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Abstract

We develop a new method to estimate the returns to R&D, their distribution, and their determinants. We model a continuous optimal treatment with outcome heterogeneity, where the treatment outcome depends on the applicant's investment. The model takes into account application costs, and isolates the effects of the treatment on the public agency running the treatment program. Under the assumption of a welfare-maximizing agency, we identify general equilibrium treatment effects and social returns to R&D. The model yields a restriction on the application equation that helps identify the parameters of the cost-of-application function. The proposed estimation strategy is applied to project level data from the granting process of R&D subsidies. We find that larger firms have higher marginal profitability of R&D. Rates of return on R&D are high and their distribution skew. Agency specific returns are non-monotonic in private returns. Project level spillovers are linear in R&D. The median increase from subsidies in the agency's utility not appropriated by the applicant is 16 000€. Application costs increase with the profitability shock and ignoring application costs severely biases the estimated rates of return upwards.

JEL Classification: D21, D6, D73, H20, H83, L59, O30, O31

Keywords: applications, effort, investment, rate of return, R&D, R&D return distribution selection, subsidies, treatment program, treatment effects, welfare.

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It has been long recognized that R&D and the distribution of benefits generated by it are crucial for economic growth. The endogenous growth literature has shown that markets typically provide too little R&D and has singled out subsidies to R&D as the main policy tool (e.g. Howitt 1999, Segerstrom 2000). R&D subsidies have also become ubiquitous in practice. They are the second largest[1] and fastest growing form of industrial aid in developed countries (Nevo 1998); the U.S. has had several programs (Lerner 1999) and currently spends $1.5 billion a year on one R&D subsidy program alone;[2] and the EU exempts R&D subsidies from its state aid rules. In Finland where our data originates, R&D subsidies are the most important tool of innovation policy (Georghiu et al. 2003). Some central questions concerning R&D remain however open. For example, there is no research on how spillovers are related to the level of R&D at project level, and on whether subsidies go to projects where (increases in) private and social returns are most highly positively correlated nor is there much evidence on the joint distribution of private and social returns to R&D. Further, we know surprisingly little about the programs that allocate R&D subsidies. How do the public agencies running programs decide subsidy levels? How do potential applicants decide whether or not to apply? What are the public agencies' and the applicants' costs and benefits from the program, and how are they determined? To answer these questions we advance a new method which builds on the well-established treatment effects literature and the recent advances in structural industrial organization. Our empirical application uses detailed project level data on R&D investments plans and project characteristics, and R&D subsidy decisions by a government agency.

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[1] Largest being regional aid. Pretschker (1998) states that financial support schemes constitute the predominant type of government policy towards industrial R&D.

[2] 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.

The methods of the treatment effects literature have found surprisingly few applications in industrial organization. Our objectives require construction and estimation of a structural model of the application and selection process into a voluntary treatment program. The institutional setting in our data differs however considerably from those usually studied in the treatment effects literature. We therefore model a continuous, potentially multidimensional, optimal treatment with outcome heterogeneity. The treatment outcome is a function of the applicant's investment, which in turn is a function of the received treatment. The model takes into account application costs, and isolates the effects of the treatment that are specific to the agency. In addition, the theoretical model yields a restriction on the application equation that helps identify the parameters of the application cost function. Central to the model is the specification and interpretation of unobserved (to the econometrician) shocks. We obtain economic interpretation for the application equation and all estimated parameters. Given our parameterization of the model, it also yields estimation equations that bear close resemblance to those traditionally used in e.g. the returns to education literature.

Under the assumption of a benevolent public agency, our model identifies general equilibrium treatment effects and social returns to R&D. As our data come from a small economy, where a large part of high-technology production is exported, it is very likely that most consumer surplus lies outside the economy. Therefore, if the agency maximizes domestic welfare, the social R&D benefits are mostly technological spillovers to other domestic firms. Whilst such spillovers do not necessarily correspond to global benefits from R&D, they do have a high priority in the policy-making of countries that export a large part of their high-technology production.

We find that the returns appropriated by the agency but not by the firm are non-monotonic in private R&D returns when measured over projects. Spillovers are linear in

R&D expenditures and positive in expectation for 97% of the firms in our sample. Private rates of return are very high and their distribution skew, following earlier findings at least since Griliches (1958). Larger firms and firms with higher value added current production have higher marginal profitability of R&D. Moving an R&D project to a larger firm will create a larger surplus that is not appropriated by the firm. Non-applicants' projects generate larger returns on investments, but applicants' projects generate larger joint rates of return on subsidies, defined as the sum of the applicant's and agency's benefits divided by the subsidy. The public agency obtains a return of 9% on its subsidy program, and in allocating the subsidies, the agency generally adheres to the publicly announced principles.

Our model allows us to identify application costs. We find that neglecting application costs causes a significant upward bias of the order of 70-90 percentage points in estimated joint rates of return. We also identify a potential selection problem that is related to the important role of unobservable R&D profitability and application cost shocks: A positive shock to marginal profitability of R&D leads to an even larger positive shock to application costs. Thus firms with more profitable inventions are less likely to apply, ceteris paribus, due to higher opportunity costs of applying, creating a negative selection bias. This contrasts with the received view of a potential upward bias in the estimated effect of subsidies on R&D (e.g., Lerner 1999, Wallsten 2000). Finally, there is evidence that previous contacts with the public agency may reduce application costs.

As has already become apparent, our paper incorporates ingredients from several literatures. Methodologically we draw on structural industrial organization (surveyed by Reiss and Wolak, 2004) and on the treatment effects (see e.g. Heckman, LaLonde, and Smith 1999, and Blundell and Costa-Dias 2002, for surveys) and structural labor supply literatures (surveyed by Blundell and MaCurdy 1999), whereas our empirical application relates to the literatures on innovation and the effects R&D subsidies. The existing literature on the effects of R&D subsidies is extensive but, unfortunately, characterized by subtle points of inconclusive controversy (see David, Hall, and Toole 2000, and Klette, Møen and Griliches 2000, for surveys), and methodologically mostly distinct from our approach. Structural modeling has, however, turned out to be fruitful in many other areas of innovation research; see, e.g., Pakes (1986) on patent value, Levin and Reiss (1988) on cost-reducing and demand creating R&D, Lanjouw (1998) on patent value and litigation, Eaton and Kortum (2002) on the role of trade in diffusing the benefits of new technology, Jovanovic and Eeckhout (2002) on the impact of technological spillovers on the firm size distribution, and Petrin (2002) on the welfare effects of new products. In the structural industrial organization literature, Wolak (1994) and Gagnepain and Ivaldi (2002) are close to ours methodologically. Our paper has also a link with the literature on revealed bureaucrat preferences (McFadden 1975, 1976).

Recent examples of the structural treatment effects literature that have bearing on our set-up, questions or methods include Keane and Moffitt's (1998) study of multiple welfare programs, and Keane and Wolpin (2001) and Cameron and Taber (2004) who evaluate the effects of tuition subsidies and borrowing constraints. Other papers in the treatment program literature that have a close relation to ours are Heckman and Robb (1985), Maddala (1983, ch. 9), Manski (2000), and Heckman and Smith (2004) who stress the application and selection decisions and Heckman, Smith and Taber (1996) who study how the objectives of the office holders affect the selection decisions (cf. Heckman, Heinrich and Smith 1997). Willis and Rosen’s (1979) classic contribution on education is in many ways close to ours. Prior to us, continuous treatment effects are theoretically modeled, e.g., by Heckman (1997). Imbens (2000) and Lechner (2001) generalize the standard discrete zero-one treatment model into models of multiple treatment levels.[3] Heckman, Lochner and Taber (1998) and Davidson and Woodbury (1993) suggest procedures to identify general equilibrium treatment effects. Dehejia (2005), like us, models the selection decisions of the public agency.

Advances in the research of R&D and R&D subsidies have been hampered by lack of sufficient data. For example, the established but unsettled literature on the R&D-size relationship (see e.g. Cohen 1995) relies almost exclusively on firm level data. The only paper we know that studies the granting and application side of R&D subsidies is Blanes and Busom (2004). They estimate reduced form models of the joint application and granting decision. Their main finding that firms even in the same industry have different application thresholds both within and between the agencies supports our model and results.

We have access to rich data from Tekes (the National Technology Agency of Finland), the sole source of R&D subsidies in Finland. Finland provides a neat case for our study because i) innovation policy has long been a central theme in government policy, ii) partly because of successful policy, Finland has particularly rapidly transformed to a technology intensive economy (see e.g. Trajtenberg 2001), and iii) subsidies and, as a result, Tekes, constitute the main innovation policy tool. For example, there are no R&D tax benefits that could jeopardize the policy analysis. The data contain all the subsidy applications, the agency's internal ratings of the applications and its decisions over a two- and half-year period (Jan. 2000 – June 2002). The information on applications is matched to data on over 14 000 Finnish firms that constitute a large proportion of potential applicants.

As our method may be applied to other treatments, we present a generic version of our treatment program model in Section II. We explain the institutional background and data in

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[3] Although Imbens (2000) does not explicitly further generalize his model, it is evident that it could also

Section III. The generic model is then tailored to fit the institutional background in Section IV. There we also explain identification and estimation. Econometric results are reported in Section V, and implications of the model in Section VI. Conclusions are in Section VII.

II. The theoretical model

We want to model the following situation: There is a pool of potential applicants who have projects that require costly investments. The applicants need to decide whether or not to apply to a treatment program. A treatment lowers the marginal (shadow) cost of the investment, and all agents know the effect of the treatment. The program is run by a public agency whose utility function includes applicants' utility as an argument. The agency decides what treatment to give to each actual applicant, subject to constraints. For the moment, we do not allow for the screening and evaluation of project proposals by the agency but consider them in Section IV.

The generic model of this section accommodates various interpretations. For example, one can think of expected employment as a project.[4] Our empirical application resembles what Jaffe (2002) calls a 'canonical' research grant program as our applicants are firms, they have R&D projects, the agency is Tekes (the National Technology Agency of Finland) and a treatment is an R&D subsidy. We model the treatment program as a four-stage game of imperfect information between the applicant and the agency. In stage zero, nature draws the types of the players from a common knowledge prior distribution. In stage one, the applicant decides whether or not to apply to the program. In Section IV, we allow an application to include a proposal for an investment level. In stage two, the agency decides

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accommodate continuous treatments.

[4] According to Heckman and Smith (1995) the treatments offered by educational programs such as JTPA are often also available to those who do not participate in the program. One could thus think of educational programs reducing marginal costs of educational investment. The situation we model is also close to the one in Roberts, Maddala and Enholm (1978) who study what determines whether a regulated firm requests a review of its regulated rate of return.

the level of treatment, s, $s \in [0,1)$. As will be specified below, the treatment level is subject to minimum and maximum constraints if the application is accepted. The level is zero if there is no application or the application is rejected. In stage three, after receiving the treatment, the applicant makes the investment, R, $R \in [0, \infty)$.

We next introduce a set of assumptions some of which serve our objective of building a structural econometric model instead of a pure theory model.

A.1. Both the agency's and the applicant's utility functions are continuous and everywhere differentiable in their decision variables. The applicant's utility function is concave.

