Welfare Effects of R&D Support Policies*

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Abstract

We conduct a welfare analysis of R&D subsidies and tax credits using a model of innovation policy incorporating externalities, R&D participation and financial frictions, taking the model to Finnish R&D project-level data. Subsidies and tax credits increase R&D by 30–50% relative to laissez-faire, primarily through the intensive rather than the extensive margin. Tax credits increase welfare 0.6% whereas subsidies reduce welfare 0.7% once application costs are accounted for. However, tax credits cost the government 90% more than subsidies, and limiting the fiscal cost of tax credits significantly reduces their welfare benefits. Financial frictions do not matter.

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

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1 Introduction

R&D subsidies and tax credits are widely used to encourage private sector R&D: E.g., OECD countries spend more than $50 billion on them annually.[1] Both policies aim at stimulating R&D by reducing its cost for firms, but they operate differently: Subsidies are discretionary, project-specific R&D cost reductions after a costly application and selection process, whereas a tax credit policy is a commitment to a uniform R&D cost-reduction rule. We develop and apply a framework to compare the impacts of R&D subsidies, tax credits, and several benchmark policies: Laissez-faire, removal of financial frictions, and first and second best. We assess the impacts of the policies at the intensive and extensive margins of R&D on profits, spillovers, direct cost to government and, ultimately, welfare.

Public support for private R&D is traditionally justified by appropriability problems and financial frictions: Firms may under-invest because R&D outputs are non-rival and hard to appropriate, and because R&D is opaque and relies on non-collateralizable human capital, making its external financing costly. These arguments trace back at least to Arrow (1962) and are detailed, e.g., in Hall and Lerner (2010) and Bloom, Van Reenen, and Williams (2019). Government innovation policy officials often add the objective to entice non-R&D-performing firms to start R&D.[2] This objective may also be justified: Corporate innovation and sources of productivity growth appear to become increasingly concentrated to incumbent firms

[1] We multiply business R&D measured in 2010 US$ (adjusted by PPP) by the percentage of government financed R&D. Data source: `https://www.oecd.org/en/data/datasets/main-science-and-technology-indicators.html`, accessed 29.12.2023.

[2] E.g., the Finnish R&D subsidy organization provides specific funding for firms to start R&D (`https://www.businessfinland.fi/en/for-finnish-customers/services/funding/tempo-funding`, accessed 6.4.2025).

(e.g., Garcia-Macia, Hsieh, and Klenow, 2019, Bessen and Wang, 2024, and Akcigit and Goldschlag, 2025), which may be a suboptimal way to organize innovation across firms (Cohen, 2010, and Akcigit and Kerr, 2018).

We build a dynamic model of the subsidy application and allocation process that incorporates all three rationales for public support to private R&D. Using revealed preference, we identify the structural parameters by estimating four key decisions: The firm's project level R&D investment yields information on the marginal profitability of R&D and the cost of external finance; the R&D participation decision allows us to identify the fixed costs of R&D; the subsidy application decision is informative about the costs of applying; and 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. Incorporating the extensive margin is important both for evaluating the effects of R&D support policies and for replicating the stylized fact that many firms never invest in R&D; thus, various studies of the R&D support policies incorporate the extensive R&D margin (e.g., González, Jaumandreu, and Pazó, 2005, Arqué-Castells and Mohnen, 2015, Peters et al., 2017, OECD, 2020, and Dechezleprêtre et al., 2023).

We take the model to detailed R&D project-level data from Finland where the ratio of R&D to GDP is among the highest. In the early 1980s, a government agency (Tekes) was established to provide R&D subsidies to firms, and other public financial support to R&D were abolished.[3] We use the large variation in government subsidy decisions - Figure 1 displays the distribution of the project-level fraction of R&D cost covered by the

[3]Finland's highly regarded (Veen et al., 2012) R&D subsidy regime is comparable to, e.g., Belgium's Germany's, the Netherlands' and to the US SBIR programs. Tekes became a part of a larger government organization, Business Finland, in 2018.

government among all applicants - that most studies ignore.

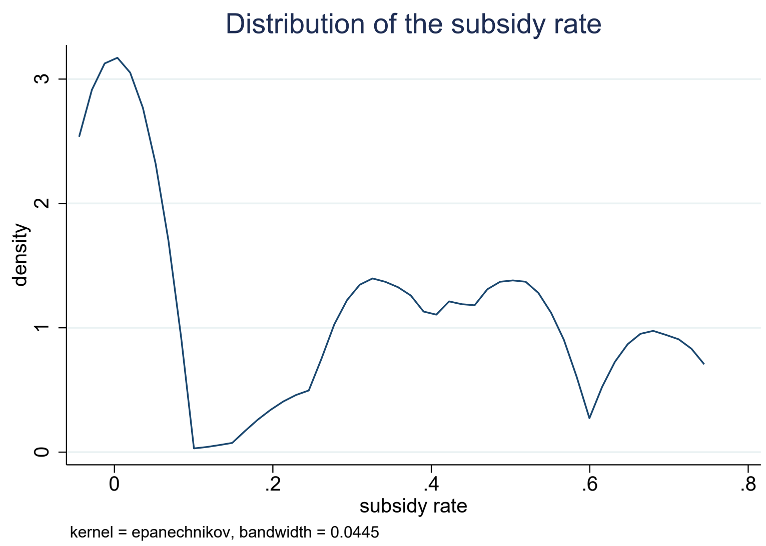

Figure 1. Distribution of the subsidy rate

In our welfare analysis, we compare R&D subsidies with an optimal R&D tax credit policy. R&D subsidies can be tailored but only for projects that undergo the costly application and selection process revealing information about the expected externalities of those projects. In contrast, R&D tax credits can potentially reach a much larger share of the firm population at the cost of being "one-size-fits-all". The large variation in subsidy rates displayed in Figure 1 suggests heterogeneity in spillovers and therefore a need for tailoring; simultaneously, the low fraction of (even R&D performing) firms applying for and being granted subsidies in our data suggests that the application process severely restricts the reach of policy.

We find that first and second best increase welfare by 2.2%, tax credits by 0.6%, but subsidies slightly (0.7%) reduce welfare once firms' application costs are accounted for. The costs and uncertainty associated with the subsidy application process not only limit the reach of subsidy policy but also make it inefficient: The right firms from the welfare perspective do not always apply. Moreover, being discretionary, the subsidy policy fails to internalize its effects on application costs. The optimal tax credit rate is 34%. Due to their substantially larger reach, tax credits cost the government 89% more than subsidies. However, we also find that capping the total spending on tax credits and the maximum amount each firm can claim, nearly eliminates the welfare benefits of the policy.

Conditional on investing, R&D subsidy and tax credit policies increase R&D investments by 29–47% relative to the laissez-faire regime. In contrast, subsidies hardly affect R&D participation, and tax credits increase it by 1.0%. The difference between the policies shows up when compared with the first best regime: R&D subsidies achieve close to the first best investment level but only for those firms that receive them, whereas tax credits achieve close to first best R&D participation.

We estimate the value of spillovers to be 58 cents per euro of R&D. Although the differences in spillovers across the policy regimes are similar to the differences in the R&D investments, profit differences are smaller: Tax credits increase the total corporate profits by 3.6% and subsidies by 0.7%. Profits turn out to be the main element of welfare. An explanation for spillovers being low relative to profits is that a significant fraction of positive externalities generated by Finnish R&D such as technological spillovers and consumer surplus are likely flowing outside Finland, and should be ignored by a Finnish agency, whereas the agency should internalize many negative R&D externalities such as cost duplication and business stealing.

Our theoretical analysis shows that financial frictions justify larger support but only if fixed costs of R&D and spillovers are in the intermediate range, implying that the existence of financial frictions alone cannot justify support. Otherwise, larger financial frictions have either no or a strictly *negative* impact on the optimal subsidy rate. Moreover, estimated financial frictions are small and hardly affect counterfactual outcomes. Thus, our results support the view (advanced, e.g., by Bloom, Van Reenen, and Williams, 2019) that the existence of financial frictions is not necessarily a reason to subsidize R&D and hence contrast with the emphasis of financial frictions in motivating R&D support (e.g., Bronzini and Iachini, 2014, Howell, 2017, OECD, 2020, and Dechezleprêtre et al., 2023).

Our robustness analyses suggest that welfare in the R&D subsidy and tax credit regimes would match laissez-faire only if average R&D subsidy application costs fell by 95% and 89% of R&D-performing firms failed to claim R&D tax credits. Thus, our welfare ranking of the policies should be robust to over-estimating application costs and the take-up of tax credits. Moreover, although some of our welfare interpretations rest on the assumption that the Finnish agency seeks to maximize domestic welfare, our framework enables a consistent comparison of different policy regimes from the agency's perspective, regardless of its actual objectives. For example, if agency idiosyncrasies or favoritism influenced its decisions, our approach would hold the effects of such factors constant across regimes. Hence, they would not affect the welfare ranking of the regimes or other quantitative outcomes such R&D participation and investment, though the interpretation of results related to spillovers could differ.

We believe to be the first to build and estimate a microeconomic model of innovation policy in which R&D externalities, financial frictions, and fixed cost of R&D simultaneously affect government support, R&D investment levels, and R&D participation. The extensive empirical literature on the effects of R&D support policies has focused on the causal effect of a policy on some outcome variable (e.g., on private R&D) rather than welfare.[4] Nor do the existing models provide a solid foundation for a welfare analysis: E.g., our own previous work (Takalo, Tanayama, and Toivanen, 2013a, hereafter TTT) assumes, despite evidence to the contrary, perfect R&D participation and financial markets. In addition to allowing for the extensive R&D margin and financial frictions, we differ from TTT (2013a) in that our main contribution is a counterfactual analysis of different R&D policies, which, e.g., requires modeling of corporate taxes and tax credits.

Precursors in the literature estimating structural models of innovation include, besides TTT (2013a), González, Jaumandreu, and Pazó (2005) who study R&D subsidies with the external margin, Doraszelski and Jaumandreu (2013) who focus on R&D and productivity, and Peters et al. (2017) who use a dynamic empirical model to uncover the fixed and sunk costs of R&D. Matcham and Schankerman (2023) develop and estimate a model of the patent application and screening process. Also relevant are Arqué-Castells and Mohnen (2015) who study the impact of fixed and sunk costs of R&D on the effectiveness of R&D subsidies, Boller, Moxnes, and Ulltveit-Moe (2015) who study the link between R&D, imports and exports, and Chen and Xu (2023), who estimate an industry equilibrium model with R&D spillovers. Kireyev (2020), Bhattacharya (2021), and Lemus and Marshall (2021) study innovation contests, with Bhattacharya's application being on government support.

[4] Surveys include García-Quevedo (2004), Cerulli (2010), and Zúñica-Vicente et al. (2014), recent contributions Bronzini and Iachini (2014), Einiö (2014), Howell (2017), Hünermund and Czarnitzki (2019), Dechezleprêtre et al. (2023), and Santoleri et al. (2024).

We study similar questions as Acemoğlu et al. (2018), Akcigit, Hanley, and Stantcheva (2022), and Akcigit, Ates, and Impullitti (2025). We differ from this macro-oriented literature in terms of data and modeling, but our welfare results and estimate of the optimal R&D tax credit are close to theirs. Our approach to identifying spillovers and social returns complements the one by Bloom, Schankerman, and Van Reenen (2013).

Next, we outline the Finnish institutional environment for R&D and our data. We explain our model in Section 3 and its estimation in Section 4. Sections 5 and 6 contain estimation results and the counterfactual experiments. Section 7 concludes.

2 Institutional Environment and Data

Institutional Environment

Finland transformed rapidly from a resource- to an innovation and knowledge-based economy at the end of the millennium (Trajtenberg, 2001). The R&D/GDP ratio in Finland doubled over the last two decades of the 20^{th} century and overtook that of the US (see Appendix A). The Finnish innovation policy hinges on direct R&D subsidies. During our observation period 2000-2008 there were no R&D tax credits. Tekes, where our subsidy data comes from, is the main public organization providing funding (grants and loans) for private R&D. Some other public organizations provide limited finance for innovative firms, but their funding is not specifically for R&D investments nor consist of subsidies.

During our observation period, Tekes's mission was to promote "*the development of industry and services by means of technology and innova-*

tions. 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, 2011). Moreover, Tekes emphasizes the domestic welfare effects of its funding.[5] Although alleviating innovative firms' financial frictions had traditionally been seen as one of Tekes's goals, access to finance was considered no major problem for the Finnish firms in the boom years preceding the global financial crisis (Hyytinen and Pajarinen, 2003, and Hyytinen, 2013). In 2012 Tekes's funding was circa 600M€, up from circa 400M€ in 2004 (see Appendix A). In its funding decisions, Tekes emphasizes small and medium sized enterprises (SMEs), but large companies may also obtain funding from Tekes. Tekes's 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's decision making in detail, one of us spent 11 months in Tekes. A funding application to Tekes describes an R&D project. After receiving the application, a team of experts reviews the proposed project and interviews the applicant's representatives, before grading it in several dimensions. 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, i.e., the share of the R&D expenses of the project that Tekes commits to reimburse. Tekes has detailed rules on eligible expenses which, e.g., exclude the costs of external finance. Tekes

[5]As an example, when some supported companies were sold abroad, a technology director of Tekes reassured the public that "*Our goal is that economic benefits [of our funding] remain in Finland*" (Flink, 2005).

also primarily reimburses variable R&D expenses such as wages because they are easy to allocate to projects. The minimum subsidy rate is zero, meaning that the application is rejected, and the maximum depends on the applicant's SME status, and is either 0.5, 0.6 or 0.7. Tekes has several safeguards against misreporting (e.g., subsidies are paid against receipts – see TTT, 2013a). The danger of misreporting should thus be much smaller than in some other environments (Boeing and Peters, 2024).

Data

Our data comes from two main sources: From Tekes, we obtain detailed data on all project level R&D subsidy applications for 2000-2008. These data include the applied amount of funding, internal screening outcomes, final funding decisions, 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 (see Appendix B for details).[6] Compared with TTT (2013a), our data cover a considerably longer time period and is richer, containing information, e.g., on the realized R&D expenditures and reimbursements at the project level for successful applicants, on firm level R&D also for firms not receiving subsidies and on funding from other sources.

Descriptive statistics in Table 1 show that applicant and non-applicant firms in our data are 14 and 17 years on average; their average number of employees are 121 and 101, and their average sales per employee 19

[6]We follow TTT (2013a) and randomly choose one application for those firms with more than one application in a given year and in calculating the subsidy rate as the sum of grants and subsidized loans divided by the planned R&D investment.

000€ and 22 000€ (normalized to 2005 euros). Of the applicant and non-applicant firms, respectively, 83% and 86% are SMEs, 19% and 13% are eligible for EU regional aid, and 83% and 59% invested in R&D in the preceding year. These differences between applicants and non-applicants are statistically significant. On average, 62% of the firms invest in R&D and 18% apply for subsidies.[7]

Table 1 also displays descriptive statistics for successful and rejected applicants; here the differences are statistically insignificant, except for the differences in R&D investment and past subsidy application behavior. The average subsidy rate of successful applicants is 0.35, and their average actual R&D investment over the (max. 3 years) lifetime of a project is 483 000€. As 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 tails. Using the modified grades, the average technological challenge and commercial risk are 2.08 and 2.31.

