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Innovation Policy Reform

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1 Introduction

Investments in innovation are perceived both by academics and policy makers important for the enhancement of economic growth and welfare, and fraught with market failure. These perceptions are mirrored in actual innovation policy: different policies that seek to correct market failure(s) by increasing private sector investment in R&D have a central role in many developed countries (e.g. the EU Lisbon agenda, Small Business Innovation Research Program in the U.S.) and are used also by some developing countries (e.g. India has both an R&D tax credit and R&D subsidies). The two main innovation policy tools are R&D subsidies and tax incentives for R&D. R&D subsidies are the second largest and fastest growing form of industrial support in OECD countries (Nevo 1998) and used by all OECD countries (Warda 2006). Also tax incentives for R&D are increasingly popular: 20 out of 27 OECD countries offered some form of R&D tax reliefs in 2006. Industrialized countries have also been active in changing their innovation policies: several countries have e.g. introduced R&D tax reliefs since the early 1990s. There exists a large but inconclusive literature on the effects of both policy instruments on private R&D investments (Hall and van Reenen 2000 survey the R&D tax credit and David, Hall and Toole 2000 the R&D subsidy literature), yet essentially no empirical work that seeks to compare and contrast, let alone derive the optimal levels, of these two major tools of innovation policy. Given the importance of innovation, the size of perceived market failure(s) mirrored in the extent to which developed and, increasingly, developing nations, resort to using both R&D subsidies and tax incentives

for R&D and the frequency of changes in policy, there seems to be a need to analyze innovation policy. The objective of this paper is to provide such an analysis.

To accomplish a comparison of different innovation policies, one has two possibilities. The first one is to collect data on policy changes such as the recent movement in e.g. Norway from a subsidies only - regime to a regime of both subsidies and R&D tax credits (see Moen and Haegeland 2007). This approach would allow one to estimate the treatment effects of the policy (change). The second possibility is to build a structural model, estimate its parameters within a given policy regime and then use the structure and estimated parameters to answer counterfactual questions (see Heckman and Vytlacil 2006a,b and Abbring and Heckman 2006). The latter approach has the added appeal that one can potentially solve for optimal new policies and can more generally compare several policies. We take this second route in this paper and study an economy, Finland, that only uses R&D subsidies. We keep the (policy) environment constant in other respects and study the following counterfactual questions: What are the welfare effects of an optimally designed innovation policy reform compared to i) no innovation policy, and ii) current policy? Do current R&D subsidies yield a higher or a lower social surplus than optimal R&D tax credits? Which firms benefit and which firms lose? What is the tax burden created by the optimal policy?

We build on the recent work by Takalo, Tanayama and Toivanen (2008) (henceforth TTT) who construct a structural model of the R&D subsidy allocation process and estimate it using Finnish R&D project level data. Besides offering high quality data for our purposes, Finland is an interesting case in

its own right: e.g. Trajtenberg (2001) has pointed out that Finland is one of the few countries that have managed to considerably improve their innovation performance over the last few decades. In Finland, only R&D subsidies are in use, although there is an ongoing debate about the introduction of an R&D tax credit. We assume throughout that the objectives of the government are those revealed by the structural estimation of the model using data from a R&D subsidies only - regime. This could be viewed as a strength of our approach as whatever the government objectives, we keep them constant over different policy regimes.

Two market failures are regularly invoked to justify government support for private R&D: first, the wedge between social and private returns that can manifest itself at both the intensive and/or extensive margins and second, financial market imperfections. TTT only incorporated the intensive margin. We extend that work to include both the extensive margin and heterogenous cost of finance. We extend their work in other ways, too: First, by adopting a more general form for the profit function; second, by estimating the model using improved data on firm characteristics that allows us to control better for past innovative activities of firms through information on patents, past successes in the application process, R&D investments, and R&D employees; and third, by using actual instead of planned R&D expenditure. Most important, we derive the socially optimal level of an R&D tax credit, and the privately optimal R&D investments in the different regimes, and conduct counterfactual analyses.

The identification of different model parameters rests on different sources of variation which we feel are rather intuitive: We identify how R&D affects

profitability by using variation in actual R&D investments; parameters of the spillovers (per dollar of R&D) from agency subsidy decisions; parameters governing the cost of applying for a subsidy from the yes-no-decision to apply (or not) for a subsidy; and the fixed cost of R&D from the discrete decision to (not) invest in R&D. Estimating all the equations as a system would be prohibitive, not least because in order to estimate some of them we need to calculate expectations which are based on parameter estimates from other equations. These different equations are therefore estimated in an order that allows us an easy way imposing parameter values estimated at an earlier stage in the estimation process.

Most of the existing empirical work on R&D subsidies and tax credits utilizes reduced form models. Our work complements the existing literature by modeling explicitly the market failures used to motivate the reduced form approaches. Explicit modeling brings with it some potential advantages: the interrelationships between the mechanisms affecting the dependent variables are made clear, and may help in understanding what are the critical assumptions one needs to make in order to identify the model. Somewhat surprisingly, we find that an increase in the cost of finance leads to a reduction, not an increase, in the optimal subsidy. The effect of a fixed cost of R&D, generating the extensive margin used to justify activist innovation policy, may lead to lower or higher subsidies. Our model thus throws some light on the alleged mechanisms used to motivate activist policies, and suggests that they do not always provide a foundation for government intervention.

The use of a structural model leads unavoidably not only to benefits, but also to costs, notably the need of imposing parameter restrictions. The

potentially most controversial assumption, made already by TTT, is that the shock on the spillovers that a dollar of R&D generates is not correlated with the shock the the private quality of the idea, i.e., to the shock determining the private profitability of the R&D project. It is important to note that this assumption does not remove the endogeneity problem with which the reduced form R&D subsidy papers attempt to deal in various ways.[1] TTT tested and could not reject this assumption. We point out that while potentially controversial, this assumption allows us to estimate spillovers per dollar of R&D at the level of an individual R&D project; something that has not been achieved before. Additionally, given that the focus of this paper is not only on estimated parameter values, but also on a counterfactual, the assumption of exogeneity of explanatory variables is more crucial than in TTT whose interest was in treatment effects.

We find that an optimal R&D tax credit and R&D subsidies yield significantly higher R&D investment and spillovers than what would be generated by a laissez-faire regime. The difference in private profits is however small. Both activist policies - R&D tax credits and R&D subsidies - yield outcomes that are close to each other. A crucial difference between the policies is that one (the tax credit) is available to all, the other (subsidies) is available only upon application. R&D subsidies generate almost the same level of spillovers as an R&D tax credit despite less than 10% of firms getting a subsidy: This is explained by the fact that subsidies can be tailored for each applicant's R&D project. This result shows that an important aspect of an R&D sub-

[1]The reason is that the subsidy is still endogenous through the shock to the quality of the project which determines the private profitability of the R&D project and affects the costs of applying for a subsidy.

sidy - regime is that it provides the government information about private sector R&D projects; information that would not be obtained in a tax credit regime. In terms of overall welfare all the three regimes amount to the same once we take into account the shadow cost of public funds. We compare our estimated optimal R&D tax credit to tax incentives used in other countries, and find that its effective impact is somewhat above the average of actual policies, but well below the most generous tax treatments. [2]

The rest of the paper is organized as follows: we briefly describe the prevailing Finnish innovation policy model in the following section. In section three, we present the model. As the model is built around the existing Finnish policy of using R&D subsidies only, it at the same time characterizes what an (by assumption) optimal R&D subsidy policy looks like. Section four is devoted to deriving an optimal innovation policy reform by replacing subsidies with a tax credit. We proceed by first deriving the optimal tax subsidy assuming no extensive margin, and then introduce these. We also derive the laissez-faire benchmark for active innovation policies. In section five we present our data. Section six is devoted to explaining our estimation approach and to reporting our estimation results. Counterfactual calculations are reported in section seven. We then contrast our findings with the stylized facts of innovation policy in different countries in section eight before concluding the paper in section nine.

[2] [?]has reviewed the use of different innovation policy tools in OECD countries.

