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Interest rates, R&D investment and the distortionary effects of R&D incentives

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ABSTRACT

This paper conducts the first analysis of how interest rates are related to firms' allocation of investment between R&D and non-R&D activities and how R&D incentives alter this relationship. It theoretically predicts that if firms receive incentives mostly in the form of grants and subsidies that reduce their dependence on external finance, their share of R&D spending increases (decreases) during a credit tightening (easing). Conversely, if tax credits are the primary incentive, firms decrease (increase) their share of R&D spending during a credit tightening (easing). The paper demonstrates empirical support for these predictions by using firm-level financial and sector-level R&D incentives data and a unique methodology that focuses on the within firm allocation of investment.

1. Introduction

It is well-known that research and development (R&D) activities are difficult to finance externally given the nonrivalry feature of most innovations (c.f., Arrow, 1962; Nelson, 1959; Schumpeter, 1942). This observation, together with the widely-held belief that R&D yields positive externalities, has been used to justify external support and governments' tax incentives for R&D. Some empirical findings, a few of which we discuss below, also validate these support mechanisms.

The analysis in this paper expands the general understanding of R&D financing and incentives by identifying a theoretical reallocation of investment between R&D and non-R&D activities when borrowing spreads change. It finds that the direction and strength of the reallocation depends on R&D incentives. These incentives are of two types: external (both private and government) grants and subsidies, and tax credits. When incentives are mostly in the form of the former, an increase in funding costs prompts firms' to reallocate funds towards R&D activities. These results are reversed when tax credits are the primary R&D incentive. In the second half of the paper, these relationships are tested and confirmed by using firm-level financial and sector-level R&D incentives data and a unique identification strategy that focuses on the within firm allocation of investment. The findings indicate that firms increase their share of R&D activities in their total investment

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expenditures when funding costs rise, with the reallocation mechanism strongest for the firms with a high degree of R&D activity. Consistent with the theoretical predictions, incentives in the form of external grants and loans reinforce and tax incentives mitigate the reallocation of funds to R&D activities.

The implication of these findings is that funding costs, in addition to their effects on aggregate investment, can affect the composition of investment, increasing the share of high growth, high-technology activities when they rise for example. Given that these activities are associated with skilled-labor and that labor costs are the largest component of R&D spending, our findings also imply that changes in credit market conditions may change the composition of the labor market. Specifically, the presence of R&D activity increases the fluctuations of demand for unskilled labor that is prompted by changes in borrowing costs. Incentives that aim to increase the level of R&D activity also decrease these distortionary effects only if they are in the form tax credits (the more common form of government support for R&D). By contrast, grants and loans, the larger of the two incentives, amplify the distortionary effects on output and labor markets.

Our theoretical predictions come from a dynamic model that includes a generalized version of Romer (1990) type technology. Firms that use this technology accumulate stocks of both R&D and physical capital and they receive tax credit and loans/grants for R&D activities. Loans and grants decrease the firms' reliance on external funding and thus tightening credit conditions cause a disproportionate decline in their non-R&D investment (which is fully financed externally) and an increase in the share of R&D activity. In our model, higher levels of R&D tax credits skew the composition of investment towards R&D by lowering unit costs. These cost advantages, however, become relatively less important at higher interest rates. Firms that receive incentives mostly in the form of tax credit, therefore, experience a decrease in the share of their R&D activities when credit conditions tighten. Overall, we identify distortionary effects of R&D incentives on the investment allocation of firms. We predict that these effects may depend on the level of interest rates and the type of incentive, with external grants and loans increasing and tax credits decreasing the share of R&D during a credit tightening.

We proceed by using firm level balance sheet data and sector level R&D incentives data to test some predictions from our model. Our firm level data are at the quarterly frequency, they are obtained from the COMPUSTAT database, and they span the 2010:Q1-2015:Q4 time period. This database provides observations for firms' R&D and non-R&D investment as well as other firm-specific characteristics such as liquidity, financial constraints and profitability. The types of variables that we use in our investigation of investment behavior and the definitions of our constructed variables are common in the literature. The distinctive parts of our analysis rather lie in our methodology. First, we focus on the within firm allocation of funds to R&D versus non-R&D activities as opposed to the more common approach of exploring cross-firm variation. Second and to the best of our knowledge, this paper makes the first attempt at empirically determining the relationship between funding costs (captured by various types of corporate bond spreads) and the allocation of investment between R&D and non-R&D activities. Our within-firm focus here is critical as it allows us to control for firm level fixed effects that can change across time (and that perhaps could be related to funding costs) and thus could not be accounted for with standard empirical models with time and firm (time-invariant) fixed effects.

Our initial results, obtained from a difference general method of moments (GMM) dynamic panel estimator, show an increase (decrease) in the share of R&D investment when credit spreads increase (decrease). Consistent with our model's optimality conditions, we find that the reallocation of funds from non-R&D activities to R&D activities is much stronger for firms with a high share of R&D compared to low R&D firms whose reallocation of investment is instead more responsive to changes in their financial constraints.

Next, we incorporate R&D incentives into our analysis by collecting data compiled by two separate surveys. The degree of external grants and loans are obtained from the National Science Foundation, Business Research and Development and Innovation Survey (BRDIS) and R&D tax credits are from the Internal Revenue Service's, Statistics of Income (SOI), Statistics on Corporation Research Credit. Both sets of data are available at the sector level and annual frequency. We add these data to our firm level dataset by matching the firms' sectors with those in the two surveys. Classifying firms as low/high tax credit and low/high external support, we find, consistent with our theoretical prediction that firms in sectors that receive high external support but low tax credits are also the ones whose share of R&D investment in total investment increases (decreases) the most when funding costs rise (drop). Our empirical findings are robust to alternative definitions of funding costs, the dependent variable, and external support and tax credit.

Our findings have implications for the effects of credit conditions (and the policies that create these conditions) on volatility and growth of economies. During easy credit conditions, for example, the composition of investment shifts towards non-R&D activities that may also be more volatile due to higher interest rate sensitivity. By contrast, while economic activity is low ensuing a credit tightening, there is also less volatility since R&D activities, the more robust form of investment, has a higher share. The distortionary effects of R&D incentives that we identify imply that while government tax credits decrease the robustness of R&D spending and render these activities more similar to non-R&D activities, external grants and loans increase the robustness of R&D. Our results also predict and imply that R&D spending, a crucial determinant of long-run growth of economies and economic productivity, may be insulated from short-run credit conditions. This insulation, though, comes at a price as R&D activities are cross-subsidized with non-R&D activities. This in turn could imply that an economy with a high share of R&D in production could potentially experience higher volatility in unskilled labor and more general output markets.

There is a vast and long-standing literature on the determinants of R&D and non-R&D investment behavior of firms. There is an agreement in this literature that the Modigliani–Miller theorem is violated for investment decisions of firms as their optimal decisions hinge on their capital structure and borrowing constraints. Empirical studies such as Fazzari et al. (1988), Kaplan and Zingales (1997), Fazzari et al. (2000) study the role of these financial factors for non-R&D investment decisions. Hall (1993), Hall (2002), Himmelberg and Petersen (1994), Hall and Lerner (2010), Brown et al. (2009) and Brown and Petersen (2011) do the same by focusing on R&D financing.[2] The latter two studies also provide evidence that equity finance and liquidity are increasingly used to smooth out the fluctuations in R&D spending of manufacturing firms.[3] Our choice of firm-specific variables, including those that measure financial constraints and liquidity, is informed by these seminal papers. Unlike the aforementioned and other studies in the literature, our paper makes a first attempt at analyzing the intra-firm allocation of investment between R&D and non-R&D activities and determining how this allocation depends on credit conditions and R&D incentives.

In the absence of credit constraints, the optimal decision about whether to invest in innovative investment or capital investment depends on the opportunity cost of investment over the business cycle. Since the opportunity cost of reallocating resources towards innovative investment is smaller during recessions, the usual observation is that R&D is countercyclical over the business cycle (Aghion et al., 2012; Aghion and Saint-Paul, 1998). However, several papers demonstrate that when financing constraints are binding, R&D investment of a constrained firm may fall during recessions, implying a procyclical R&D investment (Aghion et al., 2005; 2012). Other studies reach a similar conclusion. Himmelberg and Petersen (1994), and Hall and Lerner (2010), for example, show that R&D could be procyclical due to liquidity effects. The procyclicality of R&D in Barlevy (2007) is due to the fact that labor costs are easier to finance during expansions. Given the stylized fact that borrowing spreads are countercyclical, our empirical results imply, consistent with the latter set of studies, that R&D investment is procyclical. In addition, however, we find that R&D's share in total investment is countercyclical and that this result is reinforced by research grants/subsidies. This finding is consistent with Brown and Petersen (2015) which shows that firms spend more cash to protect their R&D investment due to larger adjustment cost associated with R&D. In our theoretical framework, the countercyclicality of R&D share is rather driven by the distortionary effects of R&D grants and loans.

Despite the general notion that public policies are necessary given the positive externalities associated with R&D, evidence for the effectiveness of these policies is mixed. While studies such as Hall (1993), Hines Jr (1994), Bloom et al. (2002) and Wilson (2009) find that government tax credits are ineffective in increasing R&D spending in the short-term, findings of Rao (2016) and Thomson (2015) indicate otherwise. By contrast, the literature (e.g. Hellmann and Puri, 2002; Howell, 2017; Lerner, 2002; Neicu et al., 2016; Sørensen, 2007; Wallsten, 2000) on the effects of R&D subsidies (government and private) and the external funding of R&D (especially with venture capital) resoundingly agree that subsidies and external funding spur R&D, and have positive outcomes for firms' performance. Unlike the studies mentioned above, we study the distortionary effects of tax credits and subsidies jointly and we find that they have opposite effects on firms' investment decisions.

We should also point out that R&D incentives and R&D tax credits are not the only form of incentives that aim to promote R&D growth. Intellectual property rights (IPR) protection is an example of an alternative tool that also enhances R&D activities and competes with other incentives in doing so. The literature on this form of R&D incentives points to a similar disagreement on its effects. Specifically, while studies such as Acemoglu and Akcigit (2012), Chu et al. (2014), Zeng et al. (2014), and Chu and Cozzi (2018) show stronger protections increase R&D investment, promote innovation and increase economic growth, other studies reveal opposite results. Furukawa (2007) and Futagami and Iwaisako (2007), for example, show that stronger IPR can decrease productivity and welfare, respectively, and studies such as Horii and Iwaisako (2007), Chu et al. (2012), and Iwaisako and Futagami (2013) show that IPR can negatively affect long-run economic growth. While our investigation is different since we do not investigate the implications for economic growth directly and since we consider other types of R&D incentives, the contrast in the findings of this literature also calls for a more nuanced and rigorous analysis of the pros and cons of different types of R&D incentives.

