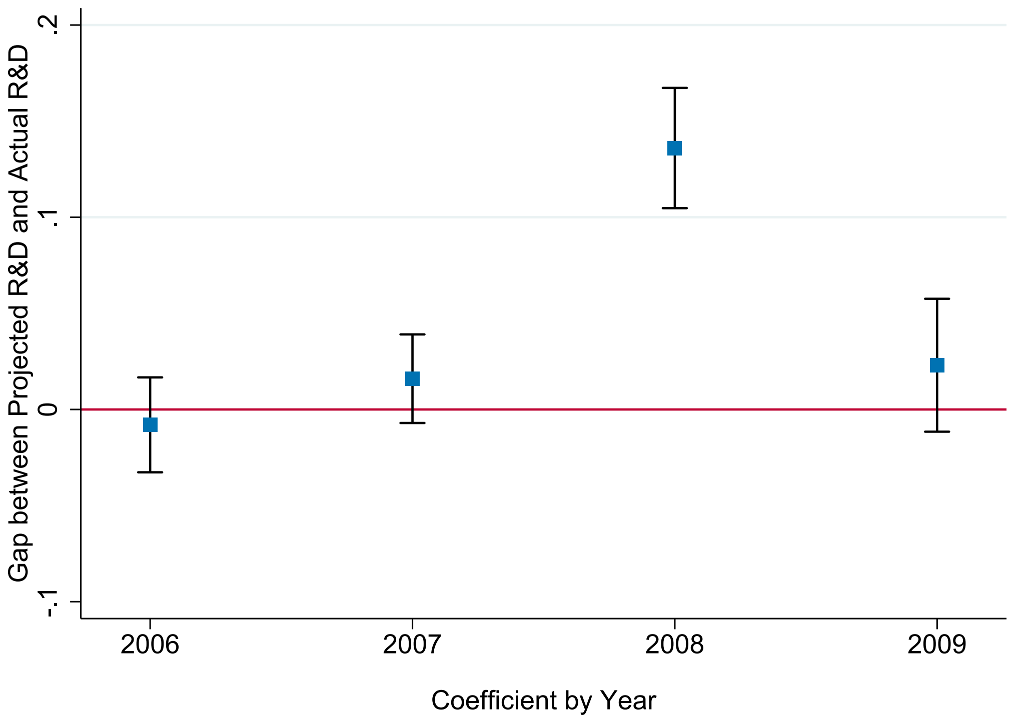
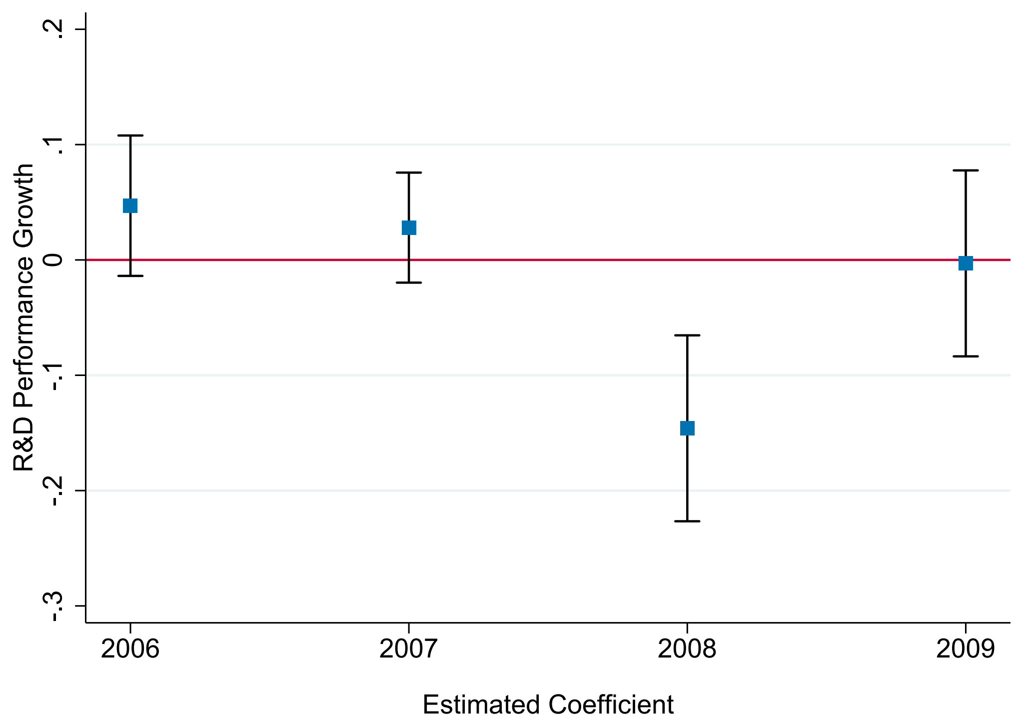
Figure 1: Percentage Gap: Actual vs. Expected R&D