2 Finnish innovation policy

We confine ourselves to a discussion of public sector support to private sector R&D. Since the early 1980s, the main policy tool of Finnish innovation policy has been the Finnish Funding Agency of Technology and Innovation, or Tekes.[3] Tekes grants R&D subsidies, low-interest loans, and so-called capital loans[4] and is the principal public financier of private R&D in Finland. The primary objective of Tekes is to promote the competitiveness of Finnish industry and the service sector by providing funding and advice to both business and public R&D. To this end Tekes strives to increase Finnish firms' R&D and risk-taking. Tekes is also responsible for allocating funding from European Regional Development Funds (ERDF), which is meant for the less-favored regions.[5]

Besides funding business R&D, Tekes finances feasibility studies, and R&D by public sector including scientific research. In 2001 Tekes funding amounted to 387 million. Almost exactly 2/3s of the nearly 3000 applications

[3] For a more thorough description of Finnish innovation policy of the early 2000's, and a description of Finnish innovation more generally, see e.g. Geoghiu et al (2003).

[4] Low-interest loans are soft in that if the project turns out to be a commercial failure, the loan may not have to be paid back. A capital loan granted is included in fixed assets in the balance sheet. A capital loan can be paid off only when unrestricted shareholders' equity is positive. Collateral cannot be part of a capital loan contract.

[5] Finnish regions are heterogenous: e.g. some 20% of the population lives in the capital region in Southern Finland, where also a large part of the economic activity and most of R&D takes place.

were accepted. The number of applications by the business sector for R&D funding was over 1300, 2/3 of which were accepted. Business sector subsidies amounted to over 200 million euros. Tekes' business R&D funding consists of grants, low-interest loans and capital loans. The share of each instrument in 2001 was 69 %, 18% and 13% of the total funding allocated to business R&D. Subsidies' share of applications (granted amount) was 83 (67) %.

The application process runs as follows (see Tanayama 2007for a more detailed description): First, a firm decides whether or not to apply for a subsidy. After receiving an application Tekes grades it and then decides on the subsidy level. This is subject to minimum (zero) and maximum (50 or 60% depending on whether or not the applicant is an SME) constraints.[6] Our understanding is that this process is well known among potential applicants. In our analysis, we use the two most important (as declared by Tekes' officials in our discussions) grading dimensions: the technical challenge of the project, and the marketing risk of the project. Tekes' public decision criteria are: the project's effect on the competitiveness of the applicant, the technology to be developed, the resources reserved for the project, the collaboration with other firms within the project, societal benefits, and the effect of Tekes' funding. Tekes takes into account whether the application comes from an SME. The funding also has a regional dimension through ERDF.

The purpose and the budget of the R&D project for which Tekes funding is needed are included in the application as is the applied amount of funding. Tekes' subsidy is granted as a share of to-be-incurred R&D costs. Actual

[6]These have changed somewhat since our observation period. See www.tekes.fi. The EU SME definition requires that a firm has less than 250 employees and has either sales less than 40 million euros or a balance sheet of less than 27 million euros.

funding is only given after the R&D investments are made. It covers the promised share of incurred costs up to a specified euro limit. The limit prevents Tekes from covering costs extraneous to the project proposal.

3 The Model

The model consists of three types of players: A firm with an R&D project, an agency that gives R&D subsidies, and financiers offering private funding for R&D. The R&D project involves both a variable investment and a fixed cost. We assume that it has no funds of its own, but it can try to tap both the private and the public sector for external funding. As in Holmström and Tirole (1997) the firm's ability to borrow is constrained by a (interim) moral hazard problem. We assume that all private sector financiers (unlike the public financier) have access, at a cost, to a monitoring technology that reduces the scope for moral hazard.

Timing of events Our model is a four-stage game of incomplete information between a firm (a potential applicant), the private and public financiers. In stage one, the firm decides whether or not to apply to a subsidy program. The application includes a proposal for an R&D project. In stage two, the public financier screens and evaluates the proposed project (if the firm applied in the first stage). It then decides the level of a subsidy, which at this stage amounts to a credible promise to reimburse ex post a share of the variable investment costs. The subsidy level can be subject to a maximum constraint that is stricly less than unity, and it is zero if there is no application or the application is rejected. In stage three, private sector financiers decide on whether to invest in monitoring and supply the rest of the needed

project funding. In stage four the firm chooses the project and invest in it. If the firm has been granted a subsidy in stage two, it will be reimbursed accordingly.

Note that the public sector financier acts as a Stackelberg leader with respect to private sector financiers in this game. Note also that the private sector financiers invest in monitoring before the firm makes the project choice. This sequential timing simplifies the analysis considerably but could in principle be relaxed.[7]

Informational assumptions We make three key informational assumptions. First, we assume for brevity that the type of the public financier is drawn from a common knowledge distribution and, in particular, is not known by the firm when it contemplates subsidy application. As will be made more precise below, the public financier's type is about how the public financier values the firm's project. This informational assumption amounts to the requirement that potential applicants are uncertain about the public financier's objective function and valuation of their projects when they make the application decision. This ensures (in line with our data) equilibrium outcomes where a firm applies for a subsidy only to be turned down. Since in our model the public financier cannot signal its type to a potential applicant, it is immaterial whether the type is private information or there is symmetric but incomplete information regarding the public financier's type at the application stage. We opt for the simpler assumption that the public financier learns its type after receiving and screening an application (i.e.

[7]A similar assumption is used by Winton (1993) and Holmström and Tirole (1997). Simultaneous decisions at this stage would generally lead to mixed-strategy equilibria.

symmetric but incomplete information regarding the public financier's type prevails at the application stage).

Second, we assume that the firm's investment is non-verifiable to third parties (e.g., to courts) and that hence neither public nor private funding decisions can be written contingent on the firm's investment. This gives rise to a standard moral hazard problem.

Compared with our second informational assumption and standard corporate finance models, where typically the project type affecting its returns is, e.g., a borrower's private information and unknown to a (private sector) lender, our first informational assumption may sound unorthodox. However, there is much less theoretical literature about public funding of private R&D. To us, it is quite reasonable to think that the firm, when contemplating application, does not exactly know what the public financier is maximizing and how the public financier values the firm's project. This kind of ambiguity is less of an issue in case of private financiers since they are assumed to maximize their profits. To avoid complexities arising from signalling games, we assume that the project type is common knowledge.

Third, we assume that the shock to spillovers generated by the firm's R&D, internalized by the agency but not the firm nor the private financiers, is not correlated with the shock that determines the private profitability ("quality") of the R&D project. As noted in the introduction, this assumption does not remove the endogeneity problem that the reduced form R&D subsidy literature has attempted to solve through various ways, but allows us to 1) transform the endogeneity problem into a selection problem (we only observe the project level R&D investments of firms that apply and receive a subsidy)

and 2) estimate the agency decision rule to uncover the spillovers generated by R&D.

Other assumptions While we think that our first two informational assumptions are rather harmless, we make one further assumption which is quite strong: We assume that the public financier's budget constraint does not bind. This is only motivated by simplicity and should be relaxed in future work, but we do impose a cost of financing on the public financier. To facilitate the empirical implementation of the model we assume that the public funding can only be extended towards variable costs. In line with our empirical application, we also assume that the public funding cannot cover the costs of external finance.

Equilibrium concept We focus on perfect Bayesian equilibria where, in stage one, a potential applicant correctly anticipates the type-contingent strategies of the public financier in stage two, and where the player's strategies are sequentially rational. Since we want to estimate the key equations of the model, we use more specific functional forms than would be necessary from a purely theoretical point of view.

Structure of the remaining section The rest of this section is structured as follows: We start by showing how we model the imperfect capital market. The two key ingredients are the firm's choice of project (type) which naturally depends on the production technology, and the financier's monitoring decision. We then proceed to explain the firm's optimal R&D decision and its participation decision (i.e., whether or not it invests in R&D). There-

after we show how the agency's decision-making is modeled, and finish the section by describing the optimal first stage choice of the firm, i.e., whether or not to apply for a subsidy.

3.1 Production technology and project choice

In our model a firm needs to incur both a variable cost R_i and a fixed cost W_i to undertake an innovation project i. If the firm invests both R_i and W_i, we specify that the project yields, conditional on success (and gross of fixed cost W_i), expected discounted profits of

$$\Pi_i = \alpha_i^{\gamma_i - 1} \left(\frac{R_i^{\gamma_i} - 1}{\gamma_i} \right) \tag{1}$$

where $\alpha_i \equiv e^{\alpha_0 - \varepsilon_i}$ (inversely) determines the productivity, conditional on success, of the firm's investment in innovation. The parameter $\gamma_i \in (0, 1)$ in turn is inversely related to the concavity of the project's return in R&D, conditional on success. The reason that the parameter α_i is raised to the power $\gamma_i - 1$ is technical and will become clear with the first order condition: It allows us to derive an estimable (log) R&D equation. While α_i and γ_i are thus related, it is helpful to think of the former as a measure of the quality of the project (idea) and the latter as a measure of the concavity of profits in R&D. It is plausible to think that the firms and projects differ both in the productivity and in the concavity of the project returns. When $\gamma_i \to 1$, the conditional return becomes linear in R_i and when $\gamma_i \to 0$, the standard logarithmic return function emerges. All profits are taxed at the rate τ.