2. A partial equilibrium framework with R&D investment

In this section we build a partial equilibrium model with R&D investment to illustrate the effects of R&D incentives on the investment allocation of firms.

2.1. Model overview

The model features two imperfectly competitive intermediate good producers that maximize a stream of dividends by choosing how much labor to hire and how much to invest. The output of the two firms is combined into a single wholesale good by a perfectly competitive final good producer. While both firms can choose to accumulate physical capital, only one

[2] Hall and Lerner (2010) offer a detailed discussion of R&D financing and an extensive review of the literature on financing constraints that apply to R&D.

[3] There have also been recent attempts at understanding the role of funding costs for R&D spending in a general equilibrium analysis. Perez-Orive et al. (2017), for example, show that the interaction between intangible capital, that is used for R&D, and interest-rates can play a role in productivity and output growth by altering asset prices. In particular, a decrease in interest rates increases the price of intangible assets and reduces the ability of firms to buy intangible capital by reducing the accumulation of savings. Döttling and Perotti (2015) show that intangible capital is mostly financed by equity because it is hard to collateralize. Therefore, lower demand for external finance results in a decrease in interest rates.

of the firms, hereafter referred to as the R&D firm, can do R&D investment. The R&D firm receives subsidies that reduces its borrowing costs. These subsidies are the source of distortions in the model. The other firm, i.e., the non-R&D firm, is not subsidized. Investment expenditures for both firms are externally financed at an exogenously determined interest rate.[4] The relationship between the firms' investment decisions and this interest rate receives the spotlight throughout our analysis.

As an alternative to investment, we allow the stock of R&D to accumulate with labor. Using this definition of technological process, we then derive the relationship between the two firms' relative demand for labor and the skilled-unskilled labor wage gap in Appendix A.

2.2. The intermediate and final good producers

The R&D firm, one of the two intermediate good producers, chooses the amount of labor, investment and dividend payments to maximize the following function:

$$\max \sum_{t=\tau}^{T} \beta^{t-\tau} D_{1,t} \quad s.t.$$
$$D_{1,t} = P_{1,t}Y_{1,t} - WL_{1,t} - R_{t-1}\left[I^{(f)}_{1,t-1} + (1-\xi)I^{(rd)}_{1,t-1}\right] - R^{(s)}_{t-1}\xi I^{(rd)}_{1,t-1} + s^{(k)}I^{(rd)}_{1,t-1} \tag{1}$$

$D_{1,t}$ here represents dividend payments and $s^{(k)}$ is the tax credit parameter that represents the credits received from the government for R&D investment, $I^{(rd)}_{1,t-1}$. This parameter can more specifically be interpreted as the corporate tax credits associated with R&D activities. The other form of R&D incentives, external funding subsidies, are captured by the parameter ξ such that ξ share of R&D expenditures are financed at a low interest rate of $R^{(s)}_{t-1}$. The remaining amount of R&D investment, as well as its non-R&D investment ($I^{(f)}_{t-1}$) are financed at the higher market rate of R_{t-1}. The lower value of $R^{(s)}_{t-1}$ can either be interpreted as the impact of government loan guarantees, low cost external funding (private or government), external grants, or that R&D expenditures are internally financed (an important source of R&D funding in empirical findings). While the latter two imply that $R^{(s)}_{t-1} = 1$, we assume, without loss of generality, that all forms of incentives apply so that $R_{t-1} > R^{(s)}_{t-1} > 1$.

Both firms in the model are price takers in the labor market in which a time invariant wage rate of W prevails. Although labor demand does not directly impact the R&D firm's allocation of funds between R&D and non-R&D activities in this baseline formulation, it is convenient to include labor here since we present a different version of our model in Appendix A where R&D incentives apply to labor instead of investment. The firm combines labor and firm/sector specific physical capital, $K_{1,t}$, to produce output, $Y_{1,t}$, as follows:

$$Y_{1,t} = A^{\eta}_{1,t}K^{\alpha}_{1,t}L^{1-\alpha}_{1,t} \tag{2}$$

The formulation above is the generalized version of a Romer (1990) type technology outlined in Jones and Williams (1998), where $A_{1,t}$ represents the stock of R&D that enters a standard neoclassical production function and it is treated as an alternative factor of production and a complement to physical capital. $A_{1,t}$ is usually interpreted as the stock of human capital/ideas that accumulate with research efforts, i.e., R&D in this paper. $I^{(rd)}_{1,t-1}$, therefore, affects R&D stock accumulation just as $I^{(f)}_{t-1}$ affects physical capital accumulation so that the two stock variables in Eq. (2) evolve as follows:

$$A_{1,t} = \rho A_{1,t-1} + \nu I^{(rd)}_{1,t-1} \tag{3}$$

$$K_{1,t} = (1-\delta)K_{1,t-1} + I^{(f)}_{1,t-1} \tag{4}$$

where the parameters ρ and ν account for the "standing on shoulders" and the "stepping on toes" effects associated with R&D (with $\nu < 1$ implying the presence of "stepping on toes" effects). δ represents the depreciation rate of physical capital.

Notice here that the production function in Eq. (2) exhibits increasing returns to scale for $\eta > 0$ and we are implicitly assuming that there exists a balanced growth path in the economy at which all the endogenous variables are growing at a constant rate. Our focus in this section is on the temporary deviations of the economy from this growth path when borrowing costs change exogenously. To ensure that the R&D firm does not choose only one type of investment at the balanced growth path, we assume that $\rho < 1$ and $\delta > 0$.

The non-R&D firm, the other intermediate good producer, similarly maximizes its stream of future dividends. Its maximization problem is given by,

$$\max \sum_{t=\tau}^{T} \beta^{t-\tau} D_{2,t} \quad s.t.$$
$$D_{2,t} = P_{2,t}Y_{2,t} - WL_{2,t} - R_{t-1}I^{(f)}_{2,t-1} \tag{5}$$

[4] We explain below that our main inferences are similar if we allow both firms to do R&D investment and allow only one of these firms to receive R&D incentives.

Unlike the R&D firm, the non-R&D firm invests only in physical capital. In so doing, it faces the same borrowing rate that the R&D firm faces when financing its non-R&D investment. It too is a price-taker in the labor market and it produces output according to a similar production function:

$$Y_{2,t} = A_{2,t}^{\eta} K_{2,t}^{\alpha} L_{2,t}^{1-\alpha} \tag{6}$$

Here we assume that the parameters governing the production function and the law of motion for capital are the same as those for the R&D firm, the stock of human capital is time-invariant, $A_t = A$, and that there are no technological spillovers from the R&D firm to the non-R&D firm.

The two intermediate goods are bought by a final good producer that combines them according to a Cobb-Douglas function.[5] Let Y_t denote the amount of final goods produced and γ represent the share of R&D firm's output, this function is given by,

$$Y_t = Y_{1,t}^{\gamma} Y_{2,t}^{1-\gamma} \tag{7}$$

The cost minimization problem of the final good producer, assuming that the final good is the numeraire, produces the following expressions for the price of the two intermediate goods:

$$P_{1,t} = \gamma \frac{Y_t}{Y_{1,t}} \tag{8}$$

$$P_{2,t} = (1-\gamma) \frac{Y_t}{Y_{2,t}} \tag{9}$$

2.3. Interest rate - investment relationship

To solve our model, we substitute the expressions for prices in their respective maximization problems, and derive the following first order conditions that describe the demand for labor, and non-R&D and R&D investment for the R&D firm, respectively:

$$W = (1-\alpha)\gamma^2 \frac{Y_t}{L_{1,t}} \tag{10}$$

$$R_t = \alpha\gamma^2 \frac{Y_{t+1}}{K_{1,t+1}} \tag{11}$$

$$(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)} = \eta\nu\gamma^2 \frac{Y_{t+1}}{A_{1,t+1}} \tag{12}$$

For the non-R&D firm the first order conditions describe labor and non-R&D investment demand only:

$$W = (1-\alpha)(1-\gamma)^2 \frac{Y_t}{L_{2,t}} \tag{13}$$

$$R_t = \alpha(1-\gamma)^2 \frac{Y_{t+1}}{K_{2,t+1}} \tag{14}$$

As mentioned above, the primary insight we want to extract from our model is the compositional effects of interest rates on investment behavior. This information can be extracted in two ways from the first order conditions above: 1) By investigating the relationship between interest rates and the allocation of investment between R&D and non-R&D activities within the R&D firm 2) By investigating the how interest rates change the share of R&D investment in total investment within the R&D firm. We begin conducting these investigations by deriving the following two ratios (derived from Eqs. (11) and (12)), respectively.

$$\frac{A_{1,t+1}}{K_{1,t+1}} = \frac{\nu I_{1,t}^{(rd)} + \rho A_{1,t}}{I_{1,t}^{(f)} + (1-\delta)K_{1,t}} = \frac{\eta\nu}{\alpha}\left(\frac{R_t}{(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}}\right) \tag{15}$$

$$\begin{aligned} \frac{A_{1,t+1}}{A_{1,t+1}+K_{1,t+1}} &= \frac{\nu I_{1,t}^{(rd)} + \rho A_{1,t}}{\nu I^{(rd)} + I_{1,t}^{(f)} + (1-\delta)K_{1,t} + \rho A_{1,t}} \\ &= \frac{\eta\nu}{\alpha}\left(\frac{R_t}{((1-\xi)+\eta\nu/\alpha)R_t + \xi R_t^{(s)} - s^{(k)}}\right) \end{aligned} \tag{16}$$

[5] We use this functional form to make the model tractable. It is possible to obtain similar inferences by using a more common aggregator such as a CES.

It is important to note here that while the equations above do not provide a closed form solution for the proportion of R&D and non-R&D investment expenditures, they allow us to determine how interest rates change the allocation of investment between these two types of activities. The reason is that the two stock variables, $A_{1,t}$ and $K_{1,t}$, appearing in the numerator and denominator of the ratios are state variables in our model. The two investment variables, by contrast, are decision variables (the central decision variables in our analysis). Any effects of interest rates on the relative stocks of knowledge and capital, therefore, feed only through the changes in the two investment items. Hereafter, we will only include the relative stocks of knowledge and capital when investigating the effects of interest rates to simplify the notation. Our discussion will however emphasize the relative changes in R&D and non-R&D investment activities.

The inferences from the two equations above are similar. By construction, the proportion of R&D stock within the firm is positively related to the rate at which R&D investment increases the R&D stock. Similarly, the proportion of capital stock increases as its share in the production function increases. The relative share of R&D stock also increases with R&D incentives. Specifically, the two ratios in Eqs. (15) and (16) are positively related to $s^{(k)}$ and ξ as higher positive values of these parameters lower unit costs of R&D and prompt a higher level of R&D activity.

