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Welfare Effects of European R&D Support Policies*

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Abstract

We estimate the welfare effects of government support to private R&D using comparable R&D project level data from Belgium, Finland, and Germany. In a counterfactual analysis we evaluate the existing policies against alternative policies, including first best. There is considerable heterogeneity in R&D investments, R&D participation rates, spillovers, and profits across firms. Socially optimal R&D participation rates are only marginally higher than those observed in the data, suggesting that most of the benefits from activist policies come from increasing R&D in firms already doing R&D rather than from enticing new firms to start R&D. We find that activist policies increase R&D substantially, but have essentially no effect on welfare. We also find that the gap between laissez-faire and first- and second-best policies is narrow at 3-4 per cent. EU-wide innovation policy is clearly more effective than national ones.

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1 Introduction

The efforts by governments to induce more private sector R&D through subsidies, soft loans and various tax incentive schemes have spread rapidly internationally, so much so that essentially all developed countries have at least some type of support, and an increasing number of developing countries is following suit (OECD 2011). The resources devoted to such support are substantial, exceeding 100 billion USD annually for the OECD countries. With some notable exceptions, innovation policy is still largely conducted within national borders even though it is well established that both knowledge spillovers and other benefits (such as consumer surplus from new goods) spread internationally (e.g. Eaton and Kortum 1999). We make three contributions to further our understanding of the efficiency of the existing and the benefits of different innovation policies: First, using comparable data from 3 European countries (Belgium, Finland, Germany), we estimate the parameters of a structural model of R&D investment and R&D support decisions. Second, we perform a counterfactual analysis of the benefits of the existing and alternative national policies and third, we conduct a counterfactual experiment where the EU centrally organizes the distribution of R&D subsidies, thereby internalizing spillovers from one Member state to another.[1]

The two widely cited motivations for supporting private sector R&D are appropriability problems that lead to spillovers, and financial market imperfections (seminal references are Arrow 1962 and Nelson 1959). Our discussions with civil servants running subsidy schemes has also revealed that they

[1]NOTE: the last one is currently under construction.

see fixed costs of R&D as a large potential impediment to firms starting to invest in R&D. We extend the model developed by Takalo, Tanayama and Toivanen (2013a,b, 2014, TTT henceforth) that encompasses these effects to allow for the simultaneous existence of R&D subsidies and R&D tax credits. In the model, firms, which all have R&D ideas (of varying quality) but lack of funds to implement them, make four decisions: whether or not to apply for a subsidy; whether or not to invest in R&D, and conditional on investing, in which project to invest and how much. If a firm decides to apply for a subsidy, the government agency needs to decide what fraction of the R&D cost to cover. Finally, before being able to invest, the firm must raise the required funding from private sector financiers that face a double moral hazard problem as in Holmstrom and Tirole (1997).

The approach uses revealed preference: The firm's decision of how much to invest in R&D is informative of the marginal private benefits of R&D; the decision whether or not to invest reveals fixed costs of R&D; and the decision whether or not to apply for a subsidy allows us to identify the costs of applying for government support. The government's subsidy decision is also informative: it tells us how the domestic government benefits vary as a function of firm (project) characteristics. Combining information of private benefits (firm profits) with those of public benefits (spillovers of all kind; see e.g. Bloom, Schankerman and van Reenen 2013) and costs of support allows us to make welfare statements. A central feature of the approach is that it takes the current government objectives, as revealed by government decisions, as given, and evaluates other policies against that benchmark. In other words, we ask how well other policies do, using the existing policy, as revealed through government decisions, as a benchmark. For simplicity, we call this metric welfare.

