EXPECTED BENEFITS OF INNOVATION POLICY

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Abstract

R&D subsidies are one of the most important innovation policy tools in both theory and practice. We study the expected welfare effects of targeted R&D subsidies using detailed R&D project level data from Finland. To achieve our objective, we model the application and R&D investment decisions of firms and the subsidy granting decisions of the public agency in charge of the program. In our model, subsidies affect firms' optimal R&D investments as in endogenous growth models. The model allows for a continuous optimal subsidy with outcome heterogeneity, takes into account heterogenous application costs, and identifies the effect of subsidy on the agency running the program. Under the assumption of a welfare-maximizing agency, we identify general equilibrium effects of subsidies. We find that expected effects of subsidies are very heterogenous and application costs low on average. We find that the social rate of return on targeted subsidies is 30-50%, but that spillover effects of subsidies are smaller than effects on firm profits.

KEYWORDS: applications, effort, investment, R&D, selection, subsidies, treatment program, welfare.

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1. Introduction

It is widely recognized that R&D and the distribution of benefits generated by it are crucial for economic growth (e.g. Aghion and Howitt 1998 and 2009). Endogenous growth theory has shown that markets typically generate a suboptimal amount of R&D and has singled out public subsidies to R&D as one of the main policy tools (e.g. Aghion and Howitt 1998, chap. 14, Howitt 1999, and Segerstrom 2000). R&D subsidies have also become ubiquitous in practice. They are one of the largest and fastest growing forms of industrial aid in developed countries (Nevo 1998 and Pretschker 1998); the U.S. has several programs (Lerner 1999) and spends \$1.5 billion a year on one R&D subsidy program alone;[1] and the EU exempts R&D subsidies from its state aid rules. In Finland where our data originates, R&D subsidies were drastically increased amid a deep economic recession of the early 1990s and are now the most important tool of innovation policy (Georghiu et al. 2003).

Reflecting the theoretical and practical importance of R&D subsidies, there is a large literature estimating the effect of R&D subsidies on private R&D investments ("additionality") and other measures of innovative performance (see e.g. David, Hall and Toole 2000, and Klette, Møen and Griliches 2000 for surveys). In this paper, we complement this literature by building a structural model that describes firms' selection into a subsidy program as a function of the firms' application and R&D investment decisions as well as the public agency's subsidy decision. We estimate our model with rarely available R&D project level data on the subsidy application and allocation process.[2] However, we slightly depart from much of the earlier empirical literature in that the R&D equation generated by our model is a first-order condition analogous to the

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[1] The Small Business Innovation Research Program, SBIR: "In FY (fiscal year) 2001, [the SBIR program] produced 3,215 Phase I awards and 1,533 Phase II awards for approximately \$1.5 billion dollars". Phase I is the startup phase. Awards of up to \$100,000 for approximately 6 months support exploration of the technical merit or feasibility of an idea or technology. Phase II awards of up to \$750,000, for as many as 2 years, expand Phase I results. During this time, the R&D work is performed and the developer evaluates commercialization potential. Only Phase I award winners are considered for Phase II. Quotation and information are from http://www.sba.gov/sbir/indexwhatwedo.html, visited on January 21, 2004.

[2] The literature typically uses firm or more aggregate level data. A notable exception is Henderson and Cockburn (1996) who have also access to R&D project level data.

research arbitrage equation of the modern growth theory. As a result, subsidies in our model lower the firms' marginal R&D costs, increasing firms' research intensity as in growth theory. This implies a restriction on the amount of "additionality" created by subsidies. The parameter restriction (which we cannot reject) is not only theoretically motivated but also directly arises from the design of the subsidy policy we study.[3] Our approach yields estimates of the expected benefits of R&D and subsidies accruing to the firms (which we call the *firm effect*) and to the agency (which we label the *spillover effect*), and of the costs of applying for subsidies. These allow an ex-ante welfare assessment of the subsidy program.

The model. In our model, firms with R&D ideas first decide whether or not to apply for a subsidy. Conditional on this decision and the outcome of the application, they decide how much to invest in the R&D project. The agency running the program decides the level of the *subsidy rate*, i.e., the fraction of R&D cost that the agency pays, conditional on receiving and screening application.

The data. We have access to rich R&D project level data from Tekes (the Finnish Funding Agency for Technology and Innovation), the main source of R&D subsidies in Finland. Finland provides an interesting case because innovation policy relying on R&D subsides has been a central theme in government policy[4], and the country rapidly emerged from the economic crisis of the early 1990s as a technology intensive economy (see e.g. Trajtenberg 2001). The data contain all the subsidy applications with details of the planned R&D projects, the agency's internal ratings of the applications and its decisions over a two- and half-year period (Jan. 2000 –

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[3] In our empirical application the subsidy decided by the agency is clearly defined at the level at which we model firm behavior: the agency decides what per cent (if any) of the R&D costs of the project (not the firm) the agency reimburses, and we simply model it accordingly.

[4] For example, there are no R&D tax benefits.

June 2002).[5] The information on applications is matched to data on over 14 000 Finnish firms that constitute a large proportion of potential applicants. To get acquainted with the actual decision making process, one of us spent eleven months in Tekes. Among other things she participated in the decision making meetings.

Identification. In the literature on the effect of R&D subsidies the main concern has been the endogeneity of the subsidy. We need to take a stand how this endogeneity arises. We allow that spillovers are a function of the shock determining the private profitability of R&D, but need to assume that the spillover per dollar of R&D (the *spillover rate*) is independent of that shock. While restrictive, this assumption generates, in line with the existing literature, endogenous *subsidies*. This endogeneity leads in our data to a sample selection problem as we observe the project level R&D plans for only those firms who apply for a subsidy (whereas the existing literature mostly uses (survey) data where firm level R&D is observed for all firms). In solving the sample selection problem we can also take advantage of an exclusion restriction embedded in the Finnish R&D subsidy environment: The EU rules allow the Finnish agency to grant larger subsidies to small and medium sized enterprises (SMEs) than larger firms. The SME definition is decided at the EU-level and we believe can safely be viewed as exogenous.

While the identification of our model rests on neither distributional nor unusual functional form assumptions,[6] the interpretation of some of our results hinge on potentially controversial modeling choices. Prior literature unfortunately provides little help in modeling

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[5] Since we observe firms' R&D plans, not their actual R&D investments, our data are different from what are used in most ex-ante and ex-post evaluation studies (e.g. Todd and Wolpin 2005 and Heckman and Vytlacil 2006a). While this means that our study is certainly not the final say on the evaluation of the R&D subsidy programs, it also means that we have a unique window to the program evaluation: we use the data that forms the basis of the firms' application and the agency's subsidy decisions. Our calculations are thus informative of the decision makers' preferences and the consequences of their decisions prior to uncertainty about project outcomes unfolding. A policy should (at least) at this stage exhibit benefits that are larger than costs.

[6] As will become clear later, we make one key distributional (covariance) assumption, which provides a way of estimating agency decision rule. It does not affect our other results. We also estimate the model semi-parametrically and the functional form assumptions we need to impose are certainly no stronger than those commonly used. As in Heckman and Vytlacil (2005), we do not need to impose all the traditional exogeneity assumptions regarding the explanatory variables to be able to measure treatment effects, or to calculate the rate of return on the program.

and interpreting the objective of the agency running the subsidy program.[7] We assume that the agency completely internalizes firm profits; that it may receive benefits (e.g. consumer surplus, spillovers, and private benefits to civil servants) that the firm does not internalize – these are what we label, without implication, the spillover effects; and that it cares about the out-of-pocket cost of subsidies.[8] Given these we identify, at a minimum, how the agency expects to benefit from a given subsidy. At a maximum, if one is willing to assume that the agency acts as a benevolent social planner, we identify expected general equilibrium effects of subsidies. In this sense our approach complements existing work on estimating general equilibrium treatment effects (see Heckman, Lochner and Taber 1998, and Abbring and Heckman 2006). The costs of applying, the agency's opportunity cost of finance, and its lack of ability to commit to a subsidy level ex ante mean that the program does not need to cover its costs even when all decisions are optimal, as dictated by our revealed preference approach.

Our identification of general equilibrium effects is certainly debatable. However, most of our results are not affected by the interpretation of the agency's objective function. For example, the agency's objective function is irrelevant for our results on the level and heterogeneity of subsidies' effect on firm profits and application costs. In addition, we provide insights into how firm and project characteristics affect the decisions of an agency granting R&D subsidies. Given the importance of this policy tool, this information ought to be valuable for future research.

Results. We report four main findings. First, the expected effects of subsidies on both the firms' (the firm effect) and the agency's (the spillover effect) utility are very heterogenous. Second, application costs vary greatly and shocks to application costs and marginal profitability of R&D are positively correlated. That is, the better the project, the less likely a firm is to apply for a subsidy. This is intuitive once one observes that a major part of the application costs that

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[7] McFadden (1975, 1976) represent early work using a related revealed preference approach to public sector decision making.

[8] Blanes and Busom (2004) and Feldman and Kelley (2006) discuss various possible objectives of an agency, and Tanayama (2007) describes in detail the multilayered decision-making process used by the agency we study.

we uncover comes from opportunity costs. Third, the spillover effects of subsidies are smaller than their effect on firm profits. Note that in principle our estimates capture only within country spillovers, not spillovers to other countries. Fourth, we find that the expected rate of return on the subsidy program is of the order of 30-50%. In addition to the main findings, some of our parameter estimates are of independent interest, indicating, e.g. economies of scale in the spillover rate.

Literature. From the extensive literature seeking to estimate whether R&D subsidies lead to "additionality", the paper closest to ours is González, Jaumandreu, and Pazó (2005) who focus on the effectiveness of subsidies in stimulating private R&D when there are fixed costs of starting a project. Using Spanish data, they find that subsidies can encourage non-R&D performing firms to start investing in R&D. They, like us, assume that firms act partly on expected subsidies. However, we cannot use their appealingly simple way of deriving expectations. We view our approach as complementary to theirs and to other work following a similar approach.[9] Our approach and data allow for richer heterogeneity than earlier research while taking the endogeneity of subsidies into account, produces information on hitherto unmeasured objects, and holds the promise of being able to accommodate the important aspects now excluded through extensions of our model and data on ex-post values of key variables.

Methodologically, our paper belongs to a small but growing literature using structural empirical models in economics of innovation, originating from the seminal works of Pakes (1986) and Levin and Reiss (1988). Related to our study, structural modelling has been used to study R&D spillovers and technology diffusion (see e.g. Eaton and Kortum 2002, Jovanovic and Eeckhout 2002, and Xu 2008). But to the best of our knowledge, structural models have not been previously used to study R&D subsidies, although Ferrari, Verboven and Degryse (2008) consider subsidization of ATM technology investments as a counterfactual. From this

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[9] Other related contributions to the effects of subsidies include Wallsten (2000), Lach (2002), Czarnitzki and Licht (2006) and Criscuolo, Martin, Overman and Van Reenen (2007).

methodological perspective, our paper is closest to research on regulator-firm interaction, in particular to Wolak (1994) (cf. Reiss and Wolak 2005, chap. 9) and Gagnepain and Ivaldi (2002). [10]

We present our model in detail in Section 2. We explain the institutional background and data in Section 3 and statistical assumptions, identification and estimation in Section 4. Econometric results are reported in Section 5. In Section 6 we present estimates of the effects of subsidies and our estimate of the agency's return on the R&D subsidy program, exploring also their sensitivity to distributional assumptions. Conclusions are in Section 7.

2. The model

We model the subsidy program as a four-stage game of incomplete information between a firm with an R&D project and the agency. In stage zero, the players' types are determined. As will become clear later, the type of a player is project-specific, contributing to the player's valuation of a project. The agency has a three-dimensional type, $t^A = (\eta, \omega_c, \omega_m) \in \Re^3$, drawn from a common knowledge joint distribution. The firm's R&D project has a two-dimensional type, $t^F = (\varepsilon, \nu_0) \in \Re^2$, drawn from a common knowledge bivariate distribution. Given our assumption of one project per firm, we talk interchangeably of "firm", "project" and "applicant" type in what follows. Conditional on publicly observed information the shocks are independently distributed.

In stage one the firm decides whether or not to apply for a subsidy for its R&D project. In stage two, the agency, whose objective function is assumed to include the firm's profits as an argument, screens and evaluates the proposed project. It then decides the subsidy rate, s, $s \in [0, \bar{s}\,]$ and $\bar{s} \leq 1$, which is the share of the investment cost covered by the agency. In stage three, the

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[10] Since a subsidy can be viewed as a treatment, there is also a link to the literature on structural modelling of treatment effects, first advocated by Heckman and Robb (1985) and Björklund and Mofitt (1987), and recently summarized by Abbring and Heckman (2006) and Heckman and Vytlacil (2006a,b).

firm makes the R&D investment, R, $R \in [0,\infty)$, with or without the subsidy. The subsidy is then sR, i.e., the subsidy rate times the R&D investment of the firm.

Our model builds on the following key assumptions:

A.1. A potential applicant is uncertain about the agency's valuation of the applicant's project.