A.2. The applicant's type is common knowledge. The agency's type is private information.

A.3. The treatment cannot be misused.

A.4. There are no constraints on applicant's investment.

A.5. The agency's budget constraint does not bind.

A.6. The applicant's investment is non-contractible.

A.7. The level of treatment is $[\underline{s}, \bar{s}]$, $0 \le \underline{s} < \bar{s} < 1$.

A.8. All potential general equilibrium effects are captured by the agency's utility function.

A.1. ensures that the model behaves nicely. In particular, the applicant's best-reply to a treatment in stage three will be unique and given by a function. Because the agency's utility function is rather complex, we do not assume its concavity but use A.1. in seeking the conditions for a unique equilibrium of the game. The informational asymmetry in A.2. regarding the players' types generates (in line with our data) equilibrium outcomes where the applicant applies for a treatment only to be turned down. By the agency's type we mean how it values the applicant's project (see below), and A.2. amounts to assuming that the applicant does not know exactly the benefit the agency will receive from the project. In practice, it may be neither desirable nor possible to make the agency fully transparent.[5] A.3. excludes moral hazard problems in the use of a treatment.[6] By A.4., the unique solution to the applicant's maximization problem in stage three is interior. This assumption rules out credit rationing.[7] A.5 is motivated by simplicity, but we do impose a cost of financing on the agency.[8] A.6. is more realistic as it prevents the applicant and the agency from writing a binding contract specifying the amount the applicant invests conditional on the treatment it receives. A.7. corresponds with our application, and leads to a rather general way of modeling the treatment. A.8. is a weaker form of the standard, heavily criticized (e.g. Heckman, Lochner and Taber, 1998), assumption in the treatment literature that excludes general equilibrium effects. In principle the agency should be a benevolent social planner that takes into account all effects of the treatment. If this is the case, our model will identify general equilibrium treatment effects.

We focus on perfect Bayesian equilibria where, in stage one, the applicant correctly anticipates the type contingent strategies of the agency in stage two, and where the

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[5] The alternative and perhaps more standard assumption would reverse the informational asymmetry so that the agency's type is common knowledge but the applicants' type is private information. Although this would also generate rejected applications, it would lead to signalling, unnecessarily complicating the analysis. Moreover, the way we model the informational asymmetry is appealing in our empirical application because of the centralized subsidy allocation. A problem with our approach is that the agency could in principle give the optimal treatment without an application. Thus, we should strictly speaking assume that the applicant's type becomes common knowledge only upon the application. In so far the applicant cannot signal her type the assumption is inconsequential.

[6] In practice, moral hazard temptations are certainly pervasive with monetary treatments, as in our application. As a result, Tekes has several safe-guards 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. Because the safe-guards are common knowledge, and the misuses found in the audits or otherwise are rare, we think that the assumption depicts equilibrium behavior.

[7] Although financial market failure has traditionally been a rationale for R&D subsidies, the revealed motivations for R&D subsidies have become increasingly spillover-oriented. 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. As the Finnish financial market is not particularly well developed, the same trend should be observed 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 application: although Tekes also grants low-interest loans, most firms were not interested in them. As the Finnish financial market is not particularly well developed, the same trend is observed in many other industrialized countries, as the survey by Hall (2002) confirms.

[8] This is admittedly a strong assumption and we plan to take the agency budget constraint into account in future work.

applicant's and agency's strategies are sequentially rational. In this extensive form game the applicant's posterior belief concerning the agency's type is immaterial so there is no need to specify the belief formation. As a result, we can solve the game by backward induction, starting from the applicant's maximization problem in stage three. The applicant chooses the level of investment, R, $R \in [0, \infty)$ to maximize

$$(1) \qquad \Pi(R, s) = \pi(R) - (1 - s)R\,.$$

The first term in (1), $\pi(R)$, with $\pi(0) = 0$, captures the applicant's expected discounted private utility from the project, net of investment costs. Equation (1) shows how we restrict the treatment s to be the share of the investment cost covered by the agency.[9] With this formulation, A.1 implies that $\pi(R)$ is concave. The first-order condition $\partial\pi/\partial R = 1\text{-}s$ gives us R^*(s), the applicant's best-reply function.

In stage two, the agency chooses the treatment s, $s \in [\underline{s}, \bar{s}]$, to maximize its expected discounted utility conditional on its type

$$(2) \qquad U(R(s),s) = V(R^*(s), \eta) + \Pi(R^*(s),s) - gsR^*(s) - F.$$

In (2), g ($g>1$) is the constant opportunity cost of agency resources, e.g., the opportunity cost of tax funds, and F is the sum of the applicant's fixed cost of applying and the agency's fixed cost of processing the application. The applicant's utility directly enters the agency's utility function and it has an equal weight to $V()$.

The interpretation of $V()$ is fundamental to our analysis. It captures the effects of the applicant's investment on the agency beyond the applicant's utility and the direct costs of treatment and the application process. Examples are externalities from firm R&D or from individual investments in human capital, and program-mandated payments to the agency

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[9] The generalization to the case where the treatment also has an effect on π is straightforward but we believe the formulation given by (1) is not only simple but fairly general. For example, in a social program such as JTPA, the treatment might reduce costs of attending an educational course (see, e.g., Heckman and Smith, 1995). Heckman and Smith (1995) explain how JTPA directs the participants of the program to take courses

(such as in JTPA). At the level of individual decision makers *V*() can include idiosyncratic benefits from giving a certain treatment such as direct bribes or indirect ones, e.g., through a revolving door mechanism. In principle, such effects of the applicant's investment can also be negative or decreasing in the investment level. In what follows, we call *V*() agency specific utility. The agency's type is given by η, which has a common knowledge probability density function $\phi(\eta)$ and cumulative probability density function $\Phi(\eta)$. In our application, η reflects the benefits from the R&D project which the agency appropriates, but which are unobserved by the applicant. It is quite natural to think that the applicant is uncertain, e.g., about the agency's expectation of the extent of spillovers or consumer surplus created by its project.

Because the agency is assumed to be subject to minimum and maximum constraints in choosing the treatment level (A.7), we form the Lagrangean

$$(3)\quad L(s,\lambda_1,\lambda_2) \equiv U(R^*(s),s) - \lambda_1(\underline{s}-s) - \lambda_2(s-\bar{s})$$

and by using (2) write out the first order conditions:

$$(4a)\quad \frac{\partial L}{\partial s} = \frac{\partial V}{\partial R}\frac{dR^*}{ds} - gR^*(s) - gs\frac{dR^*}{ds} + \frac{\partial \Pi}{\partial R}\frac{dR^*}{ds} + R^*(s) + \lambda_1 - \lambda_2 \le 0,\ s\frac{\partial L}{\partial s} = 0,$$

$$(4b)\quad \frac{\partial L}{\partial \lambda_1} = s - \underline{s} \ge 0,\ \lambda_1\frac{\partial L}{\partial \lambda_1} = 0,$$

$$(4c)\quad \frac{\partial L}{\partial \lambda_2} = \bar{s} - s \ge 0,\ \lambda_2\frac{\partial L}{\partial \lambda_2} = 0\ .$$

The term $\frac{\partial \Pi}{\partial R}\frac{dR^*}{ds}$ in (4a) is zero by the envelope theorem. As a result, the agency only needs to know the applicant's reaction function.[10] Although the informational requirements

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that are available also to non-participants with higher tuition fees. By lowering the cost of taking in a course, the program participants may choose more courses than identical non-participants.

[10] Given this knowledge the agency can infer the applicant's utility function up to the constant of integration. In our application, the constant equals the discounted expected profits from all other activities of the applicant, bar the R&D project for which the firm sought subsidies.

can sound challenging, we explain later how they are often less demanding than seems from the outset.

We are left with four effects of the treatment on the agency. The first effect is indirect through $V()$, the second and the third are direct and indirect cost effects on the agency and the fourth is a direct cost effect on the applicant. An interior solution to (4a) is thus given by $s^*(\eta)$ that solves $\frac{dR^*}{ds}\left(\frac{\partial V}{\partial R} - gs\right) + (1-g)R^*(s) = 0$. Note that since $\partial^2\Pi/\partial R\partial s$ is positive, the treatment and the applicant's investments are complements and, as a result, $dR^*/ds>0$. Thus, as $g>1$, we can have an interior solution only if the applicant's investment generates sufficiently large agency specific benefits, e.g., positive externalities. In other words, if the applicant's investment decreases $V()$, the optimal treatment level is minimal.[11]

To characterize the application decision, we assume that $\partial^2 V/\partial R\partial\eta>0$ and that this is common knowledge. The applicant can then calculate the expected treatment to be

$$(5) \qquad E[s] = \Phi(\underline{\eta})\underline{s} + \int_{\underline{\eta}}^{\overline{\eta}} s^*(\eta)\phi(\eta)d\eta + [1-\Phi(\overline{\eta})]\overline{s},$$

where $\underline{\eta}$ and $\overline{\eta}$ denote the values of η at which the minimum and maximum treatment constraints begin to bind and where $s^*(\eta)$ is an interior solution to (4a).

In stage one, the applicant decides to apply if the expected utility from applying is at least as large as that from not applying. Because the expected utility from not applying is $\Pi(R^*(0),0)$ the applicant's decision rule can be written as

(6)

$$\Phi(\underline{\eta})\Pi(R^*(\underline{s}),\underline{s}) + \int_{\underline{\eta}}^{\overline{\eta}} \Pi(R^*(s^*(\eta)),s^*(\eta))\phi(\eta)d\eta + [1-\Phi(\overline{\eta})]\Pi(R^*(\overline{s}),\overline{s}) - K \geq \Pi(R^*(0),0),$$

where K is the strictly positive cost of applying.

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[11] If the treatment had an effect on the applicant beyond the cost reduction, $\partial^2\Pi/\partial R\partial s$ could be negative, i.e., the treatment and the applicant's investments could be substitutes. In such a case, even non-minimal treatments could be justified if the applicant's investment were harmful from the agency's point of view.

We now specify the conditions for the agency's utility function that guarantee a unique equilibrium. Let us define

$$f(s) \equiv \left(\frac{dR}{ds}\right)^2 \left(\frac{\partial^2 V}{\partial R^2} + \frac{\partial^2 \pi}{\partial R^2}\right) + \frac{dR}{ds}(1-g) + \frac{d^2 R}{ds^2}\left(\frac{\partial V}{\partial R} - gs\right).$$

PROPOSITION. If $f(s^*(\eta))<0$, there is a unique equilibrium characterized by the application rule (6), the optimal treatment level $\underline{s}$ for $\eta \leq \underline{\eta}$, $s^*(\eta)$ for $\eta \in (\underline{\eta}, \bar{\eta})$ and $\bar{s}$ for $\eta \geq \bar{\eta}$, and the applicant's investment rule $R^*(s)$.