To formalize the moral hazard problem and the role of monitoring, we

assume that, prior to investing R_i, the firm can choose from two projects. A "good" project succeeds with a high probability p_i, $p_i \in (0,1)$, but provides no private benefits. A (very) "bad" project succeeds with a lower probability $p_{Li} < p_i$ but yields large private benefits equal to B_i. Without loss of generality we assume that $p_{Li} = 0$ and that B_i is extremely large ($B_i \longrightarrow \infty$). The assumption of extremely large B_i means that if the firm can freely choose the project, it will always pick up the very bad project. By investing in monitoring the private financier can eliminate the very bad project from the firm's choice set. Hence, conditional on monitoring, the firm will choose the good project.

3.2 Private finance and monitoring

We follow corporate finance literature and assume competitive financial markets. We assume (as in Holmström and Tirole 1997), that monitoring is costly and the private financier needs to be provided with incentives to monitor. More specifically, to prevent the firm from choosing the extremely bad project the private financier must bear an unobservable private monitoring cost c_i per unit of funds extended to the firm. Since the firm has no liquid funds of its own and since, as in our empirical application, the public financier provides the subsidy ex post, the private financier must first fund the whole investment and is then partially reimbursed by the public financier. Note that the cost of monitoring is assumed to be project specific.

Let us denote the private sector financier's share of the project return, conditional on success, by π_i^B (superscript B standing for a "bank"). This

implies that the private financier needs to get at least

$$\pi_i^B \geq \frac{c_i\left(R_i + W_i\right)}{p_i} \tag{2}$$

to invest in monitoring. The private financier is willing to supply this amount if the zero-profit condition holds:

$$\Pi_i^B = p_i \pi_i^B - (1+\rho)\left(R_i + W_i\right) - c_i\left(R_i + W_i\right) + s_i R_i \geq 0. \tag{3}$$

In (3) $1+\rho$ is market rate of return (the opportunity cost of financier's funds) and s_i is the subsidy rate provided by the public financier. Equation (3) shows how the private financier first funds the whole investment $R_i + W_i$ and is then reimbursed by the public financier a fraction $s_i R_i$ of the variable costs. As mentioned, we assume that the public financier reimburses neither fixed costs nor the cost of external finance.

Rearranging (3) gives

$$\pi_i^B \geq \frac{\left(1+\rho+c_i\right)\left(R_i+W_i\right) - s_i R_i}{p_i}. \tag{4}$$

Because of the competitive financial market, (2) and (4) can be written as equalities. As a result, the financier will receive

$$\pi_i^B = \max\left\{\frac{c_i\left(R_i + W_i\right)}{p_i}, \frac{\left(1+\rho+c_i\right)\left(R_i+W_i\right) - s_i R_i}{p_i}\right\},$$

but since $W_i \geq 0$, $\rho > 0$, and $s_i < 1$ (in our empirical application $s_i \leq \overline{s}_i = \{0.5, 0.6\}$), it is immediate from the above equation that the financier's IC is

slack, i.e., that the financier's share of project returns is given by

$$\pi_i^B = \frac{(1+\rho+c_i)(R_i+W_i) - s_i R_i}{p_i}. \tag{5}$$

3.3 R&D investment

Because the firm has no liquid funds of its own and the firm chooses R_i to maximize $\Pi_i^F = p_i \left(\Pi_i - \pi_i^B\right)$ (with superscript F referring to the firm),[8] which can be rewritten by using (1) and (5) as

$$\Pi_i^F = \frac{a_i^{\gamma_i - 1}}{\gamma_i}\left(R_i^{\gamma_i} - 1\right) - (r_i - s_i) R_i - r_i W_i, \tag{6}$$

where $r_i \equiv 1+\rho+c_i$ captures the cost of external funding raised from private capital market, and a_i subsumes both the probability of success and α_i. Since the objective function (6) is concave in R_i, the first-order condition

$$R_i = a_i^{-1}\left(\frac{1}{r_i - s_i}\right)^{\frac{1}{1-\gamma_i}} \tag{7}$$

gives the firm's optimal investment $R_i(s_i)$ as an increasing function of the subsidy level and a decreasing function of the costs of external private capital. Note that the profits generated by the optimal investment given by (7) need to be large enough to ensure that the firm's participation constraint is satisfied. This requires that

$$\frac{1}{a_i \gamma_i}\left[\left(\frac{1}{r_i - s_i}\right)^{\frac{\gamma_i}{1-\gamma_i}}(1-\gamma_i) - a_i^{\gamma_i}\right] - r_i W_i \geq 0 \tag{8}$$

[8] Π_i^F is defined as gross of tax. As corporate tax is multiplicative, they do not affect the FOC of the firm.

must hold. If this were not the case, the firm would not invest and equation (8) is the firm's individual rationality (IR) constraint.

3.4 Public funding

The public financier's utility from the applicant's project i is given by

$$U_i = V_i R_i(s_i) + \Pi_i^F + \Pi_i^B - g s_i R_i(s_i) \tag{9}$$

where $g > 1$ is the constant opportunity cost of the public resources, e.g., the opportunity cost of tax funds. As (9) shows, the firm's and private financier's profits directly enters the public financier's utility function. Function V_i in (9) determines the public financier specific returns from the project. That is, V_i captures the effects of the firm's project on the public financier beyond the firm's and private financier's payoffs and the direct costs of subsidy. In our empirical application, V_i can include externalities from a firm's R&D such as consumer surplus or technological spillovers to other firms. Note that V_i can also be negative, e.g., due to duplication of R&D costs, business stealing effects, and negative environmental externalities.

As (9) also shows the public financier specific returns V_i are assumed to be linear in the investment level. This simplification - which is again made with the empirical implementation of the model in mind - may seem unrealistic but similar assumptions are common in the literature on growth and R&D spillovers.[9]

We specify that $V_i \equiv \overline{V_i} + \eta_i$, with η_i capturing the type of the public

[9] This assumption allows the existence of a steady state in endogenous growth models.

financier, drawn from the common knowledge distribution with pdf $\phi(\eta)$ and cdf $\Phi(\eta)$ and $\overline{V_i}$ being the the mean spillover per dollar of R&D of project i. As mentioned, it is known by the public financier when it makes the subsidy decision but is not known by the firm when it makes the application decision. Our informational assumptions mean that the potential applicant is uncertain about how the public financier, after screening the project proposal, sees the project and its potential to generate spillovers, consumer surplus, or private benefits to the public financier's civil servants.

In stage two the public financier, after receiving and screening the application, chooses the subsidy level, s_i, to maximize (9), taking account (7), (8), and (3) as well as the constraints for s_i. Since (5) implies $\Pi_i^B = 0$ (the assumption of competitive financial markets) we can rewrite the public financier's program as

$$\max_{s_i} U_i = V_i R_i(s_i) + \Pi_i^F(R_i(s_i), s_i) - g s_i R_i(s_i) \tag{10}$$

subject to

$$R_i = a_i^{-1}\left(\frac{1}{r_i - s_i}\right)^{\frac{\gamma_i}{1-\gamma_i}}, \tag{i}$$

$$\frac{1}{a_i\gamma_i}\left[\left(\frac{1}{r_i - s_i}\right)^{\frac{\gamma_i}{1-\gamma_i}}(1-\gamma_i)_i - a_i^{\gamma_i}\right] \geq r_i W_i, \tag{ii}$$

$$s_i \leq \overline{s_i}, \tag{iii}$$

as well as the non-negativity constraints for s_i and U_i.

Let us first characterize the solution to the public financier's unconstrained problem. By using the envelope theorem and (6) the first-order

condition for the public financier's unconstrained problem (10) is given by

$$s_i \equiv s_i^* = \frac{V_i - r_i\,(g-1)\,(1-\gamma_i)}{1+\gamma_i\,(g-1)} \tag{11}$$

Notice that the optimal subsidy is decreasing in cost of finance r_i: At least in our model, financial market imperfections do not lead to higher, but to lower subsidies. Equation (11) shows how the public financier's unconstrained decision rule is naturally increasing in the project valuation, V_i, and decreasing in the shadow cost of public funds, g. It is also decreasing in the costs of private capital r_i.

