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Welfare Effects of R&D Support Policies*

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Abstract

We construct a model of innovation incorporating R&D externalities, R&D participation, financial market imperfections, and application and allocation of R&D subsidies, estimate it using Finnish R&D project level data and conduct a welfare analysis. The intensive, not the extensive R&D margin is important. Financial market imperfections are small. Tax credits and subsidies do not reach first best R&D but increase R&D 29-47% compared to laissez-faire. Welfare effects are small: Tax credits increase welfare 1%; subsidies reduce welfare once application costs are taken into accout. In terms of fiscal cost, tax credits are 90% more expensive than R&D subsidies.

KEY WORDS: R&D subsidies, R&D tax credits, extensive and intensive margin, financial market imperfections, welfare, counterfactual, economic growth.

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1 Introduction

A large body of evidence suggests that enhanced productivity through innovation is the main driver of economic growth. Economic theory, starting with Nelson (1959) and Arrow (1962), suggests that market failures provide a motivation for government intervention regarding private R&D investments. An increasing number of countries resort to R&D subsidies and tax credits to encourage private sector R&D: e.g., OECD countries spend in excess of $50 Billion on such financial support annually.[1] The existing literature is however not always well-suited for guiding the extent and allocation of such support. Theoretically oriented studies often assume that all firms invest in R&D when data shows otherwise; empirical research mostly does not differentiate between the effects of support at the extensive and intensive margins of R&D, and seldom contrasts R&D subsidies and tax credits. Despite producing a number of insights into the causal effects of R&D tax credit and subsidy policies, the vast empirical literature fails to address the ultimate question: are these R&D support policies welfare enhancing or not?[2] In this paper we develop and apply a framework that allows for comparisons of the impact of public support at the extensive and intensive margins; of the welfare impacts of R&D subsidies, R&D tax credits; laissez faire policy of no government support, first and second best, and an economy without financial market imperfections.

The two well-known market failures motivating public support to private R&D are appropriability problems and financial market imperfections. Government innovation policy officials often add to this list the objective to entice non-R&D-performing firms to start investing in R&D. We incorporate in our model all these three rationales for public support to private R&D. We use revealed preference to identify the structural parameters by estimating four key decisions: the firms' project level R&D investments yield information on parameters governing the marginal profitability of R&D and the cost of external finance; the decision to invest in R&D allows us to identify the fixed costs of

[1] We arrive at this figure by multiplying Business Enterprise R&D (BERD) measured in 2010 PPP US$ by the percentage of BERD financed by government (OECD Main Science and Technology Indicators www-site, accessed Sept 16th 2015).

[2] See surveys by Garciá-Quevedo (2004), Cerulli (2010), and Zúñica-Vicente et al. (2014). More recent contributions include Bronzini and Iachini (2014), Einiö (2014), Howell (2017) and Hünermund and Czarnitzki (2019) on R&D subsidies, and Dechezleprêtre et al. (2016) on R&D tax credits.

R&D; the decision of a firm to apply for subsidies is informative about the costs of application; and finally, the government agency's decision of what fraction of R&D costs to reimburse allows us to identify the parameters of the government utility function.

We take the model to a detailed R&D project-level data from Finland where the ratio of R&D to GDP is among the highest in the world. In the mid 1980s a government agency (Tekes) was established to provide R&D subsidies to firms, and other public financial support to R&D (e.g., R&D tax credits) were abolished.[3] From Tekes, we obtain data on project level R&D subsidy applications, including the applied amount of funding, internal screening outcomes and final funding decisions, the realized project expenses and reimbursements, and information on other sources of funding. We match these Tekes' data to the R&D survey and balance-sheet data from Statistics Finland. We have also been able to observe the project-level decision making process at Tekes.

In our welfare analysis, we first displace R&D subsidies with an optimally calculated R&D tax credit to contrast the two main government financial support policies for private R&D. To provide benchmarks, we consider a laissez-faire regime with no government support and the first and second best regimes where the government can directly determine the level of private R&D investments (without and with a concern for firms' zero profit constraint), and a regime without financial market imperfections.

Our model shows how the calculation of optimal R&D subsidies and of optimal R&D tax credits becomes become more complex when the extensive margin of R&D is introduced. In particular, the effect of financial market imperfections on the level of optimal support delicately depends on the margin at which the support operates. In our counterfactuals, 40% of Finnish firms do not invest in R&D, nor should they, as their R&D ideas are neither privately nor socially profitable. Subsequently, the two R&D support policies have on average almost no impact at the extensive margin. However, conditional on investing, there are large differences in the level of R&D: compared to laissez-faire, the R&D sup-

[3]Finland's R&D subsidy regime is comparable to those of e.g. Belgium, Germany, the Netherlands and to the US SBIR programs, and is highly regarded. An evaluation of Tekes (van der Veen et al. 2012, pp. 29) concludes that "Tekes richly deserves its international reputation as a leading technology and innovation agency". Yet, this evaluation and other similar evaluations of Tekes and subsidy programs of other countries, cannot answer the question of whether tax payers' money is well spent or not. A contribution of our paper is to provide a tool for such a welfare analysis.

port policies increase R&D investments by 29-47%, and the first best regime by more than 100%. The main difference between the two support regimes is that R&D subsidies tailor support to particular projects quite successfully while reaching only a small fraction of R&D performing firms. Reflecting the aforementioned ability of the government to tailor R&D subsidies to achieve welfare gains, the projects receiving R&D subsidies are clearly larger than average. In contrast, R&D tax credits are available to all firms, but on the same terms. In terms of fiscal cost, tax credits are over 90% more expensive than R&D subsidies.

We estimate the value of spillovers to be 58 cents per euro of R&D. While the differences in spillovers across the policy regimes are of the same order of magnitude as differences in the R&D investments, differences in profits are small. As it turns out that profits are the main element of welfare, we find only small differences in welfare across the regimes. An explanation for spillovers being low relative to profits is that a significant fraction of spillovers generated by the Finnish R&D are likely flowing outside Finland, and should be ignored by a Finnish agency. Estimaed financial market imperfections are small and hardly affect the welfare analysis.

We differ from the majority of papers on public support to private R&D in that we build a model to derive the estimation equations. One of our four main estimation equations is a familiar-looking R&D equation albeit with a structural interpretation. According to our data, firms' innovation efforts are heterogenous, which appears to be well-understood by innovation policy makers. We use the ensuing large variation in government subsidy decisions - Figure 1 displays the distribution of the fraction of R&D cost covered by the government - that most papers ignore.

[Figure 1. Distribution of the subsidy rate]

We believe to be the first to build and estimate a microeconomic model of innovation policy where R&D externalities, financial market imperfections and fixed cost of R&D affect the distribution of government support, R&D investment levels, and R&D participation decisions. The estimation of the model provides a basis for a welfare evaluation of R&D support policies. While the empirical literature on the effects of R&D support policies is extensive, it has focused on estimating the causal effect of a policy on some other outcome variable (e.g., on private R&D) rather than welfare. Nor do the existing models provide a solid foundation for a welfare analysis: for example, while useful as a starting point, the model in Takalo, Tanayama and Toivanen (2013a, TTT henceforth) assumes perfect financial markets even though imperfections arising from informational asymmetries are a pervasive feature of innovation finance (see surveys by Hall and Lerner 2010, and Kerr and Nanda 2015). Also, in violation of data, in that model all firms invest in R&D. It is also challenging to compare the merits of R&D subsidies and R&D tax credits without integrating them in a unified framework.

Methodologically, our paper is close to the macro-oriented literature on optimal R&D policy (e.g., Acemoğlu et al. 2018, and Akcigit, Hanley, and Stantcheva 2019). We differ from this literature both in terms of data and modeling, but our welfare results are quite close to those in Acemoğlu et al. (2018) and our estimate of the optimal R&D tax credit close to the optimal linear R&D subsidies reported by Acemoğlu et al. (2018).[4] Our data are more disaggregated and we offer a richer model of the R&D subsidy process, i.e., who applies, who gets and how large subsidies, but in a partial equilibrium context. Our approach to identifying spillovers and social returns complements the one introduced by Bloom, Schankerman, and van Reenen (2013), and our result on the intensive margin being more important than the extensive margin is reminiscent of Garcia-Macia, Hsieh and Klenow's (2019) results.

Our precursors in the small literature estimating structural models of innovation include (besides TTT 2013a) González, Jaumandreu, and Pazó (2005) who focus on R&D subsidies, Peters et al. (2017) who use a dynamic empirical model to uncover the fixed and sunk costs of R&D, and Doraszelski and Jaumandreu (2013) who study R&D and productivity. Also relevant are Xu (2008), who estimates an industry equilibrium model with R&D spillovers, Arqué-Castells and Mohnen (2015) who study the impact of fixed and sunk costs of R&D on the effectiveness of R&D subsidies, and Boller, Moxnes and Ulltveit-Moe (2015) who study the link between R&D, imports and exports.

We proceed by first discussing the Finnish institutional environment for R&D and our data in the next section. We turn to our model in section 3. Section 4 is devoted to explaining how we estimate our model. Estimation results

[4]The working paper version of Akcigit, Hanley and Stantcheva (2017), too, includes an optimal linear R&D subsidy close to our optimal R&D tax credit.

are presented in section 5 and section 6 contains the counterfactual experiment. Section 7 concludes.

2 Institutional Environment and Data

2.1 Institutional Environment

As pointed out by Trajtenberg (2001), Finland rapidly transformed from a resource- to an innovation and knowledge-based economy at the end of the millennium. The R&D/GDP ratio in Finland doubled over the two decades and overtook that of the US (see Appendix A). The bulk of Finnish R&D is conducted by the private sector; its share has been slowly increasing.

The Finnish innovation policy hinges on direct R&D subsidies. During our observation period 2000-2008 there were no R&D tax credits. Tekes (which became part of a larger government organization, Business Finland, in 2018; we call the organization Tekes for brevity) where our subsidy data comes from is the main public organization providing funding (grants and loans) for private R&D. Some other public funding organizations provide some limited finance for innovation, but their funding is not focused on R&D investments and does not generally consist of subsidies.

During our observation period Tekes' mission was to promote "*the development of industry and services by means of technology and innovations. This helps to renew industries, increase value added and productivity, improve the quality of working life, as well as boost exports and generate employment and well being*" (Tekes 2008 and 2011). In 2012 Tekes' funding was circa 600M€, up from circa 400M€ in 2004 (see Appendix A). A large majority of Tekes' funding goes to firms, the rest to universities and other research institutes. In its funding decisions, Tekes emphasizes small and medium sized enterprises (SMEs), especially those seeking growth in global markets. However, large companies may also obtain funding from Tekes.

According to Tekes, its funding decisions are based on "*the novelty of the project, market distance, and the size of the company*" (Tekes 2011). To acquaint ourselves with Tekes' decision making in detail, one of us spent 11 months in Tekes. After receiving an application, a team of Tekes' experts reviews the application and conducts a thorough interview with the applicant's representatives. Tekes' experts grade the project proposal in several dimensions. In practice, the technological challenge and commercial risk are the two most important grading dimensions; thus we focus on them in estimating ancillary grading equations as in TTT (2013a); see Appendix B. The expert team then makes a proposal for a funding committee which decides the subsidy rate. The maximum financing share may reach, depending on the applicant and the project, 70% of the project costs. Tekes can give firms that satisfy the European Union (EU) criterion for SMEs a 10 percentage point higher maximum financing share than for large companies.

2.2 Data

Our data comes from two main sources: from Tekes, we obtain detailed data on all project level R&D subsidy applications for years 2000-2008. These data include the applied amount of funding, internal screening outcomes and final funding decisions, the realized project expenses and reimbursements, and information on other sources of funding. We match these data to the R&D survey and balance-sheet data from Statistics Finland. We end up with 22 504 firm-year observations for 6 077 firms.[5] In contrast to TTT (2013a), our data cover a longer time period and contain information on the actual (instead of planned) R&D expenditure and reimbursements at the project level for successful applicants, information on firm level R&D for all firms, as well as information on funding from other sources.

We show descriptive statistics in Table 1. The average ages of applicant and non-applicant firms in our data are 14 and 17 years, respectively; their average numbers of employees are 121 and 101, and their average sales per employee are 19 000€ and 22 000€ (normalized to year 2005). Of the applicant and non-applicant firms in our data, 83% and 86%, respectively, are SMEs, 19% and 13% are located in the regions eligible for EU regional aid, and 83% and 59%

[5]We follow TTT (2013a) and randomly choose one application for those firms with more than one application in a given year. This choice follows from our model in which each firm only receives one R&D idea per year. Relaxing this assumption provides a challenging task for future research. We also follow TTT (2013a) in calculating the subsidy rate as the sum of grants and subsidized loans divided by the planned R&D investment. As a robustness test, we repeat the analysis using only grants (see section 6). We explain how we trim the estimation sample and provide some further descriptive statistics of our data in Appendix B.

invested in R&D in the preceding year. All these differences between applicants and non-applicants are statistically significant. As the figures of Table 1 imply, on average roughly 63% of the firms invest in R&D and 18% apply for subsidies.

Table 1 displays descriptive statistics for accepted and rejected applicants; here the differences are not statistically significant, except for the differences for investing in R&D and for having applied previously for a subsidy. For those firms that obtain a subsidy, the average subsidy rate is 0.35. The average actual R&D investment over the (max. 3 year) lifetime of a project is 483 000€. Turning to the Tekes evaluation grades, we convert (see Appendix B) the original Likert scale 0-5 of both technological challenge (*tech*: ranging from 0 = "no technological challenge" to 5 = "international state-of-the-art") and commercial risk (*risk*: ranging from 0 = "no identifiable risk" to 5 = "unbearable risk") to scale 1-3 because of few observations at the tales. Using the modified grades, the average technological challenge is 2.1 and the average commercial risk is 2.3.

[Table 1]

A key data challenge is to observe firms' funding costs and opportunities at a project level. There is no consensus on how to measure financial constraints at a firm level (e.g., Farre-Mensa and Ljunqvist 2016) and attempts to measure financial constraints at a project level are rare. Our Tekes-data contains several potentially unique measures of access to finance at a project level, but only one is available for a larger number of firms: the cashflow available to finance the proposed project. Using this information, we first measure the ratio of available cashflow to the planned R&D investment size. As shown by Table 1, the mean ratio for all successful applicants and for those successfull applicants who had not invested in R&D in the previous year are 1.12 and 1.16, respectively, with both median ratios being 1. A cashflow-to-investment ratio above one may indicate an absence of financial constraints.

3 The Model

Our model builds on TTT (2013a,b). The main extensions are corporate taxation with R&D tax credits, financial market imperfections, and fixed costs of R&D. In TTT (2013a), we build and estimate a model that overlooks these three features. The model in TTT (2013b), which has not been estimated, adds the fixed costs of R&D. While we outline the model and discuss the main arguments leading to our results in the body of the paper, we relegate technical details and proofs to Appendix C .

3.1 Assumptions and Payoffs

We consider interactions among a public *agency* allocating R&D subsidies, a continuum of *firms* with access to R&D projects, and many competitive private sector *investors* with access to liquid funds. All agents are risk neutral and for brevity there is no time preference.

Each firm needs to invest a *fixed cost* $F \in [0,\infty)$ and a *variable cost* $R \in (0,\infty)$ to undertake an R&D project. Following Holmström and Tirole (1997), we assume that the firms can choose between two projects. A good project pays

$$\pi(R) = A \ln R, \tag{1}$$

with probabilty $P \in (0,1)$ and 0 otherwise. In equation (1), $A \in (0,\infty)$ is a constant shifting the project returns.[6] Firms' project successes are *i.i.d*; thus, there is no aggregate uncertainty. A bad project fails with probability one but yields non-verifiable private benetifs for (the decision maker of) the firm.

Firms have no liquid funds of their own. Since the public agency at maximum reimburses a fraction of the investment, the firms must raise external funding from outside investors. Investors can flexibly raise funds at a constant rate $r \in [1,\infty)$. As in Holmström and Tirole (1997), an investor can eliminate the bad project from the firm's action set by incurring a *monitoring cost* $c \in [0,\infty)$ per unit of investment. The private benefits are assumed to be large enough to make the bad project privately attractive to the firm unless the investor monitors. (We formalize this stament in Appendix C – see Assumption 2 and Lemma 1.) To raise funds, a firm promises to repay its investor $\pi^I \in [0,\infty)$ if its project is successful. This *repayment promise* accommodates both debt and equity inter-

[6]We employ the logarithmic R&D technology specified by equation (1) to obtain our econometric model. We have also experimented with the functional form $\pi(R) = A(R^{1-\gamma} - 1)/(1-\gamma)$ in which $\gamma \in [0,\infty)$. This functional form yields logarithmic conditional profits when $\gamma \to 1$. As our data strongly suggests that $\gamma \approx 1$, we impose the logarithmic functional form from the outset for both simplicity and computational gain. While the logarithmic technology is easy to work with, it has a somewhat awkward property: even with no fixed costs, the firm needs to invest at least $R > 1$ to make positive revenue. Therefore, in equilibrium the firm will either choose $R = 0$ to secure zero payoff, or $R > 1$ (see Lemma 3 in Appendix C).

pretations.[7]

The expected payoff of an investor who chooses to finance and monitor a firm's project when the firm offers a *financing contract* $\left(R,\pi^I\right) \in [0,\infty)^2$ and the agency awards a *subsidy rate* $s \in [0,\bar{s}]$, $\bar{s} < 1$, to the project is given by

$$\Pi^I(s,R,\pi^I) = (1-\tau)\left[P\pi^I - (r+c)(R+F) + sR\right]. \tag{2}$$

In equation (2), $\tau \in [0,1]$ is the *corporate tax rate.* As corporate taxation is only introduced to allow for a welfare analysis of R&D tax credits (see section 6), we make corporate taxation neutral with respect to R&D investments and subsidy decisions: We assume that each investor is large so that the law of large numbers can be applied to the investor's asset portfolio. As the project successes are *i.i.d.*, we invoke the common assumption that the empirical mean equals the expecation with probability one (see Judd 1985) and, consequently, a fraction $P(1-P)$ of the investor's projects will succeed (fail). Because expenses of both successful and failed projects are tax deductible against the revenues from the successful projects, the investor's net investment cost $((r+c)(R+F) - sR)$ of an individual project is tax deductible even if the project fails. While similar assumptions are common in the banking literature – e.g., models in the tradition of Diamond and Dybvig (1983) apply the law of large numbers to banks' liabilities – here the assumption could be relaxed at the cost of making the firm's cost of external funding and R&D investments as well as the agency's subsidy decisions functions of τ.