Proof: In stage three, the applicant has a well-defined best-reply function $R^*(s)$ because of A.1. In stage two, the agency maximizes its expected utility conditional on its type. There is a unique type-contingent optimal treatment if the second order condition for the Lagrangean (3) holds. Since we have linear constrains, it suffices to show that $U(R^*(s), s)$ is concave when evaluated at $s^*(\eta)$. Differentiating (2) twice, we see that $U(R^*(s), s)$ is concave if $\left(\frac{dR}{ds}\right)^2 \left(\frac{\partial^2 V}{\partial R^2} + \frac{\partial^2 \Pi}{\partial R^2}\right) + 2\frac{dR}{ds}\left(\frac{\partial^2 \Pi}{\partial R \partial s} - g\right) + \frac{d^2 R}{ds^2}\left(\frac{\partial \Pi}{\partial R} + \frac{\partial V}{\partial R} - gs\right) + \frac{\partial^2 \Pi}{\partial s^2} < 0$. Using the envelope theorem ($\partial\Pi/\partial R=0$) and (1) leaves us $f(s)$. If $f(s^*(\eta))<0$, there is a unique maximum that solves (4a-c). Since we assume that $\partial^2 V/\partial R \partial \eta > 0$, the optimal treatment level is increasing in η. Therefore the optimal type-contingent treatment is $\underline{s}$ for $\eta \leq \underline{\eta}$, $s^*(\eta)$ for $\eta \in (\underline{\eta}, \bar{\eta})$ and $\bar{s}$ for $\eta \geq \bar{\eta}$. As a result, the applicant correctly anticipates that the expected treatment is given by (5) and makes the application decision according to (6). Because the type-contingent action of the agency in stage two is unique, the left-hand side of (6) has a unique value. In stage one the applicant either applies or does not apply, and there is thus a unique utility maximizing action in each stage of the game. *QED.*

It is rather hard to characterize when $f(s^*(\eta))<0$ without specifying functional forms. In our econometric specification, $f(s^*(\eta))<0$. Note that $f(s^*(\eta))<0$ is only a sufficient condition for a unique equilibrium. For example, if $f(s^*(\eta))>0$, we also have a unique equilibrium where the optimal treatment level is always either the minimum or the maximum treatment and accordingly, the applicant's investment is always either $R(\underline{s})$ or $R(\bar{s})$. Given her knowledge of the agency type distribution, the applicant can again calculate the expected treatment and make optimal application decision using a rule similar to (6).

III. Finnish innovation policy, Tekes and data[12]

A. Innovation policy and Tekes

In 2001 Finland invested 3.6 per cent of GDP – 5 billion euros - on R&D. Tekes is the principal public financier of private R&D in Finland.[13] The primary objective of Tekes is to promote the competitiveness of Finnish industry and the service sector by providing funding and advice to both business and public R&D. To achieve these goals, Tekes strives to increase Finnish firms' R&D and risk-taking. In addition to the primary criteria, Tekes has an explicit regional policy objective. Finnish regions differ greatly in their socio-economic characters, economic performance, and their R&D-intensity, e.g., some 20% of the population lives in the capital region in Southern Finland where also most economic activity and R&D takes place. As will be specified later, Tekes also treats firms fulfilling the official SME criterion differently.

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 euros, 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

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[12] As our application data is from Jan. 2000- June 2002, we use 2001 figures to describe the environment. One of us spent six months in Tekes to get acquainted with the actual decision making process. Public information about Tekes can be found at http://www.tekes.fi/eng/, accessed December 20th, 2004.

[13] Main public funding organizations in the Finnish innovation system in addition to Tekes are the Academy of Finland, Employment and Economic Development Centers (T&E Centers), Finnvera, Industry Investment

were accepted. In monetary terms, the business sector applied for 526 million euros while 211 million euros 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 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 suggests that they do not encounter significant financial constrains, supporting our assumption A.4 (cf. footnote 7).

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 II. There are, however, two details that are not captured by the model. First, 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. Second, Tekes screens the application and grades it in several dimensions by using a 6-point Likert scale from 0-5. According to Tekes civil servants, the most important dimensions in project evaluation concern the technological challenge of the project and its market risk.[14] Tekes' public decision criteria are: The project's effect on the competitiveness of the applicant, the

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and Sitra. Also the Foundation of Finnish Inventions (Innofin) provides financial support for innovation. See Georghiu et al. (2003) for a recent description and evaluation of the Finnish innovation policy institutions.

[14] 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

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. As mentioned above, Tekes also has an explicit regional policy objective and it takes into account whether the application comes from an SME.

Tekes' final decision is based on the proposed budget of the project before the R&D investments are made, but the actual funding is only given ex post against the incurred costs. Decision making is constrained by the rules preventing negative subsidies and very large subsidies both in relative and absolute terms. In other words, a subsidy is granted ex ante as a share of to-be-incurred R&D costs. There is an upper bound for this share: If the firm fulfils the EU SME criterion, the upper bound is 0.6, otherwise 0.5.[15] The actual funding then covers 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 prevent Tekes from covering costs extraneous to the project proposal.[16] In terms of our model, these practices amount to $\underline{s}=0$, $\bar{s}\in\{0.5,0.6\}$ and a goal of setting the euro limit at $sR^*(s)$.

Tekes also sometimes adjusts a proposed budget, both down and up, when an applicant, e.g., applies subsidies for costs that Tekes cannot cover. In practice an upward adjustment is rare and in principle occurs only if a project significantly changes character during the

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= ‘no identifiable risk’, 1 = ‘small risk’, 2 = ‘considerable risk’, 3 = ‘big risk’, 4 = ‘very big risk’, and 5 = ‘unbearable risk’.

[15] 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 the 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.

[16] As mentioned in footnote 6, the euro limit alleviates the moral hazard problem. 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 the subsidy decision is made. Tekes is also monitored both by the press and politicians. Tekes civil servants may 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.

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. We use this measure, which we call the ‘accepted proposed investment’, as our dependent variable in the R&D equation. We test the robustness of our results by using the R&D investment proposed by the applicant as an alternative dependent variable.

B. 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 originally 14 657 Finnish firms come from Asiakastieto Ltd, which is a for-profit company collecting, standardizing, and selling firm specific quantitative information.[17] Asiakastieto’s data are based on public registers, for example, firms’ official profit sheet and balance sheet statements, and include all the firms who file their data in the public register. We use the 1999 cross section, i.e., all firm characteristics are recorded earlier than the application data. The sample was drawn from Asiakastieto’s registers 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 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 form a large proportion of the population of potential applicants, and they constitute our sample of potential applicants.

Some 1000 firms from outside our sample filed applications to Tekes during the observation period. 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 have limited the count to one per firm by using the first application by each firm within our observation period. [18] 722 of these applications were accepted, i.e., received a positive subsidy share. 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 are SMEs according to the official EU standard (cf. footnote 16). As explained, the SME criterion determines the upper bound of the share of the R&D costs covered by Tekes, and we therefore need to take it into account in our estimations. Sales per employee, a measure of value added, is 165 000 euros. Some 6% are exporters with no domestic sales. We use this indicator, as the firms that exclusively export should generate no domestic consumer surplus, implying that the agency specific utility should largely consist of spillovers to other domestic firms. [19]

[TABLE 1 HERE]

We also have information on two corporate governance variables. In some 14% of potential applicants, the CEO is also the chairman of the board. Such an arrangement can, on the one hand, improve the information flow between the board and the executive but, on the other hand, weakens the board's independence. The board of an average potential applicant has four to five members. A larger board is costlier but is more likely to include

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[17] More information about Asiakastieto can be found at http://www.asiakastieto.fi/en/, accessed June 20th, 2005.

[18] Several firms in our data had multiple applications during our observation period. The firms in our sample roughly account for half of all applications.

members with outside knowledge that may be useful either in conducting R&D (choosing among competing projects, organizing management of current projects, monitoring), or in the application process itself.

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. Some 21% of applications are rejected. The proposed projects involve on average an investment of 630 000 euros; the rejected proposals are clearly smaller with a mean of 385 000 euros. According to Tekes' rating, the projects have on average a technical challenge of 2 (scale 0-5), and rejected proposals have on average a lower score of 1.5. The mean risk score is also 2, and it is the same for successful and rejected applications (see the Appendix for more information).

[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 per cent as the sum of all three forms of financing, divided by accepted proposed investment. 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 in this way, only 0.4% of applicants get the maximum subsidy.[20]

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[19] We have repeated our estimations by including in the "exporter" category all firms that report exports regardless of whether they have domestic sales or not. The results are qualitatively identical, and quantitatively close to those reported.

[20] There is a cluster of firms right below the maximum subsidy: 1.9% of applicants get a subsidy which is less than one percentage point below the maximum subsidy, and 2.5% get a subsidy less than 5 percentage points

Successful applicants receive on average a subsidy that covers 32% of the R&D investment costs. We test the robustness of our results to the definition of a subsidy by using only pure subsidies as the dependent variable in the Tekes decision rule.

[TABLE 3 HERE]

IV. The econometric model

A. The operationalization of the econometric model

We now operationalize the model by tailoring it to correspond to institutional details of our application explained and by making assumptions on functional forms and unobservables. We approximate the screening process by assuming that Tekes grades each proposed project in two dimensions on a Likert scale of 5 and that this is common knowledge.[21] The resulting 25 grade combinations are modeled by a latent regression framework. We assume that the error terms are normally distributed and uncorrelated both with each other and other unobservables of the model. 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:

$$\begin{aligned} & w_{ij} = h \text{ if } \mu_{h-1} < w_{ij}^* = T_i \zeta_j + \omega_{ij} \le \mu_h \\ (7) \qquad & h = 1,\ldots,5,\ \mu_0 \to -\infty,\ \mu_1 = 1, \mu_2 = 2, \ldots, \mu_5 \to \infty \\ & \omega_{ij} \sim \text{N}(0, 1),\ \text{cov}(\omega_{ic}, \omega_{im}) = 0, \end{aligned}$$

where c stands for technological challenge, m for market risk, T_i is a vector of observable characteristics of applicants, ζ_j is parameter vector to be estimated, and ω_{ij} are the unobservable applicant-specific components. Equation (7), when applied to the two

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below the maximum. At the lower end there is no such clustering: on the contrary, no firm gets a subsidy that is less than 2.9%: however, 2.6% of applicants get a subsidy that is greater than 2.9% and less than 5% .

[21] As explained in the previous section, Tekes in principle uses 6-point Likert scale from 0-5. However, since no applicant is assigned to category 5 in the market risk dimension, and only handful of applicants is assigned to category 0 in the technological risk dimension, we merge these categories with the ones next to them.

evaluation dimensions, produces the probabilities of each of the 25 different outcome combinations. The application decision is then amended to

$$(6') \quad \sum_{t=1}^{5}\sum_{k=1}^{5} p_t^c p_k^m \{\Phi(\underline{\eta}\,|\,t,k)\pi(R(\underline{s}),\underline{s}) + \int_{\underline{\eta}}^{\bar{\eta}} \pi(R(s(t,k,\eta)),s(t,k,\eta))\phi(\eta)d\eta$$
$$+[1-\Phi(\bar{\eta}\,|\,t,k)]\pi(R(\bar{s}),\bar{s})\} - K - \pi(R(0),0) \geq 0$$

where p_t^c and p_k^m denote the probabilities of getting grades *t* and *k* in the dimensions of technological challenge and market risk.