Having solved the model, we turn to our ultimate goal: analyzing how R&D subsidies affect the relationship between interest rates and investment allocation. To this end, we use Eqs. (15) and (16) to derive the interest rate sensitivity of the two ratios as follows:

$$\frac{d(A_{1,t+1}/K_{1,t+1})}{dR_t} = \frac{\eta\nu}{\alpha}\frac{\xi R_t^{(s)} - s^{(k)}}{[(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}]^2} \tag{17}$$

$$\frac{d\{A_{1,t+1}/(K_{1,t+1}+A_{1,t+1})\}}{dR_t} = \frac{\eta\nu\gamma^2}{\alpha(1-2\gamma)}\frac{\xi R_t^{(s)} - s^{(k)}}{[(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}]^2} \tag{18}$$

We should note once again that the changes in the relative stocks of knowledge and capital here directly reflect the changes in the relative levels of R&D and non-R&D investment. Eqs. (17) and (18) illustrate two counteracting effects of government subsidies. On the one hand, we observe that if the firm receives a high level of R&D tax credit (higher $s^{(k)}$), its share of R&D investment becomes negatively related to borrowing costs (in response to an increase in interest rates, for example, $I_{1,t}^{(rd)}$ falls by more than $I_{1,t}^{(f)}$). Conversely, if a higher share of the firm's R&D investment is subsidized through lower interest rates (higher ξ), R&D investment's relative share becomes positively related to interest rates. The interpretation of the latter result is straightforward: if the firm does not finance a high share of its R&D expenditures at the market rate, it reacts less to the changes in this interest rate. To understand and illustrate the former relationship, i.e., the negative sign of $s^{(k)}$ in the numerator, it is useful and simpler to assume that $\xi = 0$ so that the unit costs of R&D and non-R&D investment are given by, $R_t - s^{(k)}$ and R_t, respectively. For any positive value of $s^{(k)}$, an increase in interest rates then causes a higher percentage increase in the unit costs of R&D investment. Simply put, the cost advantages of R&D investment dissipate as interest rates rise and R&D's share in overall investment decreases. The two counteracting effects of R&D subsidies on the interest rate sensitivity of investment allocation mentioned above are magnified when human capital share is high, physical capital share is low in the production function, and when the stepping on toes effects are low (ν is high).

So far, we've scrutinized the investment allocation decisions within the R&D firm. Next, we extend our analysis and we make a comparison across the two firms and across the different types of investment. We do so by measuring two ratios:

Total R&D firm to non-R&D firm stock of capital (human and physical capital) ratio given by,

$$\frac{A_{1,t+1}+K_{1,t+1}}{K_{2,t+1}} = \frac{\gamma^2\eta\nu}{(1-\gamma^2)\alpha}\left(\frac{R_t}{(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}} + \frac{\alpha}{\eta\nu}\right) \tag{19}$$

and the R&D stock to total physical stock of capital ratio given by,

$$\frac{A_{1,t+1}}{K_{1,t+1}+K_{2,t+1}} = \frac{\gamma^2\eta\nu}{\alpha(\gamma^2+(1-\gamma)^2)}\left(\frac{R_t}{(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}}\right) \tag{20}$$

The share parameter, γ, in Eq. (19) captures scale effects. Specifically, as the share of R&D firm's output in the production of the final good increases so does the share of its total stock of capital and R&D stock. Taking the derivatives of the two ratios with respect to interest rate, R_t, produces expressions that are similar to the sensitivity expression in Eq. (17) as they also contain the two counteracting effects of R&D incentives:

$$\frac{d\{(A_{1,t+1}+K_{1,t+1})/K_{2,t+1}\}}{dR_t} = \frac{\eta\nu\gamma^2}{\alpha(1-\gamma^2)}\frac{\xi R_t^{(s)} - s^{(k)}}{[(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}]^2} \tag{21}$$

$$\frac{d\{A_{1,t+1}/(K_{1,t+1}+K_{2,t+1})\}}{dR_t} = \frac{\eta\nu\gamma^2}{\alpha(\gamma^2+(1-\gamma)^2)}\frac{\xi R_t^{(s)} - s^{(k)}}{[(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}]^2} \tag{22}$$

These partial derivatives, too, indicate that if R&D investments are subsidized mostly through lower interest rates, the share of R&D investments and the total investment expenditures of firms with R&D activity increases in an economy when borrowing costs increase. These conclusions are reversed if R&D incentives are mostly through tax credits.

The inferences from our model are similar when both firms engage in R&D activity while only one of these firms receive incentives. It can be shown that under this scenario, an increase (decrease) in interest rates causes a larger increase (decline) in the R&D investment of the firm that receives incentives, and these incentives still affect the ratio of total R&D investment to non-R&D investment in the economy as illustrated by Eq. (20). In fact, the right-hand-side of the optimality conditions that produce the ratio of the two firms' R&D stock and the ratio of total R&D stock to physical capital are isomorphic to those in Eqs. (15) and (20), respectively.[6]

As an extension, we present a version of our model where R&D incentives affect firms' labor demand in Appendix A. In this extension, distinguishing between skilled and unskilled labor, we find, naturally, that firms receiving higher degrees of incentives shift their composition of labor towards skilled work force that is the recipient of the incentives. More interestingly, we observe that these firms experience a sharper drop in the share of their skilled labor demand when the skilled-unskilled worker wage gap increases, compared to firms that are less-incentivized. Given data limitations (i.e., the scarcity of firm-level data on skilled/unskilled labor force), we focus on our models' predictions about the relationship between external funding costs and relative R&D spending.

Before we proceed, it is useful to summarize these predictions. First, we find that firms reallocate their investments between R&D and non-R&D activities when external funding costs change. Second, we find that R&D incentives in the form of grants and subsidies skew this allocation towards (away from) R&D during a credit tightening (easing). Conversely, incentives in the form of tax credits prompt firms to decrease (increase) their share of R&D spending during a credit tightening (easing).

3. An empirical analysis

Our theoretical predictions are related to firms' allocation of spending between R&D and non-R&D activities/items. Given the dynamic panel estimator that we will be using to test these predictions, focusing on intra-firm allocation of investment is the most effective way for us to control for any unobserved firm specific determinants of the responsiveness to borrowing costs. We begin by describing our methodology.

3.1. Methodology

To measure the within firm allocation of investment, we compute the relative growth rate of R&D investment, R_RDG_{it} for each firm, indexed by i, as,

$$R\_RDG_{it} = RDG_{it} - NRDIG_{it} \tag{23}$$

where RDG_{it} and $NRDIG_{it}$ denote the growth rate of firm i's R&D and non-R&D investment expenditures at time t, respectively, and the year-over-year growth rates are measured as log-differences. R_RDG_{it} is the main dependent variable in most of our estimations. Our main independent variables are average corporate bond spreads in the market, denoted by BS_t, that capture the terms of borrowing for different types of firms. The coefficient of this variable receives the spotlight throughout our analysis as it indicates how the allocation of spending between R&D and non-R&D investment is affected by credit market conditions.

In addition to this macroeconomic variable, we also include the growth rate of various firm-specific financial ratios/indices that are commonly associated with investment behavior. Out of these variables, the one that measures firms' reliance on external finance is of particular interest to us as it is reasonable to assume that firms with a larger degree of external finance would be exposed to changes in funding costs. To account for this potential mechanism, we also interact our measure of external finance dependence (hereafter, financial constraints) with funding costs and include it in our empirical model. The remaining firm specific variables are firms' sales growth and the growth rate of financial ratios that measure firms' liquidity and the profitability of their investment. Growth rates in a given quarter are measured as percentage point changes over the same quarter of the previous year. We stack the firm-specific control variables in vector C_{it} and include it in the following dynamic panel model:

$$\begin{aligned} R\_RDG_{it} = {} & \sum_{k=1}^{4} \beta_k^{rd} R\_RDG_{it-k} + \sum_{k=1}^{4} \beta_k^{b} BS_{t-k} + \sum_{k=1}^{4} \beta_k^{f} FC_{it-k} \\ & + \sum_{k=1}^{4} \beta_k^{fb} FC_{it-k} \times BS_{t-k} + \sum_{k=1}^{4} \beta_k^{c} C_{it-k} + \epsilon_{it} \end{aligned} \tag{24}$$

[6] If firm 1 receives R&D incentives and firm 2 does not, these ratios are given by:

$$\frac{A_{1,t+1}}{A_{2,t+1}} = \frac{\gamma^2}{(1-\gamma)^2} \frac{R_t}{(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}},$$

$$\frac{A_{1,t+1} + A_{2,t+1}}{K_{1,t+1} + K_{2,t+1}} = \frac{\eta \nu}{\alpha[\gamma^2 + (1-\gamma)^2]} \left[\frac{R_t}{(1-\xi)R_t + \xi R_t^{(s)} - s^{(k)}} + (1-\gamma^2) \right],$$

respectively.

where FC_{it} is the variable that captures the degree of financial constraints for firm i. We include 4 lags of the right hand side variables by following the common practice in the analysis of quarterly investment behavior. This allows us to account for the cyclical behavior of investment, the persistence of borrowing spreads and the timing differences between actual implementation of investment and its funding.

We estimate the dynamic panel model in Eq. (24) by using the Arellano and Bover (1995) difference GMM methodology.[7] We do so because the methodology has several advantages. First, our panel has a much smaller time dimension compared to its cross-sectional dimension and the methodology is designed for such datasets. Second, it minimizes endogeneity problems by instrumenting independent variables that are not strictly exogenous with the lags of their first differences.[8] Finally, the methodology accounts for potential heteroskedasticity and serially correlation in the error terms, and fixed and random effects in the panel.

The more critical aspect of our methodology is that by measuring the growth rate of the two investment types in relative terms, it controls for any time-varying firm-specific factors (in addition to macroeconomic variables such as inflation) that may be symmetrically related to R&D and non-R&D investment growth and borrowing spreads in the economy. These time-varying effects cannot be picked up with usual applications with time-invariant firm fixed effects because the fixed effects would get dropped out from our difference GMM estimator. The way we construct our dependent variable, therefore, not only allows us to investigate the determinants of relative R&D spending but it also allows us to minimize the risks of an omitted variables bias in doing so.

3.2. Data

The quarterly firm level data that we use in our analysis are obtained from the COMPUSTAT (North America) database for the 2010:Q1-2015:Q4 period. The main reason we choose this period is to exclude the confounding effects of the Global Financial Crisis and the period leading up to it. The definitions of the firm-specific variables in our sample are presented in Table B.1 in Appendix B.