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 frictions at a firm level (Farre-Mensa and Ljungqvist, 2016) and attempts to measure financial frictions at a project level are rare. Evidence (Lian and Ma, 2021), however, suggests that lenders pay particular attention to borrowers' cashflow, and our Tekes-data contains unique information

[7]Potential explanations for the small number of subsidy applications include non-trivial application and fixed R&D costs, and firms' lack of R&D ideas. Tekes was well known by the 2000s, so lack of awareness is an unlikely explanation.

about a successful applicant's cashflow pledgeable to the proposed project. In Section 4, we use the ratio of pledgeable cashflow to the planned R&D project size to construct a measure of an external finance premium faced by a firm. The mean ratio for all successful applicants and for those successful applicants with no R&D in the previous year are 1.12 and 1.16. This ratio is less than one for 38% of the successful applicants.

3 Model of a Subsidy Policy

We extend the model of TTT (2013a) by introducing R&D tax credits with corporate taxation, financial frictions, and the extensive margin of R&D.[8] These features are critical for a welfare evaluation of R&D support policies. We outline the model and discuss the main arguments in the body of the article relegating technical details into Appendix C. We connect the model variables to both observable explanatory variables and unobserved structural shocks in Section 4.

Model Structure and Timing

We consider interactions among a public *agency* allocating R&D subsidies, a positive measure of *firms* with access to R&D projects but without liquid assets, and a finite number of competitive private sector *investors* with access to liquid funds. Investors can be equity investors (e.g., venture capitalists) or debt investors (e.g., banks). All agents are risk neutral and there is no time preference. Each firm can invest a *fixed cost* $F \in [0, \infty)$ and a *variable cost* $R \in (0, \infty)$ to undertake an R&D project, but they first

[8] The extensive margin is also included in TTT (2013b), but that model has not been estimated.

need need to raise outside funding from public and private sectors.

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	0.000	0.000	0.000	0.273	0.259	0.340	0.00	0.00	0.00	0.346	0.245	0.350
$R\&D_{actual}$	.	.	.	.	.	.	.	.	.	483 352	871 969	181 601
$1[R\&D]_t$	0.550	0.498	1.000	0.952	0.214	1.000	0.783	0.412	1.000	0.997	0.051	1.000
tech	.	.	.	2.082	0.786	2.000	1.710	0.791	2.000	2.166	0.761	2.000
risk	.	.	.	2.307	0.827	2.000	2.259	0.927	2.000	2.318	0.803	2.000
prev applicant	0.132	0.339	0.000	0.224	0.417	0.000	0.181	0.385	0.000	0.235	0.424	0.000
$1[R\&D]_{t-1}$	0.592	0.491	1.000	0.829	0.377	1.000	0.813	0.390	1.000	0.833	0.373	1.000
SME	0.860	0.347	1.000	0.830	0.375	1.000	0.833	0.373	1.000	0.829	0.376	1.000
age	17.394	13.204	14.000	14.105	11.117	11.000	13.915	11.066	11.000	14.156	11.132	11.000
#empl.	100.553	187.851	35.700	120.750	238.703	26.000	115.057	226.277	26.700	122.280	241.945	25.950
sales/empl.	0.222	0.313	0.126	0.189	0.291	0.109	0.201	0.342	0.100	0.185	0.276	0.112
region	0.126	0.332	0.000	0.185	0.389	0.000	0.174	0.379	0.000	0.188	0.391	0.000
cfratio	.	.	.	.	.	.	.	.	.	1.123	0.706	1.000
$cfratio \vert 1[R\&D]_{t-1} = 0$	.	.	.	.	.	.	.	.	.	1.159	0.707	1.000
#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 commercial *risk* of the project as evaluated by the agency, on a 1-3 Likert scale.
#Observations for *tech* and *risk* : 369 and 367 unsuccessful applicants; 1 634 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.

The dynamic game among the agents proceeds in five stages. The first two stages describe the public funding of R&D.

Stage 1: Firms' subsidy application decisions. Each firm chooses whether to incur a fixed *application cost* $K \in [0, \infty)$ to apply for a subsidy.

Stage 2: Public sector R&D funding decisions. If a firm filed an application, the agency learns the type of the firm's project, in particular its (expected) *spillover rate*, which is a continuous random variable V whose realization $v \in \mathbb{R}$ is drawn from a cumulative distribution function $\Phi(v)$ with a density function $\phi(v)$. The spillover rate reflects the agency's overall evaluation of positive and negative welfare externalities (e.g., consumer surplus, technological spillovers, business stealing, cost duplication, effects on environment and national defense) that will arise from the firm's project. For simplicity, we follow the tradition dating at least back to Ruff (1969) which postulates total spillovers to be proportional to R&D investments (see Amir, 2000 for justification); thus, total spillovers arising from the project are vR. After learning the project type, the agency decides on the *subsidy rate* $s \in [0, \bar{s}], \bar{s} < 1$, which is the agency's commitment to reimburse a share of the firm's variable R&D expenses R.

The government encounters a *shadow cost of public funds*, $g \in [1, \infty)$, when financing the private sector R&D. The government also levies a *corporate tax rate* $\tau \in [0, 1]$ on the net profits of firms and investors. Because we only introduce corporate taxation to allow for a welfare comparison of R&D tax credits with R&D subsidies, we ensure that corporate taxation affects R&D investments only via R&D tax credit rate (see Appendices C and D for details). In Section 6, we replace stages 1 and 2 by the agency's choice of an R&D tax credit rate, whereas we keep the rest of the game intact.

Stages 3 and 4 describe the private sector funding of R&D. Here we build on Holmström and Tirole (1997) in which financial frictions arise from the firm's inability to pledge its cashflow fully to outside investors.

Stage 3: Private sector R&D funding decisions. Investors have access to unlimited supply of funds at a gross *interest rate* $r \in [1, \infty)$, which reflects a central bank's policy rate (cf. Ma and Zimmermann, 2023). Investors decide whether to provide funding. If an investor extends funding for a firm, she chooses whether to stay at arm's length, or to become engaged by incurring a *monitoring cost* $c \in [0, \infty)$ that is proportional to the amount of funding. The firm and its investor sign a financing contract that stipulates the amount of funding and its cost.

Stage 4: Firms' project choices. If provided with funding, the firm chooses the project in which to invest. If the investor stays at arm's length, the firm can choose between two projects: A good project pays $A \ln R$, in which $A \in (0, \infty)$, with probability $P \in (0, 1)$ and 0 otherwise.[9] A bad project fails with probability one but yields large non-verifiable private benefits for the firm's decision maker – see Appendix C for details. By monitoring, the investor can prevent the firm from choosing the bad project. Thus, the parameter c reflects the costs incurred by external R&D financiers in tackling the (moral hazard) causes of financial frictions; in frictionless markets, $c = 0$.

Stage 5: Return realization and sharing. The agency disburses subsidies, project returns are realized, and firms and investors settle claims

[9] We employ the logarithmic R&D technology to obtain our econometric model. We have also experimented with the good project paying, in the case of success, $A(R^{1-\gamma} - 1)/(1-\gamma)$ in which $\gamma \in [0, \infty)$ – see also TTT (2013b).

according to the financing contracts. Project successes are assumed to be *i.i.d.*; thus, there is no aggregate uncertainty.

Our assumptions imply that, in stage 1, firms are uncertain about the agency's subsidy rate decisions, and may decide (in line with data) to apply only to be rejected. It seems reasonable that potential applicants have no perfect ex ante knowledge of how the agency evaluates (welfare externalities arising from) their projects.[10,11] In our econometric implementation (see Section 4), v is a function of observable firm and project characteristics, so uncertainty relates to the unobservable component of v. Timing firms' project choices after investors' monitoring decisions in turn avoids the need of considering mixed strategies. Some other timing assumptions are inconsequential or stipulated by the institutional environment. For example, the Finnish agency is 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).

Equilibrium Analysis

We focus on the pure strategy perfect Bayesian equilibria in which all agents have rational prior beliefs and maximize their payoffs by using sequentially rational strategies that are consistent with their beliefs. We refer to a series of lemmas and other results in Appendix C for proofs of the claims. For notational simplicity, we drop all other exogenous variables except for F from arguments of payoff functions.

[10]This common (e.g., Aghion, Van Reenen, and Zingales, 2013) assumption from R&D subsidy programs with private project type (cf. Takalo and Tanayama, 2010, and Lach, Neeman, and Schankerman, 2021).

[11]Conversely, financiers (such as the agency) may have informational advantage over firms (as, e.g., in Manove, Padilla, and Pagano, 2001). In practice, informational advantages may be ambiguous.

R&D investment decisions and cost of external finance (Lemmas A1-A5). In equilibrium, if an investor extends funding, she monitors; otherwise, the firm would choose the bad project and the investor would get no return for her funding. Moreover, because investors behave competitively, the investor demands an expected rate of return that covers the cost of her participation. Thus, to participate in an R&D project of size $R+F$, the investor demands a repayment that equals $(r+c)(R+F)$ in expectation. As a result, the firm's expected payoff in stage 3 is given by

$$\Pi^E(F,s,R) = (1-\tau)[\alpha \ln R - (r+c-s)R - (r+c)F], \tag{1}$$

in which $\alpha := AP$ is a constant shifting the expected profitability of R&D. The terms in the square brackets are the expected gross return, and the total variable and fixed cost of the firm's R&D investment. At this stage, the subsidy rate s of the project is known and is positive only if both the firm applied for a subsidy and the agency granted one. The parameter c in equation (1) captures financial frictions, creating a wedge between the market rate of return (r) and that required by external investors of R&D ($r+c$).

The firm chooses $R \in (0,\infty)$ to maximize $\Pi^E(F,s,R)$ subject to the investor's participation constraint yielding the firm's optimal R&D investment decision as

$$R^*(s) = \begin{cases} \mathcal{R}(s) := \frac{\alpha}{r+c-s} = \arg\max_{R\in(0,\infty)} \Pi^E(F,s,R) & \text{if } \Pi^{E*}(F,s) \geq 0 \\ 0 & \text{if } \Pi^{E*}(F,s) < 0, \end{cases} \tag{2}$$

in which $\Pi^{E*}(F,s) := \Pi^E(F,s,\mathcal{R}(s))$ can be expressed after substitution of

$\alpha/(r+c-s)$ from equation (2) for R in equation (1) as

$$\Pi^{E*}(F,s) = (1-\tau)\left\{\alpha\left[\ln\left(\frac{\alpha}{r+c-s}\right)-1\right]-(r+c)\,F\right\}. \tag{3}$$

If $\Pi^{E*}(F,s) \geq 0$, the expected project return is sufficient to cover the costs of investor participation. Otherwise, the investor refuses to provide funding and no investment is made. Thus the constraint $\Pi^{E*}(F,s) \geq 0$ defines the firm's R&D participation and $\mathcal{R}(s)$ defined in equation (2) characterizes the intensive R&D margin.

Agency decision (Lemmas A5-A7). If the agency receives a subsidy application in stage 2, the agency observes the spillover rate v, and makes its subsidy allocation decision anticipating the firm's and investor's behaviors in the later stages. The agency's expected payoff from the firm's proposed project is given by

$$U(F,v,s) := U(F,v,s,\mathcal{R}(s)) = (v-gs)\mathcal{R}(s) + \frac{\Pi^{E*}(F,s)}{1-\tau}. \tag{4}$$

The first term on the right-hand side of equation (4) captures the externalities arising from the firm's R&D project: Total spillovers ($v\mathcal{R}(s)$) and, to the extent the agency subsidizes the project, total shadow costs of public funds ($gs\mathcal{R}(s)$). The second term captures the firm's expected profit from the project. This profit is net of taxes because, for the agency, corporate tax payments are transfers and cancel out in a welfare calculation. As competition drives investors' profits to zero, they disappear from the agency's payoff. Nevertheless, the agency needs to take into account the constraint $\Pi^{E*}(F,s) \geq 0$ ensuring the investor's participation and its cost

$(r + c)$ affecting the level of R&D and the firm's profits.

The agency chooses $s \in [0, \bar{s}]$ to maximize $U(F, v, s)$ subject to the R&D participation constraint $\Pi^{E*}(F, s) \geq 0$. If the constraint is not satisfied, the agency's payoff is zero. From equation (3), we obtain two threshold values of the fixed R&D cost F, $0 < \underline{F} < \bar{F}$, which allow us to split the agency's problem into three parts: First, for high enough fixed R&D costs, $F > \bar{F}$, the agency cannot satisfy the R&D participation constraint: $\Pi^{E*}(F, s) < 0$ for all $s \in [0, \bar{s}]$. Anticipating that the firm would not invest even with the maximum subsidy rate, the agency awards no subsidy.

Second, for low enough fixed R&D costs, $F \leq \underline{F}$, $\Pi^{E*}(F, s) > 0$ for all $s \in [0, \bar{s}]$. In this case the firm will invest even without a subsidy, and the agency can ignore the R&D participation constraint in its subsidy decisions. Consequently, the agency's optimal behavior can be described by the mapping

$$s_N^*(v) = \begin{cases} \bar{s} & \text{if } v > \bar{v} := \underline{v} + \bar{s} \\ \mathcal{S}(v) := v - (r + c)(g - 1) & \text{if } v \in [\underline{v}, \bar{v}] \\ 0 & \text{if } v < \underline{v} := (r + c)(g - 1). \end{cases} \tag{5}$$

The subscript N denotes the case of a non-binding R&D participation constraint, and $\mathcal{S}(v)$ identifies for each realization $v \in \mathbb{R}$ a unique optimal subsidy rate when neither the R&D participation constraint nor the constraints 0 and $\bar{s}$ on the feasible subsidy rate bind. The thresholds $0 < \underline{v} < \bar{v}$ identify the spillover rates when the constraints 0 and $\bar{s}$ begin to bind.

Third, for intermediate levels of fixed R&D costs, $F \in (\underline{F}, \bar{F}]$, the agency scrutinizes a subsidy application from a firm facing a binding R&D participation constraint, but which the agency can overcome: The firm will invest only if it receives a sufficiently high, but still feasible, subsidy rate. The agency's optimal subsidy rule is given by the mapping

$$s_C^*(F,v) = \begin{cases} \bar{s} & \text{if } v < \bar{v} := \underline{v} + \bar{s} \\ \mathcal{S}(v) & \text{if } v \in [\tilde{v}(F), \bar{v}] \\ \tilde{s}(F) := r + c - \alpha e^{-\left[1+\frac{(r+c)F}{\alpha}\right]} & \text{if } v \in [v^0(F), \tilde{v}(F)) \\ 0 & \text{if } v < v^0(F), \end{cases} \tag{6}$$

in which the subscript C denotes the case of a (ex ante) binding R&D participation constraint, $\tilde{s}(F)$ is obtained from equation (3) as the unique subsidy rate satisfying $\Pi^{E*}(F, \tilde{s}) = 0$, and $v^0(F)$ and $\tilde{v}(F)$, with $0 \leq v^0(F) < \tilde{v}(F) \leq \bar{v}$, denote the (unique) values of v that satisfy the agency's participation constraint $U(F, v^0, \tilde{s}(F)) = 0$ and the condition $\mathcal{S}(\tilde{v}) = \tilde{s}(F)$ equalizing the optimal unconstrained and constrained subsidy rates. Equations (5) and (6) suggest that the agency awards the maximum subsidy rate $\bar{s}$ for sufficiently high spillover rates, the optimal unconstrained subsidy rate $\mathcal{S}(v)$ or the optimal constrained subsidy rate $\tilde{s}(F)$ for intermediate spillover rates, and rejects an application for sufficiently low spillover rates. The model thus predicts most of the mass points in Figure 1.