Our work contributes to the literature of structural econometric modelling of firms' R&D investment decisions (see, e.g., Bloom, Griffith, and van Reenen 2002, Jaumandreu, Gonzáles, and Pazó 2005, Doraszelski and Jaumandreu 2013, Aw, Roberts, and Xu 2011 for related contributions). The approach we take deviates from that taken in the large literature seeking to evaluate R&D support schemes (see, e.g., the surveys by Garciá-Quevedo et al. 2004, Cerulli 2010, Zúñica-Vicente et al. 2012, and Becker 2014) that focus on estimating the causal impact of public support on private R&D investments. The benefits and costs of our approach are those usually associated with structural modeling: on the one hand, we get clear economic interpretations of the model parameters, are able to conduct counterfactual analysis, and make modeling assumptions that are transparent to evaluate. On the other hand, we need to make distributional and functional form assumptions that potentially could be relaxed in reduced form work. The largest benefit in our view is that we can provide an answer to the question that should be of primary interest: Do government R&D support schemes improve welfare? In this respect perhaps the closest paper to ours is Bloom, Schankerman and van Reenen (2013) who calculate the social rate of return on R&D after carefully tracking technological spillovers and business stealing effects from a firm's R&D. We include all effects of a firm's R&D that are not internalized by the firm; the downside of our approach is that we rely on theory and government subsidy decisions to infer these.

In our counterfactual analysis, we follow TTT (2014) and first evaluate policies at the national level. We calculate model outcomes (R&D decisions, spillovers, welfare) for the existing policy in each of the countries. When then do two things: we replace the existing policy with an optimal national R&D tax credit, and then abolish all government support (the laissez-faire scenario). To provide a benchmark against which to compare these policies, we calculate two scenarios for the social planner. In the first scenario, the social planner chooses the level of R&D investment for all the firms' R&D ideas (this we call the first best); in the second, the level of R&D investment is still decided by the social planner, but the firm has a veto on whether the project gets executed or not (second best). We go beyond TTT (2014) in two ways: First, we provide these counterfactuals for three countries. Second, we analyze a European innovation policy. The difference to national policies is that the (transnational, EU) government takes into account spillovers to other Member states. We use the estimates of knowledge spillovers, generated using data on patent citations, to calculate the degree of spillovers from a project in country i to the other countries in our data set. Taking these international spillovers into account means that there is a stronger incentive to subsidize projects with positive spillovers compared to the case of the government decision-maker only internalizing domestic spillovers.

In preview of our estimation results, we find that firm characteristics affect marginal profitability of R&D (i.e., R&D investment), fixed costs of R&D (i.e., R&D participation), and application costs (i.e., the decision to apply for support) differently in different countries. They impact less the government's estimate of spillovers per euro of R&D (i.e., the subsidy rate granted to the application).

Our counterfactual analysis provides the following main results: First, activist policies, and indeed, even the socially optimal policies, do not noticeably increase the R&D participation rate compared to laissez-faire. This suggests that, taking costs into account, for a large part of the firm population, the R&D ideas they have are worth exploring neither from a private nor from a social point of view. Second, while the activist national policies generate substantially more R&D than the laissez-faire scenario, they provide only very small welfare increases, if any, compared to the laissez-faire case of no government support. Third, the optimal tax credit varies between 17% for Finland and round 50% for Belgium and Germany. Fourth, the welfare gap between the socially optimal national policies on the one hand and activist policies and laissez-faire on the other hand is small, of the order of a few percentage points. Fifth, when we study the effects of EU wide innovation policy, both the room for and the efficiency of activist policies is substantially increased compared to national policies. One should keep in mind that these results are preliminary; in particular, we are exploring the effects of a more general functional form for the profit function. Also, the EU counterfactual is only executed for Belgium, and only in a partial way

In the next section, we briefly explain the government support policies in place in the countries we study. Section 3 is devoted to an exposition of the TTT model, building on Takalo, Tanayama and Toivanen (2014). There, we also explain how we estimate the model parameters. Estimation results are presented in section 4 where we also display some descriptive statistics. We report the results of our counterfactual analysis in section 5 and offer concluding remarks in section 6.