Equation (2) shows how the investor needs to fund the whole investment $R+F$, and to cover the costs of funds r and of monitoring c. A fraction s of the realized variable R&D costs may be reimbursed by the agency. The agency reimburses neither fixed nor external financing costs. In our instutational setting, Tekes has detailed rules on eligible expenses which explicitly exclude the costs of external finance. Tekes also primarily reimburses variable R&D (wage) expenses since they are easy to allocate to subsidized projects.

[7] In an equity contract the firm's repayment promise could be written as $\pi^I = f\pi(R)$ in which $f \in [0,1]$ is the investor's share of the project returns. In Appendix C we explicitly write the repayment promise as a part of a standard debt contract, i.e., as $\min\left\{\pi^I, \max\left\{\pi(R), 0\right\}\right\}$ implying that the investor has seniority if the firm cannot honor its promise. However, we show that in equilibrium (see Lemma 3 in Appendix C) that the firm is able to make the promised repayment unless the project pays no returns and, in this case, both equity and debt contracts lead to the same outcome.

Since the investor is funding the whole investment, the expected payoff of a firm investing in the good project and offering the contract $\left(R,\pi^I\right) \in (0,\infty) \times [0,\infty)$ may be expressed as

$$\Pi^E(R,\pi^I) = (1-\tau)\left[P\left(\pi(R)-\pi^I\right)\right], \tag{3}$$

The payoffs to a firm that makes no investment ($R=0$) and to an investor who chooses not to finance a firm are zero. Since the firm has no funds of its own, the investor's no-financing decision results in $R=0$ and, consequently, in zero payoff to the firm, too.

Firms can also apply for R&D subsidies from the public agency. Upon receiving and evaluating an application the agency observes a *spillover rate* realization $v \in \mathbb{R}$ per unit of variable R&D invested in the proposed project, and decides whether to commit to reimburse a fraction s of the variable R&D costs to the firm. The expected payoff of the agency awarding a subsidy rate s to a project funded by a monitoring investor is given by

$$U\left(v,s,R,\pi^I\right) = (v-gs)R + \Pi^E_{pre}\left(R,\pi^I\right)_+ + \Pi^I_{pre}\left(s,R,\pi^I\right)_+, \tag{4}$$

in which $\Pi^j_{pre}(\cdot) = \Pi^j(\cdot)/(1-\tau),\ j=E,I$, denotes the firm's and investor's expected pre-tax profits. The profis in the agency's payoff are net of taxes since, for the agency, corporate tax payments are just transfers and cancel out in welfare calculation. In equation (4), and throughout the rest of the paper, for $x \in \mathbb{R}$ we write $x_+ := \max\{x,0\}$. Here these max operators capture the constraint that the agency cannot force the private sector to invest if investing is not profitable. The first term on the right-hand side of equation (4) captures the effects of the firm's R&D on the agency beyond the firm's and investor's payoffs. Here vR gives the total spillovers generated by the project. The assumption of a linear relation between total spillovers and investment level simplifies our analysis. Also for simplicity, we assume that the agency has no budget constraint. Instead, we assume that the agency faces a shadow cost of public funds, captured by $g > 1$ in equation (4). If $R=0$, the agency's payoff is zero.

Equation (4) is our measure of welfare. Our approach rests on the idea that identifying the parameters governing equation (4) allows us to meaningfully compare counterfactual policies to the current policy from the government's point of view without necessarily taking a stand on whether the government is a benevolent social planner or not. In particular, a spillover rate realization v of a firm's project can reflect standard positive welfare externalities of R&D investments such as consumer surplus and technological spillovers, but also private benefits from funding the project to the agency's civil servants. The spillover rate realization v can also be negative, e.g., due to duplication of R&D costs, business stealing effects, or negative environmental externalities. As we shall see, however, in equilibrium the agency rejects the application even if v is positive but sufficiently small.

We assume that v is unknown to both firms and the agency when the firms contemplate applying. As a consequence, prior to applying, the firms are uncertain about the agency's valuation of their projects and, consequently, the agency's subsidy rate decisions. This assumption of incomplete but symmetric information ensures, in line with data, equilibrium outcomes with rejected applications without the need to model complexities arising from signaling games. Furthermore, it seems reasonable that potential applicants do not exactly know ex ante how the agency evaluates their projects.[8] We model the agency's spillover rate evaluation as a realization v of a continuous, real-valued random variable V with a probability density function $\phi(v)$ and a cumulative distribution function $\Phi(v)$. (We may think of v as the agency's type drawn by Nature from a probability distribution over the type pace V.)

We also assume that applying for a subsidy involves a fixed cost, denoted by $K \in [0, \infty)$. For simplicity, we consider K non-tax deductible. In practice, application costs can also be thought of mainly consisting of non-deductible effort (Tekes requires a detailed, written application and the application process also typically involves a plenty of other communications between the applicant and Tekes' experts – see section 2.1).[9]

[8] A large corporate finance literature dating back at least to Rock (1986) (see Yang 2019 for a more recent example) uses a related, but even stronger, asumption that a provider of funding has an informational advantage over a funding recipient about the recipient's type (in our case the agency has an informational advantage about the agency's own type after receiving and screening an application but not otherwise). Nonetheless, our assumption of common knowledge about the applicants' type may ignore some interesting features of R&D subsidy programs. For example, assuming that the applicants' type is private information, Takalo and Tanayama (2010) show how the agency's subsidy decision acts as a signal about the applicants' type to private sector investors, and Lach, Neeman, and Schankerman (2021) study the possibilities to design subsidy programs so as to screen appropriate applicants.

[9] Assuming that application costs are tax deductible would complicate the analysis without creating qualitative effects: It can be shown that an increase in τ reduces the likelihood that a firm applies for a subsidy. This relation would hold even if K was deductible in corporate

The dynamic game describing the interactions of the agency, a firm and an investor proceeds in five stages: In stage 1 the firm decides whether or not to apply for a subsidy. We describe the firm's application decision by $d_a \in \{0,1\}$ in which "1" and "0" indicate an application and no-application, respectively. In stage 2 the agency evaluates the project proposal, observes the the realization of V, and decides the subsidy rate. A strategy for the agency can be described as a mapping $s(v,d_a)$ identifying for each realization of $V$and application decision $(v,d_a) \in \mathbb{R} \times \{0,1\}$ a subsidy rate on $[0,\bar{s}]$. In stage 3, after observing the subsidy rate, the firm and investor sign a financing contract: The firm's behavior in the third stage consists of two mappings $\pi^I(s)$ and $R(s)$ from the set of subsidy rates $[0,\bar{s}]$ into the set of repayment promises $[0,\infty)$ and R&D investment levels $[0,\infty)$, respectively, and the investor's strategy consists of two mappings $d_f\left(s,R,\pi^I\right)$ and $d_m\left(s,R,\pi^I\right)$ from the set of subsidy rates and contract offers $\left(s,R,\pi^I\right) \in [0,\bar{s}] \times [0,\infty)^2$ into the two $\{0,1\}$ sets financing and monitoring decisions, respectively, in which "1"s indicate financing and monitoring and "0"s indicate no-financing and no-monitoring. In stage 4 the firm chooses the project, and makes an R&D investment according to the contract. The firm's project choice in this stage may be decribed by a mapping $d_p(d_m)$ from the set of the monitoring decisions $d_m \in \{0,1\}$ into the set of projects $\{0,1\}$ in which "1" and "0" indicate a good and a bad project, respectively. In stage 5, subsidies are paid, the project return is realized, and claims are settled according to the contract.[10]

In a pure strategy perfect Baysian equilibrium the firm has rational prior beliefs about the agency's spillover rate evaluations, and chooses to apply for a subsidy if the expected profits from applying are larger than from not applying and does not apply otherwise, given the agency's and investor behavior in the

taxation. However, quantitatively, the adverse effect of τ on the application propensity would be smaller if K were deductible.

[10] Many timing assumptions are inconsequential: For example, assuming that the financing contract is not written contingent on subsidies would make only inconsequential differences – see Appendix D where we use this alternative assumption in the case of tax credits. Also, whether subsidies are paid before or after project return realizations makes no difference, and the size of the R&D project could equally well be chosen after the investor's decisions. What matters is that the firm's project choice decision comes after the investor's monitoring decision; this timing avoids the need of considering mixed strategies. Tekes is also legally prohibited from reimbursing expenses that have incurred before the application (see the Government Decree on the Funding for Research, Development and Innovation Activities 1444/2014 § 3).

later stages. After observing the spillover rate realization of the firm's project, the agency chooses a subsidy rate to maximize its payoff, given the firm's and the investor's behavior in later the stages. If the agency receives no application, or if the agency is indifferent between granting a subsidy or not, the agency will give no subsidy.[11] The investor finances and monitors the firm whenever the investor's expected payoffs to financing and monitoring are larger than from no-financing and no-monitoring, and neither finances nor monitors otherwise. The firm offers a financing contract to maximize its expected profits given the investor's behavior, and chooses the good project if the investor monitors, but the bad project otherwise. Appendix C provides a formal definition of the equilibrium.

3.2 Equilibrium Analysis

Since the agency cannot award a subsidy without an application, in equilibrium $s^*(v,0) = 0$. We simplify exposition in the equilibrium analysis and denote by $s(v) := s(v,1)$ the agency's strategy after receiving an application.

Cost of external financing, R&D investment level and R&D participation. (See Lemmas 1-4 in Appendix C for details.) The payoff to an investor who chooses not to invest is 0, whereas the payoff to an investor who chooses to invest but does not monitor is $(1-\tau)[-r(R+F)+sR] < 0$ – recall that $r \geq 1 > \bar{s} \geq s$. Therefore, in equilibrium, the firm is either investing in the good project with funds supplied by a monitoring investor or no R&D investment is made, i.e., either $d_k^*(\cdot) = 1$ for $k = f,m,p$ or $d_f^*(\cdot) = 0$.

Since investors behave competitively – we may think of a financial sector with free entry of identical investors – we can seek a financing contract $\left(\pi^I, R\right) \in [0,\infty)^2$ that maximizes the firm's expected payoff. Letting the investor's expected payoff from choosing $d_k = 1, k = f,m$, from equation (2) to

[11]These two restictions on the agency's behavior are plausible but also follow from the institutional environment: The Finnish law – the Act on Discretionary Government Transfers 688/2001 § 9 and the Government Decree on the Funding for Research, Development and Innovation Activities 1444/2014 § 3 – prevents Tekes from granting a subsidy without a formal, written application. The tie-breaking rule when the agency is indifferent can be motivated by the existence of some negligible costs involved in granting a subsidy. The tie-breaking rule matters in particular when the project will not be implemented ($R = 0$); the agency's payoff (equation (4)) for a project with $R = 0$ is $U\left(v,s,0,\pi^I\right) = 0$ for all $s \in [0,\bar{s}]$. Tekes's internal funding rules also explicitly prohibit awarding subsidizes if Tekes's "funding would have no effect on the realisation of the project" or if "the project has only a small impact on the company's business". For further details about these restrictions, see the discussion after Definition 1 in Appendix C.

be equal to 0 and solving the resulting equation for π^I yields

$$\pi^{I*}(s,R) = \frac{(r+c)(R+F) - sR}{P}. \tag{5}$$

Equation (5) identifies the minimal repayment that makes the investor willing to finance a project of size R.

After inserting equations (1) and (5) into equation (3), we can write the firm's R&D investment problem as

$$\max_{R\in[0,\infty)} \Pi^E(s,R)_+ = (1-\tau)\left[\alpha \ln R - (r+c-s)R - (r+c)F\right]_+, \tag{6}$$

in which $\alpha := AP$ is a constant shifting the expected profitability of the R&D project and $r+c-s$ captures the firm's marginal cost of R&D.

Solving the problem of equation (6) yields the firm's optimal R&D investment decision as

$$R^*(s) = \begin{cases} R^{**}(s) := \arg\max_{R>0} \Pi^E(s,R) = \frac{\alpha}{r+c-s} & \text{if } \Pi^{E**}(s) \geq 0 \\ 0 & \text{if } \Pi^{E**}(s) < 0, \end{cases} \tag{7}$$

in which the firm's expected profits from a positive equilibrium investment $\left(\Pi^{E**}(s) = \Pi^E(s, R^{**}(s))\right)$ are given by

$$\Pi^{E**}(s) = (1-\tau)\left\{\alpha\left[\ln\left(\frac{\alpha}{r+c-s}\right) - 1\right] - (r+c)F\right\}. \tag{8}$$

In the main text we focus on the range of parameters in which $\ln(\alpha/(r+c)) \geq 1$, implying that the firm's R&D productivity is sufficiently high to make R&D investments profitable without fixed costs. We characterize the equilibria when $\ln(\alpha/(r+c)) < 1$ at the end of Appendix C.

To summarize, for $s \in [0,\bar{s}]$ the equilibrium financing contract is given by $\left(R^*(s), \pi^{I*}(s)\right)$ in which the explicit formula for $\pi^{I*}(s) = \pi^I(s, R^*(s))$ can be obtained by inserting $R^*(s)$ from equation (7) into equation (5).

Agency decision. If the agency receives a subsidy application in stage 2, the agency observes the spillove rate realization v and chooses a subsidy rate s to maximize its payoff. We may write the agency's problem as

$$\max_{s\in[0,\bar{s}]} U^*(v,s)_+ = \left\{(v-gs)R^*(s) + \left[\alpha \ln R^*(s) - (r+c-s)R^*(s) - (r+c)F\right]_+\right\}_+, \tag{9}$$

in which the agency's expected payoff $U^*(v,s) = U\left(v,s,R^*(s),\pi^{I*}(s)\right)$ follows from insertion of the investor's and firm's payoffs from equations (2), (5) and (6) into equation (4).

We solve the agency's problem (equation (9)) in Lemma 5 in Appendix C. There we show that there are two threshold values of F, $\underline{F}$ and $\bar{F}$ with $\underline{F} < \bar{F}$. If $F \leq \underline{F}$, the firm's expected profits are positive even when $s = 0$. In that case the constraints on the feasible subsidy rates $(s \in [0,\bar{s}])$ imply that the agency's behavior can be described by the mapping

$$s^*(v) = \begin{cases} 0 & \textbf{if } v \leq \underline{v} := (r+c)(g-1) \\ s^{**}(v) := v-(r+c)(g-1) & \textbf{if } v \in (\underline{v},\bar{v}) \\ \bar{s} & \textbf{if } v \geq \bar{v} := \underline{v}+\bar{s}, \end{cases} \tag{10}$$

in which $0 < \underline{v} < \bar{v}$, and $s^{**}(v)$ identifies for each spillover rate realization $v \in \mathbb{R}$ a unique optimal subsidy rate when the feasibility constraints on the subsidy rate and the non-negativity constraints on the agency's and firm's payoffs are ignored. In words, the subsidy rule characterized by equation (10) implies a rejection of an application for sufficiently low spillover rate realizations, the optimal interior subsidy rate $s^{**}(v)$ for intermediate spillover rate realizations, and the maximum subsidy rate $\bar{s}$ for sufficiently high spillover rate realizations.

If $F \in (\underline{F},\bar{F}]$, the firm will invest only if it receives a subsidy. In this case the agency's optimal subsidy rule is given by the mapping

$$s^*(v) = \begin{cases} 0 & \text{if } v < v^0 \\ \tilde{s} := r+c-\alpha e^{-\left[1+\frac{(r+c)F}{\alpha}\right]} & \text{if } v \in \left[v^0,\tilde{v}\right) \\ s^{**}(v) & \text{if } v \in [\tilde{v},\bar{v}) \\ \bar{s} & \text{if } v \geq \bar{v} := \underline{v}+\bar{s}, \end{cases} \tag{11}$$

in which $\tilde{s}$ defines the unique subsidy rate at which the firm's zero-profit constraint holds as an equality (i.e., $\Pi^{E**}(\tilde{s}) = 0$), and v^0 and $\tilde{v}$, with $0 \leq v^0 < \tilde{v} \leq \bar{v}$, denote the (unique) values of v that satisfy $U^*(\tilde{s}(v^0))$=0 and $s^{**}(\tilde{v}) = \tilde{s}$, respectively. Compared to the subsidy rule (10), for a project with $v \in \left(\max\left\{v^0, \underline{v}\right\}, \tilde{v}\right)$ the rule (11) prescribes the agency to increase the subsidy rate from the unconstrainted rate $s^{**}(v)$ to $\tilde{s}$ so as to satisfy the firm's zero-profit constraint. While $\max\left\{v^0, \underline{v}\right\} \leq \tilde{v}$, v^0 may be smaller or greater than $\underline{v}$ (see Remark 1 in Appendix C). However, we have $\min\left\{v^0, \underline{v}\right\} \geq 0$. Thus, a necessary condition for the firm to obtain a subsidy is a positive spillover rate realization v for its project.