Application decision (Lemma A8). In stage 1 the firm contemplates a subsidy application. Having rational prior beliefs about the realization of V and anticipating the agency's and investor's behaviors in response to its application decision, the firm applies for a subsidy if and only if

$$\int_{-\infty}^{\infty} \max\{\Pi^{E*}\left(F, s^{*}\left(F, v\right)\right), 0\}\phi\left(v\right) dv - \max\{\Pi^{E*}\left(F, 0\right), 0\} - K \geq 0, \quad (7)$$

in which the agency's optimal subsidy rule is given by

$$s^{*}(F, v) = \begin{cases} s_{N}^{*}(v) & \text{if } F \leq \underline{F} \\ s_{C}^{*}(F, v) & \text{if } F \in \left(\underline{F}, \bar{F}\right] \\ 0 & \text{if } F > \bar{F}. \end{cases} \quad (8)$$

The first term on the left-hand side of inequality (7) captures the firm's expected payoff to applying for a subsidy. The term shows how the firm, when contemplating a subsidy application, takes expectation over all possible spillover rate evaluations and, consequently, all possible subsidy rate decisions of the agency in stage 2. The firm can then estimate, given the investor's behavior in stage 4, the investment levels resulting from those subsidy rates and, ultimately, its expected profits. The second term captures the firm's expected profits to investing without applying for a subsidy in which case the agency will not be called on to act: The Finnish law prevents Tekes from granting a subsidy without a formal, written application (see the Act on Discretionary Government Transfers 668/2001 §9 and the Government Decree on the Funding for Research, Development and Innovation Activities 1444/2014 §3). The max–operators in these two terms reflect the firm's option to invest in R&D only if doing so is profitable in expectation. The last term is the fixed application cost K.

In Lemma A8, we characterize the firm's application behavior for each of the three parameter ranges identified by the set of fixed R&D costs: No R&D participation constraint ($F \leq \underline{F}$); an R&D participation constraint that the agency can overcome ($F \in (\underline{F}, \bar{F}]$); and a prohibitive R&D participation constraint ($F > \bar{F}$).

Equilibrium. In Proposition A1 (in Appendix C) we show that for each $F \in [0, \infty)$ the game has a unique equilibrium, defined by the firm's R&D investment and subsidy application rules of equations (2), (3), and (7), and the agency's subsidy rules of equations (5), (6) and (8). This equilibrium admits a number of comparative static results. We focus on the effects of financial frictions on the agency's decisions.

Financial frictions and the optimal subsidy policy. R&D subsidies are often motivated by financial frictions, which lead to underinvestment in R&D (e.g, Bronzini and Iachini, 2014, Howell, 2017, OECD, 2020, and Dechezleprêtre et al., 2023). In our model, too, more severe financial frictions lead to underinvestment: At the extensive margin, an increase in financial frictions c makes violation of the R&D participation constraint $\Pi^{E*}(F, s) \geq 0$ more likely – see equation (3). Thus, some innovations are not created because the cost of external finance is too high, but which would be created if funding were available at the market interest rate r. At the intensive margin, the wedge between the firms' cost of funds and the market interest rate reduces R&D investment levels; equation (2) shows that the equilibrium R&D investment level $\mathcal{R}(s)$ is decreasing in c.

Nevertheless, our model also suggests (Proposition A2 in Appendix C) that underinvestment due to financial frictions justifies larger support only when both fixed costs and spillovers are at intermediate levels ($F \in (\underline{F}, \bar{F}]$ and $v \in [v^0(F), \tilde{v}(F))$). Then granting the subsidy rate $\tilde{s}$, which just overcomes the firm's R&D participation constraint, is optimal, and $\tilde{s}$ increases with c and is larger than the optimal unconstrained subsidy rate $\mathcal{S}$. Otherwise, a higher c has either no or a *negative* impact on the optimal subsidy rate. Moreover, because $\min\{v^0(F), \underline{v}\} > 0$, a positive spillover rate is a necessary condition for the agency to grant a subsidy irrespective of whether the R&D participation constraint is binding; thus, the existence of financial frictions alone cannot justify subsidies. Subsidies per se have no impact on financial frictions in our model and, from the agency's perspective, a higher c means a less efficient R&D technology.[12]

4 Econometric Implementation

We next describe the estimation and identification of the four key decision rules of the theoretical model: The intensive and extensive margins of R&D, the firm's decision to apply for a subsidy, and the agency's subsidy rate decision. The R&D investment level equation necessitates correcting for sample selection (the other main estimations do not). We also need auxiliary estimations to generate measures of financial frictions and the expected Tekes *tech* and *risk* grades when we do not observe them. We provide details of the estimation process, e.g., the order of estimation, a discussion of the auxiliary estimations and their results, in Appendix B.

We denote by $\mathbf{X}_{it}^l$ a vector of observable firm and project characteristics, and by β^l the associated parameters, in which the subscript i denotes a project (and a firm), the subscript t denotes the year and the superscript $l \in \{F, K, R, s\}$ refers to the estimation of interest. These vectors

[12] Lach, Neeman, and Schankerman (2021) characterize an optimal subsidy policy to overcome the R&D participation constraint. In Takalo and Tanayama (2010), the agency's subsidy decision in itself acts as certification, reducing financial frictions.

of observable characteristics contain at least the following variables: A 2^{nd} order polynomial in firm (log) age, (log) number of employees and sales per employee; dummies for a calendar year, an industry, an R&D investment in the previous year; and a dummy for eligibility for EU regional aid. All explanatory variables are lagged by one year.

The shocks of our four main estimation equations are structural and assumed to be normally distributed. All other shocks are assumed uncorrelated with each other but, as will be explained below, the shock to the private profitability of R&D (ε_{it}) can be correlated with the application cost shock (μ_{it}). All four shocks are unobserved by the econometrician; their observability by the agents follows the theoretical model. We bootstrap the whole estimation procedure to obtain standard errors.

R&D investment level and cost of external finance. We write the shifter of the expected profitability of R&D in equation (1) as

$$\alpha_{it} := e^{\mathbf{X}_{it}^R \beta^R + \varepsilon_{it}}. \tag{9}$$

in which ε_{it} is a random shock affecting the expected profitability of R&D project i in year t. This shock is observed by all three agents of the model.

From the first row of equation (2) we obtain an empirical counterpart for the firm's investment level as $\mathcal{R}_{it}(s_{it}) = \alpha_{it}/\left(r_t + c_{it} - s_{it}\right)$. Substituting equation (9) for α_{it} and taking logs of both sides yield

$$\ln \mathcal{R}_{it}(s_{it}) = \mathbf{X}_{it}^R \beta^R - \ln(r_t - s_{it} + c_{it}) + \varepsilon_{it}, \tag{10}$$

which is our estimation equation for the level of a firm's R&D investment, conditional on the firm launching a project. The coefficient of the term

$\ln(r_t - s_{it} + c_{it})$ is unity. By this stage, s_{it} is known, and we use the one year Euribor rate to measure r_t, the investors' cost of raising funds.

Identifying the project-specific financial frictions c_{it} is less straightforward. We assume that

$$c_{it} = \begin{cases} e^{(\ln cf_{99} - \ln cf_{it})\beta^c} & \text{if } cf_{it} < cf_{99} \\ 0 & \text{if } cf_{it} \geq cf_{99}, \end{cases} \tag{11}$$

in which cf_{99}/cf_{it} measures a *cashflow gap* of project i in year t. Here cf_{it} is the ratio of the project's pledgeable cashflow to its size, directly obtained from Tekes's data and cf_{99} is the 99^{th} percentile of the distribution of cf_{it}. Equation (11) implies that c_{it} is a decreasing function of the cashflow ratio up to a threshold and zero above it. Variation in cf_{99}/cf_{it} allows us to identify $\hat{\beta}^c$.

The idea is, in line with Holmström and Tirole (1997) and Lian and Ma (2021), that a project in which a firm has more skin in the game requires less monitoring. The advantage of our cashflow-gap measure is that it, uniquely to our understanding, is measured at the project as opposed to firm level. We consider this approach to measure financial frictions at the project level worthwhile given the lack of a consensus on how to measure them at the firm level (Farre-Mensa and Ljungqvist, 2016), even if this measure, too, is imperfect. We use the cost of external funding estimated from balance sheet data as an alternative measure of c_{it} in Appendix E.

Whereas the profitability shock ε_{it} is unrelated to all other shocks, we allow it to be correlated with the subsidy application cost shock μ_{it} (see equation (16)). Because the application cost shock affects the probability of applying and we only observe the realized R&D for subsidized projects, we face a sample selection problem regarding our R&D investment equation. To tackle this challenge, we estimate a two-stage selection model exploiting exogenous variation from a firm's SME status. In the EU, the SME status of a firm is a deterministic function of its sales, balance sheet and employment. Under EU rules (Recommendation 2003/361EC), SMEs are eligible for subsidy rates up to 10 percentage points higher. The exclusion restriction is that, conditional on firm size and other controls, the administratively determined SME status does not directly affect the profitability of R&D investment. Thus, SME status influences the likelihood of applying for and receiving a subsidy but should have no direct impact on R&D investment beyond this channel.

In the first stage, we estimate a probit model where the outcome equals 1, if the project-level R&D investment of firm i in year t is observed and 0 otherwise. We estimate this model separately for SMEs and non-SMEs – effectively interacting the SME-dummy with all explanatory variables. An LR-test strongly rejects the equality of the SME and non-SME coefficient vectors, indicating that SME status significantly affects the probability of observing an R&D investment. Using these estimates, we construct the inverse Mills ratio and include it in equation (10) to correct for sample selection bias. In the second stage, estimation of equation (10) (with equation (11) substituted in) with maximum likelihood yields $\hat{\beta}^R$, $\hat{\beta}^c$, and the variance of ε_{it} (σ_ε^2).

R&D participation. The fixed cost of launching project i is

$$F_{it} := e^{\mathbf{X}_{it}^F \beta^F + \zeta_{it}}, \tag{12}$$

in which ζ_{it} is a random shock to the fixed costs of project i in year t, observed by all agents of the model, and uncorrelated with all other shocks. We normalize the variance of ζ_{it} to one ($\sigma^2_\zeta = 1$). Using equations (2) and (3) we may express an empirical counterpart of the firm's R&D participation constraint as $\alpha_{it}\left[\ln\left(\alpha_{it}/\left(r_t + c_{it} - s_{it}\right)\right) - 1\right] \geq \left(r_t + c_{it}\right) F_{it}$. After substitution of equations (9) and (12) into this inequality, taking logs, and rearranging, we may rewrite the R&D participation constraint as an indicator function

$$\mathbf{1}_{[0,\infty)}\left(\ln\hat{\alpha}_{it} + \ln\left(\ln\left(\frac{e^{\mathbf{X}^R_{it}\hat{\beta}^R + \varepsilon_{it}}}{r_t + \hat{c}_{it} - s_{it}}\right) - 1\right)\right.$$
$$\left. - \ln\left(r_t + \hat{c}_{it}\right) - \mathbf{X}^F_{it}\beta^F - \zeta_{it}\right), \quad (13)$$

in which $\mathbf{X}^R_{it}$, $\mathbf{X}^F_{it}$, r_t and s_{it} are observed and $\hat{c}_{it}$ and $\hat{\beta}^R$ are obtained from the estimation of equation (10). The vector of parameters to be estimated is β^F. We have identifying variation as 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 (SML) because ε_{it} needs to be simulated (see Appendix B).

Agency decision. To derive an estimable equation for the agency's unconstrained optimal subsidy rate $\mathcal{S}(v)$ specified in equation (5), we define

$$v_{it} := \mathbf{X}^s_{it}\beta^s + \eta_{it}, \quad (14)$$

in which η_{it} is a random shock to the spillover rate of project i in year t, observed by the agency when evaluating an application in stage 2 of the game, but unobserved by the private sector in stage 1. Inserting equation

(14) together with the parameters r_t and $\hat{c}_{it}$ into $\mathcal{S}(v)$ of equation (5) gives

$$\mathcal{S}_{it} = \mathbf{X}_{it}^s \beta^s - (r_t + \hat{c}_{it})(g-1) + \eta_{it}. \tag{15}$$

To estimate equation (15), we set the shadow cost of public funds $g = 1.2$. Because our theoretical model suggests $\mathcal{S}_{it} > \max\{\tilde{s}_{it}, 0\}$, we use only those observed positive subsidy rates with $s_{it} > \hat{\tilde{s}}_{it}$ in which $\hat{\tilde{s}}_{it}$, an estimate of the optimal subsidy rate $\tilde{s}_{it}$ that just overcomes the firm's R&D participation constraint, is obtained by inserting equations (9) and (12), and the parameters r_t, $\hat{c}_{it}$, $\hat{\beta}^R$, and $\hat{\beta}^F$ into the definition of $\tilde{s}(F)$ of equation (6). Estimation of equation (15) by generalized two-limit Tobit provides us $\hat{\beta}^s$ and the variance of η_{it} (σ_η^2). The $\mathbf{X}_{it}^s$ vector includes the SME-dummy to accommodate the agency's priorities, and the agency's $tech_{it}$ and $risk_{it}$ grades.

Because η_{it} is assumed uncorrelated with all other shocks, including ε_{it}, the shock to the profitability of R&D, the agency decision rule is not subject to selection on unobservables. Equations (4), (10), and (14), however, show how spillovers generated by project i, $v_{it}R_{it}$, are a function of both η_{it} and ε_{it}. Thus, whereas the shock to spillovers per euro of R&D investment is uncorrelated with the shock to the private value of the R&D idea, spillovers and profits are correlated: Privately more lucrative projects create larger spillovers in absolute but not relative terms.

Having identified the parameters of equations (4), (5), and (6), we can 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.

Application decision. We specify the application costs as

$$K_{it} := e^{\mathbf{X}_{it}^K \beta^K + \mu_{it}}, \tag{16}$$

in which $\mu_{it} := \xi\varepsilon_{it} + \mu_{0it}$ is a random shock to the application costs of project i in year t and μ_{0it} is independent of the other shocks. Thus, the application cost shock μ_{it} and the profitability shock ε_{it} can be correlated, with ξ being a measure of their covariation. The sign of ξ provides information on whether and how firms with higher profitability shocks have systematically different application costs. We normalize the variance of μ_{0it} to one ($\sigma^2_{\mu_0} = 1$). The application cost shock μ_{it} is observed by the firm, but it is inconsequential whether it is observed by the agency and investors; it suffice that the agency and the investors observe the outcome of the firm's application decision.

We estimate the firm's application decision (the inequality (7)) by SML. For each simulation draw, we numerically integrate the expected discounted profits from applying (the LHS of the inequality (7) with equation (16) substituted for the costs of applying). We use all the parameters estimated in the prior estimation stages. To calculate the expected benefits from applying, we take into account the agency's grading of each subsidy application (see Appendix B). Identifying variation comes from several 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, we allow the firm's past application behavior to affect the application costs but assume it has no direct impact on the fixed cost of R&D nor on the subsidy rate. Finally, the coefficient ξ of the profitability shock ε_{it} in μ_{it} is identified from the effects of R&D (ε_{it}) on the probability of applying that are not captured by the R&D (ε_{it}) -induced (expected) profit increase from getting a subsidy as opposed to investing without one.

5 Estimation Results

We collect into Table 2 the coefficients from all main estimation equations and relegate the results of the auxiliary estimations into Appendix B.

R&D investment level and cost of external finance. Column 1 of Table 2 displays the estimated coefficients of the intensive margin R&D equation (10). These coefficients measure how firm characteristics affect the marginal profitability of R&D. Firm age, size and productivity (measured by sales per employee) affect R&D nonlinearly. 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 inverse 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.