In constructing our main dependent variable, relative R&D investment growth, we use a quarterly measure of research and development expenses and subtract the growth rate of net total investment expenditures from this. R&D expenditures represent all costs incurred during a given quarter that relate to the development of new products or services. Net total investment is not reported as a separate variable in COMPUSTAT. To construct this variable, we follow the common practice (c.f., Chang et al., 2014; Gutiérrez and Philippon, 2016; Malmendier et al., 2011) and add capital expenditures, inventory investment, acquisitions and subtract sale of property and investments, and changes in marketable securities, cash equivalents and miscellaneous investment items from this total. It should be noted here that this definition of investment does not include R&D spending and thus we are using two distinct variables to construct our dependent variable. We should also note that our investment variable is a broader measure than capital expenditures as it includes both short term and long term investment based on financial statements. The items that are used to construct net total investment are reported quarterly as year-to-date variables in the COMPUSTAT database. To obtain quarterly growth rates of investment, we measure the quarterly changes in the reported annual values of the variables mentioned above.

Our main independent variables measure borrowing spreads and the degree of financial constraints. To capture funding costs for firms we use three types of corporate bond spreads: BofA Merrill Lynch US Corporate Option-Adjusted Spread in securities with a rating of AAA, BBB and CCC (or below). The spreads are measured as the difference between the index of all bonds in a given rating category and a spot Treasury curve. These spreads, therefore, are macroeconomic variables (not firm-specific) that reflect average costs of borrowing for firms. We choose the ratings AAA, BBB and CCC to cover a broad spectrum of funding spreads and to check for the robustness of our results. To simplify the discussion of our results we often refer to borrowing spreads as funding costs below.

Our measure of financial constraints is the Kaplan–Zingales (KZ) index. This index, in addition to financial leverage, includes firm-specific characteristics such as dividend payments and cash flow. More specifically it is measured as,

$$KZ = -1.002(oibdpq/atq) + 3.319(dlcq + dlttq)/atq - 39.368(dvpq/atq) - 1.315(cheq/atq) \tag{25}$$

where the COMPUSTAT acronyms, atq, oibdpq, dlcq, dlttq, dvpq and cheq denote total assets, operating income before depreciation, debt in current liabilities, long-term debt, dividends and cash and short term investments, respectively. There is recent evidence indicating that firms increasingly rely on external funding for R&D investments, and that the external financial constraints that they face are not fully captured by their leverage.[9] In this sense, using the KZ index is the most comprehensive/accurate way to approximate external funding constraints. Although it is not clear how financial constraints impact the allocation of funds between R&D and non-R&D investment, it is common consensus that it can negatively affect non-R&D investment spending. There are three reasons for this. First, financially constrained firms also face liquidity constraints or have a worsened outlook. Therefore, they have difficulty with taking advantage of investment opportunities. Second, the management of these firms may have lower incentives to invest because the benefits of the investment goes

[7] We follow the steps in Roodman (2009) to apply this methodology.

[8] We use the first four lags of the right hand side variables in this step.

[9] See Brown et al. (2009) and Brown and Petersen (2011) for the increasing role of external finance in R&D investments and see Brown et al. (2012) for measures of financial constraints.

to bondholders, not to the shareholders, which is also referred to as the debt overhang problem. Third, the negative relationship could be due to an overinvestment problem in which the managers of firms with good growth opportunities might find it harder to invest because as debt accumulates it hurts the firm's value. A negative relationship between financial constraints and future investment is, therefore, a common finding. The distinctive feature of our methodology is that it helps us determine whether these potential negative effects of funding costs on investment apply differently to R&D and non-R&D investment.

The other standard components of empirical models of investment behavior are measures of profitability and liquidity. We incorporate the former by using the Tobin's Q and sales-to-total-assets ratio that gauge potential profits from future investments. For the liquidity measure we use the cash-and-short-term-investments-to-total-assets ratio. These variables are available at the quarterly frequency and they are also defined in Table B.1 in Appendix B.

Turning to R&D incentives, we use two data sources to measure the degree of subsidization: the National Science Foundation, Business Research and Development and Innovation Survey (BRDIS) and the Internal Revenue Service, Statistics of Income (SOI), Statistics on Corporation Research Credit database. These data are available at the sector level and annual frequency. The latest release of BRDIS and SOI are for years 2014 and 2013, respectively. For consistency, both between the two surveys and with our dataset, we collect subsidization data for the 2010 to 2013 period. As a measure of external R&D support, we use the average ratio of total domestic R&D expenditures paid by others to total domestic R&D during this period.[10] To gauge the significance of tax credits in a given sector, we use the average ratio of current-year credit for increasing research activities to total domestic R&D expenditures as our baseline measure of R&D tax incentives.[11] This way of measuring tax incentives is dictated by data availability. We should however note that our measure does not capture the entire spectrum of tax incentives that may reduce the cost of R&D activity. Moretti and Wilson (2017) construct a broader measure that includes corporate income tax rates as well as other variables that affect R&D expenditures to capture the cost of R&D activity. This measure is derived by using state level data (unlike the sector-level data that we use) for inventors in biotech industries only. Despite these fundamental differences, we find a negative correlation between our baseline R&D tax incentive measure and the unit costs of R&D in Moretti and Wilson (2017), indicating that in states with high (low) tax credits for R&D spending, unit costs of R&D is low (high). In computing the correlation, we follow several steps to convert our sector-level variable to a state-level measure and to match the state-level R&D cost measure of Moretti and Wilson (2017).[12]

To combine the sector level subsidization dataset with our firm-level dataset we begin by assigning a sector's R&D incentives ratios to the firms that are in that sector. In so doing, we match the North American Industry Classification System (NAICS) identifier for each firm with the sector in BRDIS and SOI. In our analysis of the impact of R&D support, we use the sector level data mentioned above to classify firms into groups and we investigate whether the theoretical predictions from the previous section are accurate. To do so, we designate firms as low (high) R&D funding if they are in a sector that is in the bottom (top) 40 percent in terms of the R&D funding ratio defined above. We then do the same by using the tax credit ratio and a 45 percent threshold to classify firms into high and low tax credit groups.[13]

Our sample includes 12,524 firms that engage in R&D activity during any of the quarters of our sample period. The panel is unbalanced as data for some firms are not available for each quarter in our sample period. This is especially true for R&D spending. Some of the characteristics of the firms in our sample are displayed in Table 1. During the sample period, the growth rate of R&D expenditures has outpaced the growth of non-R&D investment although it is 8.6 percent of non-R&D investment on average. The subsidization statistics indicate that external funding of R&D is the primary way in which R&D activity is subsidized. Specifically, while external funds constitute 18.8 percent of total domestic R&D expenditures, tax credits are only 3.3 percent of this item. Below we will test our main theoretical prediction that firms in sectors with high R&D funding and low tax credits (hereafter, HFLC firms) react less to changes in funding costs. It is, therefore, useful at this point to compare some of the characteristics of HFLC firms with the whole sample and those that receive low funding and high tax credit (hereafter, LFHC firms). We observe in Table 1 that HFLC firms have increased their R&D expenditures more than the rest of the firms in our sample and the LFHC firms, and that their R&D expenditures, relative to their investment, is large compared to other firms. These observations are consistent with the predictions that we made in the previous section. HFLC firms are also smaller in size, more financially constrained, more liquid and have higher profit opportunities (as indicated by their Tobin's Q) compared to the rest of the firms. It is, therefore, critical to control for these factors when identifying the independent effects of funding costs on relative R&D investment.

We should note that in our dataset firms' R&D spending is much less volatile compared to their investment activity. Specifically, when we measure within-firm variation (measured in standard deviations) of the growth of R&D and investment

[10] The database also reports the amount of R&D funding by foreigners and by the government. These figures are not the primary source of R&D support for most sectors and thus we do not use them as our baseline measure. We do, however, use these variables in our sensitivity analysis.

[11] SOI has alternative measures of tax credit incentives that we use in our sensitivity analysis.

[12] First, we used regional statistics from the Bureau of Economic Analysis to determine the sectoral shares of each states output. We then applied these shares to our baseline sector level R&D incentive ratio (current-year credit for increasing research activities to total domestic R&D expenditures) to obtain an average state-specific tax incentive ratio for the period 2010 to 2013. We then compute the correlation between this variable with the average unit R&D costs in Moretti and Wilson (2017). This study reports two unit costs: costs for highest tier (highest tax credit rate) and lowest tier (lowest tax credit rate) R&D. The correlation between our measure and these two variables were −0.36 and −0.32, respectively.

[13] These threshold values allow for more evenly populated groups of firms. Using alternative cut-off values does not change our main inferences.

Table 1
Summary statistics.

	Whole sample	High funding, low credit (HFLC)	Low funding, high credit (LFHC)
Number of firms	12,524	3,787	5,652
R&D growth (%)	8.5	11.0	6.6
Investment growth (%)	3.2	7.0	6.8
R&D / Investment	0.086	0.198	0.005
Total assets (millions)	7,674	2,469	31,731
KZ index	19.9	28.5	14.4
Tobin's Q	51.9	76.4	42.4
Cash	0.17	0.26	0.11
Sales	0.35	0.182	0.179
R&D subsidy / R&D	0.188	0.142	0.013
R&D tax credit / R&D	0.033	0.023	0.067
Within firm variation, R&D growth	0.584	0.615	0.489
Within firm variation, Investment growth	1.585	1.696	1.490
BofA AAA Spreads (%)	0.9		
BofA BBB Spreads (%)	2.3		
BofA CCC Spreads (%)	12.1		

Notes: Firms are designated as low (high) subsidy if they are in a sector that is in the bottom (top) 40 percent of all sectors in terms of the total external R&D funding rations. Similarly firms are classified into low and high tax credit groups if their sector's tax credit ratio is in the bottom and top 40 percent, respectively. For the R&D funding ratio we use the ratio of total domestic R&D expenditures paid by others to total domestic R&D. For the tax credit ratio we use the ratio of current-year credit for increasing research activities to total domestic R&D expenditures. The firm-specific summary statistics reflect average values measured both across time and firms.

Table 2
State level evidence.