If $F > \bar{F}$, $\Pi^{E**}(s) < 0$ for all $s \in [0, \bar{s}]$. Knowing that the firm would not invest even with the maximum subsidy rate, the agency awards no subsidy for such a firm.

Application decision. (See Lemma 6 in Appendix C for details.) In stage 1 the firm solves for the following problem of whether or not to apply for subsidies:

$$\max_{d_a \in \{0,1\}} d_a \left[\int_{-\infty}^{\infty} \Pi^{E**}(s(v))_+ \phi(v)\, dv - K \right] + (1 - d_a)\, \Pi^{E**}(0)_+ \tag{12}$$

The term in the square-brackets captures the firm's expected payoff to applying for a subsidy, including the fixed application cost K. The first term in the square-brackets shows how the firm, when contemplating subsidy applications, takes expectation over all possible spillover rates and, consequently, all subsidy rate evaluations of the agency. The firm can then estimate the expected investment levels resulting from those subsidy rates, and, ultimately, the firm's expected profits. The last term in the maximization problem (12) captures the expected profits if the firm does not apply for a subsidy and therefore receives no subsidy. The max operators embodied in these expected profit terms in the problem (12) reflect the firm's option to invest only if doing so is profitable in expectation.

If $F < \underline{F}$, the firm will invest even without a subsidy. In this case the firm knows that the agency's subsidy rule $s^*(v)$ is given by equation (10). Therefore the first term in the square-brackets of the problem (12) can be expressed as

$$\int_{-\infty}^{\infty} \Pi^{E**}(s^*(v))_+ \phi(v)\, dv$$

$$= \Phi(\underline{v})\Pi^{E**}(0) + \int_{\underline{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\phi(v)\, dv + (1-\Phi(\overline{v}))\Pi^{E**}(\overline{s}).$$

As a result the solution to the problem (12) is $d_a^* = 1$ if and only if

$$\int_{\underline{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\phi(v)\, dv + (1-\Phi(\overline{v}))\Pi^{E**}(\overline{s}) - (1-\Phi(\underline{v}))\Pi^{E**}(0) \geq K, \tag{13}$$

and $d_a^* = 0$ otherwise.

If $F \in [\underline{F}, \bar{F}]$, a firm contemplating a subsidy application will not invest without a subsidy. In this case the agency's subsidy rule is given by (11). Thus the firm contemplating an application knows that if $v \geq \tilde{v}$, the firm's zero-profit constraint is irrelevant for the agency's decision, and that if $v < \tilde{v}$, the firm will either receive no subsidy in which case it will not invest or it will receive subsidy $\tilde{s}$ that just satisfies the firm's zero-profit constraint, which by definition also leads to the zero profits. Therefore the solution to the problem (12) is $d_a^* = 1$ if and only if

$$\int_{\tilde{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\phi(v)\, dv + (1-\Phi(\overline{v}))\Pi^{E**}(\overline{s}) \geq K, \tag{14}$$

and $d_a^* = 0$ otherwise.

If $F > \bar{F}$, the firm knows it will get no subsidy (and would not invest even if it received the maximum subsidy rate $\bar{s}$). Therefore, the firm does not apply. ($d_a^* = 0$).

In Appendix C (Proposition 1) we show that the equilibrium is a well defined mapping on the set of fixed costs of R&D investments $F \in [0, \infty)$. This equilibrium admits a number of comparative static results. We discuss here the effects of financial market imperfections. Financial market imperfections, captured by the parameter c, unambigously reduce the level of innovation both at the intensive and extensive margins (see equations (7) and (8)). The effects of a higher c on the subsidy policy are more complex: First, if a firm is not financially constrained ($F < \underline{F}$), an increase in c calls for smaller subsidies: the optimal unconstrained subsidy rate $s^{**}(v)$ is decreasing in c and the agency's propensity to reject the application (as measured by $\underline{v}$) is increasing in c. From the agency's perspective, an increase in a firm's cost of funds means a reduction in the efficiency of the firm's R&D technology. Second, if a firm is financially constrained ($F \in [\underline{F}, \bar{F}]$), the agency should give higher subsidies to help the firm to overcome the constraints: the optimal constrained subsidy rate $\tilde{s}$ is increasing in c. On the other hand, the agency's propensity to reject the firm's application (as measured by v^0) is increasing in c in this case, too.

4 Econometric Implementation

We next describe how to estimate the agents' four key decisions in the theoretical model: the firm's decision whether to launch an R&D project and the optimal R&D investment level conditional on launching, the firm's decision to apply for a subsidy, and the agency's subsidy rate decision. We also discuss the identification of each main equation.

Our modeling approach necessitates a number of auxiliary estimations. We estimate a reduced form probit model where the dependend variable is a dummy indicating whether or not we observe the project level R&D investment of the firm. The results are used to generate the Mills ratios needed to correct for sample selection in the R&D investment equation. We estimate ordered probit regressions where the dependent variables are the grades given by Tekes to an application, correcting for sample selection. Finally, we estimate a model where the dependent variable is the log of the cashflow variable available for the R&D project, again to correct for sample selection. These grading and cashflow equations are used to predict the probability of an evaluation grade and (log) cashflow available whenever these variables are not observed in the data. We present the results of these auxiliary estimations in Appendix B.

Our model allows for two key features of the unobservables: first, spillovers and profits are allowed to be correlated; second, applicant firms are allowed to systematically differ from non-applicant firms. All estimation equations are defined at the project level except for the R&D participation decision which is at the firm level. We use the following generic notation: $\mathbf{X}^l_{it}$ denotes a vector of observable firm and project characteristics, and β^l denotes the associated vector of parameters. Subscript i denotes a project (and a firm), subscript t denotes the year and superscript $l \in \{F,K,R,s,c\}$ refers to the variable of the interest. The $\mathbf{X}_{it}^{l}$ vector contains a 2^{nd} order polynomial in firm (log) age, (log) number of employees, sales/employee, and dummies for a calendar year, an industry, an R&D investment in the previous year, and the eligibility for EU regional aid. All explanatory variables are lagged by one year. We bootstrap the whole estimation procedure to obtain standard errors.

R&D investment level and cost of external financing. Let us define the cost of monitoring as

$$c_{it} := e^{\mathbf{X}_{it}^{c}\beta^{c}}. \tag{15}$$

and the constant shifting the expected profitability of an R&D project (see equation (6)) as

$$\alpha_{it} := e^{\mathbf{X}_{it}^{R}\beta^{R}+\varepsilon_{it}}. \tag{16}$$

In equation (16), ε_{it} is a random shock affecting the expected profitability of project i in year t. This profitability shock is observed by all three agents of the model but unobserved by the econometrician.

From equation (7) we obtain an empirical counterpart for the size of the firm's R&D project as $R_{it}(s_{it}) = \alpha_{it}/(r_{it}+c_{it}-s_{it})$. Substitution of equations (15) and (16) for c_{it} and α_{it} in this equation and taking logs of both sides yields

$$\ln R_{it}(s_{it}) = \mathbf{X}_{it}^{R}\beta^{R} - \ln\left(r_{it} - s_{it} + e^{\mathbf{X}_{it}^{c}\beta^{c}}\right) + \varepsilon_{it}. \tag{17}$$

Equation (17) is our estimation equation for R&D investment, conditional on the firm launching a project. The coefficient of the term $\ln(r_{it} - s_{it} + \exp(\mathbf{X}_{it}^{c}\beta^{c}))$ is unity. By this stage, s_{it} is known, and we use the one year Euribor rate to measure r_{it}, the cost of funding for the investor. With $\mathbf{X}_{it}^{R}$, $\mathbf{X}_{it}^{c}$, r_{it} and s_{it} being observed, estimating equation (17) using maximum likelihood yields $\hat{\beta}^{R}$, $\hat{\beta}^{c}$, and the variance of ε_{it}.

There is a sample selection problem as we only observe the project level realized R&D investments of those firms that receive a subsidy. We estimate equation (17) with standard sample selection methods. For identification, we exploit the agency's goal of prioritizing SMEs in its subsidy allocation decisions (see section 2). In particular, the maximum subsidy is 10 percentage points higher for SMEs which, according to the EU definition, should employ fewer than 250 persons and have either an annual turnover not exceeding 50 million euro or an annual balance sheet total not exceeding 43 million euro (see Recommendation 2003/361EC). Since these criteria for qualifying as an SME are decided at the EU level, they can be taken as exogenous to the Finnish environment. This non-linearity of the agency decision rule in firm size means that an SME is more likely to apply for a subsidy but, conditional on the firm's size, its SME status *per se* should have no impact on its R&D investment level. Our exclusion restriction is based on the SME status of a firm which is allowed to enter the first but not the second stage.

The first stage dependent variable is a dummy taking value one if firm i obtained a subsidy in year t, and zero otherwise. The sample for the first stage consists of all firm-year observations. We view our first stage as a reduced form that captures both the decision to apply for a subsidy and the agency's subsidy decision conditional on an application. We execute the first stage by estimating the model separately for SMEs and non-SMEs; this execution is essentially equivalent to estimating a model with a full set of SME-dummy interactions.

To identify the cost of monitoring, we assume that c_{it} is a function of the ratio of the maximum available cashflow to the R&D investment size.[12] We calculate the cashflow-to-investment ratio for each project and the 99^{th} percentile of the ratio distribution. Denoting the ratio of project i in year t as cf_{it} and the 99^{th} threshold value as cf_{99}, our measure is $c_{it} = (\ln cf_{99} - \ln cf_{it})_+$, implying that $c_{it} = 0$ for those projects for whom the cashflow-to-investment ratio is at or above the 99^{th} percentile. While experimental, we consider our approach to identify financial constraints at a project level wortwhile in the absence of a consensus on how to measure financial constraints at a firm level (see, e.g., Farre-Mensa and Ljunqvist 2016). As a robustness test, we also use an estimated cost of external funding at a firm level from balance sheet data as an alternative measure of c_{it}.

R&D participation. Let the fixed cost of launcing project i take the form

$$F_{it} := e^{\mathbf{X}_{it}^F \beta^F + \zeta_{it}}. \tag{18}$$

[12]To generate an estimate of this ratio for non-applicant firms and for those applicants' projects with missing values, we project the reported cashflow-to-investment ratio to observables using a sample selection model. We use the predicted value for the firms and projects without reported ratio.

Using equations (7) and (8) we may express an empirical counterpart of the firm's participation constraint as $\alpha_{it}\left[\ln\left(\alpha_{it}/\left(r_{it}+c_{it}-s_{it}\right)\right)-1\right] \geq \left(r_{it}+c_{it}\right)F_{it}$. After substitution of equation (18) for the right-hand side of this inequality, taking logs of both sides and rearranging, we may rewrite the firm's decision of whether or not to launch an R&D project as as an indicator function

$$1_{[0,\infty)}\left(\ln\hat{\alpha}_{it}+\ln\left[\ln\left(\frac{\hat{\alpha}_{it}}{r_{it}+\hat{c}_{it}-s_{it}}\right)-1\right]-\ln\left(r_{it}+\hat{c}_{it}\right)-\mathbf{X}_{it}^{F}\beta^{F}-\zeta_{it}\right), \tag{19}$$

in which r_{it} and s_{it} are observed, and $\hat{c}_{it}$ and $\hat{\alpha}_{it} := \exp(\mathbf{X}_{it}^{R}\hat{\beta}^{R}+\varepsilon_{it})$ are obtained (excluding ε_{it}, which we simulate) from the estimation of equation (17). The vector of parameters to be estimated is thus β^{F}. We have identifying variation because the first three terms have a coefficient of unity and because the fixed cost is independent of the subsidy rate s_{it}. We use simulated (quasi-) maximum likelihood to take into account that $\hat{\alpha}_{it}$ is a function of ε_{it} (see Appendix B).

Agency decision. An estimate $\hat{\tilde{s}}_{it}$ for the subsidy rate satisfying the firm's zero-profit constraint can directly be obtained by plugging equation (18) together with the parameters $\hat{\alpha}_{it}$, r_{it}, $\hat{c}_{it}$ and $\hat{\beta}^{F}$ into the formula for $\tilde{s}$ in equation (11).

To derive an estimable equation for the agency's unconstrained optimal subsidy rate $s^{**}(v)$ specified in equation (10) we define

$$v_{it} := \mathbf{X}_{it}^{s}\beta^{s}+\eta_{it}, \tag{20}$$

in which η_{it} is a random shock to the spillover rate of project i in year t. It is observed by the agency when it evaluates an application in stage 2 of the game, but it is unobserved by the econometrician and by the firm in stage 1 (the observability of η_{it} by the investor is irrelevant.) Substitution of equation (20) into the formula for $s^{**}(v)$ in equation (10) then gives

$$s_{it}^{**} = \mathbf{X}_{it}^{s}\beta^{s}-\left(r_{it}+\hat{c}_{it}\right)(g-1)+\eta_{it}, \tag{21}$$

To estimate the agency decision rule of equation (21), we use value 1.2 for the shadow cost of public funds g, and use only those observed positive subsidy rates where $s_{it} > \hat{\tilde{s}}_{it}$ because, according to our model, $s_{it}^{**} > \hat{\tilde{s}}_{it+}$. Estimation of equation (21) by generalized two-limit Tobit provides us $\hat{\beta}^{v}$. The vector of observable firm and project characteristics $\mathbf{X}_{it}^{v}$ includes the SME dummy to accommodate the agency's priorities, and the agency's grades for each project.

Our model allows spillovers and profits to be correlated: equations (4), (17), and (20) show how spillovers generated by project i, $v_{it}R_{it}$, are a function of both η_{it} and ε_{it}. The key identifying assumption for the subsidy rate equation is that while spillovers and profits are correlated, the shock to the *spillover rate* v_{it} (i.e., spillovers per euro of R&D) and the shock to the profitability of R&D (ε_{it}) are uncorrelated. As a result the agency decision rule is not subject to selection on unobservables.

Application decision. To estimate the firm's subsidy application decision, characterized by equation (12), we specify the application costs as

$$K_{it} := e^{\mathbf{X}_{it}^{K}\beta^{K}+\mu_{it}}, \tag{22}$$

in which μ_{it} is a random shock to the application costs, observed by the firm but unobserved by the econometrician. (The observability of μ_{it} by the agency and the investor is irrelevant.)

The firm's application decision is estimated by simulated (quasi-) maximum likelihood. For each simulation draw, we numerically integrate the expected discounted profits from applying for subsidies (the expression in square brackets in equation (12) with equation (22) substituted for the costs of applying). We use all the parameters estimated in the prior stages of the estimation process. To calculate the expected benefits from applying for a subsidy, we also need to take into account the agency's grading of each subsidy application (see Appendix B). Identifying variation comes from three sources: first, the subsidy rate is a function of the SME status of a firm. Second, the R&D investment is a function of the subsidy rate. Neither of these variables ought to have a direct effect on the application cost. Third, while we allow the application cost to be a function of the firm's application behavior in the past, we assume that this variable has no direct impact on the fixed cost of R&D nor on the subsidy rate.

Statistical assumptions. The unobservables ε_{it}, ζ_{it}, η_{it}, and μ_{it} are assumed to be normally distributed with mean zero and with variances that we estimate, and uncorrelated with observed applicant characteristics. We also assume that a) $\mu_{it} = \xi\varepsilon_{it} + \mu_{0it}$, where μ_{0it} is a random shock whose variance is normalized to unity; b) $\eta_{it}, \zeta_{it} \perp \varepsilon_{it}$; c) $\eta_{it}, \zeta_{it} \perp \mu_{0it}$ and d) $\eta_{it} \perp \zeta_{it}$. As assumption a) shows, the application cost shock, μ_{it}, and the shock to the expected profitability of

R&D investments, ε_{it}, can be correlated. Thus, firms with higher profitability shocks can have systematically different application costs than otherwise similar firms. The economic interpretation of assumption b) is discussed above: spillovers are correlated with ε_{it}, but the spillover rate shock η_{it} is uncorrelated with ε_{it}. Assumptions c) and d) mean that the spillover rate shock η_{it} and the fixed cost shock ζ_{it} are uncorrelated with the application cost shock μ_{it} and with each other. The assumptions rule out a selection problem for the subsidy rate equation (21), make the subsidy rate s_{it} independent of the profitability shock ε_{it}, and render the observability of μ_{it} inconsequential for the agency. Note that assumptions b) and c) also imply that $\varepsilon_{it} \perp \mu_{0i}$. However, these assumptions introduce the selection problem for the R&D investment equation (17) discussed above. Under these assumptions, we can identify all the structural parameters of our model, including those governing the distribution of the shocks.

In our counterfactuals, the scale of monetary outcomes is determined by the level of the R&D investments. To ensure that we get the level and, in consequence, all other monetary outcomes, right in our counterfactual, we adopt the following procedure: After having estimated the model we calculate the counterfactual R&D investment levels for firms that are granted a subsidy. We then scale α_{it} by the ratio of the mean observed R&D investment of such firms in our data and the mean of the counterfactual investment, and re-estimate the model and re-calculate the counterfactual.

5 Estimation Results

We collect into Table 2 the coefficient estimates from all main estimation equations described in section 4. Results from estimating the auxiliary equations are presented in Appendix B.