A.2. A subsidy cannot be misused.

A.3. There are no constraints on the applicant's investment.

A.4. The agency's budget constraint does not bind.

A.5. The applicant's investment is non-contractible.

A.1 ensures - in line with our data – equilibrium outcomes where a firm applies for a subsidy only to be turned down. It accommodates various informational assumptions concerning the players' types. Due to our functional form assumptions (specified below), the firm can neither signal its type nor does the agency care about it. We only need to assume that the firm, when contemplating application, does not exactly know how the agency values the proposed project. For brevity of presentation, we assume that the firm's type is common knowledge and that the agency learns its type exactly after screening.[11]

A.2 excludes moral hazard problems in the use of the subsidy.[12] By A.3, the solution to the applicant's maximization problem in the last stage is interior which greatly facilitates the estimation of our model. This assumption rules out credit rationing and other discontinuities that have been emphasized in the innovation policy literature (e.g. González, Jaumandreu and Pazó 2005). While not disputing the importance of these phenomena, this assumption is the price we need to pay to make progress in modeling the whole R&D subsidy program. Moreover, credit

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[11] That is, symmetric but incomplete information regarding the agency's type prevails in the application stage. Alternatively, we could assume that the applicant has private information about the agency's valuation of its project and that the agency receives a noisy signal upon it after screening the project. Since the applicant could not credibly signal its private information in our model, this assumption would yield the same optimal application and subsidy decisions as the (more realistic) assumption we use.

[12] In practice, moral hazard temptations are certainly possible with monetary treatments. As a result, Tekes has several safeguards against expropriation. For example, subsidies are only paid against receipts, there is a euro limit to a subsidy, and a significant number of subsidized R&D projects is annually randomly audited. The Finnish media is also quite attentive to potential misuses of R&D subsidies. Because Tekes's safe-guards are common knowledge, and the misuses found in the audits or otherwise are rare, we think that the assumption depicts equilibrium behavior.

rationing and other similar non-linearities might be less important at the project level than at the firm level. For example, A.3 amounts to assuming that firms have already made the fixed project-specific R&D investments. One can defend the assumption of no fixed costs on the grounds that the applicants are existing firms who submit plans for new projects.[13] A.4 is also motivated by simplicity, but we do impose a cost of financing on the agency. A.5 is more realistic, since it prevents the firm and the agency from writing a binding contract specifying the amount the firm invests conditional on the subsidy rate.

We focus on perfect Bayesian equilibria where, in stage one, a potential applicant correctly anticipates the agency's type-contingent strategies in stage two, and where the firm's and agency's strategies are sequentially rational. In this extensive form game the firm's posterior belief concerning the agency's type after receiving a subsidy is inconsequential, so we start from the firm's maximization problem in stage three.

2.1. Objective function of the firm and stage three of the game

We specify the firm's expected discounted profits from project *i* as

$$(1) \qquad \Pi(R_i, s_i, X_i, \varepsilon_i) = \exp(X_i\beta + \varepsilon_i)\ln R_i - (1 - s_i)R_i,$$

where s_i is the subsidy rate, R_i the R&D investment, X_i a vector of observable firm characteristics, and β a vector of parameters to be estimated. The marginal profitability is affected by a random shock, ε_i, (i.e., by firm *i*'s type), uncorrelated with the observable firm characteristics, observed by the firm, and unobserved by the econometrician. As explained in the previous section, it is immaterial whether the firm's type is observable to the agency or not: For

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[13] While we make A.3 for simplicity, we also note that the revealed motivations for R&D subsidies have increasingly been based on spillovers rather than financial market failures. A study using Finnish data (Hyytinen and Pajarinen 2003), and an evaluation of Finnish innovation policy (Georghiu et al. 2003) conclude that only small, R&D intensive, growth-oriented firms may face financial constraints. The situation is similar in many other industrialized countries, as the survey by Hall (2002) confirms. The decline of the financial constraint motivation for R&D subsidies is also reflected in our data: although Tekes also grants low-interest loans, most firms were not interested in them.

simplicity, we assume that the agency observes ε_i.[14] While the first part of the profit function on the right-hand side of (1) is admittedly ad hoc (we do test the assumption of logarithmic returns to R&D), the second part is not: it is given by the agency's subsidy rate rules. It is also identical to that used both in the industrial organization and in the endogenous growth literatures on R&D subsidies (e.g. Spencer and Brander 1983, Leahy and Neary 1999, Howitt 1999, and Segerstrom 2000).

In stage three, the firm chooses its investment R_i to maximize (1). Since the objective function is concave in R_i, the first order condition

$$(2) \qquad R_i = \frac{\exp(X_i\beta + \varepsilon_i)}{1 - s_i}$$

gives the firm's optimal investment $R_i(s_i)$. Equations (1) and (2) show the economic interpretation of ε_i: a positive shock to the marginal profitability leads to a larger investment.[15]

Since we abstract from fixed costs of starting an R&D project, and assume that a subsidy has no impact on the idea behind the project, the subsidy rate in our model only affects the intensive margin without nonlinear effects. To allow a nonlinear effect of the subsidy rate we could, for example, write the last part of (1) as $(1 - s_i)^\kappa R_i$ where κ, potentially different from one, would measure additionality. We prefer our formulation for three reasons. First, the formulation $(1 - s_i)^\kappa R_i$, while useful, is ad hoc: It neither corresponds the way the effect of subsidies are generally modelled in the theoretical literature nor the R&D subsidy rules in our data.[16] Second, the interpretation of κ is somewhat ambiguous. Using a Box-Cox

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[14] We could generalize (1) to include a reservation value from other projects and to accommodate multiple projects. For each firm with multiple project applications, we could treat each project as a separate observation. If the project-specific unobservables are uncorrelated, this will not materially affect estimation. The interpretation for non-applicants would be that none of their projects resulted in an application.

[15] Our functional form assumptions create a minor problem: for very small values of ε_i the firm may prefer not investing at all to investing the amount suggested by (2). Since this would happen in our data only for extremely small values of ε_i – an R&D investment of slightly larger than one euro would be sufficient to generate positive expected profits – we ignore the problem in our empirical implementation.

[16] Theoretically justified ways to introduce non-linear effects of subsidies, e.g. via fixed start-up costs at the project level, would greatly complicate the estimation of the model.

transformation to model returns to R&D in (1) would yield the same estimation equation as the assumptions of logarithmic returns in R&D *and* $(1-s_i)^{\kappa} R_i$. Third, we cannot reject the Null that $\kappa = 1$.

2.2. Agency utility and stage two of the game

The agency's expected utility from applicant *i*'s project is given by

$$(3) \qquad U(R_i(s_i), s_i, X_i, Z_i, \varepsilon_i, \eta_i) = V(Z_i, \eta_i, R_i(s_i)) + \Pi(X_i, R_i(s_i), s_i, \varepsilon_i) - g s_i R_i(s_i) - F_i,$$

where F_i captures the fixed costs of applying and processing the application and *g* is the constant opportunity cost of the agency's resources, e.g. the opportunity cost of tax funds. As (3) shows, the firm's profits enter directly and additively in the agency's utility function.

We label *V*( ), again without implication, the *spillovers*. The interpretation of *V*( ) is important, since it captures the expected effects of the firm's project on the agency beyond the firm's utility and the direct costs of the subsidy and the application process. *V*( ) can include externalities from a firm's R&D such as consumer surplus or spillovers to other firms. It could also contain idiosyncratic benefits to the decision maker, thorough, e.g. bribes or a revolving door mechanism. This agency specific part of the agency's utility could also be decreasing in R&D, e.g. through negative environmental externalities, cost duplication or business-stealing effects.[17] Note that the interpretation of *V*( ) in no way affects our results on the determinants of private returns to R&D and application costs.

η_i in *V*( ) constitutes part of the agency's type $t^A = (\eta, \omega_c, \omega_m)$, and it is defined as a random shock to the spillovers from project *i*. It is assumed to be uncorrelated with firm characteristics, and unobserved by the econometrician. By A.1, η_i is also unobserved by the potential applicant and observed by the agency (at the latest) after application and screening

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[17] In the basic models of innovation in industrial organization and in endogenous growth theory, the positive welfare effects of R&D, typically consisting of consumer surplus and spillovers besides innovators' profits, are balanced against its negative welfare effects such as business stealing or cost duplication (see e.g. Aghion and Howitt 1992). It is perfectly plausible in theory that negative effects of an R&D investment dominate its positive externalities.

takes place. In other words, the potential applicant is uncertain about how the agency, after screening the project proposal, sees the project and its potential to generate, e.g. spillovers, consumer surplus, business stealing or private benefits to the agency's civil servants.

The spillover $V(\,)$ also includes Z_i, a vector of observable firm characteristics, which contains the same elements as X_i. In our case, after receiving a proposal for an R&D project the agency grades its quality in two dimensions, and Z_i also includes the two screening outcomes consisting of two grades on a Likert scale of 5 observed by the agency and by the econometrician but not by the firm.[18] The remaining parts of the agency's type, ω_{ic} and ω_{im}, are defined as random shocks to the screening outcome of project i in grading dimension c and m respectively (where c and m stand for technical challenge and market risk as will be explained in Section 3). We assume that the grading process, its parameters, and the distributions of ω_{ic} and ω_{im} are common knowledge. That is, conditional on observables, the firm correctly assesses the probability of getting a particular grade in each of the two grading dimensions.

In stage two, the agency chooses the subsidy rate s_i, $s \in [0, \bar{s}]$ where $\bar{s} \leq 1$, to maximize (3), taking (2) into account. To arrive at an estimable model we need to specify the effect of R_i on $V(\,)$. We assume that

(4) $\partial V / \partial R_i = Z_i\delta + \eta_i,$

where δ is a vector of parameters to be estimated. One can think of η_i as a shock to the spillover rate, i.e., spillover per dollar of R&D. An implication of (4) is that $V(\,)$ is proportional to R&D investment. While restrictive, similar assumptions are common in the industrial organization literature on R&D spillovers and in growth theory. We test this assumption below and do not reject it.

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[18] The grades cannot be included into other equations as we only observe them for applicants.

Using the envelope theorem, (1), (2) and (4), the first order condition for the agency's unconstrained problem can be written as

(5) $s_i = 1 - g + Z_i\delta + \eta_i$.

We verify later that (5) characterizes the maximum. Equation (5) shows how the agency's unconstrained decision rule is decreasing in the shadow cost of public funds, g. It is independent of the firm's type, $t^F = (\varepsilon, v_0)$, so even if the agency did not know the private shock to the marginal profitability of R&D, it would not matter. The optimal subsidy rate depends positively on the spillover shock η_i. The minimum constraint of $s=0$ binds for $\eta_i \leq \underline{\eta}_i \equiv g - 1 - Z_i\delta$ and the maximum constraint of $\bar{s}$ for $\eta_i \geq \overline{\eta}_i \equiv \bar{s} + g - 1 - Z_i\delta$.

2.3. The firm's beliefs and application costs, and the stage one of the game

In stage one, a profit maximizing firm applies for a subsidy if the expected utility from applying is at least as large as that from not applying. The firm needs to calculate expected profits from submitting an application based on its beliefs about the agency's valuation of its application. As mentioned, the agency's valuation of the project *i* depends on its type $t_i^A = (\eta_i, \omega_{ic}, \omega_{im})$, which is unknown to the firm prior to the application. Let $\phi(\eta_i)$ define firm *i*'s belief about η_i and let $\Phi(\eta_i)$ be the corresponding cumulative distribution function. Moreover, let $p_{ich}(\omega_{ic})$ and $p_{imh}(\omega_{im})$ denote the firm's beliefs (i.e. probability) that its project *i* gets grade $h \in \{1,\ldots,5\}$ in grading dimensions *c* and *m*, respectively.

The firm weights the expected profit increase from applying against its costs. We specify the costs of application as

(6) $K_i = \exp(Y_i\theta + v_i)$

where Y_i is a vector of observable firm characteristics, θ is a vector of parameters to be estimated and v_i is a random cost shock, distributed by nature, uncorrelated with observable firm characteristics, observed by the firm and the agency (again, the latter is immaterial), and unobserved by the econometrician.

Dropping the subscript *i* we can now write the applicant's decision rule as

$$(7)\qquad d = 1\left\{\sum_{ch=1}^{5}\sum_{mh=1}^{5} p_{ch}(\omega_c)p_{mh}(\omega_m)\{\Phi(\underline{\eta})\Pi(R(0),0) + \int_{\underline{\eta}}^{\overline{\eta}}\Pi(R(s(\eta)),s(\eta))\phi(\eta)d\eta \right.$$
$$\left. + [1-\Phi(\overline{\eta})]\Pi(R(\bar{s}),\bar{s})\} - \Pi(R(0),0) - K \geq 0\right\},$$

where d_i is an indicator function that takes the value one if a firm applies for a subsidy for project *i* and is zero otherwise. In (7) the summations are over the potential screening outcomes. The first term in the inner curly brackets is the expected profit in case the application is rejected. The rejection occurs when $\eta_i \leq \underline{\eta}_i$, i.e. with probability $\Phi(\underline{\eta}_i \equiv g\text{-}1\text{-}Z_i\delta)$. The second term is the expected profit when $\eta_i \in (\underline{\eta}_i, \overline{\eta}_i)$ in which case the firm receives the optimal interior subsidy rate given by (5). The third term is the probability of receiving a maximal subsidy rate multiplied by the profits with the maximal subsidy rate. This case occurs with probability $1-\Phi(\overline{\eta}_i \equiv \bar{s} + g - 1 - Z_i\delta)$. The two last terms capture the costs of applying. Besides the fixed application costs K_i, the firm takes into account the possibility of executing the project without a subsidy (as implied by A.3), in which case the project yields $\Pi(R_i(0),0)$.