We specify applicant *i*'s objective function as

$$(8) \quad \Pi(R_i, s_i, X_i, \varepsilon_i) = \pi_{i0} + \exp(X_i\beta + \varepsilon_i)\ln R_i - (1-s_i)R_i,$$

where, in line with (1), s_i is the treatment and R_i is the investment. The marginal productivity of the investment is affected by observable applicant characteristics X_i, by vector β of parameters to be estimated and by ε_i, a random shock, distributed by nature, uncorrelated with the observable applicant characteristics, observed by the firm, and unobserved by the econometrician. The reservation value including other projects is embodied in π_{i0}.

Equation (8) introduces unobservables into the applicant's objective function in an economically meaningful way.[22] However, this creates possibility that an optimal investment leads to a negative profit. In such a case the applicant prefers not to invest after receiving a subsidy, which may distort the application decision. Because the possibility arises only if both s_i and ε_i are sufficiently small, and because there is a way out of this

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[22] We could also generalize (8) to 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.

complication at the cost of a slight discontinuity at R_i=0, we ignore this possibility in what follows.[23]

We assume that the agency's utility form project *i* is given by

(9) $U(R_i, s_i, X_i, Z_i, \varepsilon_i, \eta_i) = V(Z_i, \eta_i, R_i(s_i)) + \Pi(X_i, \varepsilon_i, R_i(s_i), s_i) - gs_iR_i - F_i$,

where, similarly to (2), F_i is the sum of the fixed costs of applying and processing the application, *g* is the constant opportunity cost of the agency's resources, *V*(.) is the expected agency specific utility from the project, and η_i is the random shock to it from project *i*. In line with the theoretical model the shock is assumed to be distributed by nature, uncorrelated with applicant characteristics, observed by the agency, and unobserved by the applicant and the econometrician. Compared to (2) and (8), the new term in (9) is Z_i, a vector of observable applicant characteristics that affect the agency specific utility from the project. It may contain the same elements as X_i.

We solve the model backwards as in Section II. In stage three, the applicant optimizes (8) with respect to investment R_i. This yields

(10) $\ln R_i = X_i\beta - \ln(1-s_i) + \varepsilon_i$.

In stage two, the agency chooses a subsidy to maximize (9), taking (10) into account. To arrive at an estimable model we therefore need to specify the effect of R_i on *V*(.). In the theoretical model we formalized A.2. by assuming that $\partial V/\partial R = E[\partial V/\partial R]+\eta$. We now further assume that $E[\partial V/\partial R_i] = Z_i\delta$ where δ is a vector of parameters to be estimated. As a result,

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[23] The way out utilizes the facts that, without subsidies, the optimal investment is $R_i = \exp(X_i\beta + \varepsilon_i)$ and that $x\ln x - x$ is a convex function with a unique minimum of -1 at $x = 1$. Introducing a small discontinuity at R_i=0 into the applicant's utility function by means of the indicator function 1(R>0) would ensure that an applicant always invests a positive amount, and that the increase in (expected) utility from investing is nonnegative. This change in the utility function would yield the application rule (6') after subtracting one (euro) from the constant to get the true constant of the application cost function. The corrected decision rule could be estimated using a simulation estimator. Our estimates show that negative profits from investment in the case of not applying are extremely unlikely (of the order 10^{-22}).

(11) $\partial V/\partial R_i = Z_i\delta+\eta_i$.

A convenient implication of (11) is that

(12) $V = (Z_i\delta+\eta_i)R_i$+constant.

Equation (12) permits that the effect of the applicant's investment that is agency specific can be decreasing in the level of investment. For example, it is possible that some R&D projects exhibit negative externalities while being privately profitable. Equation (12) considerably facilitates dealing with double-censoring and sample selection. Moreover, it reduces the informational requirements for implementation of optimal subsidy decisions, since the agency needs to know nothing about the applicant's objective function. However, the remaining informational requirements, in particular the fact that the agency should know $V()$, may still be challenging in practice. Another implication of (12) is that $V()$ is proportional to R&D investment. This may be unrealistic but similar assumptions are common in the literature: We test this assumption below and do not reject it.

By using (8), (10) and (11), the agency's unconstrained decision rule can be written as

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

As a result, the probability that an applicant gets the minimum subsidy is $\Phi(\underline{s}+g-1-Z_i\delta)$ and the probability of getting the maximum subsidy is $1-\Phi(\bar{s}+g-1-Z_i\delta)$.

As to stage one, the applicant decides whether or not to apply according to (6'). We specify the fixed costs of applying as

(14) $K_i = \exp(Y_i\theta+\upsilon_i)$

where Y_i is a vector of observable applicant characteristics, θ is a vector of parameters to be estimated and υ_i is a random cost shock, distributed by nature, uncorrelated with observable applicant characteristics, observed by the firm, and unobserved by the econometrician.

By using (8), (10) and (14) and the fact that $\underline{s} = 0$ as explained in Section III, the application rule can be derived from (6') after some algebra

$$(6'')\quad d_i = 1\left[X_i\beta - Y_i\theta - \ln\sum_{t=1}^{5}\sum_{k=1}^{5} p_t^c p_k^m \left\{ \int_{\underline{\eta}}^{\bar{\eta}} \ln\left(1 - s(t,k,\eta)\right)\phi(\eta)d\eta - \left(1 - \Phi(\bar{\eta} \mid t,k)\right)\ln(1-\bar{s}) \right\} \geq \nu_i - \varepsilon_i \right].$$

In words, the application rule is given by an indicator function d_i that takes value one if firm i finds it profitable to apply for a subsidy. Our econometric model can thus be summarized by *the application equation (6''), the screening equations* (7), *the Tekes decision rule*

$$(13')\quad s_i^* = (1-g) + Z_i\,\delta + \eta_i\,,$$

with observations $d_i s_i = 0$ if $s_i^* \leq 0$ and $d_i s_i = \bar{s}$ if $s_i^* \geq \bar{s}$, and the applicant's decision rule, i.e., *the investment equation*

$$(10')\quad \ln R_i^* = X_i\,\beta - \ln(1-\bar{s}) + \varepsilon_i\,,$$

with observation $\ln R_i = d_i \ln R_i^*$.

B. Statistical assumptions, identification and estimation

We now explain our statistical assumptions, how identification takes place, and how we estimate the model. Our econometric model contains five unobservables, ω_j, ε, η and υ. They are assumed to be uncorrelated with the observed applicant characteristics. Estimating the model without imposing restrictions on the covariation of the unobservables is in principle possible by using a simulation estimator. However, assuming that ε and η are uncorrelated yields a large reduction in computational cost, as then the Tekes decision rule (13') is no longer subject to a selection problem. This means that estimation can be broken into three steps. Since our tests (see below) indicate that we cannot reject the Null of no correlation between ε and η, in estimating the model by ML, we impose

A.9 a) $\nu = (1+\rho)\varepsilon + \nu_0$, b) $\eta \perp \varepsilon$, c) $\eta \perp \nu_0$, d) $\varepsilon \perp \nu_0$, e) $\omega_j \perp \varepsilon$ f) $\omega_j \perp \eta$ g) $\omega_j \perp \upsilon_0$ h) $\eta \sim$ N(0, σ_η^2) i) $\varepsilon \sim$ N(0, σ_ε^2) j) $\upsilon_0 \sim$ N(0, $\sigma_{\nu_0}^2$).

In words, the unobservable (η) affecting the agency specific utility is uncorrelated both with the unobservable (ε) affecting the marginal profitability of the applicant's investment and with the unobservable (υ) affecting the application cost. The screening equation unobservables (ω_j) are uncorrelated with all other shocks. As A.9a) shows, there is no restriction on the correlation between υ and ε. A.9h)-j) may be relaxed when we use semi-parametric estimation methods.

The first step is the estimation of the ordered probit the screening equations (7). By using the estimates we can calculate the expected probability 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 (13'). In estimation we use the actual values for the grades from the evaluation of each project. The Tekes decision rule identifies δ, i.e., the effect of observed applicant and project characteristics on the agency specific utility derived from the project. If we impose A.9b) and A.9c), we can estimate (13') using a double-hurdle Tobit model without correcting for selection. To test whether A.9b) and c) hold, we estimate a sample selection double-hurdle Tobit and test for the significance of the Mills ratio term. We also use an alternative, more flexible, approach of nonparametrically estimating (13') by a two-limit version of Powell's (1984) CLAD estimator.

After estimating the agency's screening equation and its decision rule, we calculate the effect of subsidies on the applicant's expected profits, replacing the unobservable parts in the application equation (6'') with their estimated counterparts. In step three we then estimate the application and investment equations ((6") and (10')) by using both ML and a semi-parametric variant of the approach suggested by Das, Newey, and Vella (2003, henceforth DNV).[24] The application equation (6’’) allows us to identify how observed applicant characteristics affect the fixed costs of application without having to resort to an exclusion restriction. Our theoretical model suggests a form for the error term in the application equation and, as a result, we identify the correlation between v_i and ε_i when using ML. There is no need for a variance normalization as long as we, following theory, constrain the coefficient of the summand

$$\ln \sum_{t=1}^{5} \sum_{k=1}^{5} p_t^C p_k^M \left\{ \int_{\underline{\eta}}^{\bar{\eta}} \ln\big(1-s(t,k,\eta)\big)\phi(\eta)d\eta - \big(1-\Phi(\bar{\eta} \mid t,k)\big)\ln(1-\bar{s}) \right\}$$

to unity.[25]

Our model implies that the applicant’s best-reply function, $R_i^*(s_i)$, is increasing in treatment and is heterogenous both with respect to observables and the unobservable profitability shock. Another implication of the model is that an applicant strictly prefers proposing a budget based on a maximum subsidy per cent over proposing any smaller amount, and is indifferent between proposing that budget and any larger amount.[26] Consequently, we can use the data on proposed budgets to estimate the investment equation (10’) where we have inserted $\bar{s}$ into the equation. Correcting for selection bias by using the application equation (6’’), we obtain consistent estimates of β that determine the effect of the observable applicant characteristics on the marginal profitability of the R&D-investment. To obtain consistent standard errors in the application and investment

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[24] Manski (1989) compares relative merits of the two approaches. Manski argues that, although the nonparametric approach appears to be more flexible, it involves arbitrary exclusion restrictions. Therefore it is not necessarily preferable over the parametric approach. Here theory comes to our aid, as it suggests an exclusion restriction that can be utilized both in parametric and nonparametric estimation.

[25] This implication of our theoretical model cannot be tested. If we imposed the standard variance normalization, the coefficient of the term would be $1/\sigma_\upsilon$ instead of unity.

[26] Too see this, recall first that the applicant does not know Tekes' type (A.2) and the subsidy share is bounded above at $\bar{s}$ (A.7). As mentioned in Section IIIA, there is also an euro limit to the ex post reimbursements which is based on the proposed budget. Then, since $\partial\Pi/\partial s>0$ by (8), the applicant wants as high a subsidy as possible. Therefore it proposes an optimal project based on the maximum subsidy share, $R^*(\bar{s})$. Proposing anything less risks foregoing profits in case where the actual subsidy turns out to be larger and the applicant subsequently reoptimizes because of the euro limit. 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.

equations, we bootstrap the whole model ((6''), (7), (10') and (13')) when using both ML and the semi-parametric estimator.