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^{***}	-0.141^{***}	-0.150^{***}
	(0.051)	(0.049)	(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^{***}	.016	-0.149^{*}	-0.216^{**}
	(0.051)	(0.083)	(0.084)	(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^{**}	-.03	-0.322^{***}	-.028
	(0.113)	(0.079)	(0.112)	(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^{**}	-0.291^{***}	-0.217^{**}	-0.339^{***}
	(0.098)	(0.112)	(0.099)	(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: Innovation Outputs: Patents and Citations

	(1)	(2)	(3)	(4)	(5)	(6)
Debt/Cash	0.014	−0.060	−0.066	−0.081	−0.185**	−0.159**
	(0.071)	(0.064)	(0.058)	(0.084)	(0.076)	(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 6: R&D and Financing Need in 2008: Direct and Indirect Effects

	(1)	(2)	(3)
Debt/Cash	−0.152***	−0.328***	-.026
	(0.048)	(0.112)	(0.080)
CompShock	−0.779**	.245	−1.182**
	(0.365)	(0.769)	(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 Tim 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 byA_t. Knowledge depreciates at the rate δ and is replenished by R&D investments. The firms' knowledge stock therefore evolves according to $A_{t+1} = \delta A_t + R_t^{\alpha} D_t^{\gamma}$. The real interest rate is r, with associated discount factor $\beta = \frac{1}{1+r}$. The firm's objective can be written recursively as:

$$V_t = \max_{R,D} \pi(A_{t-1}) - R - D + \beta V_{t+1}$$

Claim 1: Steady State Investment 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 $t+1$, leaving the knowledge unchanged in all future periods. In formal terms, this implies:

$$dV_t = -1 + \beta[\pi'(A_{t+1})\frac{\partial A_{t+1}}{\partial R_t} + 1 - \delta] = 0 \quad \text{(A.1)}$$

For a steady-state investment path, we have $A_{t+1} \equiv A^*$ and $R_t \equiv R$. Substituting these expressions into (A.1), and using the fact that $\frac{1-\beta}{\beta} = r$, we can derive first-order conditions for both research and investment: $\frac{\partial \pi(A^*)}{\partial D} = \frac{\partial \pi(A^*)}{\partial R} = r + \delta$. The first part of this equality, combined with the Cobb-Douglas form of the knowledge production function, can be used to verify that $R^*/D^* = \alpha/\gamma$.

Claim 2: Idiosyncratic Shock Now consider an idiosyncratic shock that raises the costs of R&D to $\tau(R_t + D_t)$ in period t, after which they return to unity. If we consider the same perturbation to an optimal investment path described above, the Euler equations become:

$$dV_t = -\tau + \beta[\pi'(A_{t+1})\frac{\partial A_{t+1}}{\partial R_t} + 1 - \delta] = 0 \tag{A.2}$$

which can be written as $\frac{\partial \pi(A_{t+1})}{\partial I_t} = r + \delta + \kappa$,where $\kappa = (\tau - 1)/\beta$ and $I_t \in R_t, D_t$, as claimed in the text. Taking the ratio of these two equalities reveals that $\frac{\partial A_{t+1}}{\partial R_t} = \frac{\partial A_{t+1}}{\partial D_t}$, and the Cobb-Douglas knowledge production thus implies that $R^*/D^* = \alpha/\gamma$. Thus, this simple investment framework suggests that an idiosyncratic shock will reduce total R&D, but not necessarily alter the composition of R&D investment. We note that that this result uses only the optimality conditions, and does not make any assumptions about a steady-state.