2.4. Equilibrium

We complete the model by showing that there is a unique perfect Bayesian equilibrium, ensuring a meaningful econometric implementation of the model. Perfect Bayesian equilibria in our model consist of four components: 1) A firm's decision whether to apply for a subsidy or not, $d_i \in \{0,1\}$; 2) the firm's belief functions $p_{ijh}(\omega_{ij})$, $h \in \{1,\ldots,5\}$, $j \in \{c, m\}$, and $\phi(\eta_i)$ that describe a (common) assessment of how the agency values the firm's project; 3) the agency's subsidy rate decision rule $s_i = s_i^* d_i$ which determines the subsidy rate granted to project *i* given d_i; and 4) the firm's investment rule $R_i^*(s_i)$ given s_i.

PROPOSITION. There is a unique perfect Bayesian equilibrium where d_i is given by (7), s_i^* is zero for $\eta_i \leq \underline{\eta}_i$, is given by (5) for $\eta_i \in (\underline{\eta}_i, \overline{\eta}_i)$ and is $\bar{s}$ for $\eta_i \geq \overline{\eta}_i$, and $R_i^*(s_i)$ is given by (2).

Proof: For brevity of notation, we drop the subscript *i*. In stage three, the firm has a well-defined best-reply function $R^*(s)$ given by (2). In stage two, the agency maximizes its expected utility conditional on its type $t^A = (\eta, \omega_c, \omega_m)$ and receiving an application (d=1). There is a unique type-contingent optimal subsidy rate s^*, if the second order condition for the agency's decision problem holds. Since we have linear constrains of minimum and maximum subsidies, it suffices to show that $U(R^*(s),s)$ is concave when evaluated at the interior solution given by (5). Differentiating (3) twice using the fact that $\partial\Pi/\partial R=0$ shows that $U(R^*(s),s)$ is concave if

$$(8) \qquad \frac{\partial^2 V}{\partial R^2}\left(\frac{dR}{ds}\right)^2 + \frac{dR}{ds}\left(\frac{\partial^2 \Pi}{\partial R \partial s} - 2g\right) + \frac{d^2 R}{ds^2}\left(\frac{\partial V}{\partial R} - gs\right) + \frac{\partial^2 \Pi}{\partial s^2} < 0 .$$

Since from (1) and (4) we see that $\partial^2\Pi/\partial s^2$ and $\partial^2 V/\partial R^2$ are zero, (8) simplifies to $\frac{dR}{ds}\left(\frac{\partial^2 \Pi}{\partial R \partial s} - 2g\right) + \frac{d^2 R}{ds^2}\left(\frac{\partial V}{\partial R} - gs\right) < 0$. Using (1), (2) and (4) we get $\frac{R}{1-s}(1-2g) + \frac{2R}{(1-s)^2}(Z\delta + \eta - gs) < 0$, which is equivalent to $1 - 2g + \frac{2(Z\delta + \eta - gs)}{1-s} < 0$. Evaluating this inequality at the interior solution given by (5) yields -1<0. Consequently, there is a unique maximum that solves the agency's decision problem. Because the optimal unconstrained subsidy rate (5) is increasing in η, $s^*=0$ for $\eta \leq \underline{\eta}$, s^* is given by (5) for $\eta \in (\underline{\eta}, \overline{\eta})$ and $s^* = \bar{s}$ for $\eta \geq \overline{\eta}$, and this s^* determines s given d=1. If the agency does not receive an application (d=0), $s = 0$ irrespective of the agency's type. Thus, conditional on d, the type-contingent action of the agency in stage two is unique. In stage one the firm decides whether to apply or not given s^* and $p_{jh}(\omega_j)$ and $\phi(\eta)$. Since in a perfect Bayesian equilibrium the firm's choice must maximize the profits and the firm's beliefs must be consistent with the agency's strategy, d=1 only if (7) holds and d=0 otherwise. Clearly, the agency's best response to *d=1* is

$s=s^*$ so we have found a perfect Bayesian equilibrium. Since the utility maximizing action in each stage of the game is unique, the equilibrium is also unique. ■

3. Finnish innovation policy, Tekes and data[19]

3.1. Innovation policy and Tekes' subsidy program

In 2001 Finland invested 3.6 per cent of GDP – €5 billion - on R&D. There are several organizations providing public funding of private R&D in Finland, of which Tekes is by far the most important (see Georghiu et al. 2003 for a description of the Finnish innovation policy system). The primary objective of Tekes is to promote the competitiveness of Finnish industry and the service sector. To this end Tekes strives to increase Finnish firms' R&D activities and risk-taking by providing funding and advice to both business and public R&D. Tekes is also responsible for allocating funding from European Regional Development Funds (ERDF), which is meant for the less-favored regions. 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.

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, and it received 2948 applications of which almost exactly 2/3 were accepted. The number of applications by the business sector for R&D funding was 1357 and, again, 2/3 of them were accepted. In monetary terms, the business sector applied for €526 million while €211 million were granted to it.

Business R&D funding consists of grants, low-interest loans and capital loans. Tekes' low-interest loans not only have an interest rate below the market rate but they are also soft: If

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[19] As our application data is from January 2000- June 2002, we use 2001 figures to describe the environment. Public information about Tekes can be found at http://www.tekes.fi/en/, accessed May 20th 2009. Public information is supplemented by knowledge we acquired when one of us spent eleven months in Tekes to participate in the actual decision making process.

the project turns out to be a commercial failure, the loan may not have to be paid back. A capital loan granted by Tekes differs from the standard private sector debt contract in various ways: it is included in fixed assets in the balance sheet, it can be paid off only when unrestricted shareholders' equity is positive and the debtor cannot give collateral for the loan. The share of each instrument of the total funding allocated to business R&D in 2001 was 69 %, 18% and 13%. Subsidy applications covered 83 % of the amount applied whereas in terms of granted amount subsidies' share was 67%. The overlook of loans by applicants in our data suggests that they may not encounter significant financial constrains, supporting our assumption A.3 (cf. footnote 12).

The application process from the submission to the final decision, which to our understanding is well known among potential applicants, proceeds along the lines of the theory model of Section 2. In practice, Tekes screens the application and grades it in several dimensions, not two, as we assume for simplicity. The two dimensions concerning the technological challenge of the project and its market risk that we use are, however, in practice the most important ones.[20] 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 and, as mentioned above, the funding also has a regional dimension through ERDF. Putting the regional aspect aside, the funding from ERDF is subject to the same general criteria as other Tekes' funding.

An application has to include the purpose and the budget of the R&D project for which Tekes funding is needed, and the applied amount of funding in euros. Tekes' final decision is

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[20] A loose translation of grades of technological challenge is 0 = "no technical 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 market risk, it is 0 = "no identifiable risk", 1 = "small risk", 2 = "considerable risk", 3 = "big risk", 4 = "very big risk", and 5 = "unbearable risk". Since only five grades are used in practice, we, too, use a 5-grade Likert scale.

based on the proposed budget of the project before the R&D investments are made and a subsidy is granted as a share of to-be-incurred R&D costs. Decision making is constrained by the rules preventing negative subsidies and very large subsidies both in relative and absolute terms. If the firm fulfils the SME criterion determined at the EU level, the upper bound for the share of covered R&D costs is 0.6, otherwise 0.5. We use this variation in identification, imposing the exclusion restriction that the SME status has an effect only on Tekes' decision and application costs of the firms. This exclusion restriction could also be used in an analysis of additionality.[21] Actual funding is only given after the R&D investments are made, covering the promised share of incurred costs up to a specified euro limit. The limit should allow the promised reimbursement of investment costs up to the profit maximizing level but prevents Tekes from covering costs extraneous to the project proposal.[22] In terms of our model, the rules governing feasible subsidies amount to the minimum constraint of $s=0$, the maximum constraint $\bar{s} \in \{0.5, 0.6\}$, and a goal of setting the euro limit at $sR(s)$. It is our understanding that the firms are free to scale back their projects.

3.2. Data

Our data come from two sources. The project level data come from Tekes, containing all applications to Tekes from January 1st 2000 to June 30th 2002. They consist of detailed information on the project proposals and Tekes' decisions. The firm level data covering 14 657

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[21] Given our data, it is unlikely that firms deliberately keep themselves below the EU SME boundary requiring that a firm has less than 250 employees and has either sales less than 40 million euros or a balance sheet less than 27 million euros. Most of the firms in our data are well below the boundary, as 95% them have less than 110 employees, less than 14 million euros in sales, and a balance sheet of less than 11 million. As the SME criterion also maintains that large firms can hold at most 25% of a SME's equity and votes, it is unlikely that many of the SMEs are subsidiaries of large firms. We thus consider the SME status of a firm exogenous.

[22] Tekes can generally adjust a proposed budget downwards when it includes costs that Tekes cannot cover, but the euro limit a transparent safeguard against subsidy misuses (cf. footnote 12). There are also other reasons for the limit. Because Tekes has an annual operating budget, a practical decision rule is to cap the euro amount using the proposed budget, as it is the best available information at the time of the subsidy decision. Since Tekes is monitored both by the press and politicians, Tekes' civil servants may also want avoid the accusations of granting larger subsidies than originally planned. At the same time, however, there may be a desire to make the limit high enough to allow profit maximizing behavior of applicants. Within the euro limit, an upward adjustment of the proposed budget is also possible in principle but rare in practice, occurring virtually only if a project significantly changes character during the application process. Such upgrades can thus be taken as exogenous events that cannot be manipulated by Tekes to overcome the institutional limits on its subsidy allocation

Finnish firms come from Asiakastieto Ltd, which is a for-profit company collecting, standardizing, and selling firm specific quantitative information.[23] Asiakastieto's data are based on public registers and on information collected by Asiakastieto itself. The data contain, for example, firms' official profit sheet and balance sheet statements, and include all the firms who must file their data in the public register or submit the information to Asiakastieto. We also have information on the size of the board and on whether or not the CEO also acts as the chairman of the board of directors. [24]

We use the 1999 cross section from Asiakastieto's data, i.e. all firm characteristics are recorded earlier than the application data. The sample was drawn from Asiakastieto's registers in 2002 according to three criteria: i) the most recent financial statement of the firm in the register is either from 2000 or 2001; ii) the firm is a corporation; and iii) the industrial classification of the firm is manufacturing, ICT, research and development, architectural and engineering and related technical consultancy, or technical testing and analysis. Firms in these industries are the most likely to apply for funding from Tekes. After cleaning the data of firms with missing values, we are left with 10 944 firms. These firms constitute our sample of potential applicants.

The firms in our sample account for roughly half of all applications. There are three principal reasons for the exclusion of an applicant from our sample: 1) the firm did not exist in 1999; 2) the firm did not operate in the industries from which the sample was formed; and 3) the firm was so small that it was not obliged by law to send its balance and profit sheets to the official registry. The data we use in the estimations comprises 915 applications, where we use

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[23] More information about Asiakastieto can be found at http://www.asiakastieto.fi/en/, accessed May 20th 2009.

[24] The extensive empirical literature on the role of boards of directors in corporate governance (see e.g. Hermalin and Weisbach 2003 for a survey) does not provide unambiguous predictions concerning these variables. Having the CEO as the chairman of the board can, for example, improve the information flow between the board and the executive but weakens the board's independence, and a larger board is costlier but is more likely to include members with outside knowledge that may be useful either in conducting R&D (e.g. choosing among competing projects, organizing management of current projects, monitoring), or in the application process itself.

the first application in case a firm had multiple applications within our observation period. 722 of these applications were accepted, i.e. received a positive subsidy rate.

Table 1 displays summary statistics of our explanatory variables for potential applicants, and Table 2 conditions the statistics on the application decision and success. As Table 1 shows, potential applicants are heterogenous. They are on average 12 years old with 35 employees. A very high proportion of firms are SMEs according to the official EU standard (cf. footnote 21). Sales per employee, a measure of value added, is €165 000. Some 22% are exporters. In some 14% of potential applicants, the CEO is also the chairman of the board, and the board of an average potential applicant has four to five members.

[TABLE 1 HERE]

From Table 2 we see that applicants are larger than non-applicants and successful applicants larger than rejected ones. The median number of employees for non-applicants is 5, for applicants 26, and for rejected applicants 21. The applicants also tend to have larger boards. Quite naturally, applicants have more previous applications on average than non-applicants. The difference in both means and medians is 4.