	Correlation of R&D with bond spreads			Correlation of GDP with bond spreads			corr(R&D,R)-corr(GDP,R)		
Average	−0.157	−0.186	−0.115	−0.523	−0.284	−0.459	0.366	0.098	0.344
High R&D intensity states	−0.100	−0.115	−0.076	−0.628	−0.348	−0.553	0.528	0.233	0.477
Low R&D intensity states	−0.216	−0.260	−0.155	−0.412	−0.217	−0.360	0.196	−0.042	0.205
High R&D Intensity*Tax incentives/Sub.	−0.082	−0.110	−0.050	−0.595	−0.351	−0.534	0.514	0.242	0.484
Low R&D Intensity*Tax incentives/Sub.	−0.235	−0.265	−0.182	−0.447	−0.213	−0.380	0.212	−0.052	0.198

Notes: The statistics in columns 1–3 and columns 4–6 are computed as the correlation of R&D spending and Gross Domestic Product (GDP) growth with the BBB bond spread, respectively. R&D spending is from the BRDIS database. GDP growth is calculated by using state level Real GDP variable that is obtained from the BEA database. The sample period is 1997–2014.

expenditures across time and take the averages of this variation across firms we obtain the values reported in the 12*th* and 13*th* rows of Table 1 that reveal lower R&D volatility (nearly one third of investment volatility) for the whole sample and the two groups of firms. This observation is consistent with inferences from macroeconomic data.[14]

As displayed in the bottom panel of Table 1, there are substantial differences between the different bond spreads (the average values across the sample period). Since we cannot directly observe the bond rating for each firm in our sample, we check the robustness of our results to using different bond ratings throughout our analysis.

While our analysis is at the firm level, we should point out some state level evidence that provides motivation for this paper. Table B.2 in Appendix B provides some state level statistics that are the sources of this evidence (the note to the table describes how we compute these statistics). Table 2 reports some summary statistics derived from Table B.2 that are consistent with our theoretical predictions. First notice that the average of the correlations coefficients are negative for both R&D and GDP indicating a negative relationship between funding costs and these two variables. The negative relationship with funding costs is stronger for GDP than it is for R&D. More interestingly, we find that when we rank the states based on their R&D intensity and divide the sample into two equal groups, we find that in states with high R&D intensity, R&D is not as strongly related to funding costs but GDP is more strongly related to funding costs compared to states with low R&D intensity. This finding is the same for the three different bond categories that we use and it is consistent with the cross-subsidization of R&D spending with non-R&D spending that our theoretical model predicts. We get a similar result when we consider R&D subsidization and tax incentives to rank states. In so doing, we divide our R&D intensity variable with the product of the unit cost of R&D measure and the degree of R&D subsidization to obtain a measure that is consistent with the effects of subsidization and tax incentives that we uncover above.[15] In other words, in states that have a high share

[14] The standard deviation of total annual real investment growth (nonresidential private fixed investment, source BEA) and total annual R&D spending growth (source, NSF) in the U.S. from 1957 to 2015 are 7.7 percent and 4.0 percent, respectively.

[15] To obtain this variable we first transform R&D intensity, R&D subsidization and unit costs so that they have a mean of 1.

Table 3
Relative sensitivity of R&D investment to funding costs.

	Bond spreads		
	High yield bond spread CCC rating	Low yield bond spread AAA rating	Medium yield bond spread BBB rating
Funding costs	0.0085	0.0232	0.0486
	(0.0659)*	(0.0942)*	(0.0388)**
Financial constraints	0.1290	0.1277	0.1356
	(0.0135)**	(0.021)**	(0.0096)***
Financial constraints × Funding costs	0.0043	0.0363	0.0216
	(0.0001)**	(0.000)***	(0.000)***
Dependent variable lags	−0.7888	−0.7585	−0.8077
	(0.000)**	(0.000)***	(0.000)***
Tobin's Q	−0.0594	−0.0550	−0.0622
	(0.0076)***	(0.0100)**	(0.0053)***
Cash	−5.4406	−5.5446	−5.4300
	(0.000)***	(0.000)***	(0.000)***
Sales	−2.6133	−2.6840	−2.5875
	(0.000)***	(0.000)***	(0.000)***
Hansen	0.3651	0.3381	0.3635
AR2	0.2864	0.3392	0.2710
Number of observations	6,759	6,759	6,759

Notes: This table shows the results obtained by using R&D investment growth – non-R&D investment growth as the dependent variables in Eq. (24). The numbers in parenthesis are the p-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively. The statistics reported for the Hansen and AR2 tests are the p-values and z-values, respectively.

of R&D spending, a low degree of R&D subsidization and lower tax incentives, the disparity between R&D-bond spread correlation and GDP-bond spread correlation is higher. While this simple analysis leaves out critical state-level effects that may be driving the results, these statistics are all consistent with our theoretical predictions.

3.3. Initial results: Funding costs and the share of R&D spending

Our initial results, obtained by estimating Eq. (24), are displayed in Table 3. The signs of the coefficients are consistent across the three different bond ratings. The positive funding cost coefficients suggest that firms decrease their level of non-R&D investment by more than their R&D spending, thus, implicitly cross-subsidizing R&D expenditures with funds drawn away from non-R&D investment when external finance is more costly. This in turn increases the relative share of R&D expenditures within the firm. The funding cost coefficient value of 0.0085 implies that if there is a 1 percent (100 basis point) increase in high yield borrowing spreads during each of the past 4 quarters, the growth of R&D expenditures outpaces non-R&D investment by 0.85 percent in the current quarter. This effect is much larger for low and medium yield bonds (2.32 and 4.86 percent, respectively).[16] This result provides support for one of the theoretical mechanisms that we identified in Eq. (17). If R&D subsidization works mostly through external funding support (a high ξ) then there is a positive relationship between the changes in funding costs and the relative share of R&D spending. This is also consistent with the descriptive statistics in Table 1 showing that R&D's external funding is much larger than the tax incentives it receives.

Turning to financial constraints, we find that an increase in a firm's financial constraints (measured by an increase in its KZ index) affects its non-R&D investment disproportionately, causing its share to drop. Furthermore, this impact of financial constraints is stronger when funding costs are increasing as it can be inferred from the interactive term coefficients. The coefficients of the remaining variables indicate that if a firm has higher profit opportunities from investment, higher liquidity and higher sales growth, it increases the share of non-R&D investment.

The statistics reported in the bottom panel of Table 3, the p-values and z-values from Hansen and AR(2) tests, indicate that instruments as a group are valid and exogenous, and that there is no evidence for second-order serial correlation in the error term. This is also true for all other estimations in our paper.

As indicated earlier, the reason we use general bond indices instead of firm level borrowing spreads is that the latter are not available for most of the firms we have in our sample. It is therefore useful to check whether inferences obtained from alternative bond indices are similar. While our baseline measures of credit spreads give us a sense of robustness, the three indices do not exhaust the list of credit spreads that are available. In Table 4 we report the main coefficients that we obtain from Eq. (24) when we use a broader set of bond indices (the full estimation results are reported in Appendix C). The

[16] The reason for this is that high yield bond spreads have a larger mean and standard deviation. If bond spreads are standardized to have a mean of zero and a standard deviation of 1, the estimated coefficient values become more similar in magnitude.

Table 4
Alternative bond ratings.

Bond ratings	Funding costs		Financial constraints		Financial constraints × Funding costs	
CCC	0.0085	(0.0659)*	0.1290	(0.0135)**	0.0043	(0.0001)***
AAA	0.0232	(0.0942)*	0.1277	(0.021)**	0.0363	(0.000)***
BBB	0.0486	(0.0388)**	0.1356	(0.0096)***	0.0216	(0.000)***
High Yield B	0.0159	(0.0421)**	0.1241	(0.0169)***	0.0094	(0.0007)***
High Yield	0.0185	(0.0358)**	0.1267	(0.0172)**	0.0082	(0.0001)***
High Yield BB	0.0279	(0.0337)**	0.1229	(0.0231)**	0.0116	(0.0002)***
Master	0.0499	(0.0439)**	0.1357	(0.0077)***	0.0293	(0.000)***
15+ year	0.0744	(0.0528)***	0.1387	(0.0048)***	0.0415	(0.000)***
7–10 year	0.0604	(0.044)**	0.1418	(0.0036)***	0.0346	(0.000)***
3–5 year	0.0374	(0.0621)*	0.1372	(0.0057)***	0.0279	(0.000)***
1–3 year	0.0367	(0.023)**	0.1266	(0.0222)**	0.0192	(0.000)***
Moody's Baa	0.0813	(0.0336)**	0.1401	(0.0094)***	0.0368	(0.0001)***
Moody's Aaa	0.2291	(0.0432)**	0.1062	(0.1013)	0.0750	(0.006)***

Notes: To obtain the results in this table, we use R&D investment growth – non-R&D investment growth as the dependent variable and we separately use the bond spreads corresponding to the ratings listed in column 1 as the main funding cost variable in Eq. (24). The numbers in parentheses are the p-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively.

Table 5
Sensitivity of R&D and non-R&D investment to funding costs.

	Non R&D investment			R&D investment		
	High yield bond spread CCC rating	Low yield bond spread AAA rating	Medium yield bond spread BBB rating	High yield bond spread CCC rating	Low yield bond spread AAA rating	Medium yield bond spread BBB rating
Funding costs	−0.0142	−0.1701	−0.0375	−0.0074	−0.0652	−0.0253
	(0.000)***	(0.000)***	(0.0001)***	(0.0014)***	(0.000)***	(0.0818)*
Financial constraints	−0.1632	−0.1635	−0.1653	0.0001	0.0001	0.0001
	(0.0002)***	(0.007)***	(0.0041)***	(0.7991)	(0.8304)	(0.7226)
Financial const. ×	−0.0010	−0.0063	0.0007	0.0000	0.0001	0.0001
Funding costs	(0.0839)*	(0.0875)*	(0.2188)	(0.000)***	(0.000)***	(0.000)***
Dependent variable	−2.2115	−2.2002	−2.1807	−1.3037	−1.1655	−1.3843
lags	(0.0005)***	(0.0004)***	(0.0007)***	(0.000)***	(0.000)***	(0.000)***
Tobin's Q	0.0493	0.0489	0.0502	−0.0002	−0.0002	−0.0002
	(0.0132)***	(0.0139)**	(0.0197)**	(0.912)	(0.9153)	(0.8949)
Cash	4.1132	4.1877	4.1200	0.5956	0.5912	0.6152
	(0.000)***	(0.000)***	(0.000)***	(0.145)	(0.1531)	(0.1297)
Sales	1.4179	1.4094	1.4986	0.1239	0.0888	0.1201
	(0.000)***	(0.000)***	(0.000)***	(0.0659)*	(0.0522)*	(0.0516)*
Hansen	0.1391	0.1333	0.1173	0.2086	0.3001	0.2387
AR2	0.9168	0.9520	0.8683	0.6121	0.6160	0.6024
No. of observations	31,188	31,188	31,188	8131	8131	8131

Notes: This table shows the results obtained by using non-R&D investment growth and R&D growth separately as the dependent variables in Eq. (24). The numbers in parentheses are the p-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively. The statistics reported for the Hansen and AR2 tests are the p-values and z-values, respectively.

results, similar to those in Table 3, indicate a positive and significant relationship between the share of R&D spending, and funding costs and financial constraints.[17] Notice that it is not straightforward to compare the coefficient values across the different bond types as their mean values and standard deviations are considerably different. We thus refrain from doing so since it is not the primary objective of our analysis.