Note also what we cannot identify. In (8) we are unable to identify π_{i0}, the applicant's reservation value, from the constant in X_i. Our cross section estimates are however not affected by unobserved differences in the reservation value. Similarly, in (13') we cannot identify separately g, the opportunity cost of government funds, and the constant in δ. Nor can we identify $V()$, as (13') cannot be integrated to a unique number. Welfare analysis is nonetheless possible, because our functional form assumptions ensure that all projects will be carried out irrespective of the subsidy decision. Thus each project will produce the fixed component in $V()$ regardless of whether it is subsidized or not.[27] We are also unable to identify the agency's screening costs (F_i-K_i). This will result in an upward bias in the welfare calculations if these costs are significant. Finally, in the semi-parametric estimation of the selection and investment equations, the parameters of the application cost function cannot be identified.

V. Estimation results

We include the following firm characteristics into all estimation equations: age, the log of the number of employees, sales per employee, an SME dummy, a dummy for a parent company, the number of previous applications, a dummy indicating if the CEO acts as the chairman of the board, board size, and a dummy for exporters. We also include industry and region dummies.[28] In the reported specifications, we use a slightly different set of explanatory variables in the screening equations and the Tekes decision rule on the one

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[27] This is strictly speaking not true given the application rule suggested by theory. It, however, holds in the data, and would hold in the model if we introduced a discontinuity into the applicant's utility function as discussed in footnote 23.

[28] 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.

hand, and the selection and investment equations on the other. For example, we include the squares of the continuous variables only when reporting the estimations of the investment and application equations.[29] The results from the screening equations are reported in the Appendix. We also have estimated the model (by ML) 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.

A. The Tekes decision rule and agency specific benefits

In Table 4 we report the estimation results concerning Tekes' decision rule. Recall that the coefficients can be interpreted as the marginal effects of R&D on agency specific benefits. By using ML (column one) 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 (p-value 0.13) coefficient. Firm size obtains a positive and significant (at 10% level) coefficient. A possible interpretation is that in Tekes' view, moving an otherwise identical R&D project into a larger firm creates larger positive externalities, 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, everything else equal: The difference is 8.5 percentage points. The corporate governance variables and the number of previous applications have no effect.

We relegate the details of the coefficients of industry dummies to the Appendix. 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

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[29] To speed up the computation of the bootstrap we used LR-tests to narrow the set of explanatory variables in

lower. During our observation period, Tekes was actively seeking applications from the food industry, which at least partially explains the findings concerning the industry.

Another finding left to the Appendix is that regional aspects seem to influence Tekes' decision making: Firms in Eastern and Central Finland obtain subsidies that are 7-10 percentage points higher than they would obtain if they were 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. This finding is perhaps not robust as only 2% of our sample firms come from Northern Finland.

[TABLE 4 HERE]

The above results are obtained under the assumptions A.9b) and A.9c), which maintain that the error in the Tekes decision rule uncorrelated with the errors in the investment and selection equations. To test these assumptions, we ran a first stage probit selection equation[30] and re-estimated the Tekes decision rule by inserting the Mills ratio into it. The Mills ratio obtained small negative (less than 0.2 in absolute value) and imprecisely estimated coefficients in all of the several specifications that we tried. This suggests that our assumptions A.9b) and A.9c) of no correlation are reasonable. The economic significance of the no-correlation finding is tied to the interpretation of *V*(). As we will elaborate in sections VI.B and VI.C, if one is willing to assume that *V*() captures social surplus, it will most likely consist of domestic spillovers between firms in Finland. Under such an assumption, the finding implies that project specific spillover shocks are unrelated to project specific profitability shocks.

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each equation. The second order terms were excluded from the screening equations and the Tekes decision rule based on the LR-tests.

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

We also tested our assumption that *V*(), the agency specific utility, is linear in applicant investment. 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. After incorporating such terms into the Tekes decision rule, we could not reject the Null of (joint) insignificance of the terms. Again, the economic implications are tied to *V*(). Assuming that *V*() is mostly a measure of spillovers, the result suggests that project level spillovers are linear in R&D.

We also estimated the Tekes decision rule by a two-limit version of Powell's (1984) CLAD estimator.[31] This allows for nonparametric estimation of (two-limit) censored regressions. As column two of Table 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.

Finally, 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 reveals that our results are not driven by our definition of the dependent variable.[32]

B. Cost of application function

In Table 5 we report the estimates of the application cost function (equation (14)).[33] In view of the received R&D literature, it is not surprising that only a few firm characteristics

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[31] The two-limit CLAD was estimated by using the following algorithm: 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.

[32] 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 R&D investment equations' parameters 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.

significantly affect R&D related costs. Age, size, board size, SME status, CEO being chairman, and parent company status have no statistically significant effect. Sales per employee increase application costs. One interpretation is that firms producing high value added products 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. 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 141 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 35%. One prior application decreases costs by 20% and four by 58%. It seems that learning by doing is going on. Given that our data is cross sectional, however, it is possible that instead of being attributed to path-dependence, the results are generated by unobserved heterogeneity.

C. Investment equation

Recall that our investment equation (10') identifies the effects of exogenous variables on marginal profitability of log R&D. As in the case of the application cost function, 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. In column one we report the results from the specification with the quadratic terms. Only two reported variables

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[33] We only present results from the model where the log of accepted proposed investment was the dependent

carry a significant coefficient: firms with higher value-added current production have higher marginal profitability of R&D whereas it is lower in firms with CEOs as chairmen.[34]

In the specification without the quadratic terms, sales per employee and the CEO as chairman continue to carry significant coefficients. In addition, we find that larger firms, measured by the log of the number of employees, have higher marginal profitability of R&D. Henderson and Cockburn (1996), the only other study known to us that employs project level data, report a similar result.

To test the robustness of our results, we estimated the model 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 unknown distributions. The results, presented in column three of Table 6, are in line with the ML estimates: Most coefficients are within the ML 95% confidence intervals. This suggests that our ML distributional assumptions are not biasing the parameter estimates. The propensity score carries a negative coefficient as expected (significant at 12.5% level). Following DNV we interpret that there is evidence in favor of normal disturbances, because cross-validation (CV) suggests that no higher order terms of the propensity score are needed.[35]

[TABLES 6 AND 7 HERE]

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variable in the 2nd stage investment equation as results using the log of proposed investment yielded essentially identical results.

[34] Several industry and region dummies carried significant coefficients, too.

[35] 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. CV 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). Only the 1st order propensity score variable obtained a significant coefficient, and CV confirmed that we only should use the 1st order propensity score. CV-values are reported in the Appendix. We used a Gram-Schmidt ortho-normalization for the 3rd and 4th order terms in both stages.

Finally, we estimated the investment equation using the R&D investment proposed by the applicant as an alternative dependent variable. The results, presented in column four, are close to those in column one.[36] The one notable difference is that the coefficient of the CEO as chairman variable, although close in value, is no longer statistically significant. It thus seems that the definition of the dependent variable is not driving the results.

D. Covariance structure

As Table 7 shows, we are able to identify the variances of all error terms, and the covariance between the unobservables in the selection and investment equations. The coefficient determining the variance share of the unobservable of the investment equation in the unobservable of the application cost function (equation (14)) obtains a value of 1.5. 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. Similar to the finding that sales per employee increase application costs, it could be that projects with higher marginal profitability of R&D are more complicated involving tacit knowledge and are therefore more difficult to describe in an application. Moreover, the application costs are essentially opportunity costs, which should be higher for projects with higher marginal profitability of R&D.

VI. Implications of the results

The structure of our model can be utilized to back out a number of figures, some of which are reported here. We first report implications about profitability and application costs and then our findings on treatment effects and rates of return. We conclude by characterizing the distribution of R&D benefits. A key idea is to exploit the information on unobservables that the covariance structure and the selection equation yield besides the estimated

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[36] The results using the restricted specification are close to those reported in column two.

parameters. Since the indicator function in (6’’) takes value one for applicants and zero for non-applicants, we can calculate the expected values of the unobservables conditional on the value of the indicator function. In our calculations we use the results both with the accepted proposed investment and proposed investment as the dependent variables (columns one and four of Table 6).[37] The implications obtained by using the proposed investment are reported in the second column of Tables 8 and 9. We report medians.

A. Marginal profitability and application costs

Non-applicants’ expected marginal profitability of log R&D is four times higher than applicants’. This is due to the positive correlation of the marginal profitability and application cost shocks: Applicants have smaller shocks and therefore lower profitability. The difference between the median marginal profitability expected by non-applicants and applicants is much smaller, if the application decision is not used to obtain information on the unobservable application costs. Similarly, the expected discounted profits on the non-applicants' projects are 2.5 [5.5 with the proposed R&D investment as the dependent variable] million euros whereas they are only 0.5 [0.7] million euros on the applicants’ projects. Applicants also have considerably smaller median costs of application (7 700 [11 100]) than non-applicants (330 000 [1 570 000] euros). This, too, is generated by the positive correlation between the marginal profitability and application cost shocks. We find that the applicants’ projects generate an agency specific median expected discounted utility (w/o subsidies) of 18 000 [25 000], the corresponding utility from non-applicants' projects being 71 000 [152 000].[38] Applicant’s profits are thus privately and socially less valuable than those of non-applicants. However, the ratio of agency specific to private median benefits is somewhat higher for applicants than non-applicants.

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[37] Using the results from column two of Table 6 (the specification without quadratic terms of explanatory variables) made no essential difference.

[TABLE 8 HERE]

B. Treatment effects

The literature on treatment effects emphasizes the effects of the treatment on potential applicants. In our case the effect of the subsidy is included in (6’’), which shows how it differs from the standard treatment effect by taking into account the cost of applying. The expected treatment effect in our model is heterogenous as both observable and unobservable applicant characteristics affect the marginal profitability of investment and the cost of applying.

Our model suggests that a subsidy has effects on the agency beyond those on the applicant. Furthermore, if one assumes that the agency is a benevolent social planner, $V()$ will capture all general equilibrium effects of a treatment outside those appropriated by the applicant, and consequently the joint effect of the treatment on the agency and the applicant will constitute the social treatment effect.

We report gross and net treatment effects in Table 9, where the former refers to the standard calculation that does not take into account application costs. We further divide the treatment effects into private (firm), agency, and joint treatment effects, where the private gross treatment effect (on the treated) is the usually calculated one, agency treatment effects are the change in the agency specific utility caused by the treatment, and joint refers to the sum of private and agency treatment effects. Finally, we differentiate the results between the subsidy level expected prior to application (expected treatment effect) and the subsidy level granted by the agency (actual treatment effect)[39] Thus, the increase in expected discounted gross and net profits due to expected and actual subsidy are the expected and actual private gross and net treatment effects. The increase in the agency

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[38] The calculations are based on the assumption that the shadow cost of taxes, g, is 1.2. Kuismanen (2000) estimates the dead-weight loss of existing Finnish taxation to be 15% using labor supply models. Both the constant of integration and the fixed costs of screening applications (i.e., $F_i=K_i$) are ignored.

specific expected discounted utility from subsidies is the (gross) treatment effect on the agency. Similarly, the increases in gross and net expected discounted joint welfare due to subsidies are the joint gross and net treatment effects.