Let us next consider the case in which (ii) (the firm's IR constraint) binds but (iii) does not bind. Then the subsidy level is given by

$$s_i \equiv \widehat{s}_i = r_i - \left(\frac{(1-\gamma_i)}{r_i W_i a_i \gamma_i + a}\right) \tag{12}$$

There are five possibile agency decisions: First, the optimal subsidy is zero; second, that the optimal subsidy is positive and larger than $\hat{s}_i$, yielding an interior solution; third, that the optimal subsidy is the maximum subsidy; fourth, that the optimal subsidy is smaller than $\hat{s}_i$, and the agency's IR constraint is satisfied at $\hat{s}_i$; and fifth, that the optimal subsidy is smaller than $\hat{s}_i$, and the agency's IR constraint is not satisfied at $\hat{s}_i$, yielding a zero subsidy. It can be shown that if $\bar{s}_i > \hat{s}_i$, the following holds:

$$Pr[s_i* \leq 0] < Pr[U(R(\hat{s}_i)) < 0] < Pr[s_i* < \hat{s}_i] < Pr[s_i* < \bar{s}_i]. \tag{13}$$

Equation (23) can be used to construct the agency's expected decision,

and the estimator for the agency decision. Notice that from (23) it is not clear whether the existence of fixed costs of R&D increase of decrease the average subsidy. The reason for this ambiguity is that while for some values of the spillover shock fixed costs lead to a higher subsidy level than without (when the agency IR constraint is satisfied and firm IR constraint binds), in another region fixed costs lead to a lower (=zero) level of subsidies (when the firm IR constraint binds but the agency IR constraint is violated).

3.5 Firm's application decision

In stage one of the game, the firm has to decide whether or not to apply for a subsidy. In deciding whether or not to apply, it takes into account the cost of applying, K_i, and the profits it would earn were it not to apply. The decision is given by

$$d_i = 1[max\{0,\ p_{inv}E[\Pi_i^F(R_i(s_i), s_i) - W_i] - K_i\} \geq max\{0,\ \Pi_i^F(R_i(0), 0) - W_i] \tag{14}$$

where p_{inv} is the probability of the firm's IR constraint being satisfied, and $E[\Pi_i^F(R_i(s_i), s_i) = \left(\frac{1-\gamma_i}{\gamma_i a_i}\right)\left(E(r_i - s_i)^{\frac{\gamma_i}{\gamma_i - 1}} - r_i^{\frac{\gamma_i}{\gamma_i - 1}}\right)$ are the expected profits gross of fixed costs of both R&D and application, conditional on the firm's IR constraint being satisfied.

4 Optimal policy reform

The equivalent of the optimal tax policy question (see e.g. Auerbach and Hines 2002) would be to introduce tax credits into the model and then

optimize with respect to corporate taxes (subsidies) and tax credits. We will take the existing corporate tax rate as given on the grounds that it is not determined purely from an innovation policy perspective and it is precisely the two other tools, subsidies and R&D tax credits, that allow the policy maker to tailor the environment so as to discriminate between innovative and other firms. We will therefore assume 1) that the existing regime of subsidies only is implemented optimally given the regime; 2) that the social planner can replace the R&D subsidies by R&D tax credits (but not use both simultaneously);[10] and 3) that the social planner can optimize these. The question we pose is this: suppose the government decides to scrap R&D subsidies in favor of R&D tax credits and assume these have to be uniform across firms. What would the optimal R&D tax credit be? We start by introducing our way of modeling an R&D tax subsidy, proceeding to characterize the agency's derivation of the optimal tax credit, and finish the section by characterizing the benchmark laissez-faire regime.

4.1 Tax incentives

The first thing to note is that it is easy to show that R&D tax credits and R&D tax allowances amount to the same thing within our model. We therefore concentrate on tax credit. In our model the optimal level of R&D in a world of no innovation policy (or R&D subsidies only, the prevailing regime in Finland) is neutral with respect to the corporate tax rate τ which in Finland was 0.29 during our observation period 2000-2002. Introducing R&D

[10] Nothing prevents us from conducting a counterfactual analysis where both subsidies and a tax credit are used. We have however been unable to derive the optimal tax credit in the presence of subsidies. As the choice of level of the tax credit would then be arbitrary, we have chosen not to implement that counterfactual.

tax credits into the above model changes the firm's objective function from a project to:

$$\pi_i^F = (1-\tau)[a_i^{\gamma_i - 1}\left(\frac{R_i^{\gamma_i} - 1}{\gamma_i}\right) - (r_i - \tau_c)\, R_i] \tag{15}$$

where τ is the corporate tax rate on profits and τ_c is what we call the R&D tax credit. It is related to the standard tax credit as follows: $\tau_{cstand} = \tau_c(1-\tau)$. We use this transformation as it is easier to work with and allows us to compare the optimal tax credit directly to the currently used subsidies. The main difference is that the tax credit is uniform and available to all firms, whereas subsidies are tailored to each applicant. Notice that our modeling of the R&D tax credit implicitly assumes that the firm is going to get the tax credit even if the project fails. Whilst this is somewhat against the nature of a "pure" tax credit, it is in line with the tax credit rules of several countries such as the Netherlands and Norway. The optimal level of R&D in a tax credit regime is given by

$$R^{TC} = \frac{(r_i - \tau_c)^{\frac{1}{\gamma_i - 1}}}{a_i}. \tag{16}$$

4.2 Optimal level of tax incentives

With fixed costs of R&D, the planner's problem includes those firms who would execute their project even without a subsidy but will expand their project if they receive government support, those whose contribution to the

objective function of the planner is as above, and those firms who would not implement their project without a tax credit. The contribution of the latter has to be weighed by the probability of them conducting R&D. Taking the above into account and recalling that the agency sums over all firms' projects, the agency's objective function can be written as

$$U^{SP}(.) = \sum_{i} U^{SP}(R_i(\tau_c)) = + \sum_{W_i > 0} \Phi_\epsilon(\hat{\epsilon}_i(\tau_c))[V_i R_i(\tau_c) + \Pi_i^F(R_i(\tau_c)) - g\tau_c R_i(\tau_c)]. \tag{17}$$

In (17), $\hat{\epsilon}_i(\tau_c)$ is the unique value for the shock to project quality of firm i that satisfies the firm's IR constraint and $\Phi_\epsilon(\hat{\epsilon}_i(\tau_c)) \in [0, 1]$ is the probability of the firm's IR constraint being satisfied. We have written it as a function of τ_c to stress that the choice of the level of the R&D tax credit not only affects these firms' intensive margin, but also their extensive margin. $\hat{\epsilon}_i(\tau_c)$ can be solved numerically from the firm's IR constraint (8). Equation (17) has a unique maximum which we solve for numerically.

4.3 Laissez-faire benchmark

The benchmark we use for active policies is laissez-faire which we take to mean an environment with no government support for private R&D. The (privately) optimal level of R&D is then given by

$$R_i^{LF} = \frac{{r_i}^{\frac{1}{\gamma_i - 1}}}{a_i}, \tag{18}$$

and the laissez-faire levels of expected discounted profits and spillovers

by

$$\Pi_i^{LF} = \frac{1}{a_i\gamma_i}[(1-\gamma_i)r_i^{\frac{\gamma_i}{\gamma_i-1}} - a_i^{\gamma_i}] \tag{19}$$

and

$$V_i\frac{r_i^{\frac{\gamma_i}{\gamma_i-1}}}{a_i} \tag{20}$$

if the firm's individual rationality constraint is satisfied, and zero otherwise.

5 Data

Our data comes from two sources. The project level data comes from Tekes, containing all applications to Tekes from January 1^{st} 2000 to June 30^{th} 2002. It consists of detailed information on the project proposals and Tekes' decisions. The firm level data comes from Statistics Finland. It combines information from the Business Register's enterprise-level data and the statistics on research and development. The Business Register data covers enterprises' addresses, branches of industry, size categories of personnel and turnover, dates of establishments and importer/exporter data. The data sources of the Business Register are several administrative records and Statistics Finland's direct inquiries to enterprises. Statistics on research and development (R&D panel) in turn contain data on e.g. R&D expenditure and funding, R&D personnel and R&D person-years. The statistics are based on data obtained from enterprises and are compiled according to the recommendations of the OECD and EU. The period covered is 1985-2005. We use all the firms in the R&D panel that have belonged to the survey at least once during the

years 1997 - 2000. Firms that have not existed since 2000 have been excluded. Given that we treat our application period as a cross section we have constructed our covariates in the following way: First we have taken the information for 1999, if that was missing we have tried the 2000, 1998 and 1997 information respectively. Firm characteristics are thus recorded earlier than the subsidy decision.[11] After cleaning the data of firms with missing values, we are left with 6 910 firms. These firms constitute our sample of potential applicants. The firms in our sample account for roughly 35% of all applications.