Claim 3: Comparative Statics for R&D of Different Duration Finally, we consider a model where research takes longer, so the knowledge stock evolves according to $A_{t+1} = \delta A_t + R_{t-1}^{\alpha} D_t^{\gamma}$. For that model, the Euler equations for R and D respectively are

$$\begin{aligned} -\tau + \beta^2[\pi'(A_{t+2})\frac{\partial A_{t+2}}{\partial R_t} + \tau - \delta] &= 0 \\ -\tau + \beta[\pi'(A_{t+1})\frac{\partial A_{t+1}}{\partial D_t} + \tau - \delta] &= 0 \end{aligned}$$

Along a steady-state investment path, we have $A_{t+1} = A_{t+2} = A^*$. Substituting A^* into the two equations and taking a ratio reveals that $R^*/D^* = \frac{\alpha}{\gamma}\frac{\tau r + \delta}{\tau(2r + r^2) + \delta} < \frac{\alpha}{\gamma}$. Thus, when research takes longer to produce dividends than development, the composition of R&D will shift towards development, even when $\tau = 1$. A symmetric increase in the cost of R&D to $\tau > 1$ amplifies this effect because the marginal benefits of increasing R_t are more distant, and therefore smaller.

B Data Appendix

In this Appendix, we discuss in more details the 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). As we mentioned in the paper, SIRD is a survey of R&D that was run from 1972 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 very likely to be surveyed every year. 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 certainty.[49] This is either done by an R&D threshold, by a revenue threshold, or by being a large firm across each state (top 50 in sales). While the exact procedure changes year-by-year, this process implies that most large companies should be consistently sampled. In our analysis, we will focus on a consistent set of firms that is sampled both in 2007 and 2008, and we are able to follow their R&D activities between 2005 and 2009.

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.[50] While there are also conceptual reasons to focus on this specific measure of R&D inputs, our choice is also motivated by practical reasons. First, at best of our understanding, this aggregate is the only measure of total R&D inputs that can be consistently measured over the period

[49] 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.

[50] The question is asked with a slightly different format over time: however, the actual content should actually be perfectly consistent over time.

considered.

Second, several relevant other measures used in the paper can be easily constructed relative to this quantity. In particular, we can split this measure based on the type of project that is covered by the investment. As we discussed in detail in Section 3, the survey allows us to measure consistently how R&D performed is split between applied research, basic research, and development.[51] 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.[52] 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.[53]

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 for all years and in BRDIS up to 2009 (i.e. the 2010 projection). As we discuss in the paper, we use this variable to separate the effect of the shock from possible differences in ex-ante expectation among along the treatment variable.

We also replicate our 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

[51] 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.

[52] BRDIS 2008 actually provides a more detailed breakdown of this quantity.

[53] This 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).

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. While it is important to highlight these limitations, we also want to report that ex-post these differences are likely not first order (Section 4), since our estimates are very consistent across all of them.

We undertake an extensive data management process to confirm the quality and improve the coverage of our data set.[54] Given that the structure of the exact questions and the variable labels may change across surveys, we manually re-code all variables 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. In general, these adjustments are relatively rare relative to the full sample, and they are even more uncommon (if present at all) once we consider the final sample, which also matches the data to Compustat.

In the end, our final sample covers firms that: (a) were sampled in both 2007 and 2008; (b) were matched to Compustat (as described below); (c) are not financial firms or companies active in regulated sectors;[55] (d) reported all the main variables used in

[54]Our starting point we use the edited version of each reported variable.

[55]We exclude firms with NAICS within 52, 92, and 813/814.

the analysis.[56] This last filter has been imposed to make sure we satisfy the disclosure 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.

B.2 Other data sets

There are two external data sets that are also used in the paper.

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,[57] we have first matched this data set to the Standard Statistical Establishment List (SSEL) (Miranda et al., 2006).[58] We conduct this procedure in different steps, and each step we remove all matched firms from the sample.[59] 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.[60] 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.

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. As we mentioned above, the sampling for the surveys is done at the level of the establishment. However, the Census aims to only sample one establishment per firm. However, in a very small number of cases

[56] As discussed in Mezzanotti et al. (2022), we exclude foreign firms from the R&D surveys.

[57] 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.

[58] We combine together SU, MU, and MA datasets.