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)
$\ln age2$	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)
$\ln emp2$	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)
$sales/emp2$	-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)			
SME	-	-	-0.0045	
			(0.0125)	
$risk$	-	-	0.0104***	
			(0.0037)	
$tech$	-	-	0.0062	
			(0.0045)	
$prev\ applicant$	-	-	-	-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

The unreported coefficient estimates 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 $\ln cashflowgap$ (0.95) implies a roughly 1:1 relation between monitoring costs and the gap: The lower is the firm's cashflow-to-investment ratio, the higher its idiosyncratic component in its cost of external finance. The estimated mean cost of external finance $(r_t + c_{it} - 1)$ is 0.04 (p-value 0.00), supporting the evidence suggesting that access to finance was not a major problem during our observation period.

R&D participation. In column 2 we report the coefficients from the estimation of the extensive margin R&D equation (13). The results provide information about the determinants of the fixed costs of R&D, helping to understand the selection into R&D in terms of observable characteristics. The fixed costs of R&D are a nonlinear function of the number of employees and productivity. Exporters and firms in the less-developed regions have lower fixed costs. In line with Arqué-Castells and Mohnen (2015) and Peters et al. (2017), past R&D reduces the fixed R&D cost. The omitted results regarding year and industry dummies suggest that fixed costs are higher in the first two years and vary over industries.

Agency decision. Column 3 shows the estimated coefficients of the agency decision equation (15) which measure the impact of a given covariate on the subsidy rate and the spillovers per euro of R&D. We find sales per employee to have a nonlinear impact on the subsidy rate. Firms with no R&D in the previous year get a 1.6 percentage points higher subsidy rate (significant at 10% level). Our results suggest that SMEs obtain no higher subsidy rates on average, despite the higher maximum subsidy rate allowed for SMEs. Tekes's 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 evidence that Tekes targeted subsidies to any particular industry. The estimated mean spillover 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. Firm size affects positively and productivity non-linearly the cost of application. Exporters and past applicants face lower application costs, as do firms investing in R&D in the previous year and firms in less developed regions. The shock to application costs is 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. Table 3 shows the simulated fixed costs of R&D (F_{it}) and application costs (K_{it}). As is the case with discrete choice models, these costs are estimated more accurately for those firms that invest or apply for subsidies than for those that do not. Whereas the simulated mean fixed R&D cost is 1.2M€, the median is only 105 000€. Almost 40% of firms 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. The mean application cost may also seem high at 112 000€, but is explained by the long right tail: In the data, only 18% of firms apply. Application costs are lower than 1 800€ for 10% of firms.

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.

6 Counterfactual Analysis

Policies

Optimal R&D tax credit. As an alternative to the actual R&D subsidy policy, we consider an optimal R&D tax credit policy. For this purpose, we make two modifications: 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 is motivated by the tax credit regime in several countries (e.g., Belgium and the UK) where even loss-making firms can claim it: In the case of insufficient tax liability, 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 only variable R&D costs are subject to the tax credit. Until our discussion of robustness tests we also assume that all R&D performing firms 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 (2) and (3) with τ_R replacing s (see Appendix D). The agency's project-specific expected payoff with an R&D tax credit can be obtained by replacing s by τ_R in $U^*(F, v, s)$ specified in equation (4). After substituting the empirical counterparts for the other variables in $U^*(F, v, \tau_R)$, we write the agency's R&D tax credit problem as

$$\max_{\tau_R \in [0,1]} \sum_{i=1}^{\mathcal{N}} \iiint U^*(\varepsilon_i, \zeta_i, \eta_i, \tau_R)\phi(\varepsilon_i, \zeta_i, \eta_i) d\varepsilon_i d\zeta_i d\eta_i, \tag{17}$$

in which $\mathcal{N}$ is the total number of potential R&D projects in the economy and $\phi(\varepsilon_i, \zeta_i, \eta_i)$ is the joint distribution of the profit, fixed cost, and spillover rate shocks to project i. To determine the optimal R&D tax credit 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 shocks 100 times from their estimated distributions.

Whereas subsidies and tax credits have similar marginal impacts on the firms' R&D cost, they have major welfare differences. The maximization problems (4) and (17) illustrate the main welfare advantage of subsidies over tax credits: The marginal effect of tax credit on R&D is invariant across projects whereas a subsidy policy enables project-specific treatment. The subsidy application and examination processes, however, limit and may bias 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 $\sum_{i=1}^{\mathcal{N}} U^*(\varepsilon_i, \zeta_i, \eta_i, \tau_R^*)$ but the aggregate realized welfare under the optimal subsidy policy is $\sum_{i=1}^{\mathcal{N}_A}[U^*(\varepsilon_i, \zeta_i, \eta_i, s_i^*) - K_i] + \sum_{i=\mathcal{N}_A+1}^{N} U^*(\varepsilon_i, \zeta_i, \eta_i, 0)$ in which $\mathcal{N}_A \subseteq N$ is the number of applications. If $\mathcal{N}_A$ is small relative to $\mathcal{N}$, as is the case in our data, the subsidy policy can hardly generate large economy-wide effects.

Benchmarks. As benchmarks, we consider a laissez-faire economy without government interventions and a first-best policy where the social planner forces the firms to invest the desired amount in each project. As the first best investment level may render the private sector entities' joint surplus negative, we also consider the second-best (Ramsey) policy where the agency chooses the optimal level of R&D investment subject to the private sector's zero profit constraint. In these scenarios, R&D is financed at the cost of private R&D funding. To study the role of financial frictions, we also consider a laissez-faire regime in which the external finance premium c_{it} is zero for all projects. As a result, firms encounter no financial frictions, because they can flexibly raise funding at the market interest rate.

Results

We compare R&D participation, R&D investment levels, spillovers, profits and welfare across the different policy regimes. The reported means and medians are calculated over all firms and simulation draws (see Appendix E). 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 perform R&D in various policy regimes. The results suggest pervasive non-investment: 37–38% of firms fail to invest in all regimes. First-best, R&D tax credits and R&D subsidies increase R&D participation by 2.1%, 1.0% and 0.2% from laissez-faire. The estimated cost of financial frictions is small, so its removal has little effects on R&D participation. For subsidies to influence R&D participation, firms must apply, the agency must approve, and the approval must affect participation. These conditions simultaneously hold only for a few firms. For R&D tax credits, the first two are assumed to hold, but the third is weaker, as tax credits cannot be tailored to address participation constraints. Moreover, although subsidies and tax credits reduce the marginal cost of R&D and thereby make initiating R&D more attractive, the convexity of firms' profit function limits this effect. Because even in the first best world close to 40% of the firms perform no R&D, the key obstacle in improving R&D participation appears to be the quality of firms' R&D ideas rather than the inability to tailor the support without a costly application and selection process.

The results concerning tax credits are in line with Peters et al. (2017) and Dechezleprêtre et al. (2023) who find small effects of R&D tax credits at the extensive margin. On the other hand, our results suggest that tax credits achieve closer to the first best participation than subsidies, emphasizing the reach of the tax credit policy. The composition of firms investing under the one-size-fits-all tax credit policy is nonetheless likely to be inefficient: E.g., the first best may include projects with positive spillovers but negative private sector surplus which are excluded from the tax credit and laissez-faire regimes, and vice versa for the projects with positive private sector surplus but negative spillovers.

Table 4. R&D participation

Regime	mean	median	ratio
Benchmark regimes			
Laissez-faire	0.621	0.770	1.000
1^{st} best	0.634	0.780	1.021
2^{nd} best	0.621	0.770	1.000
No financial frictions	0.621	0.770	1.000
Policies of interest			
Tax credits	0.627	0.770	1.010
Subsidies	0.622	0.770	1.002

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.

R&D investment level. Table 5 shows large differences across policy regimes at the intensive margin, again in line with Peters et al. (2017) and Dechezleprêtre et al. (2023). The mean R&D investment under laissez-faire, conditional on investing (left panel), is 197 000€ per project but about 2.4 times higher under the first and second best policies. R&D subsidies and tax credits induce roughly 29–47% higher average R&D investments than laissez-faire. The R&D tax credit regime generates a somewhat higher mean investment than the subsidy regime (289 000€ versus 253 000€). The mean R&D investment of successful applicants (last row, left panel) is, however, substantially higher than investments under R&D tax credits and is close to the first best level, emphasizing the project-specificity of the subsidy policy. Financial frictions hardly affect R&D investments.

To compare the R&D intensities in different scenarios taking both the extensive and intensive margins into account, we report the unconditional means in the right panel. Given the small differences across policies in the probability to invest in R&D (Table 4), the rankings and ratios in the right panel are close to those in the left panel. R&D tax credits have a larger relative effect than subsidies when we account for the extensive margin. The R&D distribution is right-skewed: We plot the distribution from one simulation round of the counterfactual analysis across policy regimes in Figure 6. The first and second best, and R&D support policies shift the R&D distribution to the right.[13]

[13]The differences between some policy regimes are increasing in project size. In contrast, for the R&D tax credit the difference to laissez-faire is 41-44% irrespective of the measurement point.

Table 5. R&D investment

	Simulation rounds conditional on $R > 0$			All simulation rounds		
Regime	mean	median	ratio	mean	median	ratio
Benchmark regimes						
Laissez-faire	196 558	108 138	1.000	101 408	55 502	1.000
1^{st} best	475 656	265 085	2.420	234 547	146 044	2.313
2^{nd} best	464 407	267 730	2.363	230 597	142 983	2.274
No financial frictions	196 574	108 150	1.000	101 418	55 509	1.000
Policies of interest						
Tax credits	289 381	159 588	1.472	151 072	82 963	1.490
Subsidies	253 481	122 356	1.290	127 075	64 656	1.253
$s\|s > 0$	484 652	194 497	2.466			

NOTES: The figures are calculated over all 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.
$s|s > 0$ shows the average subsidy regime R&D investment conditional $R > 0$.

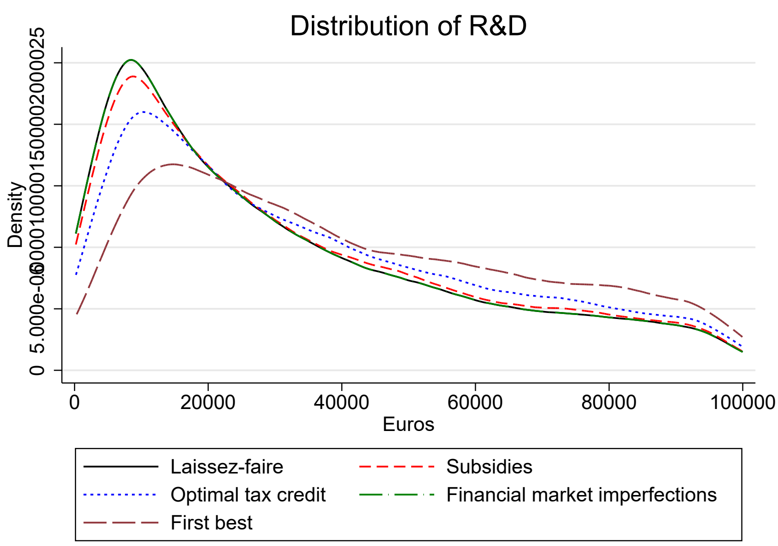

Figure 2. Distribution of counterfactual R&D investment (truncated at 100 000€)

Table 6. Profit, spillovers and welfare

	Profit			Spillovers			Welfare		
Regime	mean	median	ratio	mean	median	ratio	mean	median	ratio
Benchmark regimes									
Laissez-faire	1 170 343	559 085	1.000	55 760	33643	1.000	1 226 103	593 595	1.000
1^{st} best	1 115 867	517 719	0.953	137 743	91619	2.470	1 253 610	611 885	1.022
2^{nd} best	1 118 462	519 485	0.956	134 530	89760	2.413	1 252 992	611 257	1.022
No financial frictions	1 170 365	559 101	1.000	55 766	33648	1.000	1 226 131	593 643	1.000
Policies of interest									
Tax credits	1 212 153	582 458	1.036	83 089	50259	1.490	1 233 604	599 178	1.006
Subsidies	1 178 357	561 307	1.007	71 287	39396	1.278	1 217 671	590 015	0.993

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.

Profits. The left panel of Table 6 shows that profit differences across policy regimes are smaller than those in R&D investment as 37–38% of the firms invest in R&D in none of the regimes and are hence unaffected by the policies. The convexity of the profit function limits the profit effects for investing firms. The R&D tax credit and subsidy policies increase mean expected discounted profits by 3.6% and 0.7% from laissez-faire. Financial frictions have a negligible effect on profits. Profits in the first and second best regimes are 4.7 and 4.4% lower than in laissez-faire: The firms generating positive spillovers invest in these regimes more than the profit-maximizing level and the firms generating negative spillovers invest less.

Spillovers. Estimates reported in the middle panel of Table 6 suggest that spillovers are much lower than firm profits in all regimes, ranging from 56 000€ (4.8% of profits) under laissez-faire to 138 000€ (12% of profits) under first best. Average spillovers in the R&D tax credit regime are somewhat higher than with R&D subsidies, but for the actually subsidized firms, spillovers relative to profits are higher. Although R&D subsidies and tax credits significantly increase spillovers relative to laissez-faire (by 28 and 49%), the first and second best regimes generate even larger spillovers.

Welfare. The ultimate measure of the effectiveness of different R&D support policies is their impact on welfare. We find (right panel of Table 6) that the first and second best regimes improve welfare by 2.2% compared to laissez-faire. There is thus no significant room to increase welfare: The optimal R&D tax credit increases welfare by 0.6%. These results are comparable to Acemoğlu et al. (2018) who find that a first best innovation policy increases welfare by 4.5% and the optimal uniform R&D subsidy by 1.2%, and to Akcigit, Ates, and Impullitti (2025), in which the optimal uniform R&D subsidy increases welfare by 1.17% In Acemoğlu et al. (2018) and Akcigit, Ates, and Impullitti (2025), the uniform subsidy applies equally for all R&D investing firms and is hence similar to our optimal R&D tax credit.

Thus, although the two R&D support policies increase R&D investments and spillovers substantially, they do not improve welfare much once the shadow costs of public funds are taken into account. The costs and uncertainty associated with application process make the welfare performance of the R&D subsidy regime slightly inferior to laissez-faire: Because the agency optimizes after receiving applications, it ignores the effects of its policy on the number and costs of applications. Moreover, the right firms from a welfare perspective do not always apply for subsidies. For example, 21% of the applications in our data are rejected and only generate application costs. If application costs are ignored, the subsidy regime creates a small welfare improvement. Finally, as financial frictions have little effect on investments, they cannot have notable welfare effects either.

Parameters of policy interest. To further illustrate the performance of R&D subsidy and tax credit regimes, we calculate some parameters of policy interest. In our simulations of the R&D subsidy regime, on average 15% of firms apply for a subsidy and the mean subsidy rate, conditional on getting one, is 39% (Table 7). Both figures are close to those in the data (18% and 35%). The optimal tax credit rate τ_R^* is 34% (0.34, with a bootstrapped standard error of 0.01).[14] In calculating the optimal tax credit rate the agency recognizes that some projects should get a larger tax subsidy than the maximum subsidy rate $\bar{s}$ but that some projects should

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

be taxed because of negative spillovers. Acemoğlu et al. (2018) find the optimal uniform subsidy rate, analogous to our R&D tax credit rate, to be 39% whereas it is 54% but rapidly decreasing with trade openness in Akcigit, Ates, and Impullitti (2025). In our simulations 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€. The unconditional fiscal cost of a mean tax credit is 89% higher than that of a mean subsidy (51 000€ versus 27 000€).