Table 1 displays summary statistics of our explanatory variables for potential applicants, and Table 2 conditions the statistics on the application decision and success. Potential applicants are heterogenous. They are on average 13 years old with 93 employees. Only very few firms are not SMEs according to the official EU standard. Sales per employee, a measure of value added, is 173 000. Almost half of the firms are exporters.

[TABLE 1 HERE]

From Table 2 we see that applicants are larger than non-applicants and successful applicants smaller than rejected ones. The median number of employees for non-applicants is 20, for applicants 24, and for rejected applicants

[11] Even if we use the 2000 information for some firms, it is unlikely that the subsidy decision has affected the figures since there is a considerable lag between the application date and the subsidy decision date.

21. Unsurprisingly, applicants have more previous applications on average than non-applicants. The share of accepted applications is also higher for the applicants.

Table 3 reports information about applications and Tekes' decisions. The application data we use in the estimations comprises 2193 applications. XXX firms had more than one application. Some 20% of applications are rejected.

We test the robustness of our results to the definition of a subsidy by using only pure subsidies.

[TABLE 3 HERE]

6 Estimation and results

6.1 Estimation

Estimation proceeds in five steps. These are: 1) estimation of agency grading decisions; 2) estimation of firms' R&D investment decision conditional on investment (firms' first order condition); 3) estimation of firms' discrete decision whether or not to invest in R&D; 4) estimation of the agency subsidy decision; and 5) estimation of firms' decision whether or not to apply for a subsidy. We now explain each step, and the parameters we identify at each step.

Step 1: Agency grading rule. First, the agency grading rules for technical challenge and marketing risk are estimated using ordered probits. These are used to generate the firms' predictions on how the agency would grade their application. Data on all applications is used.

Step 2: Firm's FOC Second, the firms' R&D investment decision is estimated as a log-linearized version of (7):

$$\ln R_i = -a_{0i} - \frac{1}{\gamma_i - 1} \ln(r_i - s_i) + \epsilon_i. \tag{21}$$

Here the value of assuming that a_0 is raised to power $\gamma_i - 1$ becomes visible: We get a firm-specific coefficient on $\ln(r_i - s_i)$ while at the same time obtaining a standard additively linear error term (= the "quality" shock ϵ_i). This equation is subject to a sample selection problem in our data as we only observe the (project level) R&D investments of those firms that apply for and receive a subsidy. We therefore estimate the equation with standard sample selection methods. For identification we exploit the Tekes rule that the maximum subsidy is 10 precentage points higher for SMEs. This nonlinearity in firm size means that ceteris paribus, an SME is more likely to apply for a subsidy.The sample for the first stage consists of all firms, that of the second stage of those firms that obtain a nonnegative subsidy and whose actual R&D decision we thus observe. The first stage consists thus of the estimation of the outcome on whether a firm applied for and was granted a subsidy, and is therefore reduced form. Estimation of the investment decision (21) yields $\hat{\gamma_i}$ and $\hat{a_{0i}}$ which both are functions of observed firm characteristics (thus the i subscript in both). As explained above, we currently proceed by using an observed value for r_i.

Step 3: Firms' discrete R&D decision We use the parameters $\hat{\gamma_i}$ and $\hat{a_{0i}}$, and simulation of the profitability shocks ϵ_i to estimate the firm's discrete

decision of whether or not to invest in R&D. Here, data on all firms will be used. This step yields parameters of the fixed cost of R&D, and allows us to calculate the expected value of them.

Step 4: Agency decision In the fourth stage we estimate the agency decision rule. Here we exploit our knowledge of firm's investment plans at the time of applying since these are available for all firms that apply for a subsidy; actual investments are only available for those that receive a positive subsidy and execute the project. We also utilize the assumption that the spillover schock (η_i) and the profitability shock (ϵ_i) are uncorrelated. These features of the data and the model allow us to calculate the subsidy that satisfies the firm's IR constraint with equality ($\hat{s_i}$), up to the shock to the fixed cost (which we simulate). We then estimate the agency decision utilizing the equations

$$s_i \equiv \widehat{s}_i = r_i - \left(\frac{(1-\gamma_i)}{r_i W_i a_i \gamma_i + a} \right) \tag{22}$$

at the interior solution, and

$$Pr[s_i * \leq 0] < Pr[U(R(\hat{s_i})) < 0] < Pr[s_i * < \hat{s_i}] < Pr[s_i * < \bar{s_i}]. \tag{23}$$

The estimation equation for the agency decision rule, after specifying that $\overline{V}_i = Z_i \delta$, is

$$s_i = \frac{Z_i \delta + r_i(1-g)(1-\gamma_i) + \eta_i}{1 - \gamma_i(1-g)}. \tag{24}$$

This has to be appropriately censored at the lower and upper limits for

a subsidy. The grading and agency decision rule estimations allow us to calculate $E(r_i - s_i)^{\gamma_i/(\gamma_i-1)}$, which is needed for structural estimation of the application and R&D investment equations.

Step 4: Application costs and covariance between ν and ϵ To uncover the parameters of the application cost and correlation between the shock to application costs and the shock to the quality of the project we (re-) estimate the sample selection model. Now the first stage is the firm's decision to apply for a subsidy, and the second stage the investment decision.[13]The application equation is

$$d_i = 1[\left(\frac{1-\gamma_i}{\gamma_i a_i}\right)\left(E(r_i - s_i)^{\frac{\gamma_i}{\gamma_i-1}} - r_i^{\frac{\gamma_i}{\gamma_i-1}}\right) - K_i \geq 0]. \tag{25}$$

The application cost is parameterized as $K_i = exp(Y_i\theta + \nu_i)$, where ν_i, the shock to the cost of applying, is allowed to be correlated with the quality shock ϵ_i. This formulation allows the linearization of (25) by taking logs, and the estimation of the cost of application parameters θ as well as the parameters of the error distribution. Structural estimation requires that we include in the first stage the effect on profits from applying for a subsidy. Theory dictates that the coefficient of this term ($\ln\left(E(r_i - s_i)^{\gamma_i/(\gamma_i-1)} - r_i^{\gamma_i/(\gamma_i-1)}\right)$) be unity. We follow TTT in assuming that all explanatory variables are exogenous, and the shocks are independent of each other with the exception that ϵ_i and ν_i may be correlated. Notice in particular that, as stressed by

[13]Here we use the level of investment the firm announces in its application that it would invest. TTT offer an explanation for this level of investment being the level the firm would invest if it received the maximum subsidy.

TTT, the assumption that η_i and ϵ_i are independent does not mean that ϵ_i would not affect spillovers: it affects them through R_i. To be able to estimate the structural application decision, the first stage dependent variable is an indicator variable that takes the value one if a firm applied for a subsidy, and zero otherwise (thus different from the first stage in Step #1 of the estimation process). The second stage consists of the planned R&D investment which is observed for all applicants, not only those who obtain a nonnegative subsidy decision.

6.2 Estimation results

NOTE: WE CURRENTLY REPORT ESTIMATES OF A MODEL WITHOUT THE FIXED COST OF R&D.

We include into all estimation equations firm age, the log of the number of employees, sales per employee, a dummy for a parent company, a dummy for exporters, the number of previous applications, the share of accepted previous applications, the number of patents[14], a dummy for USPTO patents, R&D investment to sales ratio, R&D personnel per number of employees and personnel with university degree per number of employees. We also include industry and region dummies. The SME dummy is only included in the Tekes decision rule (24) and the application equation (25). We include it in (25) to allow for the possibility that SMEs' opportunity costs are different e.g. because of different access to other types of subsidies. Inclusion of the SME dummy in the application equation and exclusion of it from the R&D

[14] Our patent variable is the sum of Finnish patent applications, EPO patent applications and granted USPTO patents.

equation is sufficient for (nonparametric) identification. Our model yields additional identification through the expectation term in (25). We currently estimate the model with cost of finance set to be the period's average 12 month market interest rate plus a margin of 3 percentage points. Thus far we have succeeded in estimating reliably neither the cost of finance nor the fixed cost of R&D. We present first the parameters of the agency's objective function and move then to the estimation results parameter's describing the firms' technology.