[59] To be precise, we drop from SSEL all establishment within the same firm when one establishment matches.

[60] 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.

we have more than one establishment within the same firm. 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. Therefore, we deal with these cases by keeping the one establishment which reports non-missing sales, non-missing and positive R&D performed, when more than one is reported. If multiple establishments are still reporting after this process of elimination, we select the one establishment with the highest reported R&D. However, it is important to point out that these cases are extremely infrequently, and are unlikely to affect our inference in any way.

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.[61] As part of our project, we have also compared the matched patent data and self-reported measures of patenting activity in BRDIS and found that the two measures were largely consistent.

The main use of the patent data in the paper is 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 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: $TreatComp_i =$

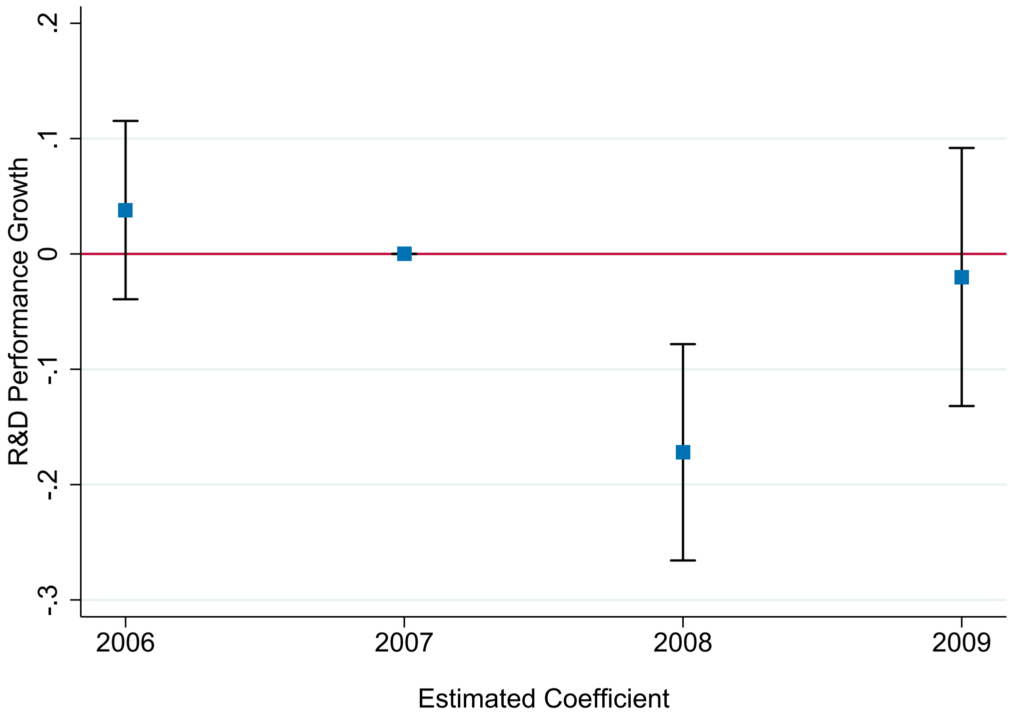
[61] https://patentsview.org/

$\frac{\sum_{j \in C_i} Closeness_{ij} Treat_j}{\sum_{j \in C_i} Closeness_{ij}}$. 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.