Table 3 reports information about applications and Tekes'decisions (see Appendix 2 for more details). Some 21% of applications are rejected. The proposed investments are on average €630 000, the rejected proposals being smaller with a mean of €386 000. According to Tekes' ratings, the projects have on average a technical challenge of 2 (scale 0-5) with the rejected proposals having a lower average score of 1.5. The mean risk score is also 2, but it is the same for successful and rejected applications.

[TABLE 2 HERE]

As explained, Tekes grants low-interest and capital loans besides subsidies. Because it is hard to calculate the value of such non-standard loans to the applicants, we pool the instruments. We thus define the subsidy rate as the sum of all three forms of financing, divided by "accepted proposed" investment.[25] As some 60% of applicants only apply for a subsidy, and over 80% are only granted a subsidy, this seems a reasonable simplification. Measuring a subsidy rate this way, 0.4% of applicants get the maximum subsidy rate.[26] Successful applicants receive on average a subsidy rate of 32%. We test the robustness of our results to the definition of a subsidy by using only pure subsidies.

[TABLE 3 HERE]

4. Econometric implementation

4.1. The model

Combining our theoretical model of Section 2 with our data described in Section 3 allows us to assess the expected benefits of subsidies both to firms and to the public agency, including the costs of applying for subsidies. In operationalizing the theoretical model we encounter a few challenges that are explained in this section. Following Section 2, we proceed backwards, beginning with the firm's investment decision in stage three.

Taking logs of both sides of the firm's first order condition (2) yields

$$\ln R_i^*(s_i) = X_i \beta - \ln(1 - s_i) + \varepsilon_i \,. \tag{9}$$

Equation (9) specifies how much a firm would invest after knowing its the subsidy rate. We however observe planned R&D investments as reported by firms in their subsidy applications, not the actual R&D investments. Hence we cannot estimate (9) as such.

To link firms' R&D plans to (9) we use our theoretical model. The model implies that an applicant strictly prefers proposing a budget based on a maximum subsidy rate over proposing

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[25] As mentioned in footnote 22, Tekes sometimes adjusts a proposed budget, e.g. when an applicant applies for subsidies for costs that Tekes cannot cover. We use the unadjusted number ("proposed investment") when estimating the investment equation.

[26] There is a cluster of firms right below the maximum subsidy rate: 1.9% of applicants get a subsidy rate which is less than one percentage point below the maximum subsidy rate, and 2.5% get a subsidy rate less than 5 percentage points below the maximum. At the lower end there is no such clustering: no firm gets a subsidy rate that is less than 2.9%: however, 2.6% of applicants get a subsidy rate that is greater than 2.9% and less than 5%.

any smaller amount, and is indifferent between proposing that budget and any larger amount.[27] Thus, applicants propose to invest the amount they would invest were they to receive the maximum subsidy rate. Substituting $\bar{s}$ for s_i in (9) gives

$$\text{(9')} \qquad \ln R_i^*(\bar{s}) = X_i\beta - \ln(1-\bar{s}) + \varepsilon_i ,$$

which we use to estimate β on our data. This feature of our theoretical model together with our data on the proposed R&D investments, not the realized ones, has another important implication: We do not need to worry about the potential endogeneity of subsidies in the investment equation (9'). Even if the spillover shock η_i were correlated with ε_i, it would not affect estimates of (9').

At the risk of belaboring the point, we note that (9) is close equations typically estimated in the literature on the additionality of R&D subsidies. In that literature, an equation analogous to (9) would be interpreted as a behavioral rule, and the subsidy transformation term (the –ln(1-s_i) term in (9)) would be multiplied by a constant, say κ, which would constitute the additionality parameter at the center of interest. Using (9'), we test and do not reject the restriction that $\kappa = 1$, which, besides being suggested by the theoretical model, directly arises from the project-level subsidy rule used by the agency. This also highlights another difference to earlier empirical work: in our model (9) is a first order condition analogous to the ones derived in the theoretical work on R&D subsidies in industrial organization and endogenous growth. Equations (9) or (9') can be used to estimate the parameters of the underlying profit function to calculate the effect of subsidies on expected discounted profits. We could calculate these effects for arbitrary values of κ. Finally, we repeat that while the existing literature focuses on firm-level relationships we operate at the project level.

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[27] Too see this, recall first that the applicant does not know the agency's type (A.1) and the subsidy rate is bounded above at $\bar{s}$. As described in Section 3.1, there is also an euro limit to the ex post reimbursements which is based on the proposed budget. Then, since $\partial\Pi_i/\partial s_i>0$ by (1), the applicant wants as high a subsidy rate as possible. Therefore it proposes an optimal project based on the maximum subsidy rate, $R_i^*(\bar{s})$. Because of the euro limit, proposing anything less risks foregoing profits in case where the actual subsidy turns out to be larger and the applicant subsequently reoptimizes. On the other hand, the applicant would never want to implement a project larger than $R^*(\bar{s})$, and it is indifferent between announcing $R^*(\bar{s})$ and any larger budget, given the assumption that it cannot misappropriate the funds.

Turning to the agency's subsidy decision in stage two, we can simply use (5)

$$(10) \qquad s_i^* = 1 - g + Z_i\delta + \eta_i,$$

with observations $s_i = s_i^* d_i$ for $s_i^* \in (0, \bar{s})$, $s_i = \bar{s}_i d_i$ if $s_i^* \geq \bar{s}$ and $s_i = 0$ if $s_i^* \leq 0$. Note that (10) is estimated using data on applicants. It thus describes the level of the subsidy rate taking into account that some applications are rejected, i.e., that observations are clustered at zero.

To estimate the screening outcomes, we assume that the agency gives each application *i* a grade $h \in \{1,\ldots,5\}$ in dimension $j \in \{c, m\}$ by using a latent regression framework. Denoting the latent value of grading dimension $j \in \{c, m\}$ for application *i* by w_{ij}^* and the observed value by w_{ij}, we get:

$$w_{ij} = h \text{ if } \mu_{h-1} < w_{ij}^* = T_i\zeta_j + \omega_{ij} \leq \mu_h$$

$$(11) \qquad h = 1,\ldots,5,\ \mu_0 \to -\infty,\ \mu_1 = 1,\ \mu_2 = 2,\ldots,\mu_5 \to \infty$$

$$\omega_{ij} \sim \mathrm{N}(0,\,1), j \in \{c, m\},\ \operatorname{cov}(\omega_{ic}, \omega_{im}) = 0,$$

where T_i is a vector of observable firm characteristics and ζ_j is a parameter vector to be estimated. The unobservables ω_{ij}, which are part of the agency's type, are assumed to be normally distributed and uncorrelated both with each other and other unobservables of the model. Firms, knowing this grading process, its parameters and the distributions of ω_{ij}, use (11) to generate the probabilities $p_{ijh}(\omega_{ij})$ of getting grade *h* in dimension *j*.

Finally, the firms' application decision rule (7) in stage one of the game can be simplified by using (1), (2), (6), and some algebra (e.g., taking logs of both sides) to

$$(12) \qquad d_i = 1\{X_i\beta - Y_i\theta + \ln[-E(\ln(1 - s_i))] \geq v_i - \varepsilon_i\}.$$

Since we only observe planned R&D for the firms that apply, not for the whole sample, a potential sample selection problem arises. We thus estimate equations (12) and (9') (with observation $\ln R_i(\bar{s}) = d_i \ln R_i^*(\bar{s})$) as a sample selection model.

Our econometric model can thus be summarized by *the screening equations* (11), *the application equation* (12), *the (modified) investment equation* (9') and *the Tekes decision rule* (10).

4.2. Statistical assumptions, identification and estimation

We now explain our statistical assumptions, how identification takes place, and how we estimate the model. We drop subscript *i* whenever no confusion arises. The five unobservables (ω_j, ε, η and v) are assumed uncorrelated with observed applicant characteristics. This is necessary to obtain correct point estimates, but as e.g. in Heckman and Vytlacil (2005), the assumption can to a great extent be relaxed while still obtaining correct estimates of rate of return and the effects of subsidies.

We also impose

A.6 a) $v = (1+\rho)\varepsilon + v_0$, b) $\eta \perp \varepsilon$, c) $\eta \perp v_0$, d) $\varepsilon \perp v_0$, e) $\omega_j \perp \varepsilon$, f) $\omega_j \perp \eta$, g) $\omega_j \perp v_0$, h) $\eta \sim$ N(0, σ_η^2), i) $\varepsilon \sim$ N(0, σ_ε^2), j) $v_0 \sim$ N(0, $\sigma_{v_0}^2$).

As A.6a shows, v and ε can be correlated with each other. A.6e-g imply that the screening equation unobservables ω_j are uncorrelated with all other shocks. A.6h-j are relaxed when we use semi-parametric estimation methods. While in line with the theoretical literature, A.6b and A6.c are probably our most controversial assumptions. The economic interpretation of A.6b is that the shock to the spillover rate (spillover per dollar of R&D) is uncorrelated with the shock to the profitability of R&D. However, since the spillover *V*( ) is a (linear) function of the applicant's investment *R*, orthogonality of ε and η does *not* meant that *V*( ) is uncorrelated with ε. In other words, we allow spillovers to depend on the shock affecting the private profitablity of R&D. From an econometric point of view, A.6b rules out endogeneity of the subsidy rate. A6.b and A6.c reduce significantly computational costs, since the Tekes decision rule (10) is no longer subject to a selection problem and estimation can be broken into three steps. We test for the correlation between ε and η and cannot reject the Null hyphothesis of no selection problem in the Tekes decision rule.

The first step is the estimation of the ordered probit screening equations (11). Using the estimates we can calculate the firms' belief that a submitted application gets a particular grade in the two evaluation dimensions. Our assumption that the unobservables are normally distributed allows us to identify the coefficients up to scale.

The second step is to estimate the Tekes decision rule (10). It identifies δ, i.e. how observed applicant and project characteristics affect the marginal effect of R&D on spillovers. This is enough to identify $V(\ )$, since a project generates utility only with positive R&D and therefore the constant of the integration of (4) is zero. As a result, $V=(Z\delta+\eta)R$. We impose (and test) A.6b and A.6c, and estimate (10) using a two-limit Tobit model. We also estimate (10) non-parametrically by a two-limit version of Powell's (1984) CLAD estimator.

In step three we aim at recovering the parameters of the application cost function (6) by estimating the application equation (12) and the investment equation (9') jointly as a sample selection model. We insert an estimate of $E(\ln(1-s))$,[28] based on the estimated screening equations and the Tekes decision rule, into (12). Estimation is done using both ML and a semi-parametric variant of the approach suggested by Das, Newey, and Vella (2003, henceforth DNV).[29] Note that β, the parameters of the investment equation (9'), enter also in (12) and thus allow for the identification of the application cost function parameters (θ) from (12). Note also that the costs of applying for subsidies, which are potentially crucial for welfare and counterfactual analyses, could not be identified without a theoretical model.

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[28] The term $\ln[-E(\ln(1-s_i))]$ can be numerically evaluated once we have estimated the parameters of the agency decision rule. We need to take into account 1) the probabilities of getting particular grades in the two grading dimensions and 2) integrate over η.

[29] Manski (1989) compares the merits of the parametric and non-parametric approaches. Manski argues that although the nonparametric approach appears to be more flexible, it involves arbitrary exclusion restrictions.

Our theoretical model imposes a form for the error term in the application equation and, as a result, we identify the correlation between ν and ε when estimating our sample selection model ((12) and (9')) using ML and assuming normal distributions for the shocks. Moreover, we can then identify the variance of the error term in (12), since following theory the coefficient of the term $E(\ln(1-s))$ is constrained to unity.[30]

We include into all estimation equations firm age, the log of the number of employees, sales per employee, a dummy for a parent company, the number of previous applications, a dummy indicating if the CEO is the chairman of the board, board size, and a dummy for exporters. We also include industry and region dummies.[31] The SME dummy is only included in the Tekes decision rule (10) and the application equation (12). We include it in (12) 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 equation is sufficient for identification of the parameters in the investment equation.

To obtain consistent standard errors in the application and investment equations ((12) and (9')), we bootstrap the whole model (9')-(12) both when using ML with normality assumptions and when using the semi-parametric DNV estimator.

There are some parameters we cannot identify. We are unable to identify *g*, the opportunity cost of government funds. Nor we can identify the agency's screening costs (*F*-*K*). If these are significant, an upward bias in the welfare calculations will arise.

5. Estimation results

In the reported specifications, we use a slightly different set of explanatory variables in the screening equations (11) and the Tekes decision rule (10) on the one hand, and the application

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[30] This implication of our theoretical model cannot be tested.

[31] We divide Finland into five regions: Southern, Western, Eastern, Northern and Central Finland. Of these, Eastern and Northern Finland are the least developed. We did try interactions between firm characteristics and industry and region dummies.

and investment equations ((12) and (9')) on the other. For example, we include the squares of the continuous variables in application and investment equations.[32] Our results are not dependent on these exclusion restrictions. We have estimated our model without imposing them, with fewer significant parameters but otherwise with very similar results. The results from the estimation of the screening equations (11) are reported in Appendix 1.