Tekes decision rule. In Table 4 we report the results concerning the Tekes decision rule, the coefficients of which can be interpreted as the marginal effects of R&D on spillovers. We find that the more challenging a project is technically, the higher is its subsidy rate. A one point increase on the 5-point Likert scale leads to a 13-14 percentage point increase in the subsidy rate. Market risk carries an insignificant coefficient. As against Tekes' stated preference that allows a 10 percentage points higher level of maximum subsidy for SMEs, it is unsurprising that SMEs are granted a higher subsidy, everything else equal: the difference is 11 percentage points. R&D investment to sales ratio, having USPTO patents, and the proportion of highly educated employees have all a negative and significant effect on the subsidy rate. This means that Tekes considers the marginal effect of additional R&D investment on spillovers to be smaller in firms that are already actively engaged in R&D. A potential explanation is that an increase in those characteristics leads to a firm better internalizing the benefits of its R&D.

[TABLE 4 HERE]

Investment function. This equation is close to what is often estimated in existing work on (treatment effect of) R&D subsidies, but our interpretation of the parameters is different in two ways: First, our investment equation identifies the effects of exogenous variables on marginal profitability of R&D investment. Second, our model yields a heterogenous effect of subsidies on R&D. Also, in our model the explanatory variables are in the coefficient of the subsidy variable, rather than entering linearly as is usual. In view of the received R&D literature, it is likely that unobserved heterogeneity accounts for a substantial part of the marginal profitability of R&D. In light of this, Table 5 contains a surprisingly large number of significant coefficients. Larger firms and firms with higher value-added current production have higher marginal profitability of R&D. All the R&D variables (R&D intensity, patent variables, proportion of highly educated employees) have a positive (but decreasing) impact on marginal profitability of R&D investment. Variables measuring past application activity (number of past applications, and fraction of successful ones) have a negative effect on R&D.

[TABLE 5 HERE]

Application cost function. In Table 6 we report the estimates of the application cost function. As we are currently lacking standard errors, we comment the point estimates only briefly. Firm size has a non-linear decreasing effect on application costs. Sales per employee increase application costs, as does the R&D/sales ratio. One interpretation is that firms producing high

value added products and services and/or are investing in R&D have complicated R&D projects based on soft information that are laborious to write down. Another is that because the opportunity costs of the effort of making and promoting an application are probably far greater than the direct monetary costs of filling in and filing it, firms with high value current production have higher opportunity costs of applying. Having a US patent significanlty reduces the application cost: The explanation could be that such firms have expertise with dealing with bureaucracy. Having highly educated workers decreases the cost of application. Both the number of past applications, and the share of successful applications decrease application costs. This results may of course be due to unobserved heterogeneity.

[TABLE 6 HERE]

Covariance structure. We are able to identify the variances of all error terms, and the covariance between the unobservables in the application and investment equations (Table 7). The coefficient determining the variance share of investment shock in the application cost shock obtains a value of 0.8. Ceteris paribus, the higher the unobserved marginal profitability of the R&D project of a firm, the less likely it is that the firm will submit an application. It could be that, similar to projects with higher sales per employee, projects with higher marginal profitability of R&D are more complicated involving tacit knowledge and are therefore more difficult to describe in an application. Or it could be that projects with higher marginal profitability of R&D have higher opportunity costs, which constitute a major part of application costs.

[TABLE 7 HERE]

7 Counterfactual calculations

The following regimes are compared: 1) no policy; 2) subsidies only (the prevailing regime in Finland); and 3) tax incentives only. We use our estimated parameter values and draw pseudorandom numbers (currently 1000) for the shocks from distributions with characteristics set to those implied by our estimated parameter values. We first use these simulation runs to calculate the optimal tax credit. We then calculate the outcome variables of interest (R&D, spillovers (= agency specific benefits), profits, and welfare). We also calculate the out-of-pocket public sector expenditure on tax allowances and subsidies, and the application costs of firms for the subsidy regime.

First we report the level (means) of R&D investment, profit, and spillovers in the laissez-faire regime (Table 8). Across the three estimated models the figures are relatively close to each other, with R&D investment being circa 500 000€, profits roughly 3M€, spillovers slightly less than 200 000€, and welfare round 3M

[FIGURE 1 HERE]

In Table 9 we report the level of the optimal tax credit (τ_c), the euro level of R&D tax credit and subsidy, and the probability of applying for a subsidy. The optimal tax credit is 0.15 which compares to an average subsidy of 0.22. In euros, a tax credit costs round 100 000 euros/firm. Finally, the probability to apply is 11%.

[TABLE 9 HERE]

7.1 Mean outcomes

In Table 10 we compare active policies to the laissez-faire outcomes. We find that active policies generate significantly higher R&D investment than laissez-faire: with a tax credit investments are 29% and with an R&D subsidy 5% higher compared to laissez-faire. A tax credit increases profits by 11% whereas R&D subsidies yield private profits that are very close to the laissez-faire profit levels. The spillovers that active policies generate are significantly above those of the laissez-faire world: It is noticeable that R&D subsidies generate bigger increase in spillovers than R&D tax credits, relative to the increases in R&D investment. This difference between the two policy tools is due to the ability of the agency to tailor subsidies to each applicant. In terms of overall welfare, taking into account also the shadow cost of public funds, neither tax relief nor subsidies fare significantly better than laissez-faire. The welfare comparison however reveals that the activist policies increase welfare only modestly, by less than 1.2 percentage points.

[TABLE 10 HERE]

7.2 Distributional effects

In Figure 2 we plot the distribution of R&D investments over the three regimes. The shift of the distribution to the right because of activist policies is clear: R&D tax credits shift the distribution noticeably more than R&D subsidies. Given the low probability of applying for subsidies, this was expected. Figure 3 shows the distribution of firm profits. Clearly, the distribution is not greatly affected by activist policies. Spillovers (Figure 4), on the other hand, display a similar shift in probability mass to the right as the R&D investment distribution.

[FIGURES 2-4 HERE]

7.3 Discussion

The welfare number above are produced ignoring any administrative costs of running the activist regimes, and the cost of compliance in the R&D tax credit regime is assumed to be zero, too. In addition, the model assumes that firms do not report as R&D anything else than real R&D investments, and clearly our result is not robust to such behavior even on a modest scale. These considerations suggest that the activist policies' effects are if anything, lower than what our estimates imply.

On the other hand, our model assumes that firms and therefore projects are in Finland; this might not be the case if Finland went for laissez-faire. Brander and Spencer (1983) is the seminal paper analyzing strategic innovation policy, demonstrating the possibility that governments may find themselves in a Prisoner's dilemma. While Brander and Spencer do not consider "footloose" R&D, it is clear that allowing relocation of R&D would only strengthen the Prisoner's dilemma. We cannot therefore rule out that we underestimate the benefits of active innovation policy.

8 Actual policies vs. optimal policies in the OECD

OECD uses the so called B -index to compare the generosity of the tax treatment of R&D in different countries (for more details on the B index see Warda 2006). B - index measures the after tax cost of one unit of R&D expenditure divided by one minus the corporate income tax rate. The rate of tax subsidy is in turn measured as 1 minus the B index: our tax credit $\tau_c = 1 - B$. Figure 5 shows how our result is positioned in the OECD statistic describing the actual rate of tax subisides in various countries. Our estimates of τ_c, i.e., OECD's 1-B, is 0.15. These are close the average tax subsidy, which is 0.18 for SMEs and 0.19 for large firms, and well below the largest tax subsidies of 0.39 and 0.37 in Spain and in Mexico respectively.

[FIGURE 5 HERE]

What is clear from our model is that the crucial issue in determining the optimal level of an R&D tax credit is the level of spillovers. Whilst impossible to prove within our model, it is our view that the low level of spillovers relative to private profits that we estimate is due to the structure of the Finnish economy. Finland is a small open economy whose population amounts to 0.01% of world population and whose R&D is roughly 1% of global R&D. It is therefore very plausible that a very good idea in terms of an idea's capacity to generate expected discounted profits is one that generates revenues primarily outside Finland. As the Finnish social planner only internalizes Finnish consumer surplus and spillovers to other domestic firms, these can (and seem to) be significantly lower than the private profits which the Finnish social planner completely internalizes.