The general inference so far is that the share of R&D expenditures in total investment increases when there is a tightening in credit conditions. This, however, does not allow us to determine how the two types of investment activity are individually related to funding costs. The reason we find positive coefficients in Table 3, for example, could be that both R&D and non-R&D spending are positively related to credit spreads and that R&D spending is more responsive. To further explore the sources of our findings in Table 3 and to rule out this unrealistic scenario, we include the growth of R&D spending and non-R&D spending separately as the dependent variable in Eq. (24). This approach also allows us to test the theoretical relationship between R&D and non-R&D spending and funding costs across firms displayed in Eq. (22), as opposed to the within firm allocation of investment. The results in Table 5 show that both types of investment activities are negatively related to credit spreads. A comparison of the magnitude of the funding cost coefficients, however, indicates that non-R&D spending is much more responsive to credit conditions. This disparity between sensitivities holds for the other independent

[17] The signs and significance of the remaining coefficient values are similar and they are not reported for brevity.

Table 6
High and low R&D firms.

	High R&D			Low R&D		
	High yield bond spread CCC rating	Low yield bond spread AAA rating	Medium yield bond spread BBB rating	High yield bond spread CCC rating	Low yield bond spread AAA rating	Medium yield bond spread BBB rating
Funding costs	0.0153	0.0713	0.0927	0.0033	-0.0304	0.0138
	(0.0043)***	(0.003)***	(0.0007)***	(0.7564)	(0.9316)	(0.7991)
Financial constraints	0.0774	0.0947	0.0870	0.4763	0.4603	0.4756
	(0.1707)	(0.1316)	(0.1721)	(0.000)***	(0.000)***	(0.000)***
Financial const. ×	0.0045	0.0400	0.0219	0.0056	−0.2262	−0.0147
Funding costs	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Dependent variable	−1.0830	−1.0773	−1.1033	−0.7998	−0.8169	−7940
lags	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Tobin's Q	−0.0398	−0.0416	−0.0438	−0.1538	−0.1278	−0.1450
	(0.2845)	(0.1143)	(0.2508)	(0.0014)***	(0.0043)***	(0.0018)***
Cash	−4.8593	−4.9275	−4.9328	−4.9666	−5.0830	−4.9080
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Sales	−2.2534	−2.3126	−2.2498	−4.7104	−5.0257	−4.7602
	(0.000)***	(0.000)***	(0.000)***	(0.001)*	(0.0005)***	(0.0008)***
Hansen	0.6309	0.5879	0.6562	0.6174	0.6387	0.6305
AR2	0.9236	0.8233	0.9419	0.6099	0.6095	0.6057
No. of observations	2681	2681	2681	4078	4078	4078

Notes: This table shows the results obtained by using investment growth, R&D growth and Investment – R&D growth as the dependent variables in Eq. (24). The estimations are conducted separately for firms with high and low share of R&D investment in their total investment. The numbers in parentheses are the *p*-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively. The statistics reported for the Hansen and AR2 tests are the *p*-values and *z*-values, respectively.

variables as well. Specifically, we find that R&D spending does not significantly react to the changes in firms' financial constraints, liquidity and the Tobin's Q. While the coefficients for sales growth and the interactive variable are significant in the R&D estimations, these are much smaller compared to the corresponding coefficients obtained from the estimations with non-R&D spending.[18]

As a final exercise, we assess how our inferences are related to the degree of R&D activity by dividing the firms engaging in this activity into two groups: high and low R&D. In a given quarter, a firm is designated as high R&D if its R&D investment as a share of its total investment in the previous quarter is greater than the average R&D-to-total-investment ratio measured across all the R&D firms in the previous quarter. Otherwise, the firm is designated as low R&D. The results obtained from these alternative samples, by using the baseline definition of the dependent variable, are reported in Table 6. The striking observation here is that the allocation of funds to R&D investment (away from other investment activities) is only significant for high R&D firms and that this mechanism is stronger compared to the baseline results. For low R&D firms, we find that the changes in financial constraints instead impact the allocation of funds between R&D and non-R&D investment. This impact, too, is much larger compared to the baseline results. Overall, our findings imply that high R&D firms' reallocation of funds from non-R&D activity to R&D activity when funding costs rise is much stronger compared to low R&D firms whose allocation of funds is instead more responsive to changes in their financial constraints.

3.4. The impact of R&D incentives

In the first half of the paper, we predicted that the effect of borrowing costs on the allocation of investment between R&D and non-R&D activities depends on the type of R&D incentives that a firm receives. If these incentives are mostly through external funding support, a credit tightening increases the share of R&D spending. By contrast, the share of R&D decreases for a firm that receives incentives mostly through tax breaks. The opposite conclusions hold under an easing of credit conditions. To test this prediction, we estimate our baseline model by using data for firms in sectors receiving high level of external funding and low levels of tax credits (HFLC firms). The reason we use this approach is that the R&D incentives data, as described above, are only available at the sector level and does not span the entire period that our firm-level dataset covers. Therefore, there is no one-to-one mapping between firms and the amount of R&D support that they receive. It is, however, reasonable to expect that if our theoretical prediction is sound, there should be a positive relationship between funding costs and the share of R&D for firms in the restricted sample that we use in this section.

The results in Table 7 show that this is true. Compared to the whole sample, HFLC firms have larger funding cost coefficients. They, therefore, experience a more substantial increase (decrease) in the share of their R&D investment, relative to non-R&D investment, when there is an increase (decrease) in funding costs. The larger interactive variable coefficient for the

[18] As an alternative test we included R&D spending and non-R&D spending as independent variables when non-R&D spending and R&D spending are the dependent variables, respectively, and we found similar results. These results are available upon request.

Table 7
The effects R&D subsidies and tax credit.

	High yield bond spread CCC rating		Low yield bond spread AAA rating		Medium yield bond spread BBB rating	
	Baseline	HFLC	Baseline	HFLC	Baseline	HFLC
Funding costs	0.0085	0.0099	0.0232	0.1378	0.0486	0.0798
	(0.0659)*	(0.0081)***	(0.0942)*	(0.0353)*	(0.0388)**	(0.0119)**
Financial constraints	0.1290	0.0224	0.1277	0.0426	0.1356	0.0413
	(0.0135)**	(0.0631)*	(0.021)**	(0.0143)**	(0.0096)***	(0.0463)**
Financial const. ×	0.0043	0.0443	0.0363	0.3107	0.0216	0.1843
Funding costs	(0.0001)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Dependent variable	−0.7888	−0.9329	−0.7585	−0.9404	−0.8077	−0.9319
lags	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Tobin's Q	−0.0594	−0.0562	−0.0550	−0.0363	−0.0622	−0.0549
	(0.0076)***	(0.0003)***	(0.0100)**	(0.0018)***	(0.0053)***	(0.0003)***
Cash	−5.4406	−4.8453	−5.5446	−4.7963	−5.4300	−4.8238
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Sales	−2.6133	−1.6050	−2.6840	−1.5557	−2.5875	−1.5939
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Hansen	0.3651	0.6105	0.3381	0.6091	0.3635	0.6016
AR2	0.2864	0.1182	0.3392	0.1518	0.2710	0.1302
No. of observations	6,759	1,759	6,759	1,759	6,759	1,759

Notes: This table reports the results obtained by estimating Eq. (24) for firms in sectors that receive a high level of R&D subsidies and a low level of tax credits (HFLC firms). Firms are designated as high subsidy if they are in a sector that is in the top 40 percent of all sectors in terms of the total external R&D funding ratios. Similarly firms are classified into the low tax credit group if their sector's tax credit ratio is in the bottom 40 percent. For the R&D funding ratio we use the ratio of total domestic R&D expenditures paid by others to total domestic R&D. For the tax credit ratio we use the ratio of current-year credit for increasing research activities to total domestic R&D expenditures. The numbers in parentheses are the *p*-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively. The statistics reported for the Hansen and AR2 tests are the *p*-values and *z*-values, respectively.

restricted sample further suggests that this disproportionate effect of funding costs is amplified for financially constrained firms. The financial constraint coefficient by itself, however, is smaller in the restricted sample thus suggesting that financial constraints cause a sharper increase in the R&D spending share of HFLC firms only if credit conditions are tighter. Turning to the remaining firm-specific variable coefficients, we observe that HFLC firms' future profit opportunities, liquidity and sales growth have a smaller impact on, albeit not substantially different from, the allocation of investment between R&D and non-R&D activities.

In what follows, we describe and report results from various tests of sensitivity and robustness that corroborate our findings on the effects of R&D support. The results from these tests are all reported on Table 8. To simplify the demonstration, we only report results from the estimations with medium yield bonds, and we only include the coefficients of the three major variables that we've focused on so far. It should be noted, however, that the remaining coefficients are similar to those in our baseline estimations in terms of sign and significance, and we obtain similar inferences with high and low yield bonds. To facilitate a comparison, we also include our baseline results on the first two rows of the table. As a first test, we investigate firms in sectors that receive low support and high tax incentives (LFHC firms), firms that are diametrically opposed to the ones that we considered above. The results indicate, consistent with our theoretical prediction that, the increase in these firms' R&D spending share in response to an increase in funding costs is not as sharp as the HFLC firms. The reinforcing effects of financial constraints are also smaller for this group.

In the next 4 rows, we report estimation results based on alternative definitions of external funding support (government and foreign funding of domestic R&D investment) and tax incentives (total tax credit / qualified expenses and regular credit / qualified regular credit expenses). Here, qualified credit expenses consist of wages for qualified services, cost of supplies and rental or lease costs of computers of which wages have the largest share. The difference between regular credit and total credit is alternative incremental credit which through the Small Business Job Protection Act of 1996 gives opportunities for small firms that are ineligible to apply for regular credit. The results based on these alternative definitions of R&D incentives provide similar inferences. The two noteworthy exceptions are the negative and large financial constraints coefficient under the government funding and total credit to qualified expenses rows. The latter result could be a byproduct of the composition of firms that file under alternative incremental credit. These firms, as indicated above, are smaller and thus face more binding financial constraints. Similarly, the overwhelming majority of the government support for R&D goes to three sectors (Professional, scientific, and technical services, Transportation equipment, and Computer and electronic products) and our results indicate that financial constraints have the opposite relationship with investment for firms that receive government support. Specifically, firms in these sectors face more severe financial constraints when they engage in investment activity compared to firms in other sectors. The interactive variable coefficient, nevertheless, indicates that during a credit tighten-

Table 8
The impact of R&D funding and tax credits, alternative tests.