Table 7. Parameters of the R&D subsidy and tax credit regimes

variable	mean
$\Pr[apply]$	0.152
$subsidy\ rate \mid s > 0$	0.385
τ_R	0.340
$\tilde{\tau}_R = \tau_R(1-\tau)$	0.250
Government cost, $s \mid s > 0$ & $R\&D > 0$	59 410
Government cost, $\tau_R \mid R\&D > 0$	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. $subsidy\ rate \mid s > 0$ is the average subsidy rate conditional on it being strictly positive. τ_R is the optimal tax credit.
Government cost $s \mid s > 0$ & $R\&D > 0$ is the average cost to the government from those projects it subsidizes in euros.
Government cost $\tau_R \mid R\&D > 0$ is the average cost to the government from those projects that claim tax credits in euros.
Government cost s and government cost, τ_R is the average cost of subsidies and tax credits, respectively, in euros.

Robustness

We gauge the sensitivity of the policy regimes in terms of welfare.[15] Given that application process constitutes a major reason for the weak welfare performance of the subsidy regime, we study the effects of a uniform reduction in application costs. We find that the average application cost would need to decrease by 95% before welfare in the subsidy regime would reach the laissez-faire level. A uniform reduction in application costs does

[15] We implement these analyses using a grid search, employing the same simulation draws used to produce our main counterfactual results.

not necessarily improve the composition of firms applying for subsidies and may thus be an inefficient way to improve welfare.

We assume full take-up of the R&D tax credit, likely creating upward bias in benefits and costs of the R&D tax credit: E.g., Verhoeven, Stel, and Timmermans (2012) and Busom, Corchuelo, and Martínez-Ros (2014)) find that some eligible firms waive R&D tax credits. To investigate the robustness of our results to this assumption, we ask what fraction of R&D investing firms would need to forgo R&D tax credits for welfare in that regime to decrease to the laissez-faire level. Ordering firms by the increase in profits due to the R&D tax credit, we find that welfare in the R&D tax credit regime reduces to the laissez-faire level when all but the 11% of firms with the highest profit gains forgo tax credits. These investigations suggest that our welfare ranking is quite robust to over-estimating application costs and the take-up of tax credits.

Our welfare estimations also ignore the agency's possible budget constraint, which is likely to create a downward bias in the estimates of the subsidy regime if the constraint is binding and an upward bias if unused budget leads to a wasteful end-of-year spending (see, e.g., Liebman and Mahoney, 2017). In the case of the R&D tax credit regime, ignoring the possible budget constraint leads to overestimation of both benefits and costs. In practice, budget concerns also often lead R&D tax credit policy designers to impose maximum caps on the tax-credit amount that a project can claim. To the extent such a cap is binding, it will eliminate the incentive effect of R&D tax credits at the intensive margin but still allow for one at the extensive margin. In the absence of an incentive effect, the R&D tax credit will be an inefficient transfer from the tax payers to the firm, dissipating welfare due to the shadow cost of public funds.

We therefore consider an R&D tax credit policy with both a project-specific maximum amount cap and a budget constraint that is equal to the (simulated) calendar-year expenditure on R&D subsidies. We keep the R&D tax credit at the (optimal) level used in the counterfactual without the two constraints. Imposing the budget and maximum amount constraints weakens the welfare performance of the R&D tax credit regime but maintains the welfare ranking of regimes: The R&D tax credit regime with the budget and maximum amount constraints increases welfare by 0.2% from the laissez-faire level. One reason for the diluted welfare performance is that 41% of R&D investing firms receive the maximum R&D tax credit and these firms receive 47% of the tax credits, but only 0.04% of the R&D investing firms started investing thanks to the maximum tax credit. Thus, a significant portion of the tax credits are wasted as inefficient transfers.

The welfare performance of the R&D tax regime would probably be further weakened if we allowed relabeling of corporate expenditures – Chen, Liu, et al. (2021) report significant relabeling in a different environment. The same concern should also apply to the subsidy regime (cf. Boeing and Peters, 2024), although in our institutional setting subsidy misreporting should be relatively rare (see Section 2). We also neglect administrative costs of the R&D support policies – Tekes's administrative costs are ca. 50€M (Tekes, 2010) a year, i.e., some 2000€ per firm. On the other hand, global welfare effects of the R&D support policies are likely understated because a large part of consumer surplus and technological spillovers generated by the Finnish R&D is captured abroad but that part is not necessarily included in the Finnish agency's objective function. Our analysis also ignores firms' international R&D location decisions, which may lead us to underestimate the national benefits of support policies.

We report the results of further robustness analyses in Appendix E: First, we estimate financial frictions using balance sheet data on interest rates. This alternative measure yields a somewhat higher estimate of financial frictions and, thus, lower estimates of R&D investment, profits and welfare. Second, we ignore subsidized loans in calculating the subsidy rate, which yields results close to those in the main text. Third, we exclude the three largest firms, which yields somewhat higher R&D investment, profits and welfare. When comparing the other policy regimes to laissez-faire, we obtain similar R&D ratios with one exception: Removing financial frictions increases R&D by 9.1% and welfare by 1.2% when using the alternative measure of financial frictions. The other ratios deviate by one percentage point at most. As a fourth (unreported) robustness test, we introduce 3^{rd} order terms into our polynomials, and an expanded set of industry dummies. Our main results remain unchanged.

7 Conclusions

We build a dynamic model of an innovation policy which incorporates the main policy motivations: Externalities, financial frictions, and R&D participation. We estimate the model using Finnish R&D project level data, which allows us to measure financial frictions at the project level. 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 objective function.

We conduct a counterfactual analysis of two wide-spread R&D support policies – a one-size-fits-all R&D tax credit policy and an R&D subsidy policy with applied for-but-tailored support – and different benchmark policies. First and second best double R&D levels from laissez-faire. The same applies to spillovers, but profits are roughly constant over policies. Profits are considerably larger than spillovers, perhaps because the Finnish agency internalizes profits fully but only cares about domestic spillovers. We find substantial heterogeneity, both on observables and unobservables, on both profits and spillovers. First and second best increase welfare 2.2% and R&D tax credits 0.6%, but R&D subsidies reduce welfare 0.7%. The optimal R&D tax credit rate is 34%, which increases fiscal costs more than 90% compared with R&D subsidies but also ultimately yields higher welfare. Imposing budget and project-specific maximum amount constraints dilute the welfare performance of tax credits, rendering a large fraction of the, ineffective transfers, but maintain the welfare ranking of the policies.

The two R&D support policies substantially increase R&D investment levels and spillovers, but have small effects on R&D participation. The difference between the support policies shows up when compared with first best: R&D subsidies achieve close to first best investments but only for those few firms that receive subsidies, whereas R&D tax credits achieve close to first best R&D participation. The subsidy application process limits the reach of the subsidy policy and is inefficiently costly, because the agency follows a discretionary policy that fails to internalize application costs, and because application costs are heterogeneous so that some wrong (right) firms end up (not) applying. We find that because a uniform reduction in application costs does not necessarily improve the composition of firms applying, it provides no easy way to increase welfare. Rather, the agency should try to induce the right (wrong) firms from the welfare perspective to apply with a higher (smaller) probability. The agency could also consider changing its discretionary subsidy policy to a rule-based policy which internalizes application costs.

Our results suggests that R&D non-investment is pervasive: 37–38% of the firms perform no R&D in all regimes; thus, even in the first best world, close to 40% of the projects should not be implemented because of not-so-promising R&D ideas. These results suggest that the only way to substantially increase R&D participation (and thereby welfare) would be to improve the quality of firms' R&D ideas, which cost-reducing policies like R&D subsidies and tax credits are hardly able to do. Moreover, our finding of large intensive- but small extensive-margin impacts suggests that the two R&D support policies may contribute to the increasing concentration of R&D to incumbent firms.

The R&D - related financial frictions are so small as to not materially affect R&D outcomes and optimal policies. An explanation might be that our data period consists of boom years when access to finance was barely an issue for the Finnish firms. Although this explanation may limit our results' external validity, these empirical results concerning the optimal policy effects are consistent with our theoretical model, which shows that the effects of more severe financial frictions on the optimal R&D support are complex and do not necessarily lead to higher support.

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Online Appendix for Takalo, Toivanen and Wahlberg: Welfare Effects of R&D Support Policies

Appendix A: Figures

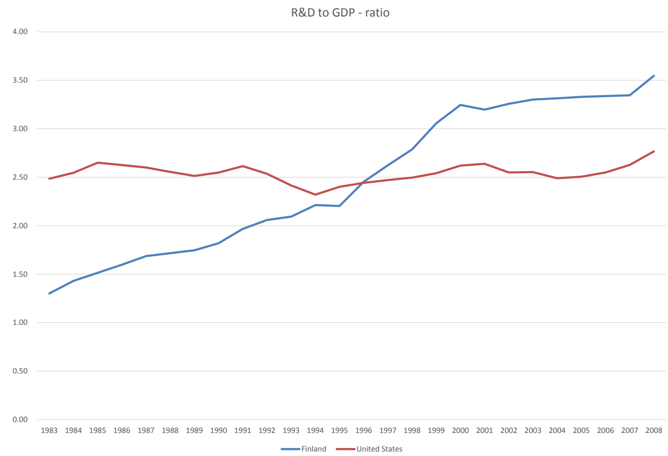
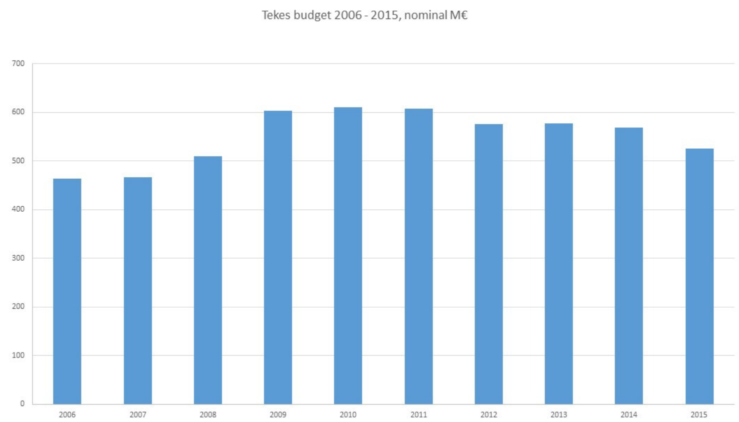


Figure A1. R&D/GDP-ratio, Finland and the US. Source: OECD Main Science and Technology Indicators.



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 the observations with negative sales (7 observations). We then exclude those firms for which we observe age at no point (17 241 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 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 do not observe R&D expenditures; these observations come from firms not included in the R&D survey of Statistics Finland.

According to the Statistics Finland www-site,[1] 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 weights had no material impact on the estimations but increased the computation time significantly, we use no weights in the reported estimations.

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

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		

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

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

Table B2. Distribution of #applications / firm

#applications	#firms	%	cum. %
0	3 979	65.48	
1	1 142	18.79	84.27
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

Flow of estimations. We have compiled the different estimation equations into Table B4 in the order that the estimation proceeds. The first estimation equation is a probit model where the dependent variable takes value 1 if we observe the cashflow prediction of firm i in year t and is 0 otherwise. This equation is used to generate an inverse Mills ratio to project the (log) cashflow of firm i in year t onto firm characteristics (estimation equation 2). These estimations generate predicted cashflows for those firm -year observations for which we fail to observe them (mostly for firms that did not apply for a subsidy in a given year). The third estimation equation is again a probit model used to generate an inverse Mills ratio for the fourth and fifth estimation equations, i.e., ordered probit - grading equations where the dependent variables are the *tech* and *risk* grades that a project of firm i in year t achieved when Tekes evaluated it. The dependent variable for the probit generating this inverse Mills ratio takes value 1 if firm i in year t applies for a subsidy and is zero otherwise.

The same inverse Mills ratio from estimation equation 3 is used to correct for sample selection bias in the first structural estimation where the dependent variable is the log of actual R&D investment of firm i in year t (estimation equation 6). The remaining structural equations need no sample selection correction. Estimation equation 7 has as its dependent variable a dummy taking value 1 if firm i invests in R&D in year t and value 0 otherwise. Estimation equation 8 is the agency's decision rule where the dependent variable is the subsidy rate. The final estimation equation is the firm's application decision: The dependent variable takes value 1 if firm i applies for a subsidy in year t and value 0 otherwise. Finally, we scale the estimates to match the predicted mean R&D investment with the realized mean (for the firm-year observations for which the R&D investment is observed)

Table B4. Estimation equations

Estimation eqn. number	Dependent variable	Econometric model	Sample selection correction	Use
Auxiliary equations				
1	1[observe cashflow]	probit	NO	generate an inverse Mills ratio for cash flow estimations
2	ln cashflow	OLS	eqn 1	generate predicted cashflow for missing observations
3	1[apply]	probit, separately for SMEs and non-SMES	NO	generate an inverse Mills ratio for *risk* , *tech* and ln R&D estimation
4	Risk	ordered probit	eqn 3	predicted grades for the agency decision rule
5	Tech	ordered probit	eqn 3	predicted grades for the agency decision rule
Structural equations				
6	ln R&D	OLS	eqn 3	parameters of the marginal profitability of R&D
7	1[R&D]	probit	NO	parameters of the fixed cost of R&D
8	subsidy rate	two-limit Tobit	NO	parameters of the agency's utility
9	1[apply]	SML probit	NO	parameters of the cost-of-applying function

NOTES: $1[x]$ indicates a dummy variable taking value 1 if x observed and 0 otherwise.

Estimating the cashflow for the project. We use the information submitted by the applicants on their cashflow. We estimate a sample selection model in which 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 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 (2013a) that past application behavior is highly correlated with current application behavior and hence also with observing the cashflow. The identifying assumption is that past application behavior is not correlated with the cashflow firms report to be pledgeable for the project. Using the results from this regression we predict the log cashflow for those firms for which we do not observe 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 (ε_{it}, ζ_{it}, η_{it}, μ_{0it}) in the structural model. We present the results of the above probit in the first column of Table B6 and those of the log cashflow equation in column two.

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 B5 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 shocks (ε_{it}, ζ_{it}, η_{it}, μ_{0it}) in the structural model. 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 B6. We use the thus generated probabilities of getting a particular grade for calculating the expected discounted profits from applying for a subsidy (see below for more detail).

Table B5. 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: The numbers in the "original" and "augmented" columns are % of observations.

The results presented in Table B6 (Table B6 is split into two panels) 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 inverse 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 B6, panel A. 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)

Table B6, panel B. 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	$risk$
$region$	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)
$prev\ applicant$	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 project (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 (Cameron and Trivedi, 2005). 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, 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 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: Technical Details and Proofs of the Theoretical Model

C.1 Technical Assumptions

Financing contract. To raise external funding, a firm offers an investor a financing contract $(R, \pi) \in (0, \infty) \times [0, \infty)$ in which the firm promises to repay the investor the amount π for the investor's funding of the firm's project with a variable size R; the investor also needs to finance the fixed cost F. If the firm cannot honor the contract, the investor can seize the project's cashflow. Because project success follows the Bernoulli distribution and because no repayment is possible upon failure, this repayment promise accommodates both debt and equity interpretations.

Firms' bad projects. A bad project fails with probability one but yields non-verifiable private benefits $b \in [PA, \infty)$ per unit of investment for (the decision maker of) the firm.