9 Conclusions

The objective of this paper was to analyze a reform in innovation policy - the introduction of R&D tax credits - that has either been undertaken, or is being considered, by many industrialized countries. To achieve this objective, we solve a structural model for the optimal R&D tax credit, and use our parameter estimates to calculate the effects of the policy change. Our model incorporates the market failures most often used to motivate activist government intervention: the intensive and extensive margin on R&D investments due to the investing firm not completely appropriating the returns of R&D, and financial market imperfections due to asymmetric information. We show

that while the first of these (the intensive margin) leads to higher subsidies, the effect of the second (the extensive margin) on the optimal subsidy is ambigous, and that of the last (financial market imperfections) is to decrease the optimal subsidy.

For purposes of comparison, we not only compare the actual policy of R&D subsidies to that of an R&D tax credit - only regime, but also compare the outcomes generated by these two policies to what would have been achieved under laissez-faire. A benefit of our approach is that we first uncover the policy maker's preferences from implementing the actual (R&D subsidy) policy, and then keep them constant when we change policies. A fundamental assumption of our approach is thus that the observed policy actions are based on optimizing behavior.

We find that the optimal R&D tax credit in Finland is 15%. We also find that private profits dominate spillovers. The most likely explanation for this is that Finland is a small open economy and therefore most of the consumer surplus and knowledge spillovers that Finnish R&D generates lie outside Finnish borders and are therefore not internalized by Finnish policy makers. This line of reasoning would suggest that the optimal Finnish R&D tax credit should be lower than in an otherwise similar but larger country.

When comparing the outcomes in the different policy regimes we find that optimal R&D tax credits and current R&D subsidies produce higher levels of R&D and spillovers than laissez-faire, with a tax credit having a larger effect than subsidies. Private profits are increased by a tax credit but not by subsidies. Once we take into account the shadow cost of public funds to calculate overall welfare all the three regimes amounts to almost the same.

Thus activist policies would be needed to be motivated by considerations that are outside our model, such as the government's objective of affecting the location of R&D.

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Table 4
Tekes Decision Rule Results

Variable	Dep. var. subsidy-intensity (all finance)
Risk	-.005 [-.023 .014]
Challenge	.138*** [.117 .159]
Age	.002** [.00003 .003]
ln(# Employees)	-.038*** [-.054 -.022]
Sales per employee, 1000€	-.000005 [-.00005 .00004]
SME dummy	.113*** [.058 .168]
Exporter dummy	.031 [-.020 .082]
# past Tekes applications	.0009*** [.0003 .001]
Share of accepted past Tekes applications	.089*** [.026 .151]
# past patents	-.00006 [-.0002 .00007]
USPTO patents dummy	-.056* [-.107 -.004]
R&D investment / sales ratio	-.001*** [-.002 -.0004]
Personnel with university degree / employees ratio	-.069** [-.139 .00007]
Foreign ownership	-.0008 [-.001 -.00006]
Constant	.141** [.023 .259]
INDUSTRY DUMMIES	YES
REGIONAL DUMMIES	YES
PERIOD DUMMIES	YES
σ_η	.255 [.239 .270]
Nobs.	1015
LogL.	-170
Wald	
Linearity 1	
Linearity 2	

Table 5

R&D In

	Coefficient [95 % confidence interval]
	-.023*
	[-.049 .003]
	.0003
	[-.0002 .0008]
	1.009***
	[.569 1.450]
	-.068***
	[-.108 -.028]
	.002***
	[.0009 .004]
	-1.93e-06***
	[-3.38e-06 -4.79e-07]
	-.203
	[-.481 .074]
	-.027***
	[-.041 -.014]
	.00008***
	[.00004 .0001]
	-2.296**
	[-4.446 -.146]
	2.207**
	[.096 4.317]
	.002***
	[.001 .003]
	-1.29e-06***
	[-1.90e-06 -6.93e-07]
	.318***
	[.095 .540]
	.006**
	[.001 .011]
	-.00001*
	[-.00002 1.70e-07]
	4.566***
	[2.630 6.502]
	-3.536***
	[-5.650 -1.423]
	.014
	[-.005 .033]
	-.0001
	[-.0003 .00007]
	3.895***
	[-5.296 -2.495]
INDUSTRY DUMMIES	YES
REGIONAL DUMMIES	YES
PERIOD DUMMIES	YES
Nobs	1382

Table 6
Application Cost Function Results

Variable	Coefficient [95 % confidence interval]
Age	.147
	[ ]
Age sq.	.-001
	[ ]
ln(employees)	-1.774
	[ ]
ln(employees) sq.	.065
	[ ]
Sales per employee, 1000€	.0009
	[ ]
Sales per employee sq.	9.82E-8
	[ ]
Exporter dummy	-.450
	[ ]
SME dummy	-.385
	[ ]
# past Tekes applications	-.364
	[ ]
# past Tekes applications sq.	.001
	[ ]
Share of accepted past Tekes applications	-20.201
	[ ]
Share of accepted past Tekes applications sq.	15.141
	[ ]
# past patents	.003
	[ ]
# past patents sq.	-4.42E-06
	[ ]
USPTO patents dummy	-1.478
	[ ]
R&D investment / sales ratio	.009
	[ ]
R&D investment / sales ratio sq.	.0001
	[ ]
Personnel with university degree / employees ratio	-7.206
	[ ]
Personnel with university degree / employees ratio sq.	2.161
	[ ]
Foreign ownership	.017
	[ ]
Foreign ownership sq.	-7.65E-06
	[ ]
Constant	6.970
	[ ]
INDUSTRY DUMMIES	YES
PERIOD DUMMIES	YES
REGIONAL DUMMIES	YES
Nobs	23458

Table 7

Covariance Structure Results

Variable	Coefficient [95 % confidence interval]
Standard deviation of the investment equation shock, σ_ε	1.059
Standard deviation of the Tekes specific utility (	

NOTES: Reported numbers are coefficient and [95% confidence interval]. For all but σ_η, these are based on a bootstrap with 400 repetitions. For σ_η, it is based on the estimated covariance

***, **, and * denote significance at 1, 5, and 10% level.

Table 8
Outcomes under laissez faire, €

	R&D investment	Profits	Externalities	Social benefit
Average	531 896	3 323 624	196 854	3 520 479
Median	532 561	2 689 322	198 198	2 890 066

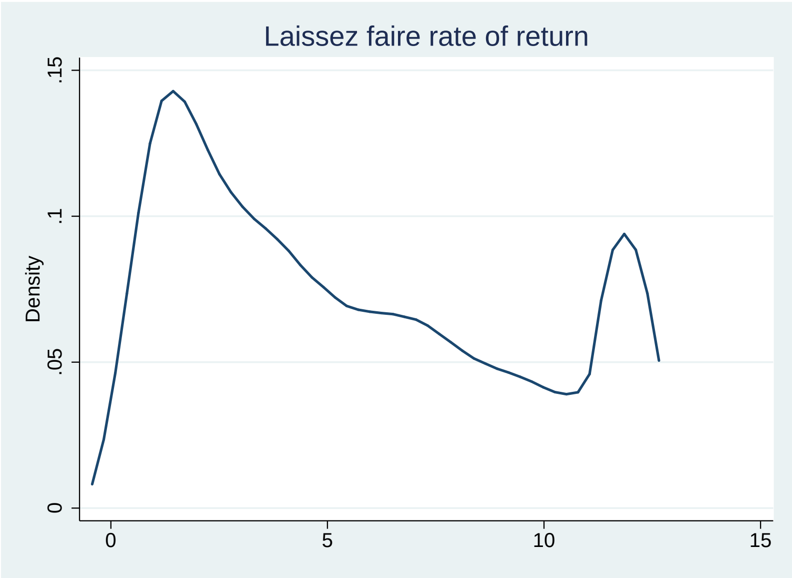
Table 9
Parameters and outcomes

Tax credit	Subsidy	Tax credit, €	Subsidy, €	Prob(Apply)
0.15	0.22	99 926	123 313	0.11