Based on our semiparametric estimations we find no evidence that the distributional assumptions of shocks are driving our parameter estimates. Our cross validation results (see Appendix 5) however reject the double normality assumptions A.6i,j on the investment and application cost shocks. To explore the robustness of our results we therefore calculate the application costs and the effects of subsidies also by estimating (12) using the semi-nonparametric estimator of Gallant and Nychka (1987). This estimator makes it feasible to recover the distribution of the shock term ($\nu - \varepsilon = \rho\varepsilon + \nu_0$) in (12) without imposing a distributional assumption on ε or ν_0. A detailed description of these robustness checks is presented in Appendices 7 and 8. We have also estimated the model (by ML with normality assumptions) by excluding the observations in the 99th size (sales) percentile, with essentially identical results to those reported. Other robustness checks will be taken up in the context of the appropriate estimation.

5.1. The Tekes decision rule and spillovers

In Table 4 we report the results concerning the Tekes decision rule. The coefficients 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 10 percentage point increase in the subsidy rate. Market risk carries a negative but insignificant coefficient. Firm size obtains a positive and significant (at 10% level)

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[32] To speed up the computation of the bootstrap we used LR-tests to narrow the set of explanatory variables in each equation. The second order terms were excluded from the screening equations (11) and the Tekes decision rule (10) based on the LR-tests.

coefficient. Moving an otherwise identical R&D project into a larger firm creates a larger spillover rate, e.g. through higher employee rents. 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 rate, everything else equal: the difference is 8.3 percentage points. The corporate governance variables and the number of previous applications have no effect. We relegate the industry and regional dummy-results to Appendix 6.

[TABLE 4 HERE]

The above results are obtained under the assumptions A.6b and A.6c, which maintain that the error in the Tekes decision rule is uncorrelated with the errors in the investment and application equations. To test these assumptions, we first estimated a probit application equation[33] and then re-estimated the Tekes decision rule by inserting the Mills ratio into it. This allows us to tackle the potential selection into the sample of applicants. The Mills ratio obtained imprecisely estimated coefficients with values close to zero in all of our several specifications, validating our assumptions of no correlation. Recall that this does not imply that spillovers are independent of profitability shocks, but rather that profitability shocks are transmitted to spillovers entirely through R&D investments.

We also tested our assumption that $V(\ )$, the spillovers from a project, is linear in the applicant's investment as implied by (4). Were $V(\ )$ non-linear in the applicant's investment, the Tekes decision rule would contain an investment term R or its interactions with observable applicant characteristics. We included these and could not reject the Null of (joint) insignificance of them.[34]

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[33] Naturally, the probit was run without the expected subsidy term, but both with and without added interactions to improve identification.

[34] This is a valid test under our assumptions A.6b and A.6c, as our investment variable is the amount the firm plans to invest in case it gets the maximum subsidy rate and it is therefore not correlated with η.

In Appendix 4 we report results from estimating the Tekes decision rule using CLAD, and an alternative dependent variable based only on pure subsidies. The results are in line with those reported here.

5.2. Cost of application function

In Table 5 we report the estimated parameters of the application cost function (equation (6)), produced by estimating the application equation (12) and the investment equation (9'). Age, CEO being chairman, and parent company status have no statistically significant effect, but firm size non-linearly decreases application costs. Sales per employee increase application costs. One interpretation is that firms producing high value added products and services 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. The size of the board decreases application costs. This may reflect the role of external knowledge in lowering application costs. Exporters have lower costs, maybe because they are relatively more experienced in dealing with government bureaucracy than non-exporting firms.

[TABLE 5 HERE]

The number of past applications has a nonlinear effect, first decreasing and then, after 118 applications, increasing application costs. Increasing the number of past applications from non-applicants' median of zero to applicants' median of two decreases application costs by 37%. One prior application decreases costs by 21% and four by 60%. It seems that learning by doing is going on. Given that our data is cross sectional it is however possible that the results are generated by unobserved heterogeneity.

5.3. Investment equation

Our investment equation (9') identifies the effects of exogenous variables on marginal profitability of R&D investment and, as discussed earlier, is closely related to the way the effect of subsidies on R&D investments is estimated in the literature. In view of the received literature, it is likely that unobserved heterogeneity accounts for a substantial part of the marginal profitability of R&D. This is also what we find, as Table 6 shows. Firms with higher value-added current production have higher marginal profitability of R&D whereas it appears to be lower in firms with CEOs as chairmen. Other findings are not robust over specifications (see Appendix 5).

The coefficient of $\ln(1-\bar{s})$ is a double test of our specification, though it is admittedly weakened by having variation only through firms' SME status. First, the coefficient could measure additionality (as e.g. in González, Jaumandreu, and Pazó 2005). In that interpretation, with a point estimate of 0.765 and a wide confidence interval, we cannot reject the Null of 1:1 additionality which our theoretical model assumes.

[TABLES 6 AND 7 HERE]

5.4. 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 (assumption A.6a) obtains a value of 1.7. 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.

6. Effects of subsidy

Our model allows us to calculate the effects of the subsidies on the firms' expected discounted profits (the firm effect), and the expected benefits captured by the agency but not the firms (the spillover effect). If one is willing to believe that the agency acts as a benevolent social planner, the sum of the effects of a subsidy on the firm and the agency constitutes the general equilibrium effect of subsidies. We report medians and means (in parenthesis) of effects, relegating the details of the calculations into Appendix 7. Recall that all effects are ex ante in the sense that they are measured prior to the launch of the R&D projects (but after the subsidy decisions).

[TABLE 8 AND FIGURE 1 HERE]

In Table 8 we report the gross firm effects that ignore the costs of application. Comparing the first row with other rows shows that ignoring the investment shock ε and application cost shock ν_0 leads to a large upward bias. By conditioning the value of the shocks on the firm being an applicant (by integrating them over the relevant regions of the shock distributions), and imposing normality on both ε and ν_0 greatly reduces the effects (row 2). This is not surprising given the finding of Section 5.4 that the applicants have smaller values of ε than non-applicants. Rows 2 and 3 reveal that using the estimated value of ε (the residual of the estimated investment equation) instead of integrating over its (imposed) normal distribution further lowers the median effects by some 40-45%, but mean firm effects are close to each other. Rows 3 and 4 in turn show that the distributional assumptions make no difference for gross firm effects effects when we use the estimated value of ε.[35] The median (mean) gross firm effect is of the order of €50 000 (€100 000).

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[35] This is because $\hat{\varepsilon} = R(\bar{s}) + \ln(1-\bar{s}) - X\hat{\beta}$ and because irrespective of the estimation method $X\hat{\beta} + \hat{\varepsilon}$ amounts to the same.

Figure 1 displays the substantial heterogeneity of gross firm effects on the applicants that receive a subsidy, calculated under the assumption that both ε and ν_0 are normally distributed and using the estimated ε.

[TABLE 9 HERE]

Table 9 presents the net firm effects that take the costs of application into account. They have been calculated both for all applicants and for applicants that received a subsidy. The net firm effects ignoring shocks are negative contrary to what we should observe but are positive once we take into account the shocks. Integration over the distributions of ε and ν_0 yields clearly lower estimates of the mean effect than using the estimated value of ε while the medians are relatively close to each other. As we relax the distributional assumptions the effects slightly increase.

[TABLE 10 AND FIGURE 2 HERE]

We then turn to spillover effects (Table 10). If the agency is a benevolent social planner caring (only) domestic welfare, they should reflect the anticipated change in e.g. domestic R&D spillovers, consumer surplus, and business-stealing effects due to a subsidy. Spillover effects are also calculated with and without the shocks. As in the case of gross firm effects effects, taking the shocks into account lowers the median effects substantially. Using the estimated value of ε yields lower estimates of the spillover effects than integrating over its (assumed) distribution. Comparison of Tables 9 and 10 suggests that firms appropriate some 60% of the total effect.

Figure 2 shows the distribution of $Z\hat{\delta}+\hat{\eta}$, which is the marginal effect of R&D on expected spillovers (recall that $V=(Z\delta+\eta)R$). The expected spillovers are increasing in R&D investments and hence in the subsidy rate for the most of the projects in our data. The expected increase in spillovers is typically between 0.25 and 0.5 per one euro of R&D and for 99% of firms, a one euro increase in R&D leads to a less than 0.85 euro increase in spillovers.[36]

[TABLE 11 HERE]

Table 11 reports our estimates of application costs. Ignoring shocks leads to very high application cost estimates, explaining the negative net firm effects. Taking the shocks into account by integrating over the distributions of ε and ν_0 reduces the estimated application costs by 85%. Using the estimated value of the investment shock ε reduces the median application cost by another €33 000, or more than 90%. Relaxing the distributional assumptions further lowers the estimate of the median (mean) application cost shock for applicants. It thus ultimately seems that for an evaluation of the actual policy, application costs may not be of first order importance. Nonetheless, our results from Section 5.4 suggests that any counterfactual policy analysis will critically depend on application costs since non-applicants have higher investment shocks and investment and application cost shocks are positively correlated.

[TABLE 12 HERE]

Finally, Table 12 shows our calculations of the expected rate of return on the subsidy program.[37] Under the assumption of a benevolent social planner the rate of return can be compared to the opportunity cost of public funds (*g*) to evaluate the program. We have used *g* = 1.2. [38] Figures in Table 12 show that once shocks are taken into account, the estimated rate of return on the subsidy policy exceeds the opportunity cost of public funds.

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[36] We trimmed the sample used in Figure 2 at the 99th percentile.

[37] The joint rate of return on the subsidy program is the overall benefits due to subsidies (net firm effect plus the spillover effect) divided by the overall cost of subsidies (granted subsidy share multiplied by the investment given by the granted subsidy), ignoring the shadow cost of taxes, and taking all applicants into account. The difference between the two columns is that the first one is based on the R&D investment predicted by our model and the second one uses the minimum of this and the R&D investment accepted by Tekes.

[38] Kuismanen (2000) estimates the dead-weight loss of existing Finnish taxation to be 15% using a labor supply model.

7. Conclusions

We analyze one of the mostly widely used innovation policy tools: R&D subsidies. We complement the existing literature by building a structural model of the R&D subsidy process and show how the selection of the subsidy by the agency and "self-rejection" by the firms – the decision whether to apply or not – provide information on hitherto unmeasured objects: spillover effects of subsidies and application costs. Our model generates an R&D equation through firms' first order condition that is close to those derived in theoretical industrial organization and endogenous growth literatures and those estimated in empirical work. More importantly, identification of our model does not depend on distributional nor functional form assumptions, and identification of the effects of the subsidy is obtained under rather weak assumptions, e.g. allowing for most explanatory variables to correlate with error terms.

Taking the model to project level data from Finland we find that large firms generate a larger spillover rate (spillover per dollar of R&D), as do technically more challenging projects. Firms with higher value added current production have higher marginal returns to R&D and higher application costs. Profitability and application cost shocks are positively related, implying that firms do not apply for subsidies for the privately most profitable projects.

We estimate ex ante effects of subsidies that reflect the revealed preferences of the key decision makers at the time they make their decisions – the firms on applying or not, and the agency on the level of subsidy. They thus embody the perceived benefits and costs of the program prior to the actual R&D investments taking place. We find considerable heterogeneity in all subsidy effects. Our estimate of the median net firm effect on the applicants that received a subsidy is close to €50 000 and the median gross spillover effect is approximately €33 000. These numbers suggest that treated firms internalize 60% of the total effect.

To produce a welfare analysis we use strong but standard assumptions. Our spillover effects can be interpreted as (domestic) externalities and our calculated rate of return on subsidies as a social rate of return if one is willing to assume that the agency giving subsidies is a benevolent social planner. In that case our estimates suggest that the expected program benefits cover the opportunity cost of public funds.

In our desire to model the whole R&D subsidy program with explicit application, allocation and investment decisions, we have overlooked some important issues that have been highlighted in the previous literature, such as fixed costs of R&D projects and financial market imperfections. These should clearly be incorporated in future work. Another difference between our and existing work is that we use firms' R&D plans. Our results are therefore informative of the expected returns to the policy and the agents prior to actual execution of the projects. While this provides a new perspective to the effects of R&D subsidies, in the future we hope to explore the differences between planned and realized R&D investments.

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Table 1

Descriptive Statistics

	Mean	S.d.	Min.	Max.
Age, years	12	9.3	1	97
# Employees	35	257	1	13451
Sales/employee, €1000	165	2157	0	206875.5
Exporter	0.22	0.42	0	1
SME	0.98	0.16	0	1
CEO is chairman of board	0.14	0.35	0	1
Board size	4.35	2.00	1	10
# past Tekes applications	0.58	3.49	0	146
Applicant	0.08	0.28	0	1

NOTES: There are 10945 observations. Data sources: Asiakastieto Ltd. otherwise; for data on applications, Tekes.