	Funding costs		Financial constraints		Financial const. × Funding costs	
Baseline	0.0486	(0.0388)**	0.1356	(0.0096)***	0.0216	(0.000)***
HFLC (Baseline definitions)	0.0798	(0.0119)**	0.0413	(0.0463)**	0.1843	(0.000)***
LFHC	0.0622	(0.0008)***	0.1518	(0.000)***	0.0630	(0.000)***
Government funding	0.0647	(0.0215)**	−0.0248	(0.000)***	0.0984	(0.000)***
Foreign funding	0.0754	(0.0141)**	0.0498	(0.0242)**	0.1821	(0.000)***
Credit/qualified expenditures	0.0350	(0.0102)**	0.2308	(0.0002)***	0.1128	(0.000)***
Credit/qualified expenditures, regular credit	0.0776	(0.0145)**	0.0557	(0.0305)**	0.1867	(0.000)***
The response of relative loan growth in standard deviations						
Baseline	0.0267	(0.0388)**	0.0746	(0.0096)***	0.0119	(0.000)***
HFLC	0.0439	(0.0119)**	0.0227	(0.0463)***	0.1014	(0.000)***
Balanced panel						
Baseline	0.0626	(0.0235)**	0.1784	(0.0013)***	0.1106	(0.0387)**
HFLC	0.0830	(0.0028)***	0.0204	(0.2996)	0.1745	(0.000)***
Fixed effects estimation						
Baseline	0.0440	(0.000)***	0.0060	(0.0050)***	−0.0019	(0.1810)
HFLC	0.0417	(0.099)*	0.0056	(0.049)**	−0.0022	(0.401)

Notes: This table reports the results we obtain when we use alternative definitions of R&D subsidies and tax credits. In addition, we report the results obtained by standardizing the dependent variable in the bottom two rows. Firms in sectors that receive a high (low) level of R&D subsidies and a low (high) level of tax credits are designated as HFLC (LFHC) firms. The numbers in parentheses are the *p*-values from tests that determine the joint significance of the coefficients. *, **, *** significant at 10%, 5%, 1%, respectively.

ing financial constraints similarly become more binding for non-R&D investment compared to R&D investment for firms that receive government support.

One factor that we have not considered when comparing coefficients is the standard deviation of the independent variables. If there is a large difference in the variation of these variables across the two samples we investigate (the baseline and the restricted sample), our comparison can be inaccurate as the coefficients of the variables with higher variation could be smaller. To account for this potential shortcoming, we standardize our variables so that the coefficients that we obtain measure the response of relative R&D spending growth to a one-standard-deviation change in the independent variable. The results from this test also produces larger coefficients for funding costs and the interactive variable in the restricted sample. Simply put, HFLC firms show a larger shift towards R&D spending during a credit tightening.

Our panel is unbalanced as firms have missing observations during our sample period. As a robustness check, we test whether our inferences are similar when we consider a more balanced panel. One problem that we face in this exercise is that some firms have missing observations during our sample period although they are solvent. If we take out these firms altogether, the number of observations become too small (especially for the restricted sample with HFLC firms) to draw any sound inferences. To construct a more balanced panel while avoiding this problem, we include firms that are in our sample for each quarter of 2009 and that have at least 20 quarterly observations (out of the 24 observations between 2010Q1 and 2015Q4). We do this because a large number of the missing observations are for year 2015. We do not omit this year completely, however, since there also firms with missing observations in the middle of our sample. The results displayed in Table 8 show that our inferences are similar. The smaller impact of financial constraints for HFLC firms is also observed in these estimations. Moreover, financial constraints become statistically insignificant in this alternative estimation.

As a final test, we conduct a fixed effects panel estimation to determine whether our results are sensitive to different estimation methodologies. In so doing, we include firm, quarter and year fixed effects individually (without interactive terms) in our baseline model and we eliminate the additional lags of the right hand side variables. We do this separately for both the full sample and the sample with only HFLC firms. The results that we obtain by following this strategy is displayed in the last two rows of Table 8. The coefficients of funding costs and leverage are similarly positive and significant. Unlike our baseline results, however, we find no statistically significant difference between the coefficients for all firms and the HFLC firms. Also different from our baseline results, the coefficients of the interactive term in these regressions is insignificant. The lags of the right hand side variables are the most likely factors that drive the disparity between the two results. Specifically, by including the lags of bond spreads in our baseline model, we are able to capture impact lags in the transmission of interest rate fluctuations on investment activity. This impact lag is a stylized fact in macroeconomics.[19] Omitting the lagged effects of funding costs on relative R&D activity, therefore, could produce an incomplete picture. As we explain above, the dynamic panel model estimator that we use is designed for models that include these lagged effects and thus this is the reason why we use it as our baseline methodology.

[19] For the transmission of the changes in federal funds rate to the real economy, for example, 6 months is a commonly used duration for impact lags.

4. Conclusion

This paper demonstrates that firms cross-subsidize their R&D investments with their non-R&D investment expenditures when external funding costs increase. This mechanism is reinforced by R&D incentives that are in the form of grants and subsidized loans, and it is weakened by tax credits to R&D. The reason is that R&D expenditures of firms receiving a high level of grants and low interest loans become less exposed to market funding costs. Firms that receive incentives in the form of tax credits, by contrast, decrease their share of R&D spending when funding costs rise because they have low unit R&D costs (due to the tax incentives) and an increase in interest rates has larger negative impact on their R&D spending compared to their non-R&D spending. We find empirical evidence for these theoretical predictions by using firm-level financial and sector level R&D incentives data, and a unique identification strategy that focuses on the within-firm allocation of investment expenditures between R&D and non-R&D activities.

One projection from our analysis is that when a credit tightening slows economic activity, it also puts it on a more stable footing as firms shift their focus to less volatile activities that are more conducive to economic growth. Conversely, the brunt of a credit easing finances more volatile activities and thus makes the economy potentially less stable going forward. It would be interesting to test this projection by using firm-level and regional/cross-country data. Specifically, one could determine whether firms engaging in R&D activities face lower volatility in their performance and fundamentals during and after credit tightening episodes compared to firms that do not report R&D spending. One could then determine whether tax credits weaken and grants/subsidies reinforce this mechanism by investigating regional data. In other words, are regions/countries with high tax incentives to R&D much more volatile after a period of high borrowing spreads compared to regions receiving grants/subsidies? Such a question should occupy future research in this promising field.

Appendix A. Wage gap-labor demand relationship

This section presents an extension of our model, which we use to discuss the relationship between the wage gap-labor demand. As mentioned earlier, an alternative form of subsidization works through labor incentives. Furthermore, a stylized fact about R&D activity is that it is a labor-intensive process. To incorporate these aspects of R&D/incentives we first modify the evolution of R&D stock as shown below so that the R&D firm hires skilled labor to enhance its stock of knowledge and human capital instead of investing in research efforts to do so.

$$A_{1,t} = \rho A_{1,t-1} + \nu L_{1,t}^{(s)} \tag{A.1}$$

Here, $L_{1,t}^{(s)}$ represents the share of labor force (hereafter, skilled labor) that is employed by the R&D firm to conduct R&D activities only. $L_{1,t}$ and $L_{2,t}$ in the equations below, have the usual interpretations, and they are referred to as unskilled labor to distinguish them from $L_{1,t}^{(s)}$. We reasonably assume that the market wage rates for skilled and unskilled labor, $W^{(s)}$ and W, are different and that the R&D firm is subsidized for hiring skilled labor. The R&D firm's budget constraint in this alternative economy can be represented as follows:

$$D_{1,t} = P_{1,t}Y_{1,t} - W^{(s)}L_{1,t}^{(s)} - WL_{1,t} - R_{t-1}I_{1,t-1}^{(f)} + s^{(l)}L_{1,t}^{(s)} \tag{A.2}$$

where $s^{(l)}$ is the subsidy parameter. These subsidies can be thought of as the payroll tax credits that firms receive from the government or external grants/loans that partially finance the firm's research hires. The optimality conditions of the two firms can be combined to derive the relative demand for skilled labor within the R&D firm and the relative demand for labor across the two firms as follows:

$$\frac{\rho A_{1,t-1} + \nu L_{1,t}^{(s)}}{L_{1,t}} = \frac{\eta \nu W}{(W^{(s)} - s^{(l)})(1-\alpha)} \tag{A.3}$$

$$\frac{L_{1,t} + \rho A_{1,t-1} + \nu L_{1,t}^{(s)}}{L_{2,t}} = \frac{\gamma^2}{(1-\gamma)^2}\left(\frac{\eta \nu W}{(W^{(s)} - s^{(l)})(1-\alpha)} + 1\right) \tag{A.4}$$

Similar to our baseline model, $A_{1,t-1}$ in the numerators of the ratios above is a state variable and thus the impact of a change in the wage gap would be absorbed by only skilled and unskilled labor. We take this feature of our model into account when discussing the effects of wage gap on the composition of skilled and unskilled labor below. Here, we define the skilled-unskilled labor wage gap as $w^* = W^{(s)} - W$. Since there are no counteracting forms of incentives in this setup, it is much simpler to illustrate the impact of changes in wage gap on the relative demand for labor by deriving the percent changes in the expressions above.[20] This derivation yields the following expressions:

$$\frac{d\left\{\left(\nu L_{1,t}^{(s)} + \rho A_{1,t-1}\right)/L_{1,t}\right\}/dw^*}{\left(\nu L_{1,t}^{(s)} + \rho A_{1,t-1}\right)/L_{1,t}} = -\frac{1}{(W^{(s)} - s^{(l)})} \tag{A.5}$$

[20] Assuming that the changes in wage gap are due to changes in $W^{(s)}$ and taking derivatives of relative labor demand with respect to $W^{(s)}$ is an alternative way to derive Eqs. (A.5) and (A.6).

$$\frac{d\left\{\left(L_{1,t}+\nu L_{1,t}^{(s)}+\rho A_{1,t-1}\right)/L_{2,t}\right\}/dw^{*}}{\left(L_{1,t}+\nu L_{1,t}^{(s)}+\rho A_{1,t-1}\right)/L_{2,t}}=-\left(\frac{W\nu\eta}{W\nu\eta+(1-\alpha)(W^{(s)}-s^{(l)})}\right)\cdot\frac{1}{(W^{(s)}-s^{(l)})(1-\alpha)} \tag{A.6}$$

The first inference here is that an increase in w^* causes a drop in the share of skilled labor within the R&D firm and a drop in the share of labor force hired by the R&D firm. More critically, the strength of this channel is positively related to the level of subsidies. The reason is that at higher levels of $s^{(l)}$, as we observed with higher levels of investment tax credit, the relative cost advantages of the subsidy diminishes as the relative wage of skilled-labor rises and thus the percent share of skilled labor in the R&D firm, and in the industry, falls. The overall conclusion here is that incentives aiming to increase skilled labor could also make firms' composition of labor more responsive to changes in the wage gap.