Corporate taxation. The firm and its investor need to pay a fraction $\tau \in [0, 1]$ of their profits to the government. We make corporate taxation neutral in the sense that it affects R&D investments only via R&D tax credit rate as follows: We assume that the investor is large, e.g., a large bank, so that the law of large numbers can be applied to the investor's asset portfolio. 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 a bank's liabilities. Because the project successes are *i.i.d.*, we invoke the common assumption that the empirical mean equals the expectation with probability one (see Judd, 1985) and, consequently, a fraction P of the investor's projects will succeed and $1 - P$ will 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 of an individual project is tax deductible even if the project fails. Moreover, we assume that all revenues are taxable except for private benefits and costs deductible except for subsidy application costs. Private benefits are non-verifiable to third parties and hence cannot be taxed. Although we assume the non-deductibility of application costs for simplicity, the subsidy application process in practice mainly involves effort costs. For example, the application process requires a detailed, written application, and plenty of other communications between the applicant and Tekes's experts (cf. Section 2).

C.2 Equilibrium Project and Financing Choices

To avoid a need to formally characterize a number of out-of-equilibrium payoffs and actions, we first solve investors' and firms' choices of financing and project types in stages 3 and 4 of the game.

Firm's project choice. In stage 4, a firm's action set depends on its investor's choice of whether to stay arm's length or monitor in stage 3. Consider first a stage-4 subgame in which the investor has accepted a financing contract $(R, \pi) \in (0, \infty) \times [0, \infty)$

proposed by a firm, but chosen to stay at arm's length. The firm is free to choose between the good and the bad project. Because the investor is funding the firm's investment, the firm's expected payoff (net of taxes) from the good project is given by

$$\Pi^E(R,\pi) = (1-\tau)P(A\ln R - \pi). \tag{A1}$$

Equation (A1) shows that, with probability P, the project yields the return $A\ln R$ from which the firm needs to repay the investor π. With probability $1-P$ the project fails, and neither the firm nor the investor gets anything. If the firm invests in the bad project, it will get bR for sure. The firm chooses the bad project if $bR \geq \Pi^E(R,\pi)$ or, using equation (A1), if

$$bR \geq (1-\tau)P(A\ln R - \pi).$$

Evaluating the right-hand side of this inequality upwards by setting $\pi = \tau = 0$, and the left-hand side downwards by setting $b = PA$, we have

$$R \geq \ln R,$$

which holds for all $R \in (0,\infty)$. Thus, if the investor stays at arm's length, the firm will choose the bad project.

In a subgame in which the investor has accepted a financing contract (R,π) proposed by the firm and monitors the firm, the bad project is eliminated from the firm's action set. As a result, the firm invests in the good project, yielding the expected payoff given by (A1). To summarize, we have the following lemma:

Lemma A1 *Assume that the investor has accepted a financing contract* $(R,\pi) \in (0,\infty)\times[0,\infty)$ *proposed by the firm. Then, the firm invests in the good project if and only if the investor monitors, and invests in the bad project otherwise.*

Investor's choice of financing type. Consider next a subgame starting from stage 3 in which the investor has accepted a financing contract (R,π), and chooses whether to monitor or stay at arm's length. If the investor monitors, the bad project is eliminated from the firm's action set. The investor's expected payoff is then given by

$$\Pi^I(F,s,R,\pi) = (1-\tau)\left[P\pi - (r+c)(R+F) + sR\right]. \tag{A2}$$

Equation (A2) shows how the investor puts up the investment $R+F$, except for a fraction $s \in [0,\bar{s}]$ of the variable R&D costs reimbursed by the agency. The level of s is known at this stage (stage 3). Note that $s = 0$ can arise either because the agency rejects the firm's subsidy application at stage 2 or because the firm forgoes a subsidy application at stage 1. The investor needs cover its costs of monitoring and raising funds (c and r). Equation (A2) implies the existence of a financing contract (R,π) that makes the investor's expected payoff $\Pi^I(F,s,R,\pi)$ non-negative.

If the investor stays at arm's length, the firm chooses by Lemma A1 the bad project which fails with probability one. Thus, the investor's payoff to arm's length financing is

$$(1-\tau)\left[-r\left(R+F\right)+sR\right]<0, \tag{A3}$$

in which the inequality follows from $r \geq 1 > \bar{s} \geq s$. We have the following Lemma:

Lemma A2 *If the investor accepts a financing contract* $(R, \pi) \in (0, \infty) \times [0, \infty)$ *proposed by the firm, the investor will monitor the firm.*

Using equation (A2) to solve $\Pi^I(F, s, R, \pi) = 0$ for π gives

$$\overline{\pi}(F, s, R) := \frac{(r+c)(R+F) - sR}{P} > 0, \tag{A4}$$

in which the inequality follows from $r + c \geq 1 > \bar{s} \geq s$. Equations (A2) and Lemma A2 imply that the definition (A4) identifies the minimum repayment that induces the investor to finance the firm.

C.3 Equilibrium Definition

Lemmas A1 and A2 suggest that arm's length financing and investments in bad projects cannot occur on the equilibrium path. We thus focus on a reduced-form game in which investors provide, if any, informed financing, and if firms obtain financing, they invest in the good project. We can then reduce the number of the agents' binary decisions into two. We describe these two decisions by $d_k \in \{0, 1\}, k \in \{a, f\}$, in which 1 and 0 indicate choosing and not choosing action d_k, and in which subscripts $k = a$ and $k = f$ refer to a firm's decision of whether to apply for a subsidy and to an investor's decision of whether to accept a financing contract. In the full game, we would have to specify further the investors' and firms' binary choices of financing and project types, and associated payoffs.

We may write a firm's expected payoff in stage 4 as

$$\widetilde{\Pi}^E(R, \pi, d_f) = \begin{cases} \Pi^E(R, \pi) & \text{if } d_f = 1 \\ 0 & \text{if } d_f = 0, \end{cases} \tag{A5}$$

in which $\Pi^E(R, \pi) = \widetilde{\Pi}^E(R, \pi, 1)$ is given by equation (A1). Similarly, an investor's expected payoff in stage 3 is given by

$$\widetilde{\Pi}^I(F, s, R, \pi, d_f) = \begin{cases} \Pi^I(F, s, R, \pi) & \text{if } d_f = 1 \\ 0 & \text{if } d_f = 0, \end{cases} \tag{A6}$$

in which $\Pi^I(F, s, R, \pi) = \widetilde{\Pi}^I(F, s, R, \pi, 1)$ is given by equation (A2).

We also write the agency's expected payoff in stage 2 as

$$\widetilde{U}\left(F, v, s, R, \pi, d_f\right) = \begin{cases} U(F, v, s, R, \pi) & \text{if } d_f = 1 \\ 0 & \text{if } d_f = 0, \end{cases} \tag{A7}$$

in which $U(F,v,s,R,\pi) = \widetilde{U}\,(F,v,s,R,\pi,1)$ is given by

$$U\,(F,v,s,R,\pi) = (v-gs)\,R + \frac{1}{1-\tau}[\Pi^E(R,\pi) + \Pi^I(F,s,R,\pi)]. \tag{A8}$$

In equation (A8), the private sector profits are net of taxes because, for the agency, corporate tax payments are just transfers and cancel out in welfare calculation.

The last rows of the payoff functions (A5)–(A7) indicate that if investors refuse to finance a firm, the firm cannot invest in which case all parties' payoffs are zero. The agency cannot force investors to provide funding and can only indirectly try to alleviate the firm's financing constraint by its choice of s: As shown by equation (A6), an investor's expected payoff depends on s.

For $F \in [0,\infty)$, let us denote by $\Gamma(F)$ the dynamic game among the agency, a firm and an investor.

Definition 1 *A profile*

$$(d_a^*(F), s^*(F,\cdot), R^*(F,\cdot), \pi^*(F,\cdot), d_f^*(F,\cdot))$$

is a pure-strategy perfect Bayesian equilibrium of $\Gamma(F)$ *if it satisfies;*

(i) For $(s,R,\pi) \in [0,\bar{s}] \times (0,\infty) \times [0,\infty)$, $\Pi^I(F,s,R,\pi) \geq 0$ *implies* $d_f^*\,(F,s,R,\pi) = 1$, *and* $\Pi^I(F,s,R,\pi) < 0$ *implies* $d_f^*\,(F,s,R,\pi) = 0$.

(ii) For all $s \in [0,\bar{s}]$,

$$(R^*(F,s), \pi^*\,(F,s)) \in \underset{(R,\pi)\in(0,\infty)\times[0,\infty)}{\arg\max}\ \widetilde{\Pi}^E\left(F,R,\pi,d_f^*\,(F,s,R,\pi)\right)$$

(iii) For $d_a = 1$,

$$s^*(F,v) \in \underset{s\in[0,\bar{s}]}{\arg\max}\,\widetilde{U}^*\,(F,v,s)\,,$$

in which

$$\widetilde{U}^*(F,v,s) := \widetilde{U}(F,v,s,R^*(F,s),\pi^*(F,s),d_f^*(F,s,R^*(F,s),\pi^*(F,s)).$$

(iv)

$$d_a^*(F) \in \underset{d_a\in\{0,1\}}{\arg\max}\,d_a\left[\int_{-\infty}^{\infty}\widetilde{\Pi}^{E*}\,(F,s^*\,(F,v))\,d\Phi(v) - K\right] + (1-d_a)\widetilde{\Pi}^*\,(F,0)\,, \tag{A9}$$

in which

$$\widetilde{\Pi}^{E*}(F,s) := \widetilde{\Pi}^E(R^*(F,s),\pi^*(F,s),d_f^*(F,s,R^*(F,s),\pi^*(F,s)).$$

Condition (i) warrants that the investor's financing behavior is rational; the investor accepts a financing contract if and only if it yields a positive expected payoff. Condition (ii) warrants that the firm's financing contract offer maximizes the firm's expected payoff, anticipating the investor's behavior. As shown by condition (iii), a subsidy application calls on the agency to act. The agency's subsequent subsidy rate choice maximizes its expected payoff anticipating the firm's and the investor's contracting behavior. If the agency receives no application, the agency is not called on to make a subsidy decision. Condition (iv) warrants that the firm's subsidy application decision maximizes its expected payoff anticipating the agency's, investor's and its own behaviors in the subsequent stages.

As is customary, we assume tie-breaking rules in favor of equilibrium. Some of these rules are institutionalized. E.g., Tekes's internal funding rules prohibit awarding subsidizes if "funding would have no effect on the realization of the project" or if "the project has only a small impact on the company's business". These rules break the agency's indifference in favor of equilibrium, e.g., when the agency knows that no project would be implemented even if it awarded a subsidy.

C.4 Technical Proofs

Lemma A3 identifies an investor's equilibrium financing behavior.

Lemma A3 *Let* $(F, s, R) \in [0, \infty) \times [0, \bar{s}] \times (0, \infty)$*. If* $\min\{\pi, A \ln R\} \geq \bar{\pi}(F, s, R\})$*, then the investor accepts a financing contract* ($d_f^*(F, s, R, \pi) = 1$)*. Otherwise, the investor refuses a financing contract* ($d_f^*(F, s, R, \pi) = 0$)*.*

Proof. A firm can at maximum credibly pledge the full project return to its investor. Thus the investor receives $\min\{\pi, A \ln R\}$ in the case of success. Equations (A2) and (A4) imply that if $\min\{\pi, A \ln R\} \geq \bar{\pi}(F, s, R)$ then

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

Hence, $d_f^*(F, s, R, \pi) = 1$.

Correspondingly if $\min\{\pi, A \ln R\} < \bar{\pi}(F, s, R)$, then

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

and $d_f^*(F, s, R, \pi_1) = 0$. ■.

Lemma A4 identifies the financing contracts that arise in equilibrium. Let us define $\bar{\pi}^*(F, s) := \bar{\pi}(F, s, \mathcal{R}(s))$ and $\Pi^{E*}(F, s) := \Pi^E(\mathcal{R}(s), \bar{\pi}^*(F, s)) \geq 0$.

Lemma A4 *For all* $(F, s) \in [0, \infty) \times [0, \bar{s}]$*, offering a financing contract* $(\mathcal{R}(s), \bar{\pi}^*(F, s))$ *is a dominant strategy for the firm. Moreover, the investor accepts the offer* ($d_f^*(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 1$) *if and only if* $\Pi^{E*}(F, s) \geq 0$ *and does not accept otherwise.*

Proof. For all $R \in (0, \infty)$, if either $A \ln R < \bar{\pi}(F, s, R)$ or $\pi < \bar{\pi}(F, s, R)$, then $d_f^*(F, s, R, \pi) = 0$ by Lemma A3 and therefore $\widetilde{\Pi}^E(R, \pi, 0) = 0$ by equation (A5).

Assume that $A \ln R \geq \bar{\pi}(F, s, R)$ and consider a repayment offer $\pi' > \bar{\pi}(F, s, R)$. Because $\min\{\pi', A \ln R\} \geq \bar{\pi}(F, s, R)$, $d_f^*(F, s, R, \pi') = 1$ by Lemma A3. The firm's payoff from equations (A1) and (A5) is then

$$\Pi^E(R, \pi') = \max\{(1-\tau)P(A \ln R - \pi'), 0\} \leq \Pi^E(R, \bar{\pi}(F, s, R)),$$

in which the inequality is strict if $A \ln R > \bar{\pi}(F, s, R)$. Hence offering $\bar{\pi}(F, s, R)$ maximizes the firm's payoff (uniquely if $A \ln R > \bar{\pi}(F, s, R)$).

Continue to assume that $A \ln R \geq \bar{\pi}(F, s, R)$. Then, $d_f^*(F, s, R, \bar{\pi}(F, s, R)) = 1$ by Lemma A3. Substitution of $\bar{\pi}(F, s, R)$ from equation (A4) for π in equation (A1) gives the firm's payoff function $\Pi^E(F, s, R)$ of equation (1) of the main text. Straightforward calculation shows that

$$\mathcal{R}(s) := \frac{\alpha}{r + c - s} = \underset{R \in [0 \infty)}{\arg\max}\, \Pi^E(F, s, R).$$

Thus offering the contract $(\mathcal{R}(s), \bar{\pi}^*(F, s))$ maximizes the firm's payoff (uniquely if $A \ln \mathcal{R}(s) > \bar{\pi}^*(F, s)$). Moreover, Lemma A3 implies that the investor accepts the offer $((d_f^*(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 1))$ if and only if $A \ln \mathcal{R}(s) \geq \bar{\pi}^*(F, s)$ which, given equations (A1) and (A4) is equivalent to the condition $\Pi^{E*}(F, s) \geq 0$. ■

Equations (1)–(4) of the main text follow from Lemma A4.

Lemma A5 *Let $(F, s) \in [0, \infty) \times [0, \bar{s}]$. In an equilibrium of $\Gamma(F)$, (i) if the investor finances the firm ($d_f^*(F, s, R, \bar{\pi}(F, s, R)) = 1$), the firm's expected payoff is given by equation (1); (ii) the firm's optimal investment rule can be described by equations (2) and (3); and (iii) the agency's expected payoff can be described by equation (4) if $\Pi^{E*}(s) \geq 0$.*

Proof. The proof of part (i) is included in the proof of Lemma A4. Part (ii): According to Lemma A4, in an equilibrium of $\Gamma(F)$, $R^*(F, s) = \mathcal{R}(s)$ if and only if $\Pi^{E*}(F, s) \geq 0$. If $\Pi^{E*}(F, s) < 0$, the investor refuses to finance the firm ($d_f^*(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 0$) implying that the firm cannot invest ($R^*(F, s) = 0$). Part (iii): The equilibrium financing contract offer $(\mathcal{R}(s), \bar{\pi}^*(F, s))$ identified by Lemma A4 implies by the definition of $\bar{\pi}(F, s, R)$ (see equations (A2) and (A4)) that $\Pi^I(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 0$. Therefore, in an equilibrium of $\Gamma(F)$ in which $d_f^*(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 1$, i.e., when $\Pi^{E*}(F, s) \geq 0$, the agency's expected payoff (A8) simplifies to

$$U^*(F, v, s) := U(F, v, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = (v - gs)\mathcal{R}(s) + \frac{\Pi^{E*}(F, s)}{1 - \tau},$$

which equals equation (4). ■

Intuitively, because investors behave competitively, the equilibrium financing contract identified by Lemma A4 maximizes the firm's expected stage-3 payoff subject to the investors' participation constraint. For the moment, we simplify proofs and proceed under the following mild restriction on parameter values:

Assumption A1 $\ln \varphi > 1$, *in which* $\varphi := \frac{\alpha}{r+c}$.