Table 2

Conditional Descriptive Statistics

	Non-Applicants	Applicants	Rejected Applicants	Successful Applicants
Age	12	12	12	12
	(9)	(10)	(10)	(9)
	[10]	[10]	[9]	[10]
# Employees	21	189	101	212
	(122)	(776)	(188)	(867)
	[5]	[26]	[21]	[27]
Sales/employee	169	122	105	126
	(2253)	(55)	(94)	(167)
	[76]	[90]	[83]	[92]
Exporter	0.19	0.57	0.52	0.59
	(0.39)	(0.50)	(0.50)	(0.49)
SME	0.99	0.85	0.86	0.85
	(0.12)	(0.36)	(0.35)	(0.36)
CEO is chairman of board	0.14	0.15	0.18	0.14
	(0.35)	(0.36)	(0.38)	(0.35)
Board size	4.2	6.2	5.9	6.3
	(1.9)	(2.4)	(2.3)	(2.5)
	[4]	[6]	[5]	[6]
# past Tekes applications	0.25	4.16	3.23	4.41
	(1.28)	(10.66)	(10.93)	(10.58)
	[0]	[2]	[1]	[2]
Nobs.	10030	915	193	722

NOTES: Number reported are mean, (standard deviation), and for other than [0,1] variables, [median]. Data sources: Asiakastieto Ltd. otherwise; for data on applications, Tekes.

Table 3
Descriptive Statistics of Tekes and Application Variables

	All Applicants	Successful Applicants	Rejected Applicants
Applied amount, €	634294	700378	385790
	(1254977)	(1363460)	(657540)
Applied for subsidy only	0.59	0.48	1.00
	(0.49)	(0.50)	(0.00)
Technical challenge	2.1	2.3	1.5
	(0.98)	(0.87)	(1.00)
	{582}	{426}	{156}
Risk	2.2	2.2	2.3
	(0.94)	(0.93)	(0.94)
	{422}	{326}	{96}
Granted subsidy rate	-	0.32	-
		(0.13)	
Granted subsidy only	-	0.84	-
		(0.60)	
Nobs.	915	722	193

NOTES: Datasource: Tekes. Reported numbers are mean, standard deviation, and {nobs}, the last in case it deviates from that reported on the last row.

Table 4
Tekes Decision Rule Results

Variable	Dep. var. subsidy-intensity (all finance)
Risk	-.020* [-.043 .003]
Technical challenge	.100*** [.076 .124]
Age	-.001 [-.003 .002]
Log employment	.019* [-.001 .039]
Sales / employment	.00005 [-.0001 .0002]
SME	.083* [-.003 .169]
Parent company	.006 [-.041 .052]
# previous applications	-.001 [-.007 .004]
CEO also chairman	.001 [-.054 .055]
Board size	-.007 [-.017 .003]
Exporter	-.021 [-.079 .038]
Constant	-.054 [-.215 .107]
σ_η	.190*** [.173 .206]
Nobs.	379
LogL.	-19.216
Wald	0.000
Linearity 1	0.659
Linearity 2	0.197
Sample sel.	.030 (.027)

NOTES: Reported numbers are coefficient and [95% confidence interval]. Wald is the p-value of a Wald test of joint significance of all RHS variables. All specifications include industry and region dummies.
Linearity 1 = the p-value of a LR-test of including the proposed R&D investment into the equation.
Linearity 2 = the p-value of a LR-test of including the proposed R&D investment into the equation, plus interactions between it and age, log employment, and sales/employee.
Sample sel. = coeff. and (s.e.) of the Mills ratio term when the 1(apply) specification same as in Table 5.
***, **, and * denote significance at 1, 5, and 10% level.

Table 5

Application Cost Function Results

Variable	Coefficient [95 % confidence interval]
Age	.019 [-.016 .709]
Age sq.	-.0001 [-.007 .0003]
Log of employment	-.423** [-10.856 -.043]
Ln(emp) sq.	.069*** [.022 1.382]
Sales/employee	.002*** [.0007 .022]
Sales/emp. Sq.	-7.97e-0.8 [-8.53e-07 1.76e-06]
SME	.591 [-.581 6.939]
Parent company	-.188 [-4.164 .119]
# Previous applications	-.236*** [-5.383 -.077]
# Prev appl. sq.	.002*** [.0005 .037]
CEO is chairman	-.243 [-1.575 .388]
Board size	-.098* [-2.486 .006]
Exporter	-.866*** [-16.604 -.181]
Constant	13.449*** [11.156 100.589]
Nobs	10944

NOTES: Confidence intervals are estimated using a bootstrap with 400 repetitions. The specification includes industry and regional dummies.

Wald is the p-value of the joint significance of all explanatory variables in the probit 1st stage regression.

***, **, *, and [a] denote that the whole 99%, 95%, 90% and 85% confidence interval has the same sign as the coefficient estimate.

Table 6

R&D Investment Function Results

Variable	Coefficient [95 % confidence interval]
Age	-.005 [-.024 .011]
Age sq.	.0001 [-.0001 .0004]
Log of employment	-.106 [-.259 .069]
Ln(emp) sq.	.024** [.003 .046]
Sales/empl.	.001** [.0001 .002]
Sales/emp. sq.	-7.42e-08 [-5.59e-07 1.74e-06]
Parent company	-.023 [-.184 .149]
# Previous applications	-.043** [-.073 -.008]
# Prev appl. sq.	.0002** [-7.26e-06 .0006]
CEO is chairman	-.097 [-.274 .097]
Board size	.008 [-.028 .050]
Exporter	-.190* [-.383 .043]
Constant	12.840*** [11.638 13.674]
Nobs.	914
Wald (d.f. X)	0.000
$\ln(1-\bar{s})$	-0.765 (0.780)

NOTES: Confidence intervals are based on a bootstrap with 400 repetitions.

Wald is the p-value of joint significance of RHS variables.

$\ln(1-\bar{s})$ coefficient reports the coefficient and the (p-value) of a χ^2-test of difference from unity.

***, **, *, and ^{a} denote that the whole 99%, 95%, 90% and 85% confidence interval has the same sign as the coefficient estimate.

Table 7
Covariance Structure Results

Variable	Coefficient [95 % confidence interval]
σ_{ε} Standard deviation of the investment equation shock	1.212*** [1.010 1.351]
σ_{η} Standard deviation of the spillover (=V( )) shock	.190*** [.173 .206]
$\sigma_{\upsilon 0}$ Standard deviation of the uncorrelated part of the application cost function shock	.791*** [.234 20.917]
$1+\rho$ Measure of the variance share of ε in υ	1.673*** [1.174 17.304]
$\rho_{\varepsilon\upsilon}$ Correlation between ε and the application equation error term	-.718*** [-.832 -.462]

NOTES: For all but σ_{η}, values are based on a bootstrap with 400 repetitions. For σ_{η}, it is based on the estimated covariance matrix.
***, **, and * denote significance at 1, 5, and 10% level.

Table 8
Gross Firm Effects

Distributional assumptions underlying estimation and integration	Calculation of shocks	Gross firm effect on applicants that received a subsidy
Double normal	No shocks	149 442 (170 984)
	Integration over ε, ν_0	81 871 (107 461)
	Actual ε	49 706 (108 902)
Double free	Actual ε	49 706 (108 902)

NOTE: Reported numbers are median and (mean).
Double normal = both ε and ν_0 are assumed to be normally distributed.
Double free = both shocks' distributions are determined (semi-)nonparametrically.

Table 9
Net Firm Effects

Distributional assumptions underlying estimation and integration	Calculation of shocks	Net firm effect on applicants	Net firm effect on applicants that received a subsidy
Double normal	No shocks	-121 926	-74 512
		(-384 093)	(-385 961)
	Integration over ε,ν_0	30 228	43 916
		(42 966)	(64 896)
	Actual ε, integration over $\rho\varepsilon+\nu_0$	31 496	46 253
		(81 263)	(103 689)
Double free	Actual ε, integration over $\rho\varepsilon+\nu_0$	33 846	49 463
		(84 965)	(107 758)

NOTE: Reported numbers are median and (mean).
Double normal = both ε and ν_0 are assumed to be normally distributed.
Double free = both shocks' distributions are determined (semi-) nonparametrically.

Table 10
Spillover Effects

Distributional assumptions underlying estimation and integration	Calculation of shocks	Spillover effect generated by applicants that received a subsidy
Double normal	No shocks	97 717 (130 802)
	Integration over ε, ν_0	56 331 (79 990)
	Actual ε	33 565 (75 720)
Double free	Actual ε	33 565 (75 720)

NOTE: Reported numbers are median and (mean).
Double normal = both ε and ν_0 are assumed to be normally distributed.
Double free = both shocks' distributions are determined (semi-) nonparametrically.

Table 11
Application Costs

Distributional assumptions underlying estimation and integration	Calculation of shocks	Application cost, Applicants
Double normal	No shocks	242 986
		(519 012)
	Integration over ε,ν_0	35 533
		(41 827)
	Actual ε, integration over $\rho\varepsilon+\nu_0$	2 431
		(4 762)
Double free	Actual ε, integration over $\rho\varepsilon+\nu_0$	503
		(1 061)

NOTE: Reported numbers are median and (mean).
Double normal = both ε and ν_0 are assumed to be normally distributed.
Double free = both shocks' distributions are determined (semi-) nonparametrically.

Table 12
Rate of return on the subsidy program

Distributional assumptions underlying estimation and integration	Calculation of shocks	Using the subsidy amount predicted by the model	Based on actual accepted costs
Double normal	No shocks	-1.62	-3.42
	Integration over ε,ν_0	0.98	1.45
	Actual ε, integration over $\rho\varepsilon+\nu_0$	1.31	1.51
Double free	Actual ε, integration over $\rho\varepsilon+\nu_0$	1.34	1.55

NOTE: Double normal = both ε and ν_0 are assumed to be normally distributed.
Double free = both shocks' distributions are determined (semi-) nonparametrically.

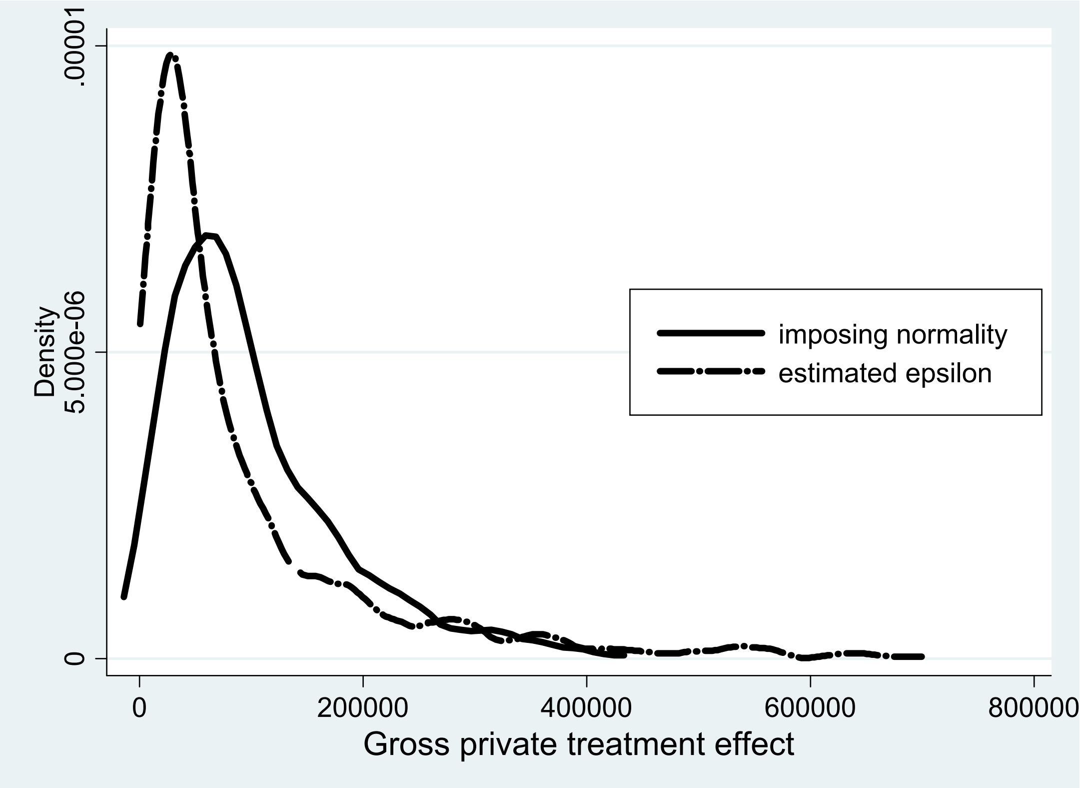

Figure 1: Distribution of the gross firm effect for applicants that received a subsidy.