[Table 2]

R&D investment level and cost of external financing. Column 1 of Table 2 displays the estimated coefficients of the intensive margin R&D equation (17). These coefficients measure how firm characteristics affect the marginal profitability of R&D. Firm age, size and productivity (measured through sales per employee) affect R&D in a nonlinear fashion. Firms in less-developed regions invest significantly less and firms that invested in the previous year significantly more in R&D. The negative coefficient of the Mills ratio indicates negative selection, i.e., firms with more profitable projects are less likely to appear in our R&D investment sample and, thus, to apply for subsidies, ceteris paribus. The estimated standard error (s.e.) of ε_{it} is 0.45 (s.e. 0.02), giving us insights into the distribution of shocks to the expected profitability of R&D project ideas. Regarding the coefficent estimates we do not report, those of industry dummies indicate significant heterogeneity in marginal profitability of R&D across industries and those of year dummies suggest that Finnish firms invested less in the base year 2005 than earlier or later.

The coefficient for the log of the cashflow gap (0.95) implies that the monitoring cost - cashflow gap elasticity is essentially unity. Intuitively the lower is the firm's cashflow-to-investment ratio, the higher the cost of external finance due to higher monitoring costs. The mean cost of finance $(r_{it} + c_{it} - 1)$ is estimated to be 0.04 (p-value 0.00).

R&D participation. In column 2 of Table 2 we report the coefficients from the estimation of the extensive margin R&D equation (19). The results provide information about the determinants of the fixed costs of R&D: the more likely the firm is to invest in R&D, the lower are its fixed costs. We find the fixed cost of R&D to be a nonlinear function of the number of employees and sales per employee. Exporters and firms in the less-developed regions have a lower fixed cost of R&D. In line with the literature (Arqué-Castells and Mohnen 2015, Peters et al. 2017), we find that having invested in R&D in the previous year reduces the fixed costs. The omitted results regarding year and industry dummies suggest that fixed costs are higher in the first two years of our data and vary over industries.

Agency decision. Column 3 shows the estimated coefficients of the agency decision equation (21). We find sales per employee to have a nonlinear impact on the subsidy rate, indicating that in the agency's view, spillovers may be a nonlinear function of a firm's productivity. Firms that did not invest in R&D in the previous year get a 1.6 percentage points higher subsidy rate (significant at 10% level). As explained, the subsidy rules allow SMEs to obtain up to 10 percentage points higher subsidy rates: however, our results suggest that SMEs do not obtain higher subsidy rates. Tekes' internal grading variables only appear to play a minor role: a one point increase in the estimated commercial risk of the project increases the subsidy rate by one percentage point. According to the unreported coefficients, the awarded subsidy rates were lower in the early years of the millennium. We find no statistically significant differences across industries. The estimated mean spillover-ratio (spillovers per euro of R&D) is 0.58 (s.e. 0.01).

Application decision. In column 4 we report results from estimating the application decision, which provide information about the determinants of application costs. We find that firm size affects positively and productivity non-linearly (first increasing, then decreasing) the cost of application. Exporters and past applicants face a lower application cost, as do firms investing in R&D in the previous year, and firms in less developed regions. We find, as in TTT (2013a), that the shocks to application costs are positively correlated with the profitability shock, though the parameter estimate is insignificant. The unreported results suggest higher application cost in the early years of our sample and considerable heterogeneity over industries.

Implications of the estimated coefficients. Using the estimated parameters we simulate the fixed costs of R&D (F_{it}) and subsidy application costs (K_{it}). The results are displayed in Table 3. As is the case with discrete choice models, these costs are estimated more accurately for those firms that (in the counterfactual) invest or apply for subsidies, than for those that do not. While the simulated mean fixed R&D cost is 1.2M€, the median is much lower at 105 000€. Almost 40% of firms in the data do not invest in R&D and the model explains these non-investments by fixed costs, resulting in the relative high mean. Fixed cost are lower than 16 000€ for the firms in the decile with the lowest fixed costs but are higher than 685 000€ for the firms in the highest cost quartile. The mean application cost may also seem high at 112 000€, but is similarly explained by the long right tail: in the data, only 18% of firms apply. Some 10% of firms have application costs lower than 1 800€.

[Table 3]

6 Counterfactual Welfare Analysis

6.1 Policies

We consider five counterfactual policies: i) an optimal R&D tax credit policy;

ii) a laissez-faire scenario without government interventions in firms' R&D investments; iii) the first-best policy where the social planner can force the firms to invest the desired amount in each project; iv) the second-best (Ramsey) policy where the social planner is constrained by the firm's zero profit condition; and v) an economy without financial market imperfections.

Optimal R&D tax credit. To analyze an optimal R&D tax credit, we make two modifications to our basic model: first, we set the subsidy rate s to zero. Second, we introduce an R&D tax credit rate $\tilde{\tau}_R \in [0,1]$. The R&D tax credit means that a firm investing R euros in R&D is reimbursed for $\tilde{\tau}_R R$ euros. It is more convenient to work with $\tau_R := \tilde{\tau}_R/(1-\tau)$, a tax credit rate adjusted to the corporate tax level.

Our modeling of the R&D tax credit policy is motivated by the tax credit regime in some countries (e.g., Belgium, Iceland, the Netherlands, and Norway, the UK) where even loss making firms can claim tax credit. For simplicity, we assume that in the case of insufficient corporate tax liability of a firm, the firm receives a full refund of unused tax credits. To facilitate the comparison of the tax credit policy with the subsidy policy, we assume that all variable R&D costs but no fixed costs are subject to the tax credit. We also assume that all firms that invest in R&D claim the tax credit. This simplifying assumption may bias the counterfactual results as evidence (e.g. Verhoeven, van Stel, and Timmermans 2012, and Busom, Corchuelo, and Martínez-Ros 2014) shows that some eligible firms fail to claim the tax credit.

Under these assumptions, the firm's optimal R&D investment rule with an R&D tax credit is equivalent to the one given by equations (7) and (8) with τ_R replacing s – see Appendix D for the derivation of the firm's investment rule with an R&D tax credit. To determine the optimal R&D tax credit level, we can hence replace s by τ_R in the project specific agency objective function (9). We then substitute the empirical counterparts from section 5 for other variables in the resulting objective function.

The optimal R&D tax credit τ_R^* then solves the following problem

$$\max_{\tau_R \in [0,1]} \sum_{i=1}^{N} \iiint U^*(\varepsilon_i, \zeta_i, \eta_i, \tau_R)\phi(\varepsilon_i, \zeta_i, \eta_i)d\varepsilon_i d\zeta_i d\eta_i, \tag{23}$$

in which N is the total number of projects in the economy and the function

$\phi(\varepsilon_i, \zeta_i, \eta_i)$ is the joint normal distribution of the profit, fixed cost, and spillover rate shocks to project i. To approximate τ_R^*, we perform a grid search over the region $\tau_R \in [0,1]$ with a step size of 0.01, and choose τ_R^* as the value that yields the highest agency welfare. We simulate the relevant shocks 100 times from their estimated distributions.

While subsidies and tax credits have identical marginal impacts on the firms' R&D investment decisions in our model, they have major differences from a welfare point of view. Comparison of the maximization problems (9) and (23) illustrates the main welfare advantage of direct subsidies over tax credits: The marginal effect of tax credit on R&D is invariant accross projects whereas a subsidy policy enables project-specific treatment. On the other hand, the application and examination process of a subsidy policy hinder access to the treatment whereas all firms investing in R&D have access to R&D tax credits: The aggregate realized welfare under the optimal tax credit policy is $\sum_{i=1}^{N} U^*(\varepsilon_i, \zeta_i, \eta_i, \tau_R^*)$ whereas the aggregate realized welfare under the optimal subsidy policy is $\sum_{i=1}^{N_A} [U^*(\varepsilon_i, \zeta_i, \eta_i, s_i^*)_+ - K_i] + \sum_{i=N_A+1}^{N} U^*(\varepsilon_i, \zeta_i, \eta_i, 0)$ in which $N_A \subseteq N$ is the number of applications. If N_A is small relative to N, as is the case in our data, the subsidy policy will hardly generate large economy-wide effects.

Laissez-faire, first and second best. In our laissez-faire scenario, there are neither R&D subsidies nor tax credits. In the first best scenario the (perfectly informed) agency chooses for each project the level of R&D investment. The agency thereby internalizes the spillovers and all the costs. We assume that R&D is financed at the same cost as private funding is provided. As the first best investment level may lead to negative profits for a firm, we also consider the second best policy where the agency chooses the optimal level of each R&D investment subject to the firms' zero profit constraints.

Removing financial market imperfections in laissez-faire. We also study what would happen if financial market imperfections could be removed, we set the monitoring cost c_{it} to zero for all projects in the laissez-faire regime. As a result, the firms' cost of external funding is equal to the funding cost of the financier.

6.2 Results

We compare R&D participation, R&D investment levels, spillovers, profits and welfare across the different policy regimes in Tables 4-6. The reported means and medians are calculated over all firms and simulation draws (see Appendix E for details). To ease comparisons we also report the ratio of a mean outcome of a policy regime to the mean outcome in the laissez-faire scenario.

R&D participation. In Table 4 we report the firms' propensity to conduct R&D in various policy regimes. Under the laissez-faire scenario, 62% of firms invests in R&D in a given year and the median investment probability over all firms is 77%. The policy interventions hardly increase R&D participation: The first best policy and R&D tax credits increase R&D participation by one percentage point or 2% from laissez-faire. Neither subsidies nor removal of financial market imperfections have marked effects. These results are in line with Dechezlepêtre et al. (2016) and Peters et al. (2017) who find little effects of R&D tax credits at the extensive margin. However, the actual differences across the regimes are somewhat larger than suggested by Table 4: for example, the first best includes some projects generating positive welfare but negative profits which are excluded from the laissez-faire scenario, and vice versa for the projects with positive profits but negative welfare.

[Table 4]

R&D investment level. Table 5 shows that, in contrast to the extensive margin, there are large differences across policy regimes at the intensive margin, again in line with Dechezlepêtre et al. (2016) and Peters et al. (2017). The mean R&D investment under laissez-faire, conditional on investing (left panel), is 197 000€ per project. The mean investment, conditional on investing, under the first and the second best policies is almost two and a half times higher. R&D tax credit and subsidy policies induce roughly 29-47% higher average R&D investments than laissez-faire but fall short of first and second best. The R&D tax credit regime generates a somewhat higher mean investment than the subsidy regime (289 000€ versus 253 000€). However, the mean R&D investment of successful applicants (last row, left panel) is substantially higher than investments under R&D tax credits and close to the first best level, emphasizing the effectiveness of the ability to tailor the subsidy to each project. The removal of financial market imperfections has next to no impact on the level of R&D investment.

To compare the R&D intensities in different scenarios taking both the extensive and intensive margins into account, we also report the unconditional means in the right panel. Given the small differences across policies in the probability to invest in R&D reported by Table 4, the rankings and ratios in the right panel are close to those in the left panel. R&D tax credits have a somewhat larger relative effect than subsidies when we also account for the extensive margin.

The medians are clearly lower than the means, indicating a right-skewed R&D distribution. To give an idea of the differences in the distribution of R&D, we plot the distribution from one simulation round of the counterfactual analysis across policy regimes in Figure 2. The first best, second best and R&D support policies shift the R&D distribution to the right.[13]

[Table 5][Figure 2. Distribution of R&D conditional on policy].

Profits. The counterfactual profit estimates are displayed in the left panel of Table 6. Profit differences across policy regimes are much smaller than those in R&D investment because, as suggested by Table 4, some 40% of the firms are investing in R&D in none of the regimes and are hence unaffected by the policies. The mean expected discounted profits are slightly higher under the two support regimes than under laissez-faire. Because the removal of financial market imperfections has little impact on R&D, profits in that regime are close to those in laissez-faire. Profits in the first and second best regimes are lower than in laissez-faire by some 5%: the firms generating positive spillovers invest in these regimes more than the profit-maximizing level and the firms generating negative spillovers invest less.

[Table 6]

Spillovers. We report spillovers estimates in the middle panel of Table 6. Spillovers are much lower than firm profits in all regimes, ranging from 56 000€ (5% of the profits) under laissez-faire to 138 000€ (12% of the profits) under

[13] Although not clearly visible from Figure 4, the differences between some policy regimes are increasing in project size. For example, the mean 50th percentile for the subsidy regime over all simulation rounds is 69 000€ and that for laissez-faire 55 000€, a difference of 25%, whereas the difference at the 90th percentile is 36%. The differences between laissez-faire and first and second best are also strongly increasing in project size. In contrast, for the R&D tax credit the difference is 41-44% irrespective of the measurement point along the distribution of R&D investment.

first best. Spillovers in the R&D tax credit regime are somewhat higher on average than in the R&D subsidy regime. While R&D subsidy and tax credit policies significantly increase spillovers (by 28 and 49%) compared to laissez-faire, the spillovers they generate are nonetheless clearly lower than those generated by the first and second best regimes.

Welfare. The ultimate measure of the effectiveness of different R&D support policies is their impact on welfare. Our welfare analysis compares counterfactual outcomes as measured by our revealed preference approach to identify the parameters of equation (9). We find (see the right panel of Table 6) that all regimes are close in terms of welfare. The first and second best regimes improve welfare by 2% compared to laissez-faire. As a result, there is no room for other policies to increase welfare significantly; a feature our analysis shares with that of Acemoğlu et al. (2018) using a different model and data. (A first best policy in Acemoğlu et al. (2018) increases welfare by 4% and uniform taxes and subsidies by 1%.) Thus, while the two R&D support policies increase R&D investments and spillovers, they do not improve welfare much once the shadow costs of public funds are taken into account. If anything, the R&D subsidy regime seems to generate lower welfare than laissez-faire. The reason for this adverse net welfare effect comes from application costs involved in the subsidy regime: since the agency does not commit to a subsidy rate rule, it does not internalize the effects of its policy on the number and costs of applications. If application costs are ignored, the subsidy regime creates a small welfare improvement. As the removal of financial market imperfections has little effect on investments, it cannot have notable welfare effects either: it only leads to a modest welfare gain that rounds to zero.

Our estimates of the welfare of the R&D support policies do not capture some relevant considerations. On the one hand, our welfare estimates are likely to be upward biased: although we take into account the firms' application costs, we ignore the agency's administrative costs which are of the order of 50 million euro (Tekes 2010) a year which amounts to some 2 000 euros per firm in our data. On the other hand, global welfare effects are likely to be understated because a large part of consumer surplus and technological spillovers generated by the Finnish R&D projects is captured abroad but that part should not be included in the Finnish agency's objective function. We also ignore firms' international R&D location decisions, which may lead us to underestimate the benefits of support policies at a national level.

We assume that all eligible firms use the R&D tax credit although evidence suggests otherwise. This assumption leads to an upward bias in both benefits and costs of the R&D tax credit policy. Our welfare estimations also ignore the agency's budget. This omission is likely to create a downward bias in the estimates if the agency's budget constraint is actually binding and an upward bias if unused budget leads to a wasteful end-of-year spending (see, e.g., Liebman and Mahoney 2017). We also assume the spillovers are a linear function of R&D and that spillovers are normally distributed; relaxing these functional form assumptions may affect our welfare results.

Policy parameters. Table 7 reports some parameters of policy interest. Across all simulations, on average 15% of firms apply for a subsidy and the average subsidy rate, conditional on getting a subsidy, is 39%. Both figures are close to those in the data (18% and 35%). We find the socially optimal tax credit rate τ_R^* to be approximately 0.34 (with a bootstrapped standard error of 0.01), which is lower than the mean subsidy rate of the successful applicants (0.39).[14] In calculating the optimal tax credit rate the agency takes into account that, on the one hand, some projects should get larger subsidies than the maximum subsidy rate $\bar{s}$ and, on the other hand, some projects should be taxed because of negative spillovers rather than subsidized. Furthermore, the optimal tax credit rate calculation takes into account the positive correlation of application cost and R&D profitability shocks, implying that an average R&D project is likely to be more profitable than an average project for which subsidies are applied for. Our optimal tax credit rate of 34% is comparable to the optimal linear R&D subsidy rates of 41% and 39% reported by Akcigit, Hanley and Stantcheva (2017) and Acemoğlu et al. (2018), respectively. In their models, the linear subsidy rate applies for all R&D investing firms and hence is in spirit similar to our R&D tax credit rate, whereas in our model and data, only some firms apply for and are granted R&D subsidies.

We find that the mean subsidy, conditional on getting one, has a fiscal cost of 59 000€, whereas the mean tax credit conditional on investing in R&D has a fiscal cost of 98 000€. When we calculate these average fiscal costs irrespective of whether a firm invests in R&D or applies for subsidies, the fiscal costs of a

[14]Since $\tau_R := \tilde{\tau}_R/(1-\tau)$, with the prevailing Finnish corporate tax rate τ of 0.26, the corresponding socially optimal $\tilde{\tau}_R^*$ is 0.25 ($\approx 0.34 \times (1-0.26)$).

mean subsidy and a mean tax credit are 27 000€ and 51 000€, respectively. However, the fiscal costs (but also R&D investment levels and welfare) under the tax credit regime are likely to be upward biased as we assume that all firms that invest in R&D get the tax credit.

[Table 7]

Robustness. We report the results of three robustness analyses in Appendix E: First, we estimate the cost of external finance using balance sheet data on interest rates; second, we use only subsidies instead of both subsidies and subsidized loans in calculating the subsidy rate; and third, we exclude the three largest firms. We find that the alternative measure yields a somewhat higher estimate of cost of external finance and, consequently, lower estimates of R&D investment, profits and welfare; using subsidies only yields results close to those in the main text; and excluding the top three firms yields somewhat higher R&D investment, profits and welfare. When we compare the other policy regimes to laissez-faire, we obtain similar R&D ratios with one exception: The no financial market imperfections-regime increases R&D by nine per cent when using the alternative cost of finance. The other ratios are either exactly the same as in our main results or deviating at most by one percentage point.