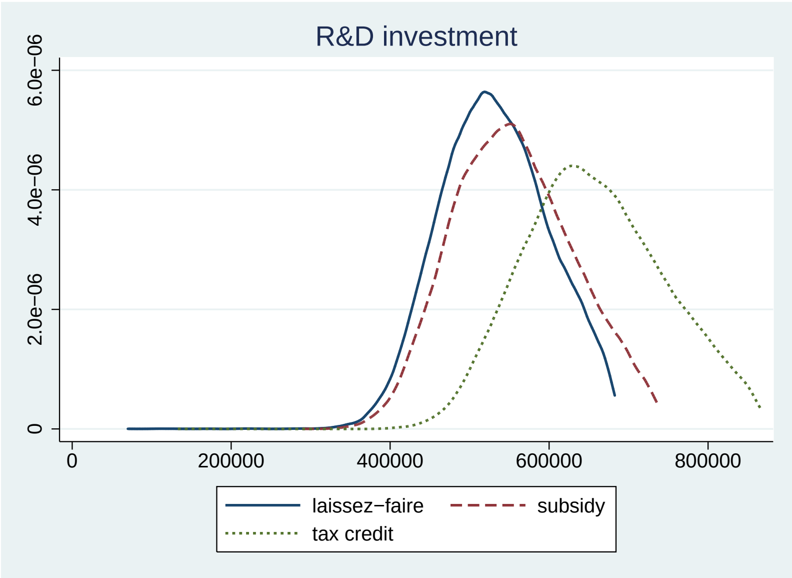
Table 10

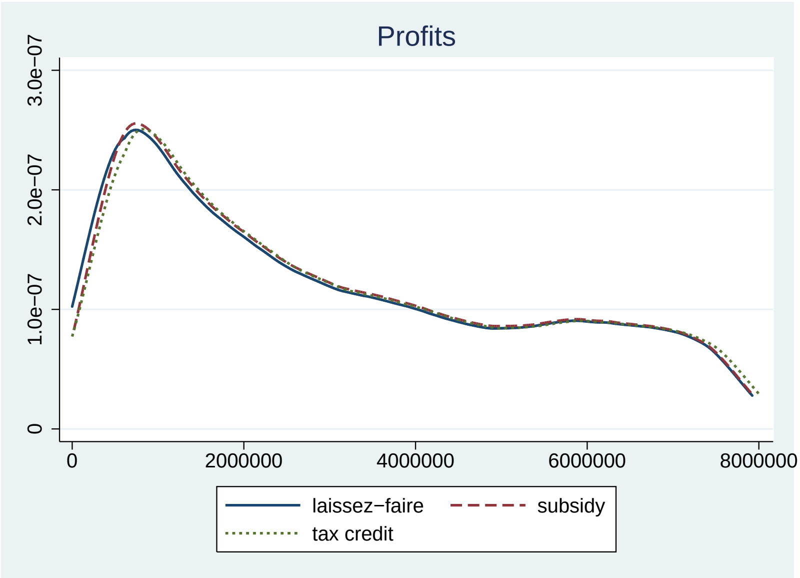
Outcome of simulations as percentage of laissez-faire outcome

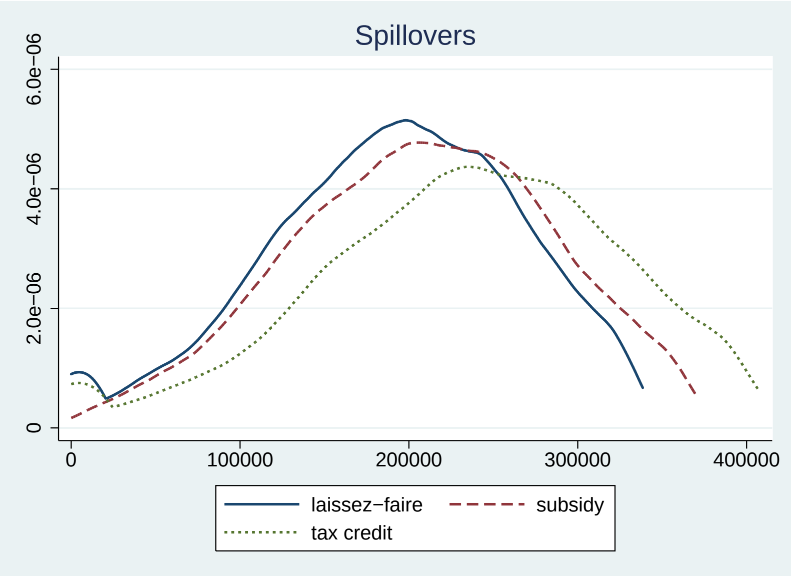
Policy regime	R&D investment	Profits	Externalities	Social benefit
Tax relief	129 %	111 %	129 %	101.17 %
Subsidy	105 %	101 %	108 %	100.24 %



Laissez faire rate of return
Density
0
.05
.1
.15
0
5
10
15

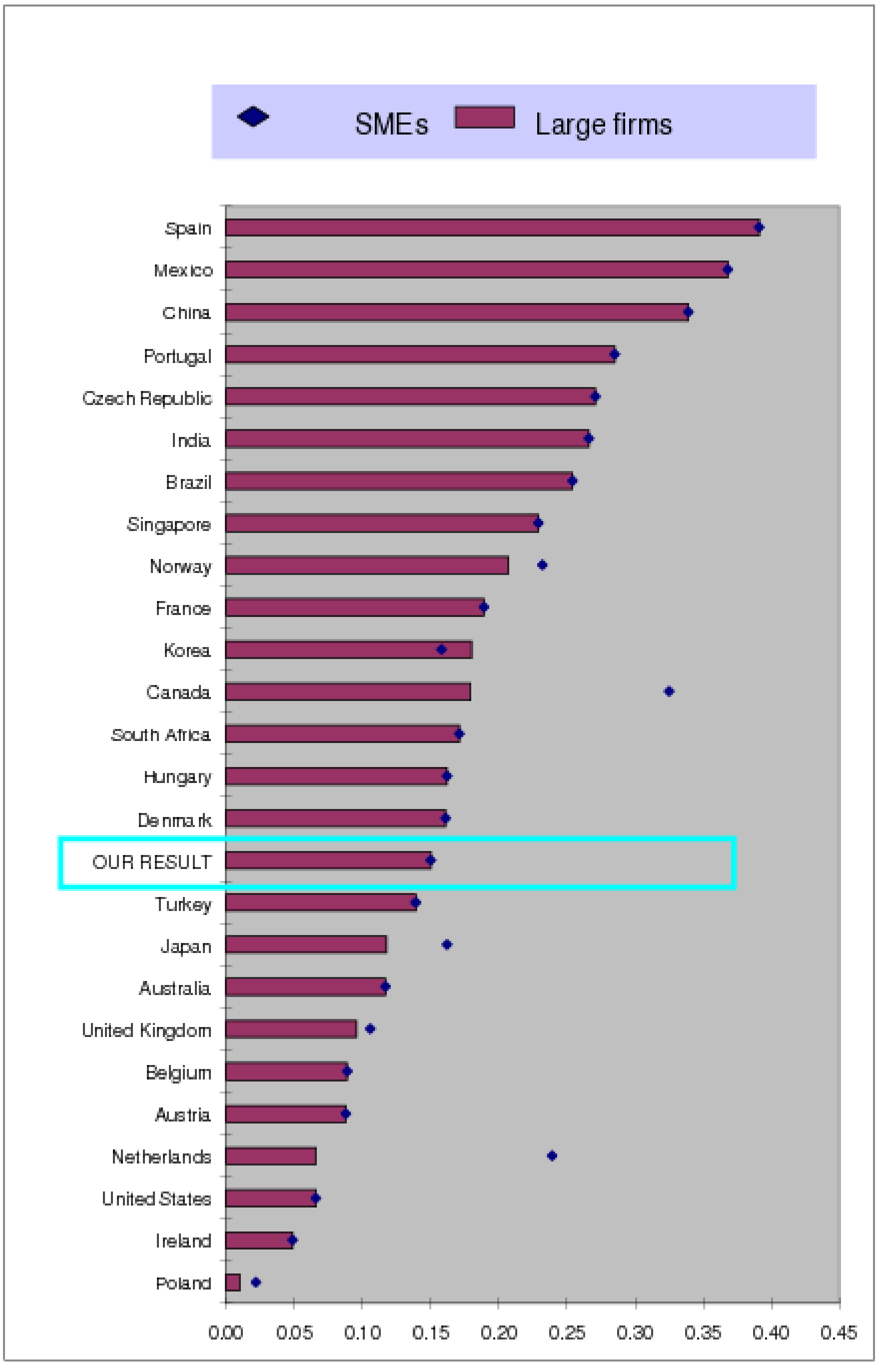

R&D investment
0
2.0e−06
4.0e−06
6.0e−06
0
200000
400000
600000
800000
laissez−faire
subsidy
tax credit


Profits
3.0e−07
2.0e−07
1.0e−07
0
0
2000000
4000000
6000000
8000000
laissez−faire
subsidy
tax credit



Spillovers
0
2.0e−06
4.0e−06
6.0e−06
0
100000
200000
300000
400000
laissez−faire
subsidy
tax credit

Data C.3.1_e Chart 6



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