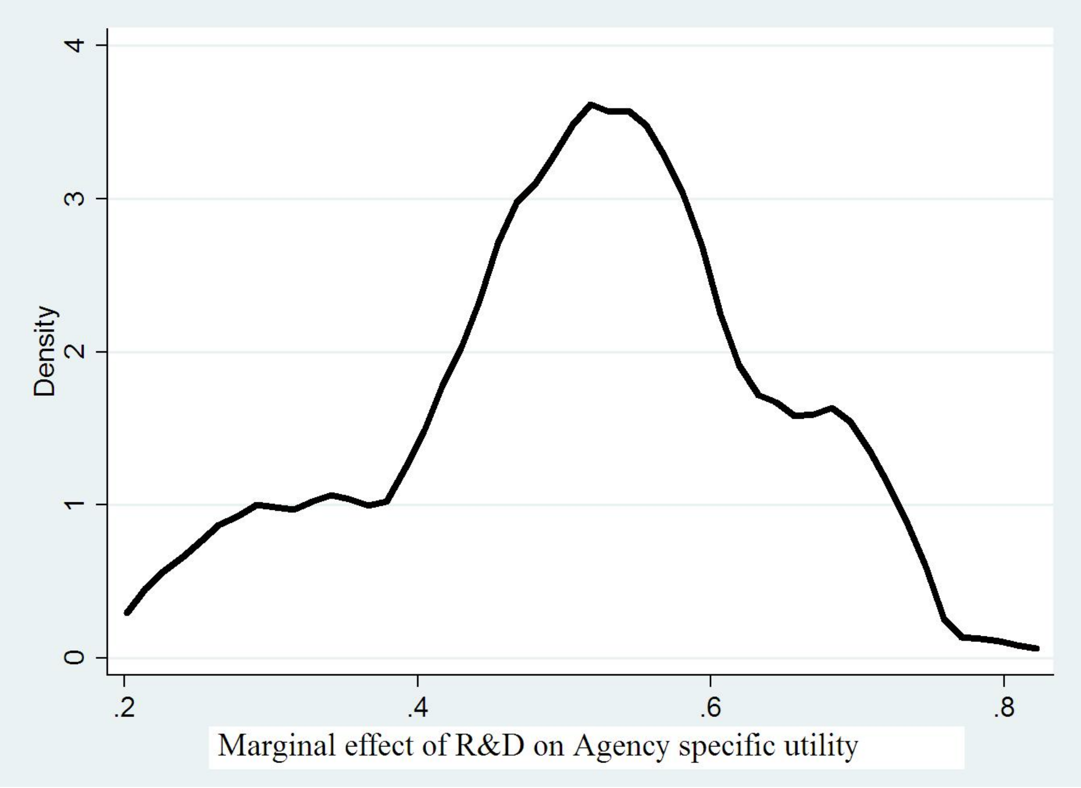

Figure 2: Marginal effect of R&D on spillovers

Appendices

In these Appendices, we report the ordered probit estimation of the Tekes grading process (Appendix 1); descriptive statistics of a) the whole application sample b) the application sample who have strictly positive accepted proposed investments, and c) the application sample for which we observe grades in both evaluation dimensions (Appendix 2); industry and region dummy descriptive statistics (Appendix 3.); robustness checks of the Tekes decision rule (Appendix 4.) and the investment equation (Appendix 5); coefficients of the industry and region dummies for the estimated equations (Appendix 6); details of how we have calculated the firm effect of subsidies (Appendix 7); and point estimates of the application cost function obtained using the semi-nonparametric estimator of Gallant and Nychka (1987) in the application equation and DNV-estimator in the investment equation (Appendix 8) .

Appendix 1: The screening equations

We have different applicant samples in the estimations of the two grading dimensions, because sometimes we only observe one or the other grade for an application. During our observation period, Tekes did not uniformly store grading data in their central database, from which our data has been collected. We use the estimation results to create the probabilities of getting a particular grade for all the 10751 (10944) observations in the estimation sample.

In the technical challenge estimation, sales per employee, number of previous applications, board size, and industry dummies (chemical, industry, electric engineering, data processing, and R&D services) increase the probability of getting a high grade in evaluation of technical challenge. Having a CEO as chairman and being in the food or paper industry decreases the probability of getting a high grade.

In the market risk estimation, sales per employee and a number of industry dummies have a negative effect on the probability of obtaining a high risk rating (high meaning higher risk). The industry dummies that carry significant negative coefficients are paper, other manufacturing, and telecoms. Being located in Western Finland also decreases the probability of being classified as high risk.

Table A.1
Estimation of the Screening Equations

Variable	Technical Challenge	Risk
Age	.002 [-.008 .012]	-.003 [-.015 .009]
Log Employees	-.006 [-.080 .068]	-.047 [-.133 .040]
Sales/employee	.001*** [.0001 .002]	-.001* [-.002 .0002]
Parent Company	-.019 [-.223 .185]	-.118 [-.357 .120]
# Previous Applications	.023* [-.0001 .046]	-.020 [-.047 .006]
CEO is chairman	-.247** [-.488 -.007]	-.014 [-.296 .268]
Board size	.080*** [.036 .123]	.033 [-.017 .082]
Exporter	.251** [.005 .498]	-.319** [-.619 -.019]
Nobs.	582	422
LogL.	-752.711	-527.563
Joint Significance	0.000	0.0000

NOTES: reported numbers are coefficient and [95% confidence interval]. Joint Significance is the p-value of a LR test of joint significance of all explanatory variables. Both specifications include industry and region dummies.
***, **, and * denote significance at 1, 5, and 10% level.

Appendix 2: Descriptive statistics of the applicant samples

Table A.2 presents the descriptive statistics for the three samples of applicants. As can be seen, the differences are minor; judging on observables, we are unlikely to have a selection problem among applicants in the subsidy equation. The only potentially worrisome difference is that in the smallest sample, the mean number of previous application is lower (2.8) than in the other two (4.2 and 4.4). The standard error also declines. Also, the proportion of telecom firms and firms in Eastern Finland are somewhat lower. As we report in the main text, we found no evidence for sample selection after testing it against the whole sample.

Table A.2
Descriptive Statistics of Different Applicant Samples

Variable	All Applicants	Applicants with strictly positive proposed accepted investment	Applicants for whom grades in both evaluation dimensions are observed
Age	12	12	11
	(9.6)	(9.5)	(9.0)
Log Employees	3.4	3.5	3.2
	(1.8)	(1.8)	(1.7)
Sales/employee	122	126	120
	(155)	(167)	(128)
SME	.85	.85	.88
	(.36)	(.36)	(.33)
Parent company	.51	.53	.48
	(.50)	(.50)	(.50)
# Previous applications	4.2	4.4	2.8
	(10.7)	(10.6)	(4.5)
CEO is chairman	.15	.14	.17
	(.36)	(.35)	(.38)
Board size	6.2	6.3	6.1
	(2.4)	(2.5)	(2.4)
Exporter	.57	.59	.58
	(.50)	(.49)	(.50)
Food	.04	.04	.03
	(.18)	(19)	(.18)
Paper	.05	.05	.04
	(.22)	(.22)	(.19)
Chemicals	.03	.04	.03
	(.18)	(.18)	(.16)
Rubber	.06	.06	.06
	(.24)	(.24)	(.24)
Metals	.08	.08	.07
	(.27)	(.27)	(.25)
Electric	.10	.11	.11
	(.30)	(.31)	(.31)
Radio and TV	.04	.04	.05
	(.20)	(.19)	(.21)
Other manufacturing	.09	.09	.09
	(.29)	(.29)	(.28)
Telecoms	.01	.01	.003
	(.09)	(.10)	(.05)
Data processing	.21	.20	.26
	(.41)	(.40)	(.44)
R&D	.15	.15	.13
	(.36)	(.35)	(.34)
Western Finland	.32	.32	.35
	(.47)	(.47)	(.48)
Eastern Finland	.12	.13	.06
	(.32)	(.33)	(.23)
Central Finland/ Oulu region	.09	.08	.09
	(.28)	(.27)	(.28)
Northern Finland / Lapland region	.02	.02	.03
	(.15)	(.14)	(.17)
Nobs.	915	722	379

Appendix 3: Descriptive statistics of the industry and region dummies for the whole sample

Table A.3
Descriptive Statistics of the Industry and Region Dummies for the Whole Sample

Variable	Mean (s.d.)
Agriculture	.0001 (.010)
Food	.045 (.207)
Paper	.061 (.239)
Chemicals	.015 (.120)
Rubber	.056 (.229)
Metals	.139 (.346)
Electric	.046 (.209)
Radio and TV	.015 (.120)
Other manufacturing	.188 (.391)
Telecoms	.009 (.095)
Data processing	.105 (.307)
R&D	.196 (.397)
Southern Finland	.453 (.498)
Western Finland	.386 (.487)
Eastern Finland	.078 (.268)
Central Finland/Oulu region	.061 (.240)
Northern Finland/Lapland	.023 (.149)

NOTES: there are 10945 observations.

Appendix 4: Robustness checks of the Tekes decision rule

We also estimated the Tekes decision rule by a two-limit version of Powell's (1984) CLAD estimator. We first estimated a LAD using all 379 observations, then excluded all observations with predicted values less than the minimum or more than the maximum allowed, and re-estimated the LAD. This was repeated until convergence.

As column two of Table A.4 shows, the results are relatively close to those obtained using Tobit ML. The only noteworthy differences are that with CLAD, the rubber industry obtains a significant positive coefficient (approximately 0.008 in value, compared with 0.012 for Tobit), and the coefficient of Central Finland is no more significant. There are some relatively large differences between the insignificant coefficients, though.

To test whether measuring the subsidy per cent by summing subsidies, low-interest loans and capital loans affect the results, we estimated the two-limit Tobit using only subsidies, excluding the loans. Column three in Table A.4. reveals that our results are not driven by our definition of the dependent variable. We also checked whether the definition of the dependent variable in the Tekes decision rule affects our parameter estimates in the sample selection model (application and R&D investment). The parameters of the R&D investment equations are virtually identical, as are most of the parameters of the application equation. All parameters in the application equation are within one standard deviation of each other.

Table A.4
Tekes Decision Rule Results

Variable	(1) ML Dep. var. subsidy-intensity (all finance)	(2) CLAD Dep. var. subsidy-intensity. (all finance)	(3) ML Dep. var. subsidy-intensity (subsidies only)
Risk	-.020*	-.020	-.024**
	[-.043 .003]	[-.046 .006]	[-.048 -.00005]
Technical challenge	.100***	.092***	.104***
	[.076 .124]	[.065 .119]	[.079 .129]
Age	-.001	-.0001	-.001
	[-.003 .002]	[-.0017 .0023]	[-.004 .001]
Log employment	.019*	.025**	.025**
	[-.001 .039]	[.008 .040]	[.004 .046]
Sales / employment	.00005	.00005	.00007
	[-.0001 .0002]	[-.000083 .000151]	[-.0001 .0002]
SME	.083*	.070	.069
	[-.003 .169]	[-.003 .138]	[-.020 .157]
Parent company	.006	.015	.008
	[-.041 .052]	[-.023 .055]	[-.040 .056]
# previous applications	-.001	-.002	-.002
	[-.007 .004]	[-.006 .002]	[-.007 .003]
CEO also chairman	.001	-.018	-.0002
	[-.054 .055]	[-.064 .028]	[-.057 .056]
Board size	-.007	-.0003	-.008
	[-.017 .003]	[-.0084 .0082]	[-.018 .003]
Exporter	-.021	-.016	-.037
	[-.079 .038]	[-.069 .038]	[-.098 .024]
Constant	-.054	-.083	-.079
	[-.215 .107]	[-.233 .028]	[-.246 .088]
σ_η	.190***	-	.196***
	[.173 .206]		[.179 .213]
Nobs.	379	379	379
LogL.	-19.216	-	-21.542
Wald	0.000	-	0.000
Linearity 1	0.659	-	-
Linearity 2	0.197	-	-
Sample sel.	.030	-	-
	(.027)		

NOTES: Reported numbers are coefficient and [95% confidence interval]. Wald is the p-value of a Wald test of joint significance of all RHS variables. All specifications include industry and region dummies.

Linearity 1 = the p-value of a LR-test of including the proposed R&D investment into the equation.

Linearity 2 = the p-value of a LR-test of including the proposed R&D investment into the equation, plus interactions between it and age, log employment, and sales/employee.

Sample sel. = coeff. and (s.e.) of the Mills ratio term when the 1(apply) specification same as in Table 5.

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

In columns (1) and (2), the dependent variable is the proportion of expenses that Tekes covers, defined as the sum of all three types of financing Tekes grants (in €, see main text) divided by accepted proposed investment. In column (3), the dependent variable is the subsidy (in €) divided by the accepted proposed investment.

Appendix 5: Robustness checks of the investment equation

We estimated the model both by ML, dropping the second order terms, and using DNV's semi-parametric sample selection estimator. We imposed otherwise the structure of the ML specification, but allowed the additively separable error terms to have an unknown distributions. The results are in line with the main ML estimates (reproduced in column 1): most coefficients are within the ML 95% confidence intervals. This suggests that our ML distributional assumptions are not biasing the parameter estimates.