The expected subsidies increase the applicants' median profits gross of application costs substantially less than the non-applicants' gross profits (12 000 [17 000] euros vs. 46 000 [99 000] euros). A comparison of the figures with the private benefits without subsidies, however, shows that the relative increase is much higher for applicants than non-applicants. Subsidies increase the applicants' expected discounted net profits by 3 000 [5 000] euros, whereas the actual subsidies increase them by 4 000 [7 000] euros. Using expected subsidies, applicants' and non-applicants' projects yield almost the same median increase in the agency specific utility (16 000 [17 000] and 13 000 [15 000] euros). The median joint gross (net) treatment effect (welfare increase) is 30 000 [36 000] (21 000 [23 000]) euros for applicants using expected subsidies.

[TABLE 9 HERE]

The estimated private returns are very high for applicants (median close to 900% [1000%]), and even higher for non-applicants. Joint returns are appreciably higher, but the differences are dominated by the very high private returns. The private returns may seem too high for comfort even keeping in mind that these figures are based on entrepreneurs' and firms' plans rather than on realizations, but most of the prior literature's results also indicate very high returns. For example, Griliches (1964) estimates a social return of 13$ on a dollar of R&D in agriculture, Mansfield et al. (1977) report an average social rate of return of over 80% and Griliches (1998, pp. 67) reports private rates of return in the interval [.03, 1.03]. The relative dominance of private returns is understandable, because Tekes and the firms operate in a small open economy from which most of the consumer

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[39] In other words, actual means that the treatment is realized. Naturally, these are still expected discounted

surplus and spillovers flow abroad.[40] If Tekes is maximizing domestic welfare, it should ignore those effects, implying that private returns constitute a large part of joint returns. The distribution of private and, hence, joint returns to R&D, is skewed for non-applicants (see Figure 1), confirming earlier results (Pakes 1986, Scherer and Harhoff 2000).

[FIGURE 1 HERE]

Finally, we have calculated joint rates of return on subsidies (that on actual subsidies can only be calculated for applicants).[41] The median gross and net joint rate of returns on the actual subsidy for applicants are 1.15 [1.14] and 0.79 [0.78]. The corresponding figures on the expected subsidy are 2.57 [2.22] and 1.72 [1.46] for applicants. For non-applicants, the median gross return on the expected subsidy is 1.28 [1.14]. The joint rate of return on the subsidy program is 9%, ignoring the opportunity cost of taxes. Returns using actual subsidies are lower because some firms get zero subsidies (no applicant expects to get zero), and some who would have generated very high returns if they had received expected subsidies, received lower subsidies and therefore generate lower returns.

The private and, therefore, joint treatment effects, conditional on expected subsidies, are substantially lower for applicants, while the agency treatment effects and joint rates of return are similar for applicants and non-applicants. The reason why applicants' projects are submitted to Tekes is that they involve much lower application costs than the projects that are not submitted. Some privately and jointly profitable projects have very high private opportunity costs of applying. The results suggest that the average joint rate of return could be much higher if the positive correlation between application costs and marginal

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effects.

[40] The literature on R&D, geography and trade (see e.g. Eaton and Kortum 2002) finds that much of the spillovers are international.

[41] The joint rate of return is defined as the sum of agency specific utility and firm profits divided by subsidy amount in euros, where the subsidy amount in euros equals subsidy times the expected R&D investment, conditional on the subsidy.

profitability could be lowered, because then society would reap the large increases in private treatment effects.

C. Distribution of benefits

In the following we assume that *V*() reflects benefits to the Finnish society that are not appropriated by the firm. It is of course questionable whether Tekes' decisions reflect social benefits or not. However, for the sake of the argument, let us proceed under that assumption. As mentioned, even if this is the case, *V*() does not measure the global social surplus: it is very likely that most of the consumer surplus and at least some of the spillovers stemming from Finnish innovations will diffuse outside Finland. Therefore, we can think that *V*() mainly consist of domestic technological spillovers. This interpretation is supported by our observation that technical challenge ratings gain a significant role in the Tekes decision rule.

We first discuss how agency specific benefits vary with R&D investments. This immediately yields the variation of the agency specific benefits with subsidies, given the complementarity of the investment and subsidy levels in our model. We then describe and characterize the joint distribution of private and agency specific expected discounted benefits from R&D. Much of the growth literature assumes that spillovers are increasing in R&D: Studying the distribution of agency specific benefits allows us to test this assumption in our data. The joint distribution in turn is central in uncovering whether the social benefits of R&D grow in proportion to private benefits or not.

Recall that we can estimate the expected discounted profits from a firm's R&D project conditional on its decision to apply for a subsidy ($\mathrm{E}[\pi()|X$, apply or not$]$), and the agency specific expected discounted utility from the project ($\mathrm{E}[V]=\mathrm{E}[Z\hat{\delta}]\mathrm{E}[R]$), up to a constant. Because we cannot identify the constant in $\mathrm{E}[Z\hat{\delta}]$, we cannot scale the values for $\mathrm{E}[V()]$, but this does not otherwise affect our ability to characterize the joint distribution.

As before, in calculating E[$Z\hat{\delta}$], we set g=1.2 and F_i=K_i. Such assumptions yield -0.14 as an estimate of the constant. Using this value, E[$Z\hat{\delta}$] is nonnegative for 97% of our observations: Figure 2 depicts the distribution of E[$Z\hat{\delta}$]. This implies that E[V()] is increasing in R&D investments and, hence, in the subsidy rate, for almost all projects in our data. The figure also reveals that for most projects, the expected increase in spillovers is between 0 and 0.2 per one euro of R&D. Moreover, because we used only observations below the 99th percentile for Figure 2, it is apparent that for 99% of firms, a one euro increase in R&D leads to a less than 0.4 euro increase in spillovers.

[FIGURES 2 AND 3 HERE]

Figure 3 presents the joint distribution of private and agency specific benefits, and a non-parametric estimate of E[V()] as a function of E[π()|X, apply or not]. [42] Regressing E[V()] on E[π()|X, apply or not] and a constant yields a coefficient of .00001, significant at the 0.1% level, while the raw correlation is .041, significant at the 1% level, but the estimated nonparametric relationship between the agency specific and private benefits is non-monotone. It is increasing in intermediate values of private benefits, but for low and high values, the estimated relationship has a negative slope. Thus, R&D projects with larger private benefits do not necessarily yield larger spillovers.

VII. Conclusions

We outline a new approach to characterize the determinants and the distribution of R&D benefits and to gain understanding of how an R&D subsidy program works. The method exploits a structural model of a treatment program and data at the firm and R&D project level. We find that unlike what is routinely assumed in the literature, our measures of spillovers and private benefits are not monotonically related. Specifically, we find that spillover and profitability shocks are unrelated. Spillovers are however linear in R&D investments. The benefits appropriated by the agency but not by the firm conducting the R&D are dominated by private benefits. Both private and social rates of return are large and their distribution skew. Large firms have higher marginal returns to R&D, and their projects yield higher agency specific returns. Profitability and application cost shocks are positively related, implying that firms do not apply for subsidies for the privately most profitable projects. Our results suggest that ignoring application costs is recommendable neither in the research of R&D subsidy treatment effects nor in practical policy making, as it leads to an upward bias of the order of 70-90 percentage points.

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[42] We have trimmed the sample at the 95th percentile to aid the visualization of the distribution. The estimate is a *k*-nearest neighbor estimate.

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Table 1

Descriptive Statistics

	Mean	S.d.	Min.	Max.
Age, years	12.320	9.3453	1	97
# Employees	35.229	257.174	1	13451
Sales/employee, 1000 euros	164.920	2156.961	0	206875.5
Exporter	0.063	.244	0	1
SME	0.975	.157	0	1
CEO is chairman of board	0.141	.348	0	1
Board size	4.350	2.003	1	10
# past Tekes applications	0.575	3.488	0	146
Applicant	0.084	.277	0	1

NOTES: There are 10944 observations. Data sources: Asiakastieto Ltd. otherwise; for data on applications, Tekes.

Table 2

Conditional Descriptive Statistics

	Non-Applicants	Applicants	Rejected Applicants	Successful Applicants
Age	12.355 (9.326) [10]	11.940 (9.557) [10]	11.777 (9.964) [9]	11.983 (9.452) [10]
# Employees	21.200 (122.282) [5]	189.001 (775.862) [26]	101.269 (187.503) [21]	212.453 (866.674) [27]
Sales/employee	168.852 (2252.692) [77.55]	121.826 (54.996) [89.72]	104.831 (94.238) [82.95]	126.369 (167.307) [91.58]
Exporter	0.059 (0.236)	0.109 (0.312)	0.119 (0.325)	0.107 (0.309)
SME	0.9860 (0.1173)	0.850 (0.357)	0.855 (0.352)	0.849 (0.358)
CEO is chairman of board	0.141 (0.348)	0.149 (0.356)	0.176 (0.382)	0.141 (0.349)
Board size	4.183 (1.873) [4]	6.177 (2.431) [6]	5.850 (2.285) [5]	6.265 (2.462) [6]
# past Tekes applications	0.247 (1.283) [0]	4.163 (10.657) [2]	3.228 (10.933) [1]	4.413 (10.576) [2]
Nobs.	10029	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, euros	634294 (1254977)	700378.2 (1363460)	385790 (657539.8)
Applied for subsidy only	0.591 (0.492)	0.482 (0.500)	1.000 (0.000)
Technical challenge	2.088 (0.982) {582}	2.312 (0.872) {426}	1.474 (1.006) {156}
Risk	2.189 (0.937) {422}	2.150 (0.925) {326}	2.302 (0.937) {96}
Granted subsidy rate	-	0.316 (0.126)	-
Granted subsidy only	-	0.839 (0.600)	-
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	(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	-.018	-.020**	-.019
	[-.041 .005]	[-.039 -.001]	[-.048 .009]
Technical challenge	.100***	.094***	.120**
	[.076 .124]	[.074 .113]	[.090 .150]
Age	-.001	.0003	-.001
	[-.003 .001]	[-.0017 .0023]	[-.004 .002]
Log employment	.0164*	.024***	.031***
	[-.003 .036]	[.008 .040]	[.007 .055]
Sales / employment	.000036	.000034	.000036
	[-.000136 .000276]	[-.000083 .000151]	[-.00017 .000243]
SME	.085**	.068*	.093*
	[-.001 .170]	[-.003 .138]	[-.011 .197]
Parent company	.006	.016	.014
	[-.040 .053]	[-.023 .055]	[-.043 .070]
# previous applications	-.001	-.002	-.003
	[-.006 .004]	[-.006 .002]	[-.009 .003]
CEO also chairman	.001	-.018	-.013
	[-.053 .055]	[-.064 .028]	[-.080 .055]
Board size	-.007	-.0001	-.009
	[-.017 .003]	[-.0084 .0082]	[-.021 .003]
Exporter	-.042	-.016	-.079*
	[-.107 .023]	[-.069 .038]	[-.161 .002]
Constant	-.060	-.103	-.197**
	[-.217 .098]	[-.233 .028]	[-.393 -.001]
σ_η	.189***	-	.225***
	[.173 .206]		[.203 .247]
Nobs.	379	379	379
LogL.	-18.636	-	-91.763
Wald	0.000	-	0.000
Linearity 1	0.690	-	-
Linearity 2	0.313	-	-
Sample sel.	.068	-	-
	(.051)		

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 the Agency covers, defined as the sum of all three types of financing the Agency grants (in euros, see main text) divided by accepted proposed investment. In column (3), the dependent variable is the subsidy (in euros) divided by the accepted proposed investment.