Assumption A1 means that in the absence of fixed costs and subsidies ($F = s = 0$), the expected net present value of the good project is positive: Parameter φ captures the marginal productivity of the project relative to the marginal cost of financing the project. Although the assumption is plausible, we will also, after Proposition A1 at the end of Appendix C, characterize equilibria when Assumption A1 is relaxed.

Lemma A6 identifies the firm's equilibrium R&D investment behavior as a function of F.

Lemma A6 *There are $\underline{F}, \bar{F} \in [0, \infty)$, with $0 < \underline{F} < \bar{F}$, such that for all $s \in [0, \bar{s}]$, $R^*(F, s) = \mathcal{R}(s)$ 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 $R^*(F, s) = \mathcal{R}(s)$. Moreover, $\mathcal{R}(s) > 1$ for all $s \in [0, \bar{s}]$.*

Proof. Lemma (A4) implies that, in equilibrium, either $R^*(F, s) = \mathcal{R}(s)$ or $R^*(F, s) = 0$ depending on whether $\Pi^{E*}(F, s) \geq 0$ or not. For $s = 0$, we observe from equation (3) that $\Pi^{E*}(F, 0) \geq 0$ when

$$F \leq \underline{F} := \varphi (\ln \varphi - 1). \tag{A10}$$

Because equation (3) also implies that $\partial \Pi^{E*}(F, s) / \partial s > 0$ on $[0, \bar{s}]$ (recall that $r + c \geq 1 > \bar{s}$), $\Pi^{E*}(F, s) > 0$ for all $s \in (0, \bar{s}]$ if the inequality (A10) holds. Thus, $R^*(F, s) = \mathcal{R}(s)$ for $F \leq \underline{F}$ and $s \in [0, \bar{s}]$.

Similarly, letting $s = \bar{s}$ in equation (3) implies that $\Pi^{E*}(F, \bar{s}) < 0$ when

$$F > \bar{F} := \varphi \left[\ln \left(\frac{\alpha}{r + c - \bar{s}} \right) - 1 \right]. \tag{A11}$$

Because $\partial \Pi^{E*}(F, s) / \partial s > 0$ on $[0, \bar{s}]$, $\Pi^{E*}(F, s) < 0$ for all $s \in [0, \bar{s}]$ under the condition (A11). Therefore, $R^*(F, s) = 0$ for $F > \bar{F}$ and $s \in [0, \bar{s}]$. Assumption A1 and equations (A10) and (A11) imply that $0 < \underline{F} < \bar{F}$.

Next, from equation (3) we obtain the unique s solving $\Pi^{E*}(F, s) = 0$ as

$$\tilde{s}(F) = \alpha \left[\frac{1}{\varphi} - e^{-\left(1 + \frac{F}{\varphi}\right)} \right], \tag{A12}$$

which is the subsidy rate familiar from equation (6) of the main text (recall $\varphi := \alpha/(r+c)$) from Assumption A1). This subsidy rate $\tilde{s}(F)$ increases with F, with $\tilde{s}(\underline{F}) = 0$ and $\tilde{s}(\bar{F}) = \bar{s}$. Moreover, $\partial \Pi^{E*}(F, s) / \partial s > 0$ 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 $R^*(F, s) = \mathcal{R}(s)$ for $s \in [\tilde{s}(F), \bar{s}]$.

Finally, note from the proof of Lemma A4 that that the investor accepts the offer $\left((d_f^*(F, s, \mathcal{R}(s), \bar{\pi}^*(F, s)) = 1)\right)$ if and only if $A \ln \mathcal{R}(s) \geq \bar{\pi}^*(F, s) > 0$ which implies that $\mathcal{R}(s) > 1$ for all $s \in [0, \bar{s}]$. Also, because $\mathcal{R}(s)$ is increasing, Assumption A1 implies $\mathcal{R}(s) > e > 1$ for all $s \in [0, \bar{s}]$. ■

Lemma A7 identifies the agency's equilibrium behavior.

Lemma A7 *Let* $d_a = 1$. *(i) For* $F \in [0, \underline{F}]$,

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

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

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

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

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

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

Proof. According to Lemma A4, $d_f^*(F, s, \mathcal{R}(s), \overline{\pi}^*(F, s)) = 1$ if and only if $\Pi^{E*}(F, s) \geq 0$, in which case, as shown in Lemma A5, the agency's expected payoff becomes $U^*(F, v, s)$ of equation (4). According to Lemma A4, if $\Pi^{E*}(F, s) < 0$, investors refuse to finance the firm ($d_f^*(F, s, \mathcal{R}(s), \overline{\pi}^*(F, s)) = 0$). We may hence rewrite equation (A7) as

$$\widetilde{U}^*(F, v, s) = \begin{cases} U^*(F, v, s) & \text{if } \Pi^{E*}(F, s) \geq 0 \\ 0 & \text{if } \Pi^{E*}(F, s) < 0. \end{cases} \tag{A13}$$

Conditional on $d_a = 1$, the agency chooses $s \in [0, \bar{s}]$ to maximize $\widetilde{U}^*(F, v, s)$ of equation (A13). We first solve the agency's problem by ignoring the R&D participation constraint $\Pi^{E*}(F, s) \geq 0$. For this case, equation (2) implies that $R^*(F, s) = \mathcal{R}(s) = \alpha / (r + c - s)$. Using this equation and the envelope theorem to differentiate the agency's expected payoff $U^*(F, v, s)$ from equation (4) then yields

$$\frac{dU^*(F, v, s)}{ds} = \frac{\alpha}{(r + c - s)^2}\left[v - s - (r + c)(g - 1)\right]. \tag{A14}$$

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

$$s(v) = \mathcal{S}(v) := v - (r + c)(g - 1), \tag{A15}$$

which is the subsidy rate familiar from equation (5) of the main text. (Note that $s \to r + c$ may also maximize $U^*(F, s, v)$ but it violates the feasibility constraint $s \leq \bar{s}$ (as $r + c \geq 1 > \bar{s}$).)

Part (i): According to Lemma A6, the R&D participation constraint is slack if equation (A10) holds. Therefore, for $F \in [0, \underline{F}]$, equations (A14) and (A15) imply that the optimal subsidy policy is given by $s_N^*(v) = 0$ if $v < \underline{v}$ in which

$$\underline{v} := (r + c)(g - 1) > 0, \tag{A16}$$

$s_N^*(v) = \bar{s}$ if $v > \bar{v} := \underline{v} + \bar{s}$, and $s_N^*(v) = \mathcal{S}(v)$ if $v \in [\underline{v}, \bar{v}]$.

Part (ii): When $F \in \left(\underline{F}, \bar{F}\right]$, the firm will finance its investment only if it receives a sufficiently large subsidy (see Lemma A6). This constraint matters if $\mathcal{S}(v) < \bar{s}$ and $\Pi^{E*}(F, \mathcal{S}(v)) < 0$. In such circumstances the agency may consider the subsidy rate $\tilde{s}(F)$ identified by equation (A12) of Lemma A6. Note that if $\mathcal{S}(v) < \bar{s}$ and $\Pi^{E*}(F, \mathcal{S}(v)) < 0$ then $\tilde{s}(F) > \mathcal{S}(v)$, because $\tilde{s}(F) \in [0, \bar{s}]$ and $\partial \Pi^{E*}(F, s) / \partial s > 0$ on $[0, \bar{s}]$. Also, because $\mathcal{S}(v)$ 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 $s' \in [0, \tilde{s}(F))$. Thus, if $\Pi^{E*}(F, \mathcal{S}(v)) < 0$, the agency awards the subsidy rate $\tilde{s}(F)$, if any. When $F > \underline{F}$, the agency can secure zero payoff by rejecting the firm's application; thus, awarding $\tilde{s}(F)$ can be optimal only if $U^*(F, v, \tilde{s}(F)) \geq U^*(F, v, 0) = 0$. To summarize, awarding $\tilde{s}(F)$ is optimal for the agency if $\mathcal{S}(v) < \bar{s}$, $\Pi^{E*}(F, \mathcal{S}(v)) < 0$, and $U^*(F, v, \tilde{s}(F)) \geq 0$.

Because $\Pi^{E*}(F, \mathcal{S}(v)) < 0$ if and only if $\mathcal{S}(v) < \tilde{s}(F)$, we first characterize the circumstances in which $\mathcal{S}(v) < \tilde{s}(F)$. Because $\tilde{s}(F)$ is independent of v but $\mathcal{S}(v)$ is strictly increasing in v (see equations (A12) and (A15)), there exists a unique value of v, denoted $\tilde{v}(F)$, such that $\mathcal{S}(\tilde{v}) = \tilde{s}(F)$. Equations (A12) and (A15) then yield

$$\tilde{v}(F) := \alpha \left[\frac{g}{\varphi} - e^{-\left(1 + \frac{F}{\varphi}\right)} \right]. \tag{A17}$$

Because $\mathcal{S}(v)$ is strictly increasing, $\mathcal{S}(v) < \tilde{s}(F)$ for $v < \tilde{v}(F)$. Thus, only if $v < \tilde{v}(F)$, the agency may award subsidy $\tilde{s}(F) > \mathcal{S}(v)$ that just satisfies the R&D participation 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. Because $\Pi^{E*}(F, \tilde{s}(F)) = 0$ by definition, we observe from equation (4) that $U^*(F, v, \tilde{s}(F)) = U^*(v, \tilde{s}(F)) = (v - g\tilde{s}(F))\mathcal{R}(\tilde{s}(F))$. Because $\mathcal{R}(\tilde{s}(F)) > 1$ by Lemma A6, $U^*(v, \tilde{s}(F)) \geq 0$ if $v - g\tilde{s}(F) \geq 0$. Inserting $\tilde{s}(F)$ from equation (A12) into $v - g\tilde{s}(F) \geq 0$ yields $v \geq v^0(F)$ in which

$$v^0(F) := g\alpha \left[\frac{1}{\varphi} - e^{-\left(1 + \frac{F}{\varphi}\right)} \right] = \tilde{v}(F) - (g - 1)\, \alpha e^{-\left(1 + \frac{F}{\varphi}\right)}, \tag{A18}$$

in which the latter equality uses equation (A17). Because $g > 1$, $v^0(F) < \tilde{v}(F)$. 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 the private sector's participation constraints cannot be simultaneously satisfied for any positive subsidy rate, implying $s^*(F, v) = 0$.

Next, equations (A12), (A16) and(A17) allow us to write $\tilde{v}(F) = \underline{v} + \tilde{s}(F)$. Because $\tilde{s}(F) \in [0, \bar{s}]$ by Lemma A6, $\tilde{v}(F) \in [\underline{v}, \bar{v}]$ (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: $s_C^*(F,v) = 0$ for $v < v^0(F)$, $s_C^*(F,v) = \tilde{s}(F)$ for $v \in [v^0(F), \tilde{v}(F))$, $s_C^*(F,v) = \mathcal{S}(v)$ for $v \in [\tilde{v}(F), \bar{v}]$, and $s_C^*(F,v) = \bar{s}$ for $v > \bar{v}$. Also, equations (A12) and (A18) allow us to write $v^0(F) = g\tilde{s}(F)$. Because $g > 1$ and $\tilde{s}(F) > 0$ when $F > \underline{F}$ by Lemma A6, $v^0(F) > 0$.

Part (iii): If the inequality (A11) holds, Lemma A4 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 $(F,s,v) \in (\bar{F}, \infty) \times [0,\bar{s}] \times \mathbb{R}$, implying $s^*(F,v) = 0$ for $(F,v) \in [\bar{F}, \infty) \times \mathbb{R}$. ■

According to Lemmas A6 and A7, if $F \leq \underline{F}$, the fixed R&D costs are so small that they affect neither the private sector's nor the agency's decisions. In contrast, if $F > \bar{F}$, the fixed costs are prohibitively high so that the firm could not finance its investment even with the maximum subsidy $\bar{s}$. Thus, the agency awards no subsidy for such a firm. If $F \in (\underline{F}, \bar{F}]$, the firm will be able finance its investment only if it receives a sufficiently large subsidy rate on $(0, \bar{s}]$. In that case, awarding $\tilde{s}(F)$ of equation (A12) is optimal for the agency for intermediate spillover rates $v \in [v^0(F), \tilde{v}(F))$, which are small enough to make the unconstrained rate suboptimal but are high enough to satisfy the agency's participation constraint.

Lemma A8 identifies the firm's equilibrium application behavior.

Lemma A8 *(i) For $F \in [0, \underline{F}]$, $d_a^*(F) = 1$ if and only if*

$$\int_{\underline{v}}^{\bar{v}} \Pi^{E*}(F, \mathcal{S}(v))\, d\Phi(v) + (1 - \Phi(\bar{v}))\, \Pi^{E*}(F, \bar{s}) - (1 - \Phi(\underline{v}))\, \Pi^{E*}(F, 0) \geq K.$$

Otherwise, $d_a^*(F) = 0$.

(ii) For $F \in (\underline{F}, \bar{F}]$, $d_a^*(F) = 1$ if and only if

$$\int_{\tilde{v}}^{\bar{v}} \Pi^{E*}(F, \mathcal{S}(v))\, d\Phi(v) + (1 - \Phi(\bar{v}))\, \Pi^{E*}(F, \bar{s}) \geq K.$$

Otherwise, $d_a^*(F) = 0$.

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

Proof. Differentiating the objective function in the firm's application problem (A9) with respect to d_a suggests that $d_a^*(F) = 1$ if and only if

$$\int_{-\infty}^{\infty} \widetilde{\Pi}^{E*}(F, s^*(F,v))\, d\Phi(v) - \widetilde{\Pi}^{E*}(F, 0) \geq K, \tag{A19}$$

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

Part (i): If $F \leq \underline{F}$, Lemmas A4 and A6 imply that the firm is able to finance its investment ($d_f^*(F, s, \mathcal{R}(s), \pi^*(F,s)) = 1$) for all $s \in [0, \bar{s}]$. Thus, $\widetilde{\Pi}^{E*}(F,s) = \Pi^{E*}(F,s)$ by equation (A5). Lemma A7 in turn implies that $s^*(F,v) = s_N^*(F,v)$. Therefore, the first term in the left-hand side of equation (A19) can be written as

$$\int_{-\infty}^{\infty} \widetilde{\Pi}^{E*}(F, s^*(F,v))\, d\Phi(v) = \Phi(\underline{v})\, \Pi^{E*}(F, 0)$$

$$+ \int_{\underline{v}}^{\bar{v}} \Pi^{E*}(F, \mathcal{S}(v))\, d\Phi(v) + (1 - \Phi(\bar{v}))\, \Pi^{E*}(F, \bar{s}).$$

As a result, equation (A19) can be rewritten as

$$\int_{\underline{v}}^{\bar{v}} \Pi^{E*}(F, \mathcal{S}(v))\, d\Phi(v) + (1 - \Phi(\bar{v}))\, \Pi^{E*}(F, \bar{s}) \tag{A20}$$

$$- (1 - \Phi(\underline{v}))\, \Pi^{E*}(F, 0) \geq K,$$

in which the first and second term describe the firm's expected profits from receiving an optimal unconstrained subsidy rate and a maximum subsidy rate upon application, and in which the third term describes the net opportunity cost to applying taking into account that, with probability $\Phi(\underline{v})$, the firm's subsidy application will be rejected. The claim in part (i) follows: For $F \leq \underline{F}$, $d_a^*(F) = 1$ if and only if condition (A20) holds and $d_a^*(F) = 0$ otherwise.