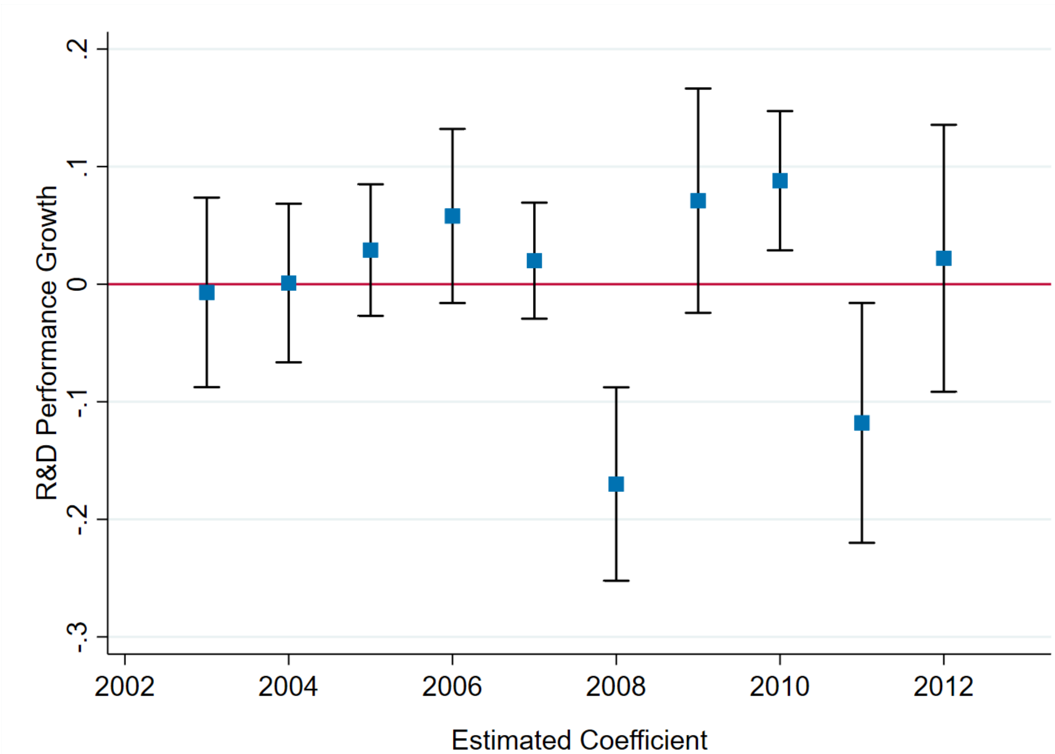
C Supplemental Figures

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 20121. 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. 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.

D Supplemental Tables

Table A.1: R&D and Financing Need in 2008: Robustness Alternative Treatments

	(1)	(2)	(3)	(4)
Debt/Cash W1	-0.092^{***}		-0.090^{***}	
	(0.030)		(0.029)	
Debt/Cash BP		-0.083^{***}		-0.080^{***}
		(0.028)		(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.2: R&D and Financing Need in 2008: Robustness Alternative Treatments

	(1)	(2)	(3)	(4)
Short/Asset (W5)	-2.581^{***}	-2.598^{***}		
	(0.857)	(0.857)		
Short/Asset (W1)			-1.312^{***}	-1.185^{***}
			(0.457)	(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.3: R&D and Financing Need in 2008: Robustness Alternative Outcomes

VARIABLES	(1)	(2)	(3)	(4)
Debt/Cash	-0.133^{***}	-0.089^{*}	-0.146^{***}	-0.103^{**}
	(0.050)	(0.049)	(0.049)	(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.4: 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.5: Funding Gap vs. Balance Sheet Strength

	(1)	(2)	(3)
Debt/Cash	-0.139^{***}	-0.149^{***}	-0.139^{***}
	(0.048)	(0.048)	(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.6: R&D and Financing Need in 2008: Federal Support and Outsourcing

	(1)	(2)	(3)	(4)
Debt/Cash	.076	.068	-.013	-.019
	(0.092)	(0.093)	(0.052)	(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 Adjustment Across Types of Costs: Robustness with firm controls

	(1)	(2)	(3)	(4)
Debt/Cash	-0.157^{***}	.028	-.141	-0.203^{*}
	(0.051)	(0.084)	(0.085)	(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.8: R&D Employment and Financing Need in 2008

	(1)	(2)
Debt/Cash	-0.229^{***}	-0.215^{***}
	(0.073)	(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.9: R&D and Financing Need in 2008: Direct and Indirect Effects, with controls

	(1)	(2)	(3)
Debt/Cash	-0.143^{***}	-0.274^{**}	-.031
	(0.049)	(0.113)	(0.079)
CompShock	-0.626^{*}	.356	-1.159^{**}
	(0.360)	(0.766)	(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.10: Elasticity of Patenting: Research versus Development

	(1)	(2)	(3)
Lag IHS(Research)	0.014***		0.020***
	(0.002)		(0.003)
Lag IHS(Development)		0.033***	0.039***
		(0.004)	(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 hypoerbolic sine function. The 1-year lagged of the outcome is included as a control. Heteroskedasticity Robust Standard Errors are reported in parenthesis.