As a fourth (unreported) robustness test, we introduce 3^{rd} order terms into our polynomials, and an expanded set of industry dummies. This last counterfactual produces results that are similar to our main results.

7 Conclusions

Many governments around the world provide financial support to private R&D; such policies have a solid basis in economic theory. A large empirical literature applies the tools of the treatment effect literature on both R&D tax credits and subsidies. While this literature has produced numerous important insights, the ultimate objective of policy evaluation – welfare effects – has rarely been addressed regarding R&D support policies.

This paper presents an attempt to study of the welfare effects of innovation policies. We build and estimate a model of an innovation policy, incorporating the main policy motivations, and conduct a counterfactual analysis of different R&D support policies. We use self-reported cashflow data of the R&D subsidy applicants to measure the cost of finance. In a departure from most existing work, we use the variation in government R&D subsidy rate decisions to identify the parameters of the government's utility function.

Our model yields theoretical results that concern both the regularly cited policy motivations and the interpretation of the R&D investment equation. Contrary to conventional wisdom, financial market imperfections lead to a decrease in the optimal level of support at the intensive margin. At the extensive margin the conventional view of a positive effect is observed. Quantitatively, however, we find little effects of financial market imperfections on R&D.

We find that larger and more productive firms invest more. The firms that invest more at the intensive margin also have higher fixed costs of R&D. The agency takes firm characteristics into account in deciding the optimal subsidy rate. Costs of applying for subsidies are heterogeneous and matter for the effectiveness of a R&D subsidy policy.

In the counterfactual analysis R&D tax credits and R&D subsidies yield significantly higher R&D investment levels than laissez-faire, but do not increase R&D participation. In contrast to R&D tax credits, R&D subsidies achieve close to first best investments for those firms that receive a subsidy, but subsidies reach only a fraction of firms. R&D tax credits are almost twice as costly as R&D subsidies from a fiscal point of view but ultimately perform better in terms of welfare. First and second best R&D levels are twice as large as under laissez-faire. The same effects apply to spillovers, but profits are roughly constant over policies. We find that profits are considerably larger than spillovers; an explanation for this result might be that the Finnish agency internalizes profits fully but internalizes only those spillovers that remain in Finland. Since the profit effects dominate, the differences in welfare effects of policies are small: first and second best yield 2% more welfare than laissez-faire. Given this space for welfare improvements, it is unsurprising that the R&D tax credit and subsidy policies fail to improve welfare markedly despite increasing R&D and spillovers by 25% or more.

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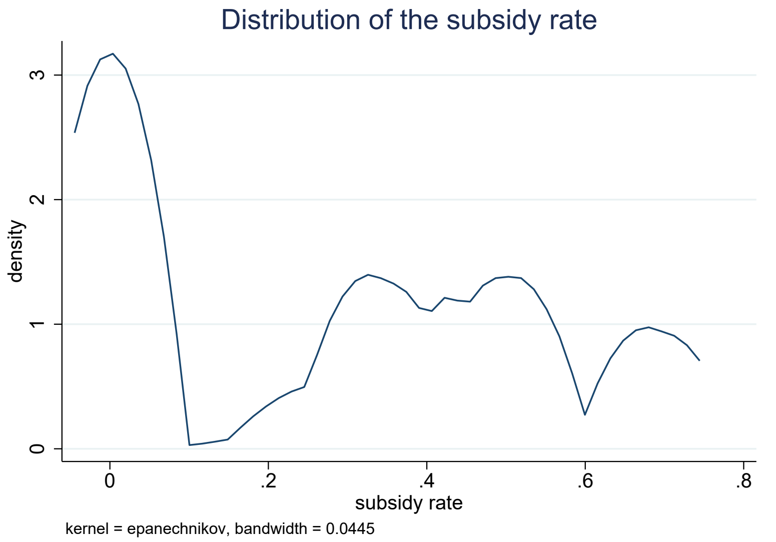


Figure 1. Distribution of the subsidy rate

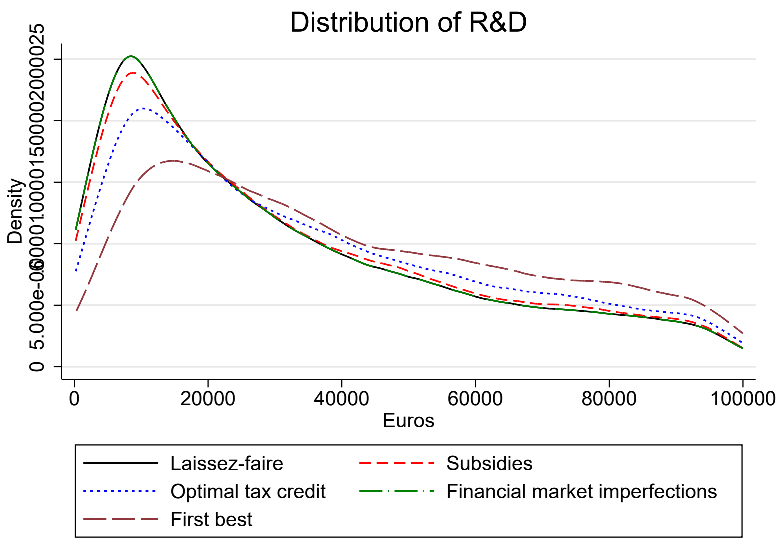


Figure 2. Distribution of counterfactual R&D investment (truncated at 100 000€)

Table 1. Descriptive statistics

	Non-applicants			Applicants			Rejected applicants			Successful applicants		
	mean	s.d.	p50	mean	s.d.	p50	mean	s.d.	p50	mean	s.d.	p50
$subsidy\,rate$	0.00	0.00	0.00	0.27	0.26	0.34	0.00	0.00	0.00	0.35	0.24	0.35
$R\&D_{actual}$	.	.	.	.	.	.	.	.	.	483 352	871 969	181 601
$1[R\&D]_t$	0.55	0.50	1.00	0.95	0.21	1.00	0.78	0.41	1.00	1.00	0.05	1.00
$tech$	.	.	.	2.08	0.79	2.00	2.08	0.79	2.00	2.17	0.76	2.00
$risk$	.	.	.	2.31	0.83	2.00	2.31	0.83	2.00	2.32	0.80	2.00
$prev\,applicant$	0.13	0.34	0.00	0.22	0.42	0.00	0.18	0.39	0.00	0.24	0.42	0.00
$1[R\&D]_{t-1}$	0.59	0.49	1.00	0.83	0.38	1.00	0.81	0.39	1.00	0.83	0.37	1.00
SME	0.86	0.35	1.00	0.83	0.38	1.00	0.83	0.37	1.00	0.83	0.38	1.00
age	17.39	13.20	14.00	14.11	11.12	11.00	13.92	11.07	11.00	14.16	11.13	11.00
$\#empl.$	100.55	187.85	35.70	120.75	238.70	26.00	115.06	226.28	26.70	122.28	241.95	25.95
$sales/empl.$	0.22	0.31	0.13	0.19	0.29	0.11	0.20	0.34	0.10	0.19	0.28	0.11
$region$	0.13	0.33	0.00	0.19	0.39	0.00	0.17	0.38	0.00	0.19	0.39	0.00
$cfratio$	.	.	.	.	.	.	.	.	.	1.12	0.71	1.00
$cfratio\|1[R\&D]_{t-1} = 0$	.	.	.	.	.	.	.	.	.	1.16	0.71	1.00
#Observations	18 538			3 966			840			3 126		

NOTES: Monetary values are in year 2005 euros. Observations are at firm-year level.

$subsidy\,rate$ is the fraction of the R&D investment in the project reimbursed by the agency.

$R\&D_{actual}$ is the realized R&D investment in the project. $1[R\&D]_t$ takes value 1 if the firm invested in R&D in year $t$and 0 otherwise.

$tech$ and $risk$ are the technological challenge and commerrcial risk of the project as evaluated by the agency, on an 1-3 Likert scale.

#Observations for $tech$ and $risk$: 369 and 367 unsuccessful applicants; 1 634 and 1634 successful applicants.

$prev\,applicant$ takes value 1 if the firm applied for a subsidy in year $t-1$ and 0 otherwise.

$1[R\&D]_{t-1}$ takes value 1 if the firm invested in R&D in year $t-1$and 0 otherwise.

SME takes value 1 if the firm in year t is an SME according to the EU guidelines and 0 otherwise. age is the age of the firm in year t in years;

sales/employee is in 100 000 euros, *region* takes value 1 if the firm is located in a region eligible for EU regional aid and 0 otherwise.

$cfratio$ is the available cashflow for the project divided by planned R&D investments. #Observations for $cfratio$:1 952 (1 620 for which $1[R\&D]_{t-1} = 1$).

The difference between the sample averages of $cfratio$ and $cfratio|1[R\&D]_{t-1} = 0$ is significant at 1% level.

All differences between the sample averages of non-applicants and applicants are significant at 1% level.

The differences in the sample averages of $1[R\&D]_t$ and $prev\,applicant$ between successful and rejected applicants are significant .

Table 2. Coefficient estimates

	R&D investment	R&D participation	subsidy rate	application
ln*age*	-0.5300**	-0.4224	-0.0076	-0.2652
	(0.2621)	(0.3135)	(0.0287)	(0.2968)
ln*age*2	0.0833*	0.0739	0.0024	0.0715
	(0.04923)	(0.0584)	(0.0058)	(0.0558)
ln*emp*	0.0536	0.1945***	-0.0082	0.0174
	(0.0569)	(0.0660)	(0.0075)	(0.0613)
ln*emp*2	0.0364***	0.0171*	-0.0015	0.0277***
	(0.0076)	(0.0091)	(0.0012)	(0.0083)
$sales/emp$	2.3152***	2.0867***	-0.1414***	2.7154***
	(0.4382)	(0.4982)	(0.0371)	(0.4763)
$sales/emp$2	-1.1956***	-1.0176***	0.1006***	-1.3645***
	(0.2621)	(0.3001)	(0.0239)	(0.2844)
exporter	-0.0170	-1.3884***	0.0084	-0.2366*
	(0.0871)	(0.1000)	(0.0077)	(0.1344)
region	-0.2710***	-0.9290***	-0.0045	-0.5353***
	(0.0838)	(0.0990)	(0.0088)	(0.1068)
RD_{t-1}	0.4204***	-2.6989***	0.0156*	0.0217
	(0.1107)	(0.1245)	(0.0088)	(0.4329)
Mills	-0.5214***	-	-	-
	(0.1768)			
#Obs.	2 289	22 504	1 123	22 504

NOTES: standard errors (in parentheses) are bootstrapped (399 rounds) .*** p<0.01, ** p<0.05, * p<0.1.

Table 2. Coefficient estimates

	R&D investment	R&D participation	subsidy rate	application
SME	-	-	-0.0045	
			(0.0125)	
risk	-	-	0.0104***	
			(0.0037)	
tech	-	-	0.0062	
			(0.0045)	
prevapplicant	-	-	-	-0.3271***
				(0.0488)
$\ln cashflowgap$	0.9540***	-	-	-
	(0.2129)			
σ_ε	0.4541***	-	-	-
	(0.0239)			
σ_η	-	-	0.0981***	-
			(0.002)	
ξ	-	-	-	0.9659
				(1.067)
#Obs.	2 289	22 504	1 123	22 504
Year dummies	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES

NOTES: standard errors (in parentheses) are bootstrapped (399 rounds). *** p<0.01, ** p<0.05, * p<0.1

Table 3. Fixed cost of R&D and cost of subsidy application

	mean	s.d.	p10	p25	median	p75
Fixed cost	1 204 784	5 027 150	16 115	32 967	104 704	685 460
Application cost	111 791	57 266	1 823	71 233	100 204	138 530

NOTES: The cost figures are from the counterfactual simulations.

Percentiles are calculated over firm averages.

Table 4. R&D participation

Regime	mean	median	ratio
Laissez-faire	0.62	0.77	1.00
1^{st} best	0.63	0.78	1.02
2^{nd} best	0.62	0.77	1.00
Tax credits	0.63	0.77	1.02
Subsidies	0.62	0.77	1.00
No financial market imperfections	0.62	0.77	1.00

NOTES: The figures are calculated over all simulation rounds and firms.

Ratio = the mean for the regime in question divided by the laissez-faire mean.

Table 5. R&D investment

Simulation rounds conditional on $R > 0$				All simulation rounds		
Regime	mean	median	ratio	mean	median	ratio
Laissez-faire	196 558	108 138	1.00	101 408	55 502	1.00
1^{st} best	475 656	265 085	2.42	234 547	146 044	2.31
2^{nd} best	464 407	267 730	2.36	230 597	142 983	2.27
Tax credits	289 381	159 588	1.47	151 072	82 963	1.49
Subsidies	253 481	122 356	1.29	127 075	64 656	1.25
No financial market imperfections	196 574	108 150	1.00	101 418	55 509	1.00
$s \vert s > 0 \,\&\, R\&D > 0$	484 652	194 497	2.47			

NOTES: the figures are calculated over over simulation rounds and firms with $R > 0$ (left panel) or all simulation rounds and firms (right panel).

ratio = the mean for the regime in question divided by the laissez-faire mean.

$s|s > 0 \,\&\, R\&D > 0$ shows the average R&D investment from the subsidy regime conditional on a firm receiving a subsidy.

Table 6. Profit, Spillovers and Welfare

	Profit			Spillovers			Welfare		
Regime	mean	median	ratio	mean	median	ratio	mean	median	ratio
Laissez-faire	1 170 343	559 085	1.00	55 760	33643	1.00	1 226 103	593 595	1.00
1^{st} best	1 115 867	517 719	0.95	137 743	91619	2.47	1 253 610	611 885	1.02
2^{nd} best	1 118 462	519 485	0.96	134 530	89760	2.41	1 252 992	611 257	1.02
Tax credits	1 212 153	582 458	1.04	83 089	50259	1.49	1 233 604	599 178	1.01
Subsidies	1 178 357	561 307	1.01	71 287	39396	1.28	1 217 671	590 015	0.99
No financial market imperfections	1 170 365	559 101	1.00	55 766	33648	1.00	1 226 131	593 643	1.00

NOTES: The figures are calculated over all simulation rounds and firms. Ratio = the mean for the regime in question divided by the laissez-faire mean.

Table 7. Counterfactual estimates

variable	mean
$\Pr[apply]$	0.15
$subsidy\, rate \vert s > 0$	0.39
τ_R	0.34
$\tilde{\tau}_R = \tau_R(1-\tau)$	0.25
Government cost, $s \vert s > 0 \,\&\, R\&D > 0$	59 410
Government cost, $\tau_R \vert R\&D > 0$	98 389
Government cost, s	26 644
Government cost, τ_R	51 365

NOTES: the figures are calculated over all simulation rounds and firms unless stated otherwise.

$\Pr[apply]$ is the average probability to apply for a subsidy. $subsidy\, rate|s > 0$ is the average subsidy

rate conditional on it being strictly positive. τ_R is the optimal tax credit.

Government cost $s|s > 0 \,\&\, R\&D > 0$ is the avgerave cost to the government from those projects it subsidizes in euros.

Government cost $\tau_R|R\&D > 0$ is the avgerave cost to the government from those projects that claim tax crdits in euros.

Government cost s and government cost, $\tau_R$are is the average cost of subsidies and tax credits, respectiveluy, in euros.

Appendix: For online publication

Appendix A: Figures

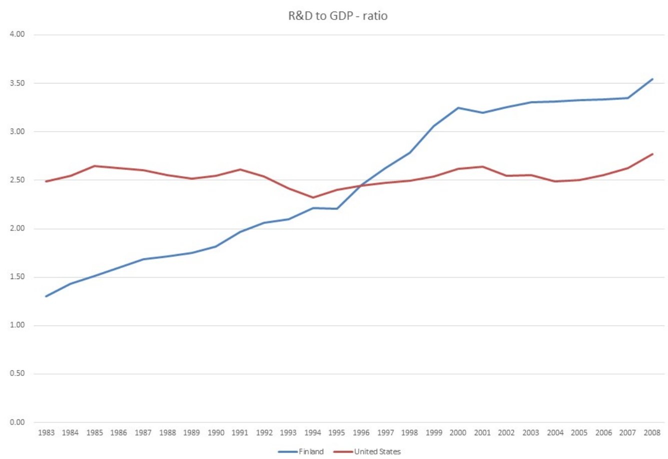
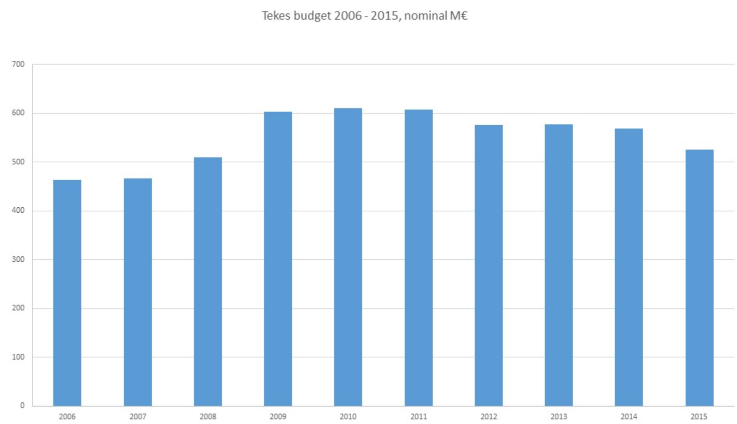


Figure A1. R&D/GDP-ratio, Finland and the US. Source: OECD Main Science and Technology Indicators.