Table 5
Application Cost Function Results

Variable	Value
Age	.013
	[-.019 .273]
Age sq.	-7.375e-06
	[-.004 .0004]
Log of employment	-.381
	[-3.884 .125]
Ln(emp) sq.	.050
	[-.015 .418]
Sales/employee	.002**
	[.0004 .015]
Sales/emp. Sq.	-1.986e-07
	[-8.84e-07 1.61e-06]
SME	.236
	[-.609 3.750]
Parent company	-.127
	[-2.488 .226]
# Previous applications	-.221**
	[-3.877 -.019]
# Prev appl. sq.	.002**
	[.0002 .028]
CEO is chairman	-.326
	[-1.308 .222]
Board size	-.101
	[-1.406 .028]
Exporter	-.736**
	[-6.685 -.029]
Constant	11.830***
	[10.404 14.638]
Nobs	10751
LogL.	-18.636
Wald (d.f. 29)	0.000

NOTES: Reported numbers are coefficient and [95% confidence interval]. Statistics refer to the probit 1st stage regression from the results of which the cost function coefficients have been backed out. 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 * denote significance at 1, 5, and 10% level.

Table 6
R&D Investment Function Results

Variable	(1) ML Dep. var. accepted proposed investment	(2) ML Dep. var. accepted proposed investment	(3) DNV Dep. var. accepted proposed investment	(4) ML Dep. var. proposed investment
Age	-.005 [-.027 .008]	.002 [-.005 .006]	.0001 [-.030 .025]	-.005 [-.029 .006]
Age sq.	.0002 [-.00003 .0005]	-	.0002 [-.0002 .0005]	.0001 [-.00007 .0004]
Log of employment	-.077 [-.191 .234]	.042** [.012 .134]	-.024 [-.362 .327]	-.130 [-.290 .203]
Ln(emp) sq.	.015 [-.022 .030]	-	-.001 [-.039 .036]	.022 [-.017 .043]
Sales/ employee	.001*** [.0001 .002]	0.0008*** [.0006 .001]	.001** [.0003 .003]	.001* [-.0002 .002]
Sales/emp. sq.	-1.95e-07 [-7.31e-07 1.29e-06]	-	-2.9e-07 [-1.01e-06 1.33e-06]	-1.53e-07 [-6.10e-07 1.58e-06]
SME	-.258 [-.561 .202]	-.281 [-.434 .011]	-.011 [-.766 .815]	-.063 [-.500 .350]
Parent company	.020 [-.134 .262]	.066 [-.026 .210]	-.091 [-.438 .236]	-.035 [-.186 .173]
# Previous applications	-.047 [-.061 .020]	-.006 [-.012 .001]	-.295 [-.748 .174]	-.047 [-.069 .004]
# Prev appl. sq.	.0003 [-.0003 .0005]	-	.002 [-.005 .011]	.0003 [-.0001 .0006]
CEO is chairman	-.182* [-.362 .003]	-.198** [-.336 -.069]	-.158 [-.368 .066]	-.107 [-.278 .080]
Board size	-.008 [-.031 .049]	.008 [-.005 .046]	-.065 [-.207 .086]	.007 [-.021 .066]
Exporter	-.255 [-.400 .037]	-.198 [-.301 .001]	-.398 [-.849 .162]	-.118 [-.280 .173]
Propensity score	-	-	-13.363[a] [-28.604 3.440]	-
Constant	13.234*** [10.920 13.638]	12.401*** [11.224 12.475]	-	13.002*** [10.965 13.428]
Nobs.	722	722	688	915
Wald (d.f. X)	0.000	0.000	0.000	0.000
$\ln(1-\bar{s})$	0.158 (0.181)			-0.718 (0.740)

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. The SME dummy was excluded from the test regressions due to collinearity with $\ln(1-\bar{s})$.

***, **, *, and [a] denote significance at 1, 5, 10, and 15% level.

Table 7
Covariance Structure Results

Variable	Value
σ_{ε} Standard deviation of the investment equation shock	1.120*** [.834 1.256]
σ_{η} Standard deviation of the Tekes specific utility (=V()) shock	.189*** [.173 .206]
$\sigma_{\upsilon 0}$ Standard deviation of the uncorrelated part of the application cost function shock	.456*** [.111 12.552]
ρ Measure of the variance share of ε in υ	1.485*** [1.052 11.010]
$\rho_{\varepsilon\upsilon}$ Correlation between ε and the application equation error term	-.766*** [-.879 -.153]

NOTES: Reported numbers are coefficient and [95% confidence interval]. For all but σ_{η}, these are based on a bootstrap with 400 repetitions. For σ_{η}, it is based on the estimated covariance matrix. ***, **, and * denote significance at 1, 5, and 10% level.

Table 8
Implications of the Model, I

Entity	(1) Dep. var. log of accepted proposed investment	(2) Dep. var. log of proposed investment
Expected marginal profitability of log R&D, applicants	45228.72	62708.76
Same for non-applicants	199844.4	427592.4
Expected discounted profits from R&D w/o subsidies, euros, applicants	487485.9	673571.1
Same for non-applicants	2455946	5487330
Tekes specific expected discounted utility (=V()) from the projects w/o subsidies, euros, applicants	17611.46	25183.04
Expected application cost, euros, applicants	7657.862	11106.59
Same for non-applicants	326129.1	1567572

NOTES: Reported numbers are medians. Gross (Net) profits refers to gross (net) of application costs. The figures are calculated assuming g = 1.2 (g= shadow cost of public funds).

Table 9
Implications of the Model, II

Entity	(1) Dep. var. log of accepted proposed investment	(2) Dep. var. log of proposed investment
Increase expected discounted gross profits due to expected subsidies, euros, applicants	12000.34	17231.23
Same for non-applicants	45882.42	98874.66
Increase in expected discounted net profits due to expected subsidies, euros, applicants	3208.659	5174.192
Increase in expected discounted net profits due to actual subsidies, euros, applicants	4217.539	6857.951
Increase in expected discounted Tekes specific utility (=V()) from granting the expected subsidy, euros, applicants	15688.89	16820.58
Same for non-applicants	13181.76	14913.33
Increase in expected discounted joint gross welfare due to expected subsidies, euros, applicants	29740.05	35917.49
Increase in expected discounted joint net welfare due to expected subsidies, euros, applicants	20870.01	23129.74
Private rate of return on R&D w/o subsidies, applicants	9.719	10.739
Same for non-applicants	11.205	12.837
Joint rate of return on R&D w/o subsidies, applicants	12.547	12.151
Same for non-applicants	12.651	13.012
Joint rate of return on expected subsidies, gross, applicants	2.568	2.222
Joint rate of return on expected subsidies, gross, non-applicants	1.286	1.154
Joint rate of return on actual subsidies, gross, applicants	1.153	1.140
Joint rate of return on expected subsidies, net, applicants	1.716	1.459
Joint rate of return on actual subsidies, net, applicants	.785	.778

NOTES: Reported numbers are medians. Gross (Net) profits refers to gross (net) of application costs. The figures are calculated assuming g = 1.2 (g= shadow cost of public funds). Non-applicant application costs do not include unobservables, and are hence downward biased.