Cross-validation(see Table A.5b) suggests that the (double) normality assumption does not hold in the data. We used the same trimming and transformation DNV. The transformation gives exact sample selection correction for Gaussian disturbances. The trimming explains the difference in the sample size compared to ML estimations. We tried up to the 4th order terms for the variable capturing the effect of subsidies on expected discounted profits in the 1st stage, and started from the ML specification. Cross-validation indicated that we should include the subsidy-terms up to the 3rd order, but should not include interactions of the other explanatory variables. In the 2nd stage, we kept the same specification as in ML, and experimented with including up to the 4th order transformation of the propensity score (without interactions with explanatory variables). We used a Gram-Schmidt ortho-normalization for the 3rd and 4th order terms in both stages.

Table A.5.a
R&D Investment Function Results

Variable	(1) ML Dep. var. proposed investment	(2) ML Dep. var. proposed investment	(3) DNV Dep. var. proposed investment
Age	-.005	-.002	-.013
	[-.024 .011]	[-.008 .005]	[-.092 .089]
Age sq.	.0001	-	.0002
	[-.0001 .0004]		[-.0003 .0008]
Log of employment	-.106	.068^a	.052
	[-.259 .069]	[-.013 .128]	[-.497 .736]
Ln(emp) sq.	.024**	-	.003
	[.003 .046]		[-.047 .034]
Sales/empl.	.001**	0.001***	.001^a
	[.0001 .002]	[.0007 .002]	[-.0004 .004]
Sales/emp. sq.	-7.42e-08	-	-1.73e-07
	[-5.59e-07 1.74e-06]		[-1.19e-06 1.25e-06]
Parent company	-.023	-.002	-.015
	[-.184 .149]	[-.143 .167]	[-.843 .888]
# Previous applications	-.043**	-.009	-.090
	[-.073 -.008]	[-.019 .004]	[-1.924 1.253]
# Prev appl. sq.	.0002**	-	.0006
	[-7.26e-06 .0006]		[-.011 .015]
CEO is chairman	-.097	-.100^a	-.054^a
	[-.274 .097]	[-.285 .079]	[-.396 .105]
Board size	.008	.022	.013
	[-.028 .050]	[-.020 .058]	[-.402 .439]
Exporter	-.190*	-.072	-.061
	[-.383 .043]	[-.329 .139]	[-2.678 2.236]
Propensity score	-	-	3.257
			[-121.150 112.261]
Propensity score2			-7.347
			[-127.516 77.826]
Propensity score3			31.505
			[-37.036 66.101]
Constant	12.840***	12.008***	-
	[11.638 13.674]	[11.115 12.956]	
Nobs.	914	914	876
Wald (d.f. X)	0.000	0.000	0.000
$\ln(1-\bar{s})$	-0.765	-0.108	
	(0.780)	(0.165)	

NOTES: Reported numbers are coefficient and [95% confidence interval]. Confidence intervals are based on a bootstrap with 400 repetitions. In columns (1)-(3) the dependent variable is the log of accepted proposed investment: in column (4) it is the log of proposed investment.

Wald is the p-value of joint significance of RHS variables. The constant is not identified when using DNV.

$\ln(1-\bar{s})$ coefficient reports the coefficient and the (p-value) of a χ^2 -test of difference from unity.

***, **, *, and ^{a} denote that the whole 99%, 95%, 90% and 85% confidence interval has the same sign as the coefficient estimate.

Table A.5.b

Cross-validation of the Application and R&D Investment Equations

Specification	Application Equation	R&D Investment Equation
Linear term	0.0595	1.0246
+2nd power	0.0602	1.0227
+2nd and 3rd power	0.0586	1.0217
+2nd -4th power	0.0635	1.0234
+ 2nd and 3rd powers and 1st order interactions between continuous variables	0.0982	-

Notes: the linear term is the effect of expected subsidies on expected discounted profits in the application equation, and the propensity score transformation that DNV use (Mills ratio) in the R&D investment equation. The base specification is the same as in the ML estimations.

Cross-validation figures were calculated using equation (2.22) in Yatchew (1998).

Appendix 6: Coefficients of industry and region dummies

The only industry dummies with significant coefficients are food (p-value .000) and data processing (p-value .081). Using metal manufacturing firms as a reference group, firms in the food industry received a substantially higher subsidy, of the order of 25 percentage points, whereas data processing firms obtained subsidies that were 6.5 percentage points lower. During our observation period, Tekes was actively seeking applications from the food industry, which at least partially explains the findings concerning the industry.

Regional aspects affect Tekes decisions: firms in Eastern and Central Finland obtain subsidies that are 7-10 percentage points higher than those in Southern Finland. That regional policy matters is, however, debatable, as the city of Oulu, which is located in Central Finland is one of the R&D centers in Finland. Moreover, we find that firms in the depressed and sparsely populated Northern Finland do not get higher subsidies.[39]

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[39] This finding is perhaps not robust as only 2% of our sample firms come from Northern Finland.

Table A.6
Estimated Industry and Region Dummy Parameters

Variable	Tekes Decision Rule Table A.4			Application Cost Function Table 5	R&D Investment Function Table A.5.a		
Column	(1)	(2)	(3)		(1)	(2)	(3)
Food	.242***	.224***	.262***	.222	-.524**	-.480**	-.560*
	[.115 .368]	[.091 .357]	[.132 .392]	[-1.515 2.720]	[-.881 -.151]	[-1.00 -.269]	[-1.184 .219]
Paper	-.028	.016	-.028	.354	.191	.184	.122
	[-.151 .094]	[-.116 .148]	[-.156 .099]	[-0.507 10.445]	[-.140 .550]	[-.350 .343]	[-1.452 1.120]
Chemicals	.096	.060	.114	.901	.219	.233	.239
	[-.038 .230]	[-.092 .212]	[.024 .252]	[-3.292 3.257]	[-.352 .731]	[-.162 .752]	[-.663 .903]
Rubber	.011	.082	.011	.269	.111	.106	.089
	[-.086 .107]	[-.029 .193]	[-.089 .111]	[-.381 3.970]	[-.211 .458]	[-.213 .407]	[-.391 .820]
Metals	.006	.016	-.0008	.555^{a}	.370***	.340**	.275
	[-.087 .098]	[-.087 .119]	[-.096 .094]	[-.005 5.738]	[.091 .634]	[-.067 .472]	[-.492 .923]
Electric	-.041	-.006	-.034	.019	.286**	.330**	.293
	[-.124 .041]	[-.101 .088]	[-.119 .051]	[-8.945 .595]	[.044 .575]	[-.030 .540]	[-1.129 1.956]
Radio and TV	-.021	.006	-.009	.531	.649**	.652**	.659*
	[-.129 .086]	[-.113 .126]	[-.120 .102]	[-3.192 1.807]	[.125 1.201]	[.247 1.183]	[-.279 1.600]
Other manufacturing	-.017	.002	-.008	.536	.195	.150	.071
	[-.105 .071]	[-.098 .103]	[-.099 .083]	[-.122 10.378]	[-.078 .470]	[-.379 .217]	[-.760 .811]
Telecoms	-	-	-	.831*	.491^{a}	.547*	.457
				[-.295 10.181]	[-.180 1.225]	[-.084 1.08]	[-.910 2.878]
Data processing	-.072*	-.040	-.066	-.562	.200	.327	.314
	[-.154 .010]	[-.135 .055]	[-.151 .019]	[-18.026 .372]	[-.091 .521]	[-.029 .484]	[-2.229 2.690]
R&D	.002	.035	.003	.088	.071	.090	.114
	[-.083 .087]	[-.060 .131]	[-.085 .090]	[-4.200 .576]	[-.215 .353]	[-.286 .226]	[-.359 .374]
Western Finland	.017	.023	.015	.399	.242***	.231**	.237^{a}
	[-.029 .064]	[-.030 .076]	[-.033 .063]	[-.427 1.124]	[.084 .414]	[.012 .328]	[-.089 .379]
Eastern Finland	.094**	.090**	.118*	-.429^{a}	-.450***	-.399***	-.370
	[.005 .184]	[.013 .193]	[.026 .210]	[-9.837 .053]	[-.675 -.196]	[-.548 -.059]	[-1.724 .891]
Central Finland/Oulu region	.063*	.030*	.071*	-.015	.048	.071	.078
	[-.012 .139]	[-.052 .112]	[-.007 .149]	[-5.404 .453]	[-.225 .355]	[-.246 .255]	[-.772 1.146]
Northern Finland/Lapland	-.031	-.039	-.019	-.024	.095	.140a	.136
	[-.159 .096]	[-.174 .097]	[-.151 .113]	[-2.497 1.770]	[-.262 .593]	[-.027 .715]	[-.243 .717]

NOTES: in the Tekes decision rule equations, we excluded the telecommunications dummy because of problems in the bootstrap that were due to the low proportion of telecommunications firms in our sample of firms with both Tekes evaluation grades. ***, **, *, and ^{a} denote significance at 1, 5, 10, and 15% level. Southern Finland is our base region.

Appendix 7. Calculation of the firm effect

We have calculated the firm effects in three ways. Below we show the calculation of net firm effect (NFT) in each of the three ways. All the other effects are calculated in similar manner. First, to demonstrate the importance of shocks, we ignore them. This gives us

$$NFT_i^1 = -\exp(X_i\beta)\ln(1-s_i) - \exp(Y_i\theta).$$

Second, when assuming normal distributions for ε and v_0, we can calculate the expected effects of a subsidy conditional on applying by integrating over the relevant part of the distribution. Thus, (12) and A.6a imply that for applicants, it must hold that

$$X_i\beta - Y_i\theta + \ln E\left[-\ln(1-s_i)\right] \geq v_i - \varepsilon_i = \rho\varepsilon_i + v_{0i}.$$

Rearranging we get

$$\varepsilon_i \leq \frac{1}{\rho}\left(X_i\beta - Y_i\theta + \ln E\left[-\ln(1-s_i)\right] - v_{0i}\right) = \bar{\varepsilon}_i.$$

Using this threshold for investment shock with actual granted subsidies, NFT for applicants can be written as

$$NFT_i^2 = \int_{-\infty}^{\infty}\int_{-\infty}^{\bar{\varepsilon}_i} \frac{\left[-\exp(X_i\beta+\varepsilon_i)\ln(1-s_i) - \exp(Y_i\theta + (1+\rho)\varepsilon_i + v_{0i})\right]f(\varepsilon)d\varepsilon}{F(\bar{\varepsilon})} g(v_0)dv_0$$

where $f(\,)$ and $g(\,)$ are the probability density functions of ε and v_0 respectively (both assumed to be normal), and $F(\,)$ is the cumulative distribution function of ε.

Third, we can recover the investment equation shock ε from the investment equation (9) and insert it in the firms' profit function (1). It can also be inserted in the application cost function (6), since A.6a yields $v_i = (1+\rho)\varepsilon_i + v_{0i} = \varepsilon_i + \xi_i$, where $\xi_i \equiv \rho\varepsilon_i + v_{0i}$. The last term in parenthesis is the error term in the application equation (12). We then integrate over ξ_i when calculating the application costs. Only the third method is available when we estimate the application equation semi-nonparametrically. Using this third method NFT can be written as

$$NFT_i^3 = -\exp(X_i\beta + \hat{\varepsilon}_i)\ln(1-s_i) - \left[\frac{\int_{-\infty}^{\bar{\xi}_i} \exp(Y_i\theta + \hat{\varepsilon}_i + \xi_i) h(\xi) d\xi}{H(\bar{\xi})} \right]$$

where $\bar{\xi}_i = X_i\hat{\beta} - Y_i\hat{\theta} + \ln[-\ln(1-s_i)]$, $\hat{\varepsilon} = \ln R + \ln(1-\bar{s}) - X\hat{\beta}$ and $h(\,)$ is the probability density function of ξ (either normal or the estimate provided by Gallanta and Nychka (1987)) and *H*( ) the corresponding cumulative distribution function.

Appendix 8. Point estimates of the application equation based on semi-parametric estimation

In producing these estimates, we used the semi-nonparametric estimator of Gallant and Nychka (1987) in the application equation and the DNV-estimator in the investment equation. The Gallant and Nychka estimation is based on the code written by Stewart (2004). Because estimation is very slow we have not calculated via bootstrap the confidence intervals. The point estimates are within the confidence interval of the point estimates produced using the double normal assumption and reported in Table 5.

Table A.8
Point Estimates of the Application Cost Function Based on Semi-parametric Estimation

Variable	Coefficient
Age	.006
Age sq.	.00003
Log of employment	-.099
Ln(emp) sq.	.026
Sales/employee	.002
SME	.425
Parent company	-.089
# Previous applications	-.532
# Prev appl. sq.	.004
CEO is chairman	-.164
Board size	-.058
Exporter	-.522
Const.	13.479
Food	.111
Paper	.180
Chemicals	.911
Rubber	.224
Metals	.355
Electric	.146
Radio and TV	.589
Other manufacturing	.290
Telecoms	.545
Data processing	-.325
R&D	.213
Western Finland	.257
Eastern Finland	.-257
Central Finland/Oulu region	.096
Northern Finland/Lapland	.168