Part (ii): If $F \in (\underline{F}, \bar{F}]$, Lemma A7 implies that $s^*(Fs) = s_C^*(F, s)$. Thus the firm contemplating a subsidy application knows that if and only if $v \geq \tilde{v}(F)$, the agency will award a sufficiently high subsidy rate $s \in (\tilde{s}(F), \bar{s}]$ to make $\widetilde{\Pi}^{E*}(F, s) = \Pi^{E*}(F, s) > 0$ and that if $v < \tilde{v}(F)$, the firm will either receive no subsidy in which case the firm cannot finance its investment and makes no profits, or it will receive subsidy $\tilde{s}(F)$ that just satisfies the R&D participation constraint, which by definition also leads to zero profit for the firm. Therefore the application constraint (A19) can be rewritten as

$$\int_{\tilde{v}}^{\bar{v}} \Pi^{E*}(F, \mathcal{S}(v))\, d\Phi(v) + (1 - \Phi(\bar{v}))\, \Pi^{E*}(F, \bar{s}) \geq K. \tag{A21}$$

The claim in part (ii) follows: for $F \in (\underline{F}, \bar{F}]$, $d_a^*(F) = 1$ if and only if the condition (A21) holds and $d_a^*(F) = 0$ otherwise.

Part (iii): If $F > \bar{F}$, Lemmas A6 and A7 stipulate that the firm cannot finance its investment even if it received a maximum subsidy, and therefore the agency awards no subsidy. As the firm makes no profits from applying for a subsidy, equation (A19) cannot hold. As a result, for $F > \bar{F}$, $d_a^*(F) = 0$. ■

Proposition A1 summarizes Lemmas A1 − A8 and shows how the equilibrium is a well defined mapping on $F \in [0, \infty)$.

Proposition A1 *In the unique equilibrium of* $\Gamma(F)$, $\pi^*(F, s) = \overline{\pi}^*(F, s)$ *for all* $s \in [0, \bar{s}]$. *There are* $\underline{F}, \bar{F} \in [0, \infty)$, *with* $0 < \underline{F} < \bar{F}$ *such that:*

(i) If $F \in [0, \underline{F}]$, *then for all* $s \in [0, \bar{s}]$, $d_f^*(F, s, \mathcal{R}(s), \overline{\pi}^*(F, s)) = 1$ *and, hence,*

$R^*(F,s)=\mathcal{R}(s)$. *Moreover,* $s^*(F,v)=s_N^*(v)$*, and* $d_a^*(F)=1$ *if and only if*

$$\int_{\underline{v}}^{\bar{v}} \Pi^{E*}(F,\mathcal{S}(v))\,d\Phi(v)+(1-\Phi(\bar{v}))\,\Pi^{E*}(F,\bar{s})-(1-\Phi(\underline{v}))\,\Pi^{E*}(F,0)\geq K$$

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

(ii) If $F\in(\underline{F},\bar{F}]$*, then for* $s\in[\tilde{s}(F),\bar{s}]$*,* $d_f^*(F,s,\mathcal{R}(s),\bar{\pi}^*(F,s))=1$ *and, hence,* $R^*(F,s)=\mathcal{R}(s)$ *and, for* $s\in[0,\tilde{s}(F))$*,* $d_f^*(F,s,\mathcal{R}(s),\bar{\pi}^*(F,s))=0$ *and, hence,* $R^*(F,s)=0$*. Moreover,* $s^*(F,v)=s_C^*(F,v)$*, and* $d_a^*(F)=1$ *if and only if*

$$\int_{\tilde{v}}^{\bar{v}} \Pi^{E*}(F,\mathcal{S}(v))\,d\Phi(v)+(1-\Phi(\bar{v}))\,\Pi^{E*}(F,\bar{s})\geq K.$$

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

(iii) If $F\in(\bar{F},\infty)$*, then for all* $s\in[0,\bar{s}]$*,* $d_f^*(F,s,\mathcal{R}(s),\bar{\pi}^*(F,s))=0$ *and, hence,* $R^*(F,s))=0$*. Hence,* $s^*(F,v)=0$ *and* $d_a^*(F)=0$*.*

Let us now discuss the consequences of Assumption A1. As shown in the proof of Lemma A6, the key role of Assumption A1 is to ensure that $\underline{F}>0$. Suppose that Assumption A1 fails to hold so but a less stringent condition $\ln[\alpha/(r+c-\bar{s})]\geq 1$ holds. Then we have $\underline{F}\leq 0\leq\bar{F}$. In this case a firm invests if and only if it receives a subsidy. Part (i) of Proposition A1 no longer exists, but parts (ii) and (iii) are unchanged except that part (ii) exists now for $F\in[0,\bar{F}]$. If $\ln[\alpha/(r+c-\bar{s})]<1$, then $\bar{F}<0$, and only the uninteresting case of part (iii) of Proposition A1 exists.

Finally, we collect the results about the effects of financial frictions on the agency's subsidy decisions. Writing the relevant variables explicitly as functions of financial frictions c, we have

Proposition A2 *(i) For* $v\in[v^0(c,F),\tilde{v}(c,F))$*,* $\tilde{s}(c,F)>\mathcal{S}(c,v)$*.*

(ii) $\min\{v^0(c,F),\underline{v}(c)\}>0$*.*

(iii) $\underline{v}(c)\lesseqqgtr v^0(c,F)$ *if and only if* $g\varphi(c)\lesseqqgtr e^{\left(1+\frac{F}{\varphi(c)}\right)}$*.*

(iv) $\mathcal{S}(c,v),\mathcal{R}(c,\mathcal{S}(c,v)),\underline{F}(c)$*, and* $\bar{F}(c)$ *are decreasing in* c*.*

(v) $\tilde{s}(c,F),\mathcal{R}(c,\tilde{s}(c,F)),\underline{v}(c)$*,* $\tilde{v}(c,F)$*,* $v^0(c,F)$ *and* $\bar{v}(c)$ *are increasing in* c*.*

Proof. Part (i): In the proof of part (ii) of Lemma A7, we prove that $\tilde{s}(c,F)>\mathcal{S}(c,v)$ for $v<\tilde{v}(c,F)$ and that $\tilde{v}(c,F)>v^0(c,F)$. Thus, $\tilde{s}(c,F)>\mathcal{S}(c,v)$ for $v\in[v^0(c,F),\tilde{v}(c,F))$.

Part (ii): Lemma A7 directly proves that $\underline{v}(c)>0$ and $v^0(c,F)>0$.

Part (iii): The condition follows from equations (A16) and (A18) after some algebra.

Part (iv): From equation (A15) we obtain $\partial\mathcal{S}/\partial c=-(g-1)<0$. Next, recall from equation (2) that

$$\mathcal{R}(c,s)=\frac{\alpha}{r+c-s}. \tag{A22}$$

Substituting $\mathcal{S}(\cdot,v)$ from equation (A15) for s in the right-hand side of equation (A22) gives

$$\mathcal{R}(\cdot,\mathcal{S}(\cdot,v))=\frac{\alpha}{(r+c)g-v},$$

from which we observe that $\mathcal{R}(\cdot, \mathcal{S}(\cdot, v))$ is strictly decreasing.

Then, recalling $\varphi(c) := \alpha/(r+c)$ from Assumption A1 and differentiating equations (A10) and (A11) with respect to c gives

$$\frac{\partial \underline{F}}{\partial c} = \varphi'(c) \ln \varphi(c) < 0$$

and

$$\frac{\partial \bar{F}}{\partial c} = -\varphi \left[\frac{1}{r+c} \big(\ln(\frac{\alpha}{r+c-\bar{s}}) - 1 \big) + \frac{1}{r+c-\bar{s}} \right] < 0,$$

in which the inequalities follow from Assumption A1 and $\bar{s} < 1 \leq r + c$.

Part (v): Differentiating equation (A12) gives

$$\frac{\partial \tilde{s}}{\partial c} = 1 + F e^{-\left(1+\frac{F}{\varphi(c)}\right)} > 0.$$

Next, substituting $\tilde{s}(\cdot, F)$ from equation (A12) for s in the right-hand side of equation (A22) yields

$$\mathcal{R}(\cdot, \tilde{s}(\cdot, F)) = e^{\left(1+\frac{F}{\varphi(c)}\right)},$$

from which we observe that $\mathcal{R}(\cdot, \tilde{s}(\cdot, F))$ is increasing (strictly increasing for $F > 0$ because $\varphi'(c) < 0$.

Then, differentiating equation (A16) and noting that $\bar{v}(c) := \underline{v}(c) + \bar{s}$ yield $\partial \underline{v}/\partial c = \partial \bar{v}/\partial c = g - 1 > 0$. Finally, differentiating equations (A17) and (A18) yield, respectively,

$$\frac{\partial \tilde{v}}{\partial c} = g + F e^{-\left(1+\frac{F}{\varphi(c)}\right)} > 0,$$

and

$$\frac{\partial v^0}{\partial c} = g \left[1 + F e^{-\left(1+\frac{F}{\varphi(c)}\right)} \right] > 0.$$

■

Part (i) of Proposition A2 together with Lemma A7 implies that whenever granting $\tilde{s}(c, F)$ is optimal, it is larger than the unconstrained subsidy rate $\mathcal{S}(c, v)$. Part (ii) together with Lemma A7 implies that a positive spillover rate is a necessary condition for the firm to obtain a subsidy irrespective of whether its R&D participation constraint is binding. Part (iii) implies that $v^0(c, F)$ and $\underline{v}(c)$ cannot be unambiguously ranked; depending on parameter values the agency's subsidy-granting threshold can be higher with or without a concern for the R&D participation. Part (iv) suggests, e.g., that the higher are financial frictions c, the smaller is the optimal unconstrained subsidy rate $\mathcal{S}(c, v)$. Part (v) in turn suggests, e.g., that the higher is c, the higher are the optimal constrained subsidy rate $\tilde{s}(c, F)$ and the agency's subsidy-granting thresholds $\underline{v}(c, F)$ and $v^0(c, F)$.

Appendix D: Derivation of Firms' 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 an R&D tax credit rate $\tilde{\tau}_R \in [0, 1]$, which firms can claim whether or not they have a corporate tax liability. We may rewrite an investor's expected payoff (A2) as

$$\Pi^I(F, R, \pi) = (1 - \tau)\left[P\pi - (r + c)(R + F)\right]. \tag{A23}$$

and a firm's expected stage-3 payoff (A1) as

$$\Pi^E(\tilde{\tau}_R, R, \pi) = (1 - \tau)\left[P\left(A \ln R - \pi\right)\right] + \tilde{\tau}_R R. \tag{A24}$$

As in Appendix C, we can identify the minimum repayment that induces the investor to finance the firm (cf. equation (A4)). Letting the investor's expected payoff from equation (A23) to be equal to 0 and solving the resulting equation for π gives

$$\overline{\pi}(F, R) := \overline{\pi}(F, 0, R) = \frac{(r + c)(R + F)}{P}. \tag{A25}$$

Because investors behave competitively, $\overline{\pi}(F, R)$ of equation (A25) identifies the equilibrium repayment obligation for all $R \in (0, \infty)$ (cf. A4). After substitution of the right-hand side of equation (A25) for π in equation (A24), the firm's expected stage-3 payoff can be expressed as

$$\Pi^E(F, \tau_R, R) = (1 - \tau)\left[\alpha \ln R - (r + c - \tau_R) R - (r + c)F\right]. \tag{A26}$$

In equation (A26), $\tau_R = \tilde{\tau}_R / (1 - \tau)$ denotes a tax credit rate that is adjusted with the prevailing corporate tax level. Equation (A26) corresponds to the firm's objective function of equation (1) save for s being replaced by τ_R. Thus, by Lemma A5, the firm's optimal R&D investment decision rule with an R&D tax credit is identical to the one given by equations (2) and (3) with τ_R replacing s.

Equation (A25) shows that the equilibrium repayment obligation is now independent of the R&D tax credit rate whereas in Section 3 the equilibrium repayment obligation is contingent on the subsidy rate (see equation (A4)). As equations (A1), (A4), (A24), and (A25) show, now the firm claims the tax credit but has to promise a higher repayment to the investor than in Section 3; everything else is unchanged from Section 3. Thus, it makes no major difference whether financing contracts are written before or after subsidy decisions and whether they are contingent on the subsidy or tax credit rates.

Appendix E: Counterfactual

Execution. For the counterfactual, we use the estimated parameter values and the assumed functional forms. We then draw shocks (ε_{it}, ζ_{it} η_{it}, μ_{it}) from their estimated (joint) distribution. We replace 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 the estimated cost of external 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 gives 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	1.000	768 507	34 023	802 530	1.000
1^{st} best	0.63	278 492	128 046	2.379	725 403	82 875	821 264	1.023
2^{nd} best	0.61	266 438	124 606	2.315	728 572	79 397	820 956	1.023
No financial frictions	0.61	127 293	58 721	1.091	774 875	37 119	811 994	1.012
Tax credits	0.62	186 563	85 054	1.584	795 997	53 771	807 921	1.007
Subsidies	0.61	196 043	85 276	1.50	788 751	55 970	802 905	1.001
$s\|s > 0$		484 753		1.50				
Only 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	1.000	1 071 675	56 106	1 127 781	1.000
1^{st} best	0.63	477 645	241 506	2.580	1 006 207	152 806	1 159 013	1.028
2^{nd} best	0.62	463 791	237 024	2.532	1 009 298	149 040	1 158 338	1.027
No financial frictions	0.62	177 509	93 625	1.000	1 071 698	56 113	1 127 811	1.000
Tax credits	0.63	281 237	150 497	1.607	1 117 539	90 199	1 137 305	1.008
Subsidies	0.62	234 441	121 442	1.297	1 079 765	74 050	1 119 216	0.992
$s\|s > 0$		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	1.000	1 198 377	56 997	1 255 374	1.000
1^{st} best	0.63	490 711	239 880	2.315	1 142 516	140 979	1 283 495	1.022
2^{nd} best	0.62	475 261	235 682	2.275	1 145 333	137 527	1 282 860	1.022
No financial frictions	0.62	200 646	103 626	1.00	1 198 399	57 003	1 255 403	1.000
Tax credits	0.63	295 412	154 354	1.49	1 241 097	84 928	1 263 048	1.006
Subsidies	0.62	255 250	127 601	1.23	1 205 536	71 470	1 247 116	0.993
$s\|s > 0$		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; ratio (welfare) is the mean welfare in the regime in question divided by the laissez-faire mean welfare.

Table E2. Counterfactual estimates

variable	balance sheet based cost of finance	only subsidies	excluding 3 largest firms
$\Pr[apply]$	0.182	0.152	0.152
$subsidy\ rate \mid s > 0$	0.420	0.420	0.390
τ_R	0.410	0.390	0.340
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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