We should note here that in our model the R&D firm does not incur any costs when adjusting investment and labor or switching between the different types of investment and labor. Although it is possible to extend our analysis to incorporate these realistic aspects of funding, the distortionary effects of R&D subsidies would be similar, albeit smaller in magnitude. To avoid confounding our analysis in this section, we do not try to draw quantitative inferences from our model. Instead, we conduct an empirical analysis to test the validity of some of the predictions above and to measure the strength of the relationships we identified.

Appendix B

Table B1
Data definitions.

Variable	Description
R&D investment	Research and development expense (xrdq). This item includes: 1. Company-sponsored research and development 2. Purchased research and development when reported as a special item 3. Research and development expense from continuing operations (for companies engagement in the primary business research and development) 4. Software development expense
Non-R&D investment	capital expenditures (capx) + increase in investments (ivch) + acquisitions (acq) + other uses of funds (sspe)- sale of PPE (siv) − sale of investment (ivstch + ivaco)
Liquidity	Cash and short-term investments (cheq)/total assets (atq)
KZ index	−1.002* (operating income before depreciation (oibdpq)/ total assets (atq)) +3.319*(debt in current liabilities (dlcq) + long term debt (dlttq))/ total assets (atq) −39.368*(dividends-preferred/preference (dvpq)/total assets (atq)) −1.315*(cash and short term investments (cheq)/ total assets (atq))
Tobin's Q	Market-to-book ratio (common shares outstanding (cshoq)* price close (prccq) +long term debt (dlttq) + debt in current liabilities (dlcq))/atq)
Sales	Sales-to-total assets (saleq/atq)
R&D external funding support	Source: BRDIS obtained from NSF. Measured as total domestic R&D expenditures paid by others to total domestic R&D.
R&D tax credits	SOI on Corporation Research Credit obtained from Internal Revenue Service. Measured as ratio of current-year credit for increasing research activities to total domestic R&D expenditures.
Funding cots	BofA Merrill Lynch US Corporate Option-Adjusted Spread in securities with a rating of AAA, BBB and CCC (or below).

Notes: The acronyms under the description column are from COMPUSTAT.

Table B2
State level evidence.

	corr(R&D,R)	corr(GDP,R)	corr(R&D,R)-corr(GDP,R)	R&D intensity	R&D subsidies	Unit costs	Intensity/(unit costs*sub)
Alabama	−0.490	−0.714	0.224	0.008	0.468	1.182	0.282
Alaska	−0.410	0.323	−0.733	0.001	0.354	1.221	0.057
Arizona	0.260	−0.850	1.110	0.015	0.239	1.091	1.124
Arkansas	−0.260	−0.540	0.280	0.003	0.115	1.200	0.441
California	−0.154	−0.749	0.595	0.032	0.149	1.107	3.794
Colorado	−0.441	−0.580	0.139	0.016	0.155	1.187	1.735
Connecticut	0.252	−0.674	0.926	0.030	0.219	1.160	2.345
Delaware	−0.038	−0.338	0.300	0.030	0.267	1.148	1.891

(*continued on next page*)

Table B2 (*continued*)

	corr(R&D,R)	corr(GDP,R)	corr(R&D,R)-corr(GDP,R)	R&D intensity	R&D subsidies	Unit costs	Intensity/(unit costs*sub)
D.C.	−0.091	−0.206	0.116	0.003	0.502	1.225	0.093
Florida	−0.241	−0.808	0.567	0.006	0.355	1.192	0.286
Georgia	−0.147	−0.822	0.676	0.007	0.165	1.120	0.743
Hawaii	−0.122	−0.391	0.269	0.003	0.294	1.078	0.155
Idaho	0.103	−0.605	0.707	0.020	0.237	1.178	1.397
Illinois	−0.472	−0.819	0.348	0.016	0.088	1.156	3.046
Indiana	0.106	−0.678	0.784	0.017	0.141	1.145	2.061
Iowa	−0.332	−0.583	0.251	0.010	0.270	1.171	0.593
Kansas	0.329	−0.601	0.929	0.014	0.311	1.152	0.763
Kentucky	−0.119	−0.614	0.495	0.005	0.237	1.206	0.370
Louisiana	−0.580	−0.093	−0.487	0.002	0.208	1.152	0.146
Maine	−0.090	−0.535	0.445	0.005	0.131	1.175	0.691
Maryland	0.148	−0.496	0.644	0.013	0.430	1.139	0.521
Massachusetts	−0.555	−0.553	−0.001	0.037	0.195	1.136	3.290
Michigan	−0.166	−0.637	0.471	0.037	0.103	1.170	6.036
Minnesota	−0.271	−0.611	0.340	0.021	0.090	1.203	3.872
Mississippi	−0.173	−0.401	0.228	0.003	0.218	1.189	0.193
Missouri	−0.577	−0.512	−0.065	0.015	0.477	1.138	0.532
Montana	−0.452	−0.693	0.241	0.003	0.163	1.166	0.304
Nebraska	0.111	−0.170	0.281	0.005	0.070	1.166	1.260
Nevada	−0.255	−0.819	0.564	0.004	0.113	1.156	0.632
New Hampshire	−0.026	−0.582	0.556	0.025	0.566	1.185	0.739
New Jersey	−0.163	−0.582	0.419	0.027	0.147	1.134	3.200
New Mexico	−0.237	−0.331	0.094	0.008	0.480	1.208	0.255
New York	−0.485	−0.418	−0.067	0.010	0.236	1.209	0.660
North Carolina	−0.272	−0.737	0.465	0.014	0.214	1.168	1.101
North Dakota	0.052	0.259	−0.206	0.007	0.088	1.124	1.308
Ohio	−0.179	−0.682	0.503	0.014	0.282	1.187	0.795
Oklahoma	−0.147	−0.407	0.260	0.004	0.123	1.196	0.485
Oregon	0.192	−0.351	0.543	0.022	0.046	1.160	7.842
Pennsylvania	−0.618	−0.705	0.086	0.016	0.082	1.140	3.320
Rhode Island	0.092	−0.539	0.630	0.020	0.131	1.082	2.719
South Carolina	−0.049	−0.810	0.761	0.007	0.230	1.161	0.543
South Dakota	−0.352	0.093	−0.445	0.003	0.140	1.156	0.351
Tennessee	−0.263	−0.648	0.385	0.006	0.148	1.198	0.682
Texas	0.089	−0.670	0.758	0.011	0.157	1.156	1.214
Utah	−0.132	−0.870	0.738	0.015	0.240	1.144	1.084
Vermont	0.034	−0.410	0.444	0.015	0.114	1.170	2.149
Virginia	−0.293	−0.600	0.308	0.010	0.461	1.188	0.372
Washington	−0.124	−0.720	0.597	0.033	0.049	1.156	11.456
West Virginia	0.274	−0.195	0.468	0.004	0.142	1.168	0.498
Wisconsin	−0.018	−0.788	0.770	0.013	0.132	1.172	1.624
Wyoming	−0.256	−0.187	−0.069	0.001	0.233	1.156	0.086

Notes: The statistics in columns 1 and 2 are computed as the correlation of R&D spending and Gross Domestic Product (GDP) growth with the BBB bond spread, respectively. R&D spending is from the BRDIS database. GDP growth is calculated by using state level Real GDP variable that is obtained from the BEA database. The sample period is 1997–2014. We measure states R&D intensity as the average of the ratio of a states total R&D spending (from the BRDIS database) to state level GDP across time. We compute the same state level averages for the degree of R&D subsidization and tax incentives. For R&D subsidization we use the R&D spending paid by others to the total R&D spending ratio. For tax incentives, we use the Moretti and Wilson (2017) unit costs of R&D.

Appendix C. Full estimation results with alternative bond ratings

Table C1
Relative R&D growth and funding costs, alternative bond ratings.

	Bond ratings									
	High Yield B	High Yield	High Yield BB	Master	15+ year	7–10 year	3–5 year	1–3 year	Moody's Baa	Moody's Aaa
Funding costs	0.0159	0.0185	0.0279	0.0499	0.0744	0.0604	0.0374	0.0367	0.0813	0.2291
	(0.0421)**	(0.0358)**	(0.0337)**	(0.0439)**	(0.0528)*	(0.044)**	(0.0621)*	(0.023)**	(0.0336)**	(0.0432)**
Financial constraints	0.1241	0.1267	0.1229	0.1357	0.1387	0.1418	0.1372	0.1266	0.1401	0.1062
	(0.0169)**	(0.0172)**	(0.0231)**	(0.0077)***	(0.0048)***	(0.0036)***	(0.0057)***	(0.0222)**	(0.0094)***	(0.1013)
Fin. Cons × Fund. costs	0.0094	0.0082	0.0116	0.0293	0.0415	0.0346	0.0279	0.0192	0.0368	0.0750
	(0.0007)***	(0.0001)***	(0.0002)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0001)***	(0.006)***

(*continued on next page*)

Table C1 (*continued*)

	Bond ratings									
	High Yield B	High Yield	High Yield BB	Master	15+ year	7–10 year	3–5 year	1–3 year	Moody's Baa	Moody's Aaa
Dependent variable lags	−0.7903	−0.8035	−0.8062	−0.8010	−0.7841	−0.8004	−0.7954	−0.8125	−0.7897	−0.7964
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Tobin's Q	−0.0555	−0.0568	−0.0541	−0.0613	−0.0659	−0.0660	−0.0611	−0.0553	−0.0686	−0.0555
	(0.0106)**	(0.0103)**	(0.0149)**	(0.0054)***	(0.0028)***	(0.0027)***	(0.0052)***	(0.0114)**	(0.0023)***	(0.0171)**
Cash	−5.4775	−5.4636	−5.4943	−5.4458	−5.4105	−5.4219	−5.4473	−5.4929	−5.4288	−5.5904
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Sales	−2.6586	−2.6299	−2.6598	−2.6197	−2.6025	−2.6018	−2.6312	−2.6306	−2.5901	−2.7572
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Hansen	0.3736	0.3745	0.3785	0.3567	0.3473	0.3468	0.3508	0.3751	0.3704	0.3866
AR2	0.2984	0.2903	0.3033	0.2752	0.2643	0.2611	0.2779	0.2962	0.2575	0.3102
Number of obs.	6,759	6,759	6,759	6,759	6,759	6,759	6,759	6,759	6,759	6,759

Notes: This table reports the full estimation results that correspond to the summarized results in Table 3.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.euroecorev.2018.09.006.

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