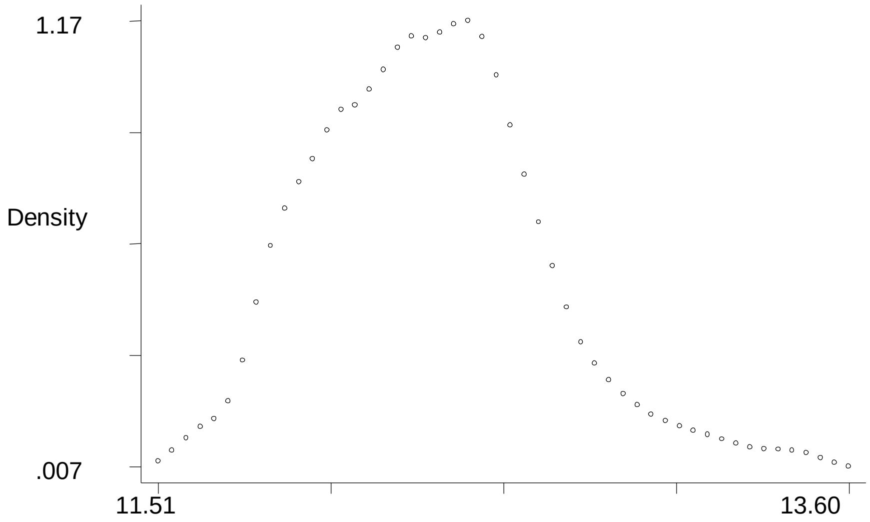

Figure 1: Private expected rates of return to R&D w/o subsidies, non-applicants

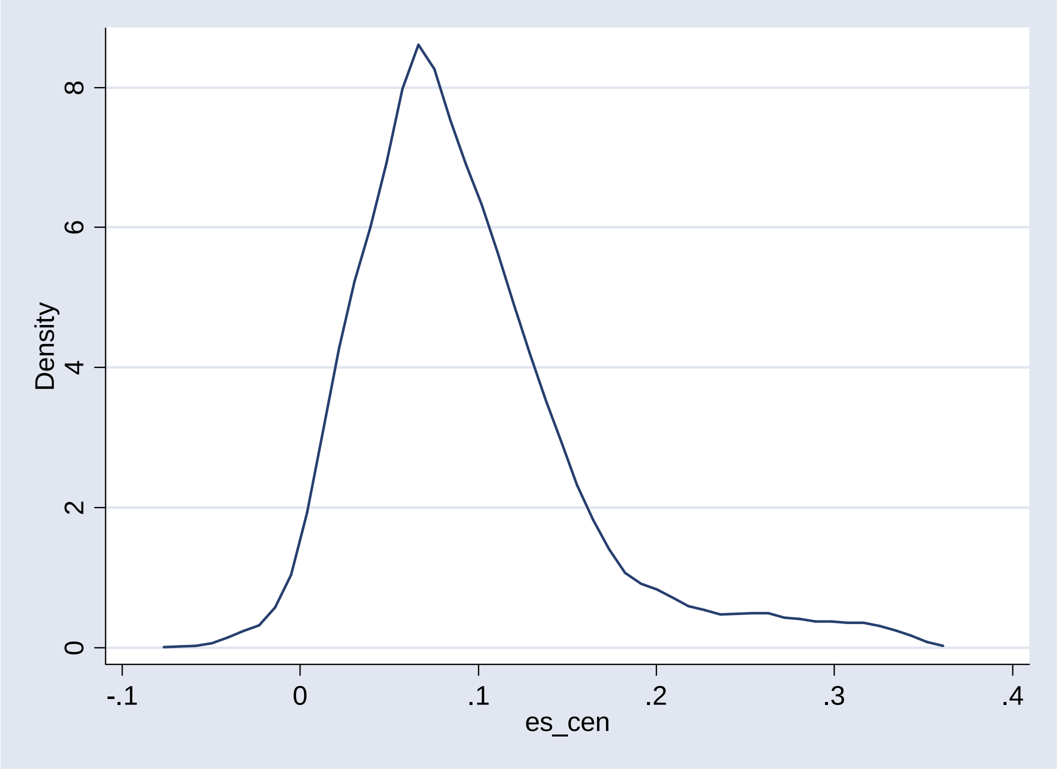

Figure 2: Distribution of $\mathrm{E}[Z\hat{\delta}]$

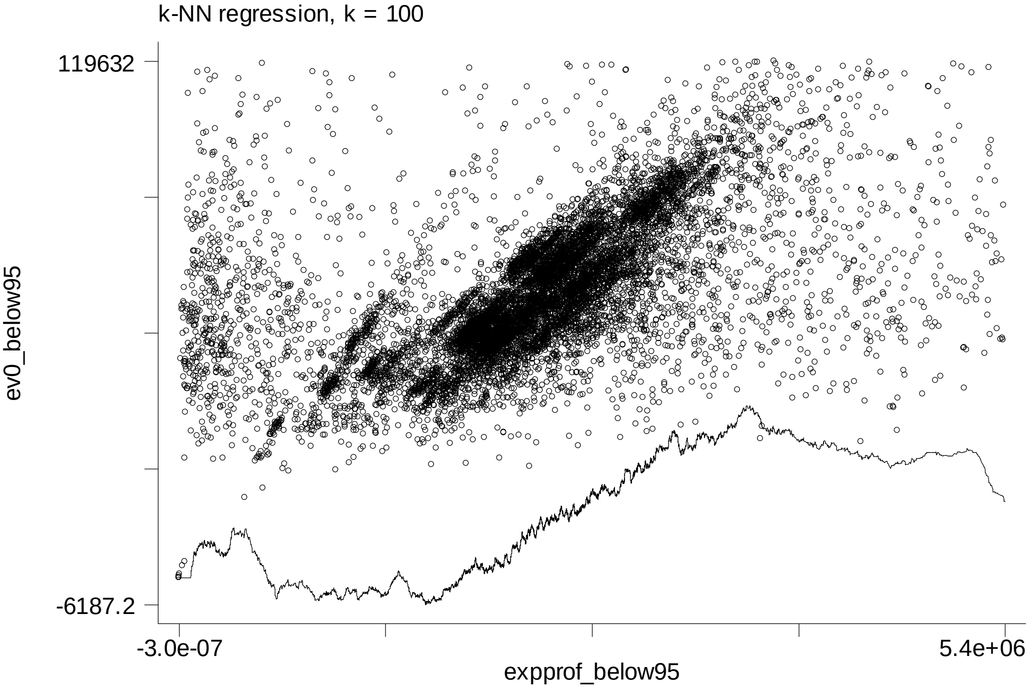

Figure 3: Joint distribution of expected discounted private and joint benefits from R&D w/o subsidies, all firms

APPENDIX A

In this Appendix, we report the ordered probit estimation of the Tekes grading process; 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; industry and region dummy descriptive statistics and their coefficients for the estimated equations; and the cross-validation figures for the 1st and 2nd stage DNV estimations.

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.

A.1. The evaluation equations

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 Evaluation Equations

Variable	Technical Challenge	Risk
Age	| .003	| -.0042379
	[-.007 .013]	[-.0164625 .0079868]
Log Employees	.008	-.0536393
	[-.076 .092]	[-.1538962 .0466177]
Sales/employee	.001***	-.0008665*
	[.0002 .002]	[-.0017846 .0000516]
SME	-.101	| .0600485
	[-.476 .274]	[-.3851782 .5052751]
Parent Company	-.002	| -.1378355
	[-.206 .202]	[-.3769572 .1012863]
# Previous Applications	.021*	-.0189169
	[-.003 .044]	[-.045992 .0081582]
CEO is chairman	| -.247**	-.0118448
	[-.487 -.006]	[-.2940517 .270362]
Board size	.078	.0331881
	[.034 .121]	[-.0160126 .0823889]
Exporter	| .170	.2292716
	[-.114 .454]	[-.1084814 .5670247]
Nobs.	582	422
LogL.	-753.92882	-528.7958
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.

A.2. Descriptive statistics of the applicant samples

Table A.2 presents the descriptive statistics for the three samples of applicants mentioned above. 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	11.940	11.983	11.425
	(9.557)	(9.452)	(8.961)
Log Employees	3.416	3.469	3.213
	(1.787)	(1.786)	(1.684)
Sales/employee	121.826	126.369	120.252
	(154.996)	(167.307)	(128.096)
SME	.850	.849	.879
	(.357)	(.358)	(.327)
Parent company	.510	.525	.478
	(.500)	(.500)	(.500)
# Previous applications	4.163	4.413	2.765
	(10.657)	(10.576)	(4.545)
CEO is chairman	.149	.141	.174
	(.356)	(.349)	(.380)
Board size	6.177	6.265	6.090
	(2.431)	(2.462)	(2.367)
Exporter	.109	.107	.116
	(.312)	(.309)	(.321)
Food	.035	.037	.032
	(.184)	(190)	(.175)
Paper	.051	.051	.037
	(.221)	(.221)	(.189)
Chemicals	.032	.035	.026
	(.175)	(.183)	(.160)
Rubber	.062	.061	.061
	(.242)	(.239)	(.239)
Metals	.079	.080	.069
	(.269)	(.272)	(.253)
Electric	.101	.108	.106
	(.301)	(.311)	(.308)
Radio and TV	.040	.039	.047
	(.197)	(.193)	(.213)
Other manufacturing	.093	.091	.087
	(.290)	(.288)	(.282)
Telecoms	.009	.010	.003
	(.093)	(.098)	(.051)
Data processing	.207	.197	.259
	(.405)	(.398)	(.438)
R&D	.148	.147	.129
	(.355)	(.354)	(.336)
Western Finland	.321	.321	.351
	(.467)	(.467)	(.478)
Eastern Finland	.115	.125	.058
	(.319)	(.331)	(.234)
Central Finland/ Oulu region	.085	.079	.087
	(.279)	(.270)	(.282)
Northern Finland / Lapland region	.022	.019	.029
	(.146)	(.138)	(.168)
Nobs.	915	722	379

A.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 Sample

Indicator	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 10944 observations.

A.4. Coefficients of industry and region dummies

Table A.4
Estimated Industry and Region Dummy Parameters

Variable	Tekes Decision Rule Table 4			Application Cost Function Table 5	R&D Investment Function Table 6			
Column	(1)	(2)	(3)		(1)	(2)	(3)	(4)
Food	.246***	.241***	.312***	.325	-.524***	-.606***	-.518*	-.522***
	[.122 .370]	[.137 .345]	[.163 .461]	[-.965 13.121]	[-.987 -.240]	[-1.00 -.269]	[-.968 .025]	[-.904 -.179]
Paper	-.017	.018	.0003	.085	.183	.013	.144	.183
	[-.140 .106]	[-.080 .116]	[-.1488 .1494]	[-1.169 1.913]	[-.335 .361]	[-.349 .343]	[-.395 .808]	[-.208 .525]
Chemicals	.094	.052	.132	.979	.163	.267	.232	.163
	[-.039 .228]	[-.060 .164]	[.029 .292]	[-.318 12.204]	[-.196 .789]	[-.170 .753]	[-.573 .889]	[-.413 .723]
Rubber	.012	.080	.008*	.228	.080	.099	.109	.080
	[-.084 .108]	[-.002 .162]	[-.111 .126]	[-.662 2.052]	[-.195 .434]	[-.213 .407]	[-.214 .542]	[-.267 .441]
Metals	.004	.013	-.014	.369[a]	.404	.231	.289	.403**
	[-.089 .095]	[-.063 .089]	[-.128 .100]	[-.217 2.842]	[-.0416 .512]	[-.067 .472]	[-.127 .708]	[.012 .658]
Electric	-.046	-.006	-.052	-.192	.254	.167	-.078	.254**
	[-.128 .036]	[-.076 .063]	[-.153 .050]	[-3.618 .597]	[-.066 .541]	[-.030 .540]	[-.678 .593]	[.019 .648]
Radio and TV	-.029	.011	-.001	.473	.603***	.621***	.486*	.603**
	[-.137 .078]	[-.077 .100]	[-.131 .128]	[-3.211 1.477]	[.238 1.184]	[.247 1.183]	[-.066 1.287]	[.082 1.197]
Other manufacturing	-.019	.013	-.016	.281	.206	-.050	.0002	.205
	[-.107 .069]	[-.060 .086]	[-.123 .092]	[-.574 3.803]	[-.353 .267]	[-.379 .217]	[-.391 .460]	[-.201 .472]
Telecoms	-	-	-	1.056[a]	.602	.514	.888*	.602
				[-.154 5.572]	[-.053 1.200]	[-.084 1.08]	[-.221 2.095]	[-.111 1.188]
Data processing	-.066*	-.028	-.058	-.432	.209	.172	-.199	.210**
	[-.140 .008]	[-.090 .033]	[-.150 .034]	[-5.276 .360]	[-.0797 .475]	[-.029 .484]	[-.917 .552]	[.017 .585]
R&D	.007	.049	.024	.178	.096	-.075	-.071	.096
	[-.073 .087]	[-.018 .117]	[-.075 .122]	[-.353 3.593]	[-.301 .243]	[-.286 .229]	[-.353 .251]	[-.178 .377]
Western Finland	.018	.026	.019	.362*	.235**	.153**	.147*	.236***
	[-.028 .064]	[-.012 .065]	[-.038 .075]	[-.022 2.083]	[.0164 .336]	[.012 .328]	[-.011 .321]	[.090 .424]
Eastern Finland	.096**	.088**	.145***	-.196	-.462**	-.374**	-.539**	-.462***
	[.007 .185]	[.014 .162]	[.037 .252]	[-.854 2.069]	[-.603 -.039]	[-.553 -.059]	[-.980 -.030]	[-.622 -.102]
Central Finland/Oulu region	.069*	.031	.102**	.096	.062	-.034	-.175	.062
	[-.006 .145]	[-.030 .092]	[.010 .193]	[-.595 1.049]	[-.277 .272]	[-.246 .255]	[-.600 .242]	[-.193 .372]
Northern Finland/Lapland	-.031	-.026	-.014	.168	.096	.281	.245	.096
	[-.158 .095]	[-.121 .070]	[-.170 .142]	[-2.891 1.272]	[-.056 .710]	[-.027 .715]	[-.188 .702]	[-.171 .507]

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.

A.5. Cross-validation

In the Table below, we present the cross-validation figures for the application and the investment equations. Cross-validation figures were calculated using equation (2.22) in Yatchew (1998).

Table A.5
Cross-validation of the Application and R&D Investment Equations

Specification	Application Equation	R&D Investment Equation
Linear term	0.0595	0.7961
+2nd power	0.0602	0.7982
+2nd and 3rd power	0.0586	0.8006
+2nd -4th power	0.0635	0.8039
+ 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.