Source: https://www.tekes.fi/globalassets/global/tekes/.../tekesin_organisaatio.pptx

Figure A2. Tekes budget 2006 - 2015.

Appendix B: Descriptive statistics and estimation details

Estimation sample

We first drop those observations where sales are negative (7 observations). We then exclude those firms for which we don't observe age at any point (17 24**1** obs.): in case employment is observed in adjacent years but not in the year in question, we substitute primarily the employment level in the previous, and secondarily the employment level in the following year. We exclude from the estimations outliers as follows: we first exclude all observations in the top 1% of the size (#employees) distribution (265 obs.); second, we drop any remaining observations in the top 1% of the age distribution (223 obs.); third, we drop those observations in the top 1% of the sales/employee-ratio distribution (179 obs.); fourth, we drop those remaining firms whose mean employment is above the 99^{th} percentile (22 obs.); the same regarding age (145 obs.); and the same regarding sales/employee (183 obs.). Finally, we drop all those remaining 2 597 firm-year observations for which we don't observe the R&D expenditure; these come from firms not included in the R&D survey of Statistics Finland.

According to the Statistics Finland www-site,[15] statistics on research and development are based on the European Union's Regulations (Decision No 1608/2003/EC of the European Parliament and of the Council and Commission Implementing Regulation No 995/2012) . The inquiry includes enterprises in different fields having reported R&D activities in the previous inquiry, enterprises having received product development funding from the Finnish Funding Agency for Technology and Innovation Tekes and the Finnish Innovation Fund Sitra, and all enterprises with more than 100 employees and a sample of enterprises with 10 to 99 employees. We experimented with using weights that correct for the sampling frame. As these had no material impact on the estimations but increased the computation time significantly, we do not use weights in the reported estimations.

Number of observations per firm

Table B1 shows the distribution of the number of observations per firm in our estimation sample.

[15] See http://tilastokeskus.fi/keruu/yrtk/index_en.html, accessed June 17, 2017).

Table B1. Distribution of #obs / firm

#obs	#firm-year obs.	%	cum. %
1	1 143	5.08	
2	2 564	11.30	16.47
3	3 048	13.54	30.02
4	2 896	12.87	42.89
5	2 985	13.26	56.15
6	2 256	10.02	66.17
7	2 009	8.93	75.10
8	2 120	9.42	84.52
9	3 483	15.48	100
Total	22 504		

Descriptive statistics on number of applications

Table B2 reports the distribution of the number of applications by firm across our estimation sample. Table B3 shows the distribution of the number of applications per in a given year.

Table B2. Distribution of #applications / firm

#applications	#firms	%	cum. %
0	3 979	65.48	
1	1 142	18.79	8427
2	493	8.11	92.38
3	224	3.69	96.07
4	123	2.02	98.09
5	65	1.07	99.16
6	22	0.36	99.52
7	17	0.28	99.80
>7	12	0.19	100
Total #firms	6 077	100	

Table B3. Distribution of #applications/ year

year	#applications
2000	454
2001	455
2002	413
2003	432
2004	472
2005	453
2006	445
2007	416
2008	426
Total # applications	3 966

Estimating the cashflow for the project

We use the information submitted by the applicants on their cashflow. We estimate a sample selection model where the first stage dependent variable is a dummy taking value one for those observations for which we observe the cashflow. The second stage dependent variable is the natural log of the reported cash flow. The explanatory variables are the same as in the main equations. The exclusion restriction is having applied earlier; we know from TTT (2013) that this is highly correlated applying and hence also observing the cashflow. The assumption is that it is not correlated with the cashflow firms report is available for the project. Using the results from this regression we predict the log cashflow for those observations for which we do not have it, correcting for the sample selection bias. We assume that the errors in these equations are normally distributed, possibly correlated with each other, and that the second stage error is uncorrelated with the shocks in the structural model (ε_{it}, ζ_{it}, η_{it}, μ_{0it}). We present the results of the above probit in the first column and those of the log cashflow equation in column two of table B5.

To create the variables we use in the structural model to measure the monitoring cost (degree of financial market imperfection), we first the 99^{th} percentile of the log cashflow distribution and then take the difference between this and observed (predicted) cashflow of a firm/project - year observation. We set this difference to zero for those project - year observations that are in the top one per cent.

Agency's grading and grading equations

Upon receiving an application the agency grades it in two dimensions, technological challenge and commercial risk, by using a 5-point Likert scale. The agency has six grades but uses only five of them in practice. A loose translation of the six grades of technological challenge is 0 = "no technological challenge", 1 = "technological novelty only for the applicant", 2 = "technological novelty for the network or the region", 3 = "national state-of-the-art", 4 = "demanding international level", and 5 = "international state-of-the-art". For commercial risk, it is 0 = "no identifiable risk", 1 = "small risk", 2 = "considerable risk", 3 = "big risk", 4 = "very big risk", and 5 = "unbearable risk". As explained in the main text, we group some grades as follows: grades 0 and 1 on the one hand, and grades 3, 4 and 5 on the other hand. Table B4 displays the original and the augmented grades' distribution.

Building on the process described in TTT (2013a, see in particular equation (9)), we estimate the two grading rules by using ordered probits. In contrast to TTT (2013a), we correct for sample selection in these estimations. The first stage dependent variable is a dummy variable taking value one if we observe the grading outcome in question. The second stage dependent variables are the grades. The first and second stage explanatory variables are the same as in the cashflow estimation. We assume that the unobservables of the two grading equations are normally distributed and uncorrelated with each other, and with the four unobservables (ε_{it}, ζ_{it}, η_{it}, μ_{0it}) of the main equations. This estimation provides us with two vectors of parameters that are used to generate a firm's prediction on how the agency would grade its application in the two grading dimensions, if the firm applied for a subsidy. Estimation is by maximum likelihood. The results are presented in Table B5. We use the thus generated probabilities for calculating the expected discounted profits from applying for a subsidy (see below for more detail).

Table B4. Distribution of agency grades, %

	tech		risk	
grade	original	augmented	original	augmented
0	0.86		0.81	
1	30.52	31.38	20.42	21.22
2	32.29	32.29	26.89	26.89
3	35.11	36.33	49	49
4	1.22		2.85	2.89
5			0.04	
#Obs.	2 546		2 596	

NOTES: numbers given are the %

of observations with a particular grade.

The results presented in table B5 are: those from the probit regression where the dependent variable is a dummy taking value one if we observe the cashflow available for the R&D project of the firm (column 1); the log cashflow equation (column 2); the probit models for the sample selection for non-SMEs (column 3) and SMEs (column 4) which are used to generate the Mills' ratio for the Tekes grades technological challenge (column 5) and commercial risk (column 6), as well as the structural equations presented in table 2.

Table B5. Cashflow and Tekes grading rule estimation: first stages of the sample selection models

	(1)	(2)	(3)	(4)	(5)	(6)
	$1[observe\ cashflow$	$\ln cashflow$	application non-SME	application SME	tech	risk
$\ln age$	-0.1471	0.0885	-0.2035*	-0.6725***	0.0386	-0.2089
	(0.1077)	(0.1542)	(0.0941)	(0.1956)	(0.1923)	(0.1942)
$\ln age2$	0.0006	-0.0113	0.0032	0.1045***	-0.0011	0.0287
	(0.0205)	(0.0284)	(0.0184)	(0.0356)	(0.0374)	(0.0368)
$\ln emp$	0.0504	0.0934***	0.1391***	-0.2163***	0.0736	-0.0730
	(0.0206)	(0.0311)	(0.0202)	(0.0608)	(0.0435)	(0.0492)
$\ln emp2$	-0.0042	0.0097**	-0.0257***	0.0385***	-0.0020	0.0000
	(0.0031)	(0.0041)	(0.0037)	(0.0067)	(0.0058)	(0.0066)
$sales/emp$	-0.1201	1.5145***	-1.2927***	0.0547	-0.2744	-1.6070***
	(0.1531)	(0.2158)	(0.1536)	(0.2388)	(0.3008)	(0.3059)
$sales/emp2$	-0.0281	-0.9066***	0.7290***	0.1069	0.2262	0.9942***
	(0.0876)	(0.1356)	(0.0888)	(0.1318)	(0.1728)	(0.1729)
$exporter$	0.2849	-0.0447	0.2720***	0.2384***	0.1115	-0.0437
	(0.0300)	(0.0438)	(0.0249)	(0.0635)	(0.0646)	(0.0610)
$region$	0.1881	-0.0704	0.2513***	0.1423*	0.0730	0.0017
	(0.0328)	(0.0395)	(0.0273)	(0.0751)	(0.0646)	(0.0656)
RD_{t-1}	0.3876	0.0401	0.4205***	0.4962***	0.2669***	0.0640
	(0.0288)	(0.0447)	(0.0229)	(0.0728)	(0.0804)	(0.0830)
$prevapplicant$	0.3226	-	0.2851***	0.4086***	-	-
	(0.0332)		(0.0303)	(0.0604)		
$Mills$	-	-1.3620*	-	-	0.1017	-0.0579
		(0.6096)			(0.1355)	(0.1394)
$Constant$	-1.6470	0.0284	-1.0192	-1.2140	-	-
	(0.1355)	(0.5442)	(0.1207)	(0.3397)		
Observations	22 504	1 952	19 232	3 272	2 003	2 001
Year dummies	YES	YES	YES	YES	YES	YES
Industry dummies	YES	YES	YES	YES	YES	YES

NOTES: bootstrapped standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Simulation for estimation

We use the simulation estimator for discrete choice introduced by McFadden (1989); see also Stern (1997). We simulate the profitability shock of the firm (ε_{it}) both for the R&D participation and the subsidy application decisions. We use 40 simulation rounds and draw the shocks using Halton sequences. The draws are the same for all estimation equations.

Expected profits from applying for subsidies

To estimate the firm's application decision, we need to deal with both agency grading and the stochastic component of agency utility, η_{it}, which are unknown to the firm contemplating application. We assume that the firm knows the probabilities of obtaining particular grades for $tech$ and $risk$, and the distribution of η_{it}. We therefore calculate for each firm and each simulation draw the expected discounted profits from obtaining a particular grade combination, integrating over the distribution of η_{it}. These profits are then weighted by the probability of getting a particular grade combination; we obtain these probabilities from the ancillary (ordered probit) grading equations. For numerical integration we use Simpson's method. The integration is repeated separately for each simulation round and each iteration.

Bootstrap

We bootstrap the whole estimation process and the generation of the optimal tax credit. We use 399 bootstrap rounds. To speed up computation, we limit the number of Newton-Raphson iterations to 5 for the R&D investment, R&D participation and application equations, while using the estimated coefficients as starting values. We restrict the number of iterations to 150 for the agency decision rule. We further restrict the number of simulation rounds for the calculation of the optimal tax credit to 50 (100 in the estimation), and restrict the support of the grid search to be [20,50] (in the estimation [0,100]). The grid step is kept at 1 (percentage point). For the calculation of the optimal tax credit, we restrict the number of simulation rounds to 50 (we use 100 rounds in the estimation).

Appendix C: Details and proofs of the theoretical model

For $F \in [0,\infty)$ we denote by $\Gamma(F)$ the dynamic game among the agency, a firm and an investor. Let us explicitly write the repayment promise as a part of a standard debt contract and replace π^I by $\min\left\{\pi^I, \pi(R)_+\right\}$ in the investor's and firm's payoffs of equations (2) and (3). Here the min operator captures the seniority of the investor's claims if the firm cannot honor its promise and the max operator reflects the limited-liability protection of the firm.

Define also

$$\Pi^{j*}(F,s) := \Pi^j\left(F,s,R^*(F,s),\pi^{I*}(F,s)\right), j = E,I.$$

and

$$U^*(F,v,s) := U\left(v,s,R^*(F,s),\pi^{I*}(F,s)\right).$$

as the players' expected payoffs to an equilibrium financing contract proposed to a monitoring investor.

Definition 1. A profile $\left(d_a^*(F), s^*(F,v,d_a), R^*(F,s), \pi^{I*}(F,s), d_f^*\left(F,s,R,\pi^I\right), d_m^*\left(F,s,R,\pi^I\right), d_p^*(d_m)\right)$ is a pure-strategy perfect Bayesian equilibrium of $\Gamma(F)$ if it satisfies;

(i) For $d_f = 1$, $d_p^*(0) = 0$ and $d_p^*(1) = 1$;

(ii) For all $\left(s,R,\pi^I\right) \in [0,\bar{s}] \times [0,\infty)^2$, $\Pi^I(F,s,R,\pi^I) \geq 0$ implies $d_k^*\left(F,s,R,\pi^I\right) = 1$, and $\Pi^I(F,s,R,\pi^I) < 0$ implies $d_k^*\left(F,s,R,\pi^I\right) = 0$ for $k = f,m$;

(iii) For all $s \in [0,\bar{s}]$, $\left(R^*(F,s), \pi^{I*}(F,s)\right)$ solve the problem $\max_{(R,\pi^I)\in[0,\infty)^2} \Pi^E\left(F,R,\pi^I\right)_+$;

(iv) For $d_a = 1$, $s^*(F,v) := s^*(F,v,1)$ solves the problem $\max_{s\in[0,\bar{s}]} U^*(F,v,s)_+$. For $d_a = 0$,$s^*(F,v,0) = 0$. Moreover, if $\{S \subseteq [0,\bar{s}] : U^*(F,v,s) = 0 \forall s \in S\}$ exists, then for $s \in S$,$s^*(F,v) = 0$.

(v) $d_a^*(F)$ solves the problem

$$\max_{d_a\in\{0,1\}} d_a\left[\int_{-\infty}^{\infty} \Pi^{E*}\left(F,s^*(F,v)\right)_+ \phi(v)\,dv - K\right] + (1-d_a)\Pi^{E*}(F,0)_+. \tag{24}$$

Note that property (iv) defining the equilibrium subsidy rate has three parts. The first part defines the agency's equilibrium strategy (whenever the agency receives an application). The two other parts contain the technical yet realistic assumptions discussed in footnote 11 of the main text. First, if the firm does not apply ($d_a = 0$), the firm receives no subsidy. We model this outcome as if the agency awarded no subsidy in response to $d_a = 0$. Second, if there are multiple subsidy rates that would lead to zero payoff of the agency, we assume that the agency awards no subsidy. These auxiliary assumptions can be relaxed at the cost of complicating the notation.

We show the game $\Gamma(F)$ has a unique equilibrium, $\left(d_a^*(F), s^*(F,\cdot), R^*(F,\cdot), \pi^{I*}(F,\cdot), d_f^*(F,\cdot), d_m^*(F,\cdot), d_p^*(\cdot)\right)$, on $[0,\infty)$. Let us first formally introduce two mild restrictions on the project return functions discussed in the main text.

Assumption 1. $\alpha/\rho \geq e$.

Assumption 2. The bad project yields non-verifiable return $b \in [\alpha, \infty)$ per unit of investment.

Assumption 1 (which is equivalent to $\ln(\alpha/\rho) \geq 1$) ensures that the productivity of the good project is sufficiently high so make the firm's R&D investment profitable if the fixed costs of R&D are ignored. While models of R&D typically must invoke similar assumptions to make the models meaningful, we will also, after Proposition 1 at the end of Appendix C, characterize equilibria when Assumption 1 is relaxed. Assumption 1 plays a small role in the proof of Lemma 4, whereas the role of Assumption 2 becomes clear in the proof of Lemma 1, which shows that whenever an R&D project is launched, the firm chooses the good project only if the investor monitors.

Lemma 1. Assume that $R > 0$. If $d_m = 0$, then $d_p^* = 0$. Otherwise, $d_p^* = 1$.

Proof. Consider the subgame in which the investor provides funding ($d_f = 1$) for some project $R > 0$ but does not monitor ($d_m = 0$). There, for all $(\pi^I, R) \in [0, \infty) \times (0, \infty)$, the firm's payoff to the bad project is bR whereas the payoff to the good project is at most $P\pi(R)$ (see equation (3)). Therefore, the firm chooses the bad project if $bR \geq P\pi(R) = \alpha \ln R$ in which the last step uses equation (1) and the definition $\alpha := AP$. Since $R - \ln R > 0$ for all $R \in (0, \infty)$, a sufficient condition for choosing the bad project is $b \geq \alpha$,which holds by Assumption 2. Otherwise, if the investor monitors ($d_m = 1$), the bad project is eliminated from the firm's action set by assumption. ■

Lemma 2 identifies the investor's equilibrium behavior and marginal costs of funds.

Lemma 2. Let $(F, s, R) \in [0, \bar{s}] \times [0, \infty)^2$.

(i) For all $\pi^I \in [0, \infty)$, $d_f^*\left(F, s, R, \pi^I\right) = 1$ only if $d_m^*\left(F, s, R, \pi^I\right) = 1$. Otherwise, $d_f^*\left(F, s, R, \pi^I\right) = 0$. Therefore, if $d_f^*\left(F, s, R, \pi^I\right) = 1$ is a part of an equilibrium of $\Gamma(F)$, the investor's marginal cost cost of funds is $\rho := r + c$.

(ii) If $\pi(R) \geq [\rho\,(R+F) - sR]/P > 0$, then $d_f^*\left(F, s, R, \pi^I\right) = 0$ for $\pi^I < [\rho\,(R+F) - sR]/P$ and $d_k^*\left(F, s, R, \pi^I\right) = 1$, $k = f, m$, for $\pi^I \geq [\rho\,(R+F) - sR]/P$. Otherwise, $d_f^*\left(F, s, R, \pi^I\right) = 0$ for all $\pi^I \in [0, \infty)$.

Proof. Recall first that for all $\pi^I \in [0, \infty)$, the investor's payoff to $d_f = 0$ is 0 and note that the investor's (non-subsidized) marginal cost of funds may be written as $rd_f + cd_m$.

(i) Lemma 1 implies that, for all $\pi^I \in [0, \infty)$, the investor's payoff to $d_f = 1$ and $d_m = 0$ is $(1-\tau)\left[-r(R+F) + sR\right] < 0$ in which the inequality follows from $r \geq 1 > \bar{s} \geq s$. Therefore, in equilibrium either $d_f^*\left(F, s, R, \pi^I\right) = 0$ or if $d_f^*\left(F, s, R, \pi^I\right) = 1$, then $d_m^*\left(F, s, R, \pi^I\right) = 1$. If $d_k^*\left(F, s, R, \pi^I\right) = 1, k = f, m$, the investor's marginal cost funds is given by $\rho := r + c$.

(ii) Assume that $\pi(R) \geq [\rho\,(R+F) - sR]/P$ in which $[\rho\,(R+F) - sR]/P > 0$ because $\rho \geq 1 > \bar{s} \geq s$. Let $\pi_1^I, \pi_2^I \in [0, \infty)$ be such that $\pi_1^I < [\rho\,(R+F) - sR]/P \leq \pi_2^I$. Then $\min\left\{\pi_1^I, \pi(R)\right\} = \pi_1^I$ and therefore

$$\Pi^I(F, s, R, \pi_1^I) = (1-\tau)\left[P\pi_1^I - \rho\,(R+F) + sR\right] < 0.$$

Part (i) then implies that $d_f^*\left(F, s, R, \pi_1^I\right) = 0$. Similarly, $\min\left\{\pi_2^I, \pi(R)\right\} \geq [\rho\,(R+F) - sR]/P$

and therefore

$$\Pi^I(F,s,R,\pi_2^I) = (1-\tau)\left[P\min\left\{\pi_2^I,\pi(R)\right\} - \rho\,(R+F) + sR\right] \geq 0.$$

Hence, $d_f^*\left(F,s,R,\pi_2^I\right) = 1$ and part (i) implies that $d_m^*\left(F,s,R,\pi_2^I\right) = 1$.

Assume that $\pi(R) < \left[\rho\,(R+F) - sR\right]/P$. Then for all $\pi^I \in [0,\infty)$, $\min\left\{\pi^I,\pi(R)\right\} < \left[\rho\,(R+F) - sR\right]/P$, and

$$\Pi^I(F,s,R,\pi^I) = (1-\tau)\left[P\min\left\{\pi^I,\pi(R)\right\} - \rho\,(R+F) + sR\right] < 0$$

and hence, part (i) implies that $d_f^*\left(F,s,R,\pi^I\right) = 0$.■

Part (i) of Lemma 2 proves that in equilibrium, either a project is funded by a monitoring investor or no project is launched. Therefore, if the project is launched, its investor's marginal cost also include monitoring costs. Part (ii) identifies the repayments that are sufficiently high to attract the investor to finance the project.

Lemma 3 identifies the repayment promises that may arise in equilibrium and shows that, in an equilibrium in which the project is launched, the firm will be able to make the promised repayment unless the project fails to pay return.

Lemma 3. For all $(F,s) \in [0,\infty) \times [0,\bar{s}]$, the equilibrium repayment is $\pi^{I*}(F,s) = \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P > 0$. Moreover, if $R^*(F,s) > 0$ is a part of an equilibrium of $\Gamma(F)$, then $\pi(R^*(F,s)) > \pi^{I*}(F,s)$ and $R^*(F,s) > 1$.

Proof. Assume that in equilibrium $\pi(R^*(F,s)) > \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P$ in which $\left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P > 0$ because $\rho \geq 1 > \bar{s} \geq s$. Note from equation (1) that $\pi(R^*(F,s)) > 0$ only if $R^*(F,s) > 1$. Then, by offering a contract $\left(R^*(F,s),\pi^{I*}(F,s)\right)$ in which $\pi^{I*}(F,s) = \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P$ the firm can secure a positive expected payoff since $\Pi^E\left(F,R^*(F,s),\pi^{I*}(F,s)\right) = P\left[\pi(R^*(F,s)) - \pi^{I*}(F,s)\right] > 0$ and Lemma 2 implies that $d_k^*\left(F,s,R^*(F,s),\pi^{I*}(F,s)\right) = 1$, $k = f,m$. Higher repayment promises are strictly dominated since $\Pi^E\left(F,R^*(F,s),\pi^{I*}(F,s)\right) > \Pi^E\left(F,R^*(F,s),\pi^I\right) \geq 0$ for $\pi^I > \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P$, whereas for smaller repayment promises $\pi^I < \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P$, Lemma 2 implies that $d_f^*\left(F,s,R^*(F,s),\pi^I\right) = 0$ and, hence, $R^*(F,s) = 0$ and the firm's payoff is zero.

Moreover, if $\pi(R^*(F,s)) < \left[\rho\,(R^*(F,s)+F) - sR^*(F,s)\right]/P$, then Lemma 2 implies that for $\pi^I \in [0,\infty)$, $d_f^*\left(F,s,R^*(F,s),\pi^I\right) = 0$. Hence, $R^*(F,s) = 0$, and the firm's payoff is zero.■

Lemma 4 identifies the firm's equilibrium R&D investment behavior.

Lemma 4. There are two values of $F \in [0,\infty)$, $\underline{F}$ and $\bar{F}$, $\underline{F} < \bar{F}$, such that for all $s \in [0,\bar{s}]$, $R^*(F,s) = R^{**}(s) > 0$ for $F \in [0,\underline{F})$ and $R^*(F,s) = 0$ for $F \in (\bar{F},\infty)$. There is also a strictly increasing function $\tilde{s} : [\underline{F},\bar{F}] \to [0,\bar{s}]$ such that if $s \in [0,\tilde{s}(F))$, then $R^*(F,s) = 0$ and if $s \in [\tilde{s}(F),\bar{s}]$ then $R^*(F,s) = R^{**}(s) > 0$.

Proof: Recall first from equation (7) that in equilibrium either $R^*(F,s) = R^{**}(s) > 0$ or $R^*(F,s) = 0$ depending on whether $\Pi^{E**}(F,s) \geq 0$ or not. For $s = 0$, we observe from equation (8) that $\Pi^{E**}(F,0) > 0$ if and only if

$$F < \underline{F} := \frac{\alpha}{\rho}\left[\ln\left(\frac{\alpha}{\rho}\right) - 1\right]. \tag{25}$$

Since equation (8) also imples that $\partial\Pi^{E**}(F,s)/\partial s > 0$ on $[0,\bar{s}]$ (recall that $\rho \geq 1 > \bar{s}$), $\Pi^{E**}(F,s) > 0$ for all $s \in [0,\bar{s}]$ if the inequality (25) holds. Thus, $R^*(F,s) = R^{**}(s)$ for $F < \underline{F}$ and $s \in [0,\bar{s}]$.

Similarly, letting $s = \bar{s}$ in equation (8) implies that $\Pi^{E**}(F,\bar{s}) < 0$ if and only if

$$F > \bar{F} := \frac{\alpha}{\rho}\left[\ln\left(\frac{\alpha}{\rho - \bar{s}}\right) - 1\right]. \tag{26}$$

Since $\partial\Pi^{E**}(F,s)/\partial s > 0$ on $[0,\bar{s}]$, $\Pi^{E**}(F,s) < 0$ for all $s \in [0,\bar{s}]$ under the condition (26). Therefore, $R^*(F,s) = 0$ for $F > \bar{F}$ and $s \in [0,\bar{s}]$. Assumption 1 and equations (25) and (26) imply that $0 \leq \underline{F} < \bar{F}$.

Finally, letting $\Pi^{E**}(F,s)$ from equation (8) to be equal to zero and solving the equality for s yields

$$\tilde{s}(F) = \rho - \alpha e^{-\left(\frac{\alpha+\rho F}{\alpha}\right)}, \tag{27}$$

which is the subsidy rate familiar from equation (11) of the main text. Note next that $\partial\tilde{s}/\partial F > 0$, $\tilde{s}(\underline{F}) = 0$ and $\tilde{s}(\bar{F}) = \bar{s}$, and recall that $\partial\Pi^{E**}(F,s)/\partial s > 0$ on $[0,\bar{s}]$. Therefore, if $F \in [\underline{F},\bar{F}]$, $\Pi^{E**}(F,s) < 0$ and hence $R^*(F,s) = 0$ for $s \in [0,\tilde{s}(F))$, and $\Pi^{E**}(F,s) \geq 0$ and hence $R^*(F,s) = R^{**}(s)$ for $s \in [\tilde{s}(F),\bar{s}]$. ■

In more words, Lemma 4 identifies two threshold values for fixed R&D costs. If F is below the lower threshold $\underline{F}$ (if equation (25) holds), the fixed costs are so low that the firm will invest even without a subsidy. In contrast, if F is above the higher threshold $\bar{F}$ (equation (26) holds), the fixed costs are so high that they prevent the firm's investment even with a maximum subsidy rate $\bar{s}$. If $F \in [\underline{F},\bar{F}]$, the firm will invest only if it receives a subsidy rate that is at least as large as $\tilde{s}(F)$ as identified by equation (27), and does not invest otherwise.

Lemma 5 identifies the agency's equibrium behavior.

Lemma 5. Let $d_a = 1$. (i) For $F \in [0,\underline{F})$,

$$s^*(F,v) = \begin{cases} 0 & \text{if } v < \underline{v} := \rho\,(g-1) \\ s^{**}(v) & \text{if } v \in [\underline{v},\bar{v}] \\ \bar{s} & \text{if } v > \bar{v} := \underline{v} + \bar{s}, \end{cases}$$

in which $0 < \underline{v} < \bar{v}$;

(ii) For $F \in [\underline{F},\bar{F}]$,

$$s^*(F,v) = \begin{cases} 0 & \text{if } v < v^0(F) \\ \tilde{s}(F) & \text{if } v \in \left[v^0(F),\tilde{v}(F)\right) \\ s^{**}(v) & \text{if } v \in [\tilde{v}(F),\bar{v}(F)] \\ \bar{s} & \text{if } v > \bar{v} := \underline{v} + \bar{s}, \end{cases}$$

in which $v^0(F)$ and $\tilde{v}(F)$, with $0 \le v^0(F) < \tilde{v}(F) \le \bar{v}$, denote the (unique) values of v that satisfy $U^*(F, v^0, \tilde{s}(F))$=0 and $s^{**}(\tilde{v}) = \tilde{s}(F)$, respectively;

(iii) For $F \in (\bar{F}, \infty)$, $s^*(F, v) = 0$ for all $v \in \mathbb{R}$.

Proof: Conditional on $d_a = 1$, the agency's problem is given in equation (9)) in which $R^*(F, s)$ is given by (7). We first solve the agency's problem by ignoring the non-negativity constrains on the firm's and agency's expected payoffs in equations (6) and (9), respectively. Equation (7) implies that in this case, $R^*(F,s)$ =$R^{**}(s) = \alpha/(\rho - s)$. Using this equation and the envelope theorem to differentiate the agency's expected payoff $U^*(F, v, s)$ from equation (9) then yields

$$\frac{dU^*(F, v, s)}{ds} = \frac{\alpha}{(\rho - s)^2}\left[v - s - \rho(g-1)\right]. \tag{28}$$

Clearly, the unique interior solution, if it exists, to the problem $\max_{s \in [0, \bar{s}]} U^*(F, s, v)$ can be expressed as

$$s^{**}(v) = v - \rho(g-1), \tag{29}$$

which is the subsidy rate familiar from equation (10) of the main text. [16]

According to Lemma 4, the firm's zero-profit constraint does not bind if equation (25) holds. Therefore, for $F \in [0, \underline{F})$,equations (28) and (29) imply that the optimal subsidy policy is given by $s^*(F, v) = 0$ if $v < \underline{v}$ in which

$$\underline{v} := \rho(g-1) > 0, \tag{30}$$

$s^*(F, v) = \bar{s}$ if $v > \bar{v} := \underline{v} + \bar{s}$, and $s^*(F, v) = s^{**}(v)$ if $v \in [\underline{v}, \bar{v}]$. The claim in part (i) of Lemma 5 follows.

To prove part (iii) of Lemma 5, note that if equation (26) holds, Lemma 4 implies that the firm makes no investments even with a maximum subsidy rate $\bar{s}$. Thus, $R^*(F, s) = 0$, and $U^*(F, s, v) = 0$ for $(F, s, v) \in (\bar{F}, \infty) \times [0, \bar{s}] \times \mathbb{R}$. Here, the tie-breaking rule included in part (iv) of Definition 1 stipulates $s^*(F, v) = 0$ for $(F, v) \in [\bar{F}, \infty) \times \mathbb{R}$.

Proving part (ii) of Lemma 5 involves an additional complexity since, when $F \in [\underline{F}, \bar{F}]$, the firm will invest only if it receives a subsidy (see Lemma 4). This complexity matters if $s^{**}(v) < \bar{s}$ but $\Pi^{E**}(F, s^{**}(v)) < 0$. In such circumstances the agency may consider the subsidy rate $\tilde{s}(F)$ identifed by Lemma 4. Note that if $s^{**}(v) < \bar{s}$ and $\Pi^{E**}(F, s^{**}(v)) < 0$ then $\tilde{s}(F) >$$s^{**}(v)$,since $\tilde{s}(F) \in [0, \bar{s}]$ and $\partial \Pi^{E**}(F, s)/\partial s > 0$ on $[0, \bar{s}]$. Also, since $s^{**}(v)$ is the unique interior solution to the problem $\max_{s \in [0, \bar{s}]} U^*(F, v, s)$, awarding any higher subsidy $s' \in (\tilde{s}(F), \bar{s}]$ would imply $U^*(F, v, s') < U^*(F, v, \tilde{s}(F))$. On the other hand, awarding any lower subsidy $s' \in [0, \tilde{s}(F))$ would imply $R^*(F, s') = 0$ and therefore $U^*(F, v, s') = 0$ for all $s' \in [0, \tilde{s}(F))$ and the tie-breaking rule included in part (iv) of Definition 1 would stipulate $s' = 0$. Thus, if $\Pi^{E**}(F, s^{**}(v)) < 0)$, the agency needs to decide between $\tilde{s}(F)$ and $s^*(F, v) = 0$. As $R^*(F, 0) = 0$,and therefore $U^*(F, v, 0) = 0$, awarding $\tilde{s}(F)$ maybe optimal if $U^*(F, v, \tilde{s}(F)) \ge U^*(F, v, 0) = 0$. To summa-

[16] Also, $s \to \rho$ maximizes $U^*(F, s, v)$ but it violates the feasibility constraint $s \in [0, \bar{s}]$ (as $\rho \ge 1 >$$\bar{s}$). In addition, $s \to \pm\infty$ constitute solutions to the first-order condition for the agency's problem, but they characterize minima (and also violate the feasibility constraint $s \in [0, \bar{s}]$).

rize, awarding $\tilde{s}(F)$ is optimal for the agency if (i) $s^{**}(v) < \bar{s}$ and $\Pi^{E**}(F, s^{**}(v)) < 0$ and (iii) $U^*(F, v, \tilde{s}(F)) \geq 0$.

Since $\Pi^{E**}(F, s^{**}(v)) \geq 0$ if and only if $s^{**}(v) \geq \tilde{s}(F)$ we first characterize the circumstances in which $s^{**}(v) \geq \tilde{s}(F)$. Because $\tilde{s}(F)$ is independent of v but $s^{**}(v)$ is strictly increasing in v (see equations (27) and (29)), there exists a unique value of v, denoted by $\tilde{v}(F)$, such that $s^{**}(\tilde{v}(F)) = \tilde{s}(F)$. Equations (27) and (29) then yield

$$\tilde{v}(F) := g\rho - \alpha e^{-\frac{(\alpha+\rho F)}{\alpha}}. \tag{31}$$

Because $s^{**}(v)$ is strictly increasing, $s^{**}(v) \geq \tilde{s}(F)$ for $v \geq \tilde{v}(F)$. Thus, only if $v < v(\tilde{F})$, the agency may award subsidy $\tilde{s}(F) > s^{**}(v)$ that just satisfies the firm's zero-profit constraint $\Pi^{E**}(F, \tilde{s}(F)) = 0$.

We next characterize the conditions in which the agency's participation constraint $U^*(F, v, \tilde{s}(F)) \geq 0$ holds. Since both the investor's and firm's zero-profit constraints are binding at $s = \tilde{s}(F)$ by definition, we observe from equation (4) that $U^*(F, v, \tilde{s}(F)) = (v - g\tilde{s}(F))R^{**}(\tilde{s}(F))$. As a result, $U^*(F, v, \tilde{s}(F), v) \geq 0$ if $v - g\tilde{s}(F) \geq 0$. Inserting $\tilde{s}(F)$ from equation (27) into $v - g\tilde{s}(F) \geq 0$ yields $v \geq v^0(F)$ in which

$$v^0(F) := g\left[\rho - \alpha e^{-\frac{(\alpha+\rho F)}{\alpha}}\right] = \tilde{v}(F) - (g-1)\,\alpha e^{-\frac{(\alpha+\rho F)}{\alpha}}, \tag{32}$$

in which the latter equality uses equation (31). Since $g > 1$, $v^0(F) < \tilde{v}(F)$. As a result, $s^*(F, v) = \tilde{s}(F)$ constitutes the optimal agency decision for $v \in \left[v^0(F), \tilde{v}(F)\right)$. If $v < v^0(F)$, the agency's and firm's participation constraints cannot be satisfied for any positive subsidy rate, implying $s^*(F, v) = 0$.

Next, note from equations (27) , (30), and(31) that we may write $\tilde{v}(F) = \underline{v} + \tilde{s}(F)$. Since $\tilde{s}(F) \in [0, \bar{s}]$ by Lemma 5, $\tilde{v}(F) \in [\underline{v}, \bar{v}]$ (recall that $\bar{v} := \underline{v} + \bar{s}$). Therefore, we can summarize the agency's optimal decision rule for $F \in [\underline{F}, \bar{F}]$ as follows: $s^*(F, v) = 0$ for $v < v^0(F)$, $s^*(F, v) = \tilde{s}(F)$ for $v \in \left[v^0(F), \tilde{v}(F)\right)$, $s^*(F, v) = s^{**}(v)$ for $v \in [\tilde{v}(F), \bar{v}]$, and $s^*(F, v) = \bar{s}$ for $v > \bar{v}$. Note also from equations (27) and (32) that we may write $v^0(F) = g\tilde{s}(F)$. Since $g > 1$and $\tilde{s}(F) \in [0, \bar{s}]$ by Lemma 5, $v^0(F) \geq 0$. ■

In more words, Lemma 5 says that if $F < \underline{F}$, the fixed R&D costs are so small that they affect neither the firm's nor the agency's decisions. In contrast, if $F > \bar{F}$,the fixed costs are so high that the firm would not invest even if it received the maximimum subsidy $\bar{s}$. Therefore, the agency awards no subsidy for such a firm. If $F \in [\underline{F}, \bar{F}]$, the firm will invest only if it receives a subsidy. Now awarding $\tilde{s}(F)$ of equation (27) is an option to the agency. Awarding $\tilde{s}(F)$ is optimal for the agency if the spillover rate is not so high to make the unconstrained rate optimal for the agency but is large enough to satisfy the agency's participation constraint.

Lemma 6 proves that $0 \leq \min\left\{v^0(F), \underline{v}\right\}$ and $\max\left\{v^0(F), \underline{v}\right\} \leq \tilde{v}(F) \leq \bar{v}$, implying that a necessary condition for the firm to obtain a subsidy is that the realization of the spillover rate V for its project is positive. However, $v^0(F)$ and $\underline{v}$ cannot be unambiguously ranked. From equations (30) and (32) we obtain the following result:

Remark 1. $\underline{v} \lesseqqgtr v^0(F)$ if and only if $g \lesseqqgtr \frac{\rho}{\alpha} e^{\left(1+\frac{\rho}{\alpha}F\right)}$.

Since $g > 1$ and $e\rho/\alpha \leq 1$ by assumption, for sufficiently small F or sufficiently large g or α/ρ, $\underline{v} > v^0(F)$. Intuitively, for $v \in \left[v^0(F), \underline{v}\right]$, if the firm invested without a subsidy the agency would prefer not to give a subsidy since the realization of V relative to shadow cost of public funds g is so small. However, because the firm does not invest at all without the subsidy, the agency prefers to grant the subsidy rate $\tilde{s}(F)$ over the firm's no-investment.

Finally, Lemma 6 identifies the firm's equilibrium application behavior.

Lemma 6. (i) For $F \in [0, \underline{F})$,

$$d_a^*(F) = \begin{cases} 1 & \text{if } \int_{\underline{v}}^{\overline{v}} \Pi^{E**}\left(s^{**}(v)\right)\phi(v)\,dv + (1-\Phi(\overline{v}))\,\Pi^{E**}(\overline{s}) - (1-\Phi(\underline{v}))\,\Pi^{E**}(0) \geq K, \\ 0 & \text{otherwise;} \end{cases}$$

(ii) For $F \in [\underline{F}, \bar{F}]$,

$$d_a^*(F) = \begin{cases} 1 & \text{if } \int_{\tilde{v}}^{\overline{v}} \Pi^{E**}\left(s^{**}(v)\right)\phi(v)\,dv + (1-\Phi(\overline{v}))\,\Pi^{E**}(\overline{s}) \geq K, \\ 0 & \text{otherwise;} \end{cases}$$

(iii) For $F \in (\bar{F}, \infty)$, $d_a^*(F) = 0$.

Proof. Differentiating the objective function in the firm's application problem (24) with respect to d_a suggests that $d_a^*(F) = 1$ if and only if

$$\int_{-\infty}^{\infty} \Pi^{E*}\left(F, s^*(F,v)\right)_+ \phi(v)\,dv - K - \Pi^{E*}(F,0)_+ \geq 0, \tag{33}$$

and $d_a^*(F) = 0$ otherwise.

(i) If $F < \underline{F}$, Lemma 4 implies that $R^*(F,s) = R^{**}(s) > 0$ for all $s \in [0,\bar{s}]$ and the agency's subsidy rule $s^*(F,v)$ is given by part (i) of Lemma 5. Therefore the first term in the left-hand side of equation (33) can be written as

$$\int_{-\infty}^{\infty} \Pi^{E*}\left(F, s^*(F,v)\right)_+ \phi(v)\,dv = \Phi(\underline{v})\,\Pi^{E**}(F,0) + \int_{\underline{v}}^{\overline{v}} \Pi^{E**}\left(F, s^{**}(v)\right)\phi(v)\,dv + (1-\Phi(\overline{v}))\,\Pi^{E**}(F,\overline{s}).$$

As a result, equation (33) can be rewritten as

$$\int_{\underline{v}}^{\overline{v}} \Pi^{E**}\left(F, s^{**}(v)\right)\phi(v)\,dv + (1-\Phi(\overline{v}))\,\Pi^{E**}(F,\overline{s}) - (1-\Phi(\underline{v}))\,\Pi^{E**}(F,0) \geq K. \tag{34}$$

Thus, as claimed in part (i) of Lemma 6, for $F < \underline{F}$, $d_a^*(F) = 1$ if and only if the condition (34) holds and $d_a^*(F) = 0$ otherwise.

(ii) If $F \in [\underline{F}, \bar{F}]$, the firm invests only if it receives a subsidy. Therefore, in equation (33), $\Pi^{E*}(F,0)_+ = 0$. The agency's subsidy rule is given by part (ii) of Lemma 5. Thus the firm contemplating a subsidy application knows that if $v \geq \tilde{v}(F)$, the agency will award a sufficiently high subsidy rate to make the firm's investment profitable and that if $v < \tilde{v}(F)$, the firm will either receive no subsidy in which case the firm makes no investment nor profits, or it will receive subsidy $\tilde{s}(F)$ that just satisfies the firm's zero-profit constraint, which by definition also leads to zero profits. Therefore the application constraint (33) can be rewritten as

$$\int_{\tilde{v}}^{\overline{v}} \Pi^{E**}(F, s^{**}(v))\,\phi(v)\,dv + (1 - \Phi(\overline{v}))\,\Pi^{E**}(F, \bar{s}) \geq K. \tag{35}$$

The claim in part (ii) of Lemma 6 follows: For $F \in [\underline{F}, \bar{F}]$, $d_a^*(F) = 1$ if and only if the condition (35) holds and $d_a^*(F) = 0$ otherwise.

(iii) If $F > \bar{F}$,Lemmas 4 and 5 stipulate that the agency awards no subsidy and the firm does not invest (even if it received a maximum subsidy). Therefore, the firm makes no profits, and equation (33) becomes $-K \geq 0$ which does not hold. As a result, for $F > \bar{F}$, $d_a^*(F) = 0$. ■

Before establishing our main result, we shorten notation and write$R^*(F) = R^*(F, s^*(F, v, d_a^*(F)))$, $\pi^{I*}(F) = \pi^{I*}(F, s^*(F, v, d_a^*(F)))$ and $d_k^*(F) = d_k^*\left(F, s^*(F, v, d_a^*(F)), R^*(F), \pi^{I*}(F\right) = 1, k = f, m, p$;as the equilibrium R&D investment, repayment promise and, project funding, monitoring and choice decision, respectively. Recall also that $s^*(F, v) := s^*(F, v, 1)$. Using this notation, Proposition 1 summarizes Lemmas 1-6.

Proposition 1. In the unique equilibrium of $\Gamma(F)$, $\pi^{I*}(F) = [\rho\,(R^*(F) + F) - s^*(F, v, d_a^*(F))R^*(F)]\,/P$ and $s^*(F, v, 0) = 0$. Moreover, there are $\underline{F}$ and $\bar{F}$ with $0 \leq \underline{F} < \bar{F}$ such that

(i) for $F \in [0, \underline{F})$, $d_a^*(F) = 1$ if and only if $\int_{\underline{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\,\phi(v)\,dv + (1 - \Phi(\overline{v}))\,\Pi^{E**}(\bar{s}) - (1 - \Phi(\underline{v}))\,\Pi^{E**}(0) \geq K$ and $d_a^*(F)$ =0 otherwise, $s^*(F, v) = 0$ for $v < \underline{v}$, $s^*(F, v) = s^{**}(v)$ for $[\underline{v}, \bar{v}]$, and $s^*(F, v) = \bar{s}$ for $v > \bar{v}$, $R^*(F) = R^{**}(s^*(F, v, d_a^*(F)))$,and $d_k^*(F) = 1$,$k = f, m, p$;

(ii) for $F \in [\underline{F}, \bar{F}]$, if $\int_{\tilde{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\,\phi(v)\,dv + (1 - \Phi(\overline{v}))\,\Pi^{E**}(\bar{s}) \geq K$, then $d_a^*(F) = 1$ and $s^*(F, v) = R^*(F) = 0$ for $v < v^0(F)$ whereas for $v \geq v^0$, $R^*(F) = R^{**}(s^*(F, v))$, $d_k^*(F) = 1, k = f, m, p$ and $s^*(F, v) = \tilde{s}(F)$ for $v \in \left[v^0(F), \tilde{v}(F)\right)$,$s^*(F, v) = s^{**}(v)$ for $v \in [\tilde{v}(F), \bar{v}(F)]$and $s^*(F, v) = \bar{s}$ for $v > \bar{v}$, and if $\int_{\tilde{v}}^{\overline{v}} \Pi^{E**}(s^{**}(v))\,\phi(v)\,dv + (1 - \Phi(\overline{v}))\,\Pi^{E**}(\bar{s}) < K$, then $d_a^*(F) = R^*(F) = d_f^*(F) = 0.$;

(iii) for $F \in (\bar{F}, \infty)$, $d_a^*(F) = R^*(F) = d_f^*(F) = 0$.

Let us now discuss the consequences of Assumption 1. As shown by the proof of Lemma 4, the key role of Assumption 1 is to ensure that $\underline{F} \geq 0$. Suppose that Assumption 1 fails to hold so but a less stringent condition $\alpha/(\rho - \bar{s}) \geq e$ holds. Then we have $\underline{F} < 0 \leq \bar{F}$. In this case the firm invests only if it receives a subsidy. Part (i) of Proposition 1 no longer exists, but parts (ii) and (iii) are unchanged except that part (ii) exists now for $F \in [0, \bar{F}]$. If $\alpha/(\rho - \bar{s}) < 0$, then $\bar{F} < 0$,and part (iii) of Proposition 1 prevails for all $F \in [0, \infty)$.

Appendix D. Derivation of the firm's optimal R&D investment rule with an R&D tax credit.

We modify our theoretical model of section 3 by setting $s = 0$ and introducing instead a R&D tax credit rate $\tilde{\tau}_R \in [0, 1]$, which the firm receives whether or not it has corporate tax liability. In this case, we may rewrite the investor's payoff (2) as

$$\Pi^I(R, \pi^I) = (1 - \tau)\left[P\pi^I - (r + c)(R + F)\right]. \tag{36}$$

and the firm's payoff (3) as

$$\Pi^E(\tilde{\tau}_R, R, \pi^I) = (1 - \tau)\left[P\left(\pi(R) - \pi^I\right)\right] + \tilde{\tau}_R R. \tag{37}$$

As in section 3, we can seek a financing contract $\left(\pi^I, R\right) \in [0, \infty)^2$ that maximizes the firm's expected payoff. Thus, letting the investor's expected payoff from equation (36) to be equal to 0 and solving the resulting equation for π^I gives

$$\pi^{I*}(R) = \frac{\rho\,(R + F)}{P}. \tag{38}$$

After substitution of equations (1) and (38) for equation (37), the problem of seeking an optimal financing contract boils down to

$$\max_{R \in [0,\infty)} \Pi^E(\tau_R, R)_+ = (1 - \tau)\left[\alpha \ln R - (\rho - \tau_R) R - \rho F\right]_+. \tag{39}$$

In equation (39), $\tau_R = \tilde{\tau}_R / (1 - \tau)$ denotes the "adjusted" tax credit rate. Equation (39) corresponds to the firm's objective function (6) save for s being replaced by τ_R. Clearly the optimal R&D investment decision rule with an R&D tax credit must be identical to the one given by equations (7)-(8) with τ_R replacing s.

Note from equation (38) that the repayment promise is now independent of the R&D tax credit rate whereas in section 3 the repayment promise is contingent on the subsidy rate (see equation (5)). As equations ((3), (5), (37) and (38) show, now the firm claims the tax credit but has to promise a higher repayment to the investor than in section 3.

Appendix E: Counterfactual

Execution

For the counterfactual, we draw shocks (ε_{it}, ζ_{it} η_{it}, μ_{it}) from their estimated (joint) distribution. We replace those draws in the top 1% with the value at the 99^{th}%. We also remove from the calculations the top 0.02% of observations with the highest simulated mean R&D investments. We use 100 simulation rounds.

Robustness

In Tables E1 and E2 we present results from our counterfactual when 1) we estimate the model using as cost of finance the estimated cost of finance based on balance sheet information, 2) ignoring (soft) loans Tekes gives and only use subsidies as our measure of s_{it} and 2) excluding the largest 3 firms in the estimation sample. The loans Tekes are soft in two senses: first, the interest rate a firm has to pay is subsidized; second, in case the project fails, the firm may not need to pay the (whole) loan back. We report the means of the same objects reported in the main text.

Table E1. Counterfactual results from the robustness tests

Balance sheet based cost of finance	R&D participation	R&D ∣ R&D > 0	R&D	ratio (R&D)	profit	spillovers	welfare	ratio (welfare)
Laissez-faire	0.61	119 579	53 825	1	768 507	34 023	802 530	1
1^{st} best	0.63	278 492	128 046	2.38	725 403	82 875	821 264	1.02
2^{nd} best	0.61	266 438	124 606	2.32	728 572	79 397	820 956	1.02
Tax credits	0.62	186 563	85 054	1.58	795 997	53 771	807 921	1.01
Subsidies	0.61	196 043	85 276	1.58	788 751	55 970	802 905	1.00
No financial market imperfections	0.61	127 293	58 721	1.09	774 875	37 119	811 994	1.01
$s \mid s > 0$		484 753		1.50				
Only Tekes subsidies	**R&D participation**	**R&D ∣ R&D > 0**	**R&D**	**ratio (R&D)**	**profit**	**spillovers**	**welfare**	**ratio (welfare)**
Laissez-faire	0.62	177 494	93 613	1	1 071 675	56 106	1 127 781	1
1^{st} best	0.63	477 645	241 506	2.58	1 006 207	152 806	1 159 013	1.03
2^{nd} best	0.62	463 791	237 024	2.53	1 009 298	149 040	1 158 338	1.03
τ_R	0.63	281 237	150 497	1.61	1 117 539	90 199	1 137 305	1.01
s	0.62	234 441	121 442	1.30	1 079 765	74 050	1 119 216	0.99
No financial market imperfections	0.62	177 509	93 625	1.00	1 071 698	56 113	1 127 811	1.00
$s \mid s > 0$		483 026						
Excluding largest 3 firms	**R&D participation**	**R&D ∣ R&D > 0**	**R&D**	**ratio (R&D)**	**profit**	**spillovers**	**welfare**	**ratio (welfare)**
Laissez-faire	0.62	200 633	103 615	1	1 198 377	56 997	1 255 374	1
1^{st} best	0.63	490 711	239 880	2.32	1 142 516	140 979	1 283 495	1.02
2^{nd} best	0.62	475 261	235 682	2.27	1 145 333	137 527	1 282 860	1.02
Tax credits	0.63	295 412	154 354	1.49	1 241 097	84 928	1 263 048	1.01
Subsidies	0.62	255 250	127 601	1.23	1 205 536	71 470	1 247 116	0.99
No financial market imperfections	0.62	200 646	103 626	1.00	1 198 399	57 003	1 255 403	1.00
$s \mid s > 0$		459 925						

NOTES: the reported numbers are the means over all firms and simulation rounds for R&D participation, R&D investment, R&D conditional on a positive subsidy rate, profit, spillovers and welfare. Ratio (R&D) is the mean R&D in the regime in question divided by the laissez-faire mean R&D;

Table E2. Counterfactual estimates

variable	balance sheet based cost of finance	only Tekes subsidies	excluding 3 largest firms
$\Pr[apply]$	0.18	0.15	0.15
$subsidy\,rate \mid s > 0$	0.42	0.42	0.39
τ_R	0.41	0.39	0.34
Government cost, $s \mid s > 0 \,\&\, R\&D > 0$	84 796	59 146	56 937
Government cost, $\tau_R \mid R\&D > 0$	76 491	109 682	100 440
Government cost, s	34 846	28 833	24 908
Government cost, τ_R	34 872	58 694	52 480

NOTES: the figures are calculated over all simulation rounds and firms.

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