2 R&D support schemes

2.1 Schemes

It is an often overlooked fact that R&D subsidy schemes are uniform neither across countries nor across time. Simplifying, one can categorize R&D subsidies into targeted (e.g., subsidies) and untargeted (e.g. R&D tax incentives) and/or national and local. Targeted aid can either be available to all firms, or e.g. specific industries can be chosen / emphasized. As an example, The Netherlands had targeted subsidy schemes during our observation period, where specific industries were targeted.[2] Spain has both targeted (subsidies) and untargeted (tax incentives) support. Spanish subsidies are mostly available to all firms, but both national and regional funding is important. Finland on the other hand had mostly targeted funding, but within that form of aid, the share of funding channeled to specific industries and/or technologies has increased over time. Germany is similar to Finland in this respect. This heterogeneity in the institutional setting, both across countries and across time, naturally partly explains the observed heterogeneity in both how firms behave and in how the agencies make decisions. The Netherlands is a case in point if one wants to illustrate that the way governments aim to induce private sector R&D changes over time. According to Pacher and Mohnen (2013a), "major shifts in the balance between these two pillars occurred after the Dutch general elections in 2010. On the one hand, the budget for generic R&D policy instruments is increasing steadily from about €370 million to more than €1.7 billion in 2012. On the other hand, specific

[2] These have since been discontinued.

subsidy instruments have stagnated or have been cut back, in particular after 2010. According to the Dutch Ministry of Economic Affairs, one of the main reasons for reducing the focus on direct R&D subsidy schemes is that fact that they have failed to provide sufficient R&D financing for SMEs (EL&I, 2011)".

We summarize the support policies in place in the countries we study, during our observation period. We include the Netherlands and Spain as comparisons. Regarding R&D tax credits, one should note that in all those countries in the table that have them, they are of the form where firms can deduct social security contributions or similar wage-related expenses. What this implies is that, contrary to "pure" R&D tax credits, even firms with no taxable profits will benefit from these. In our model, we take this feature of R&D tax credits explicitly into account.

ADD TABLE 1 HERE

2.2 Descriptive evidence

Key starting points for our analysis are that 1) firms are very heterogenous with respect to their R&D investments; 2) there is a great deal of heterogeneity in how firms utilize public support to R&D; and 3) similarly there is a large degree of heterogeneity in how muchy public support a given project receives. To demonstrate this heterogeneity, we display the descriptive statistics of our dependent variables in Table 2. Our main data sources in each country are the subsidy-granting agency on the one hand, and national R&D surveys and firm registries administered by the national statistical agencies on the other hand. We utilize data from 2000 onwards, with the actual years varying from country to country.

ADD TABLE 2 HERE

The probability of doing R&D varies from 0.4 in Belgium and Germany to 0.6 in Finland. This heterogeneity will be reflected in our estimates later on. Finnish firms are more likely to apply for subsidies, but even in Finland, the probability of applying for a subsidy in our data is less than 20% while the probability to invest in R&D is 60%. Thus, even if only those firms that end up investing in R&D were to apply, only one in three actually apply.[3] In Belgium and Germany the ratio is even lower, despite free government funds being available. Clearly, one needs to understand the selection of firms into applying for subsidies in order to understand the effects of government support.

Turning to the applicants we find that the success rate in applying, i.e., the probability of obtaining a subsidy conditional on applying for one, is lowest in Finland even though the probability of applying is the highest. Here, one should note that our German data is truncated as we only observe successful applications.[4] We take this into account in our econometric model for Germany. Germany grants the highes subsidy rates (the percentage of R&D reimbursed by the government). In Germany, already the median (successful) applicant gets 50% of costs reimbursed. The distribution of the subsidy

[3]And of course it is possible that a firm that applies and gets rejected ends up not investing in R&D.

[4]We know from other data sources that also in Germany, applications do get rejected. Those data come from specific programs and do not allow us to extrapolate to the data we use in this paper.

rate is quite disbursed in all countries, as can be seen from Figure 1. For Belgium the distribution is bimodal with one hump at zero (= rejected applications), the other at 40%. There is however quite a bit of dispersion, with some firms obtaining subsidy rates as low as 20%, and other subsidy rates as high as 80%. In Finland, there is a similar hump at zero, but otherwise the distribution is quite distinct from the Belgian one.

ADD FIGURE 1 HERE

The R&D investments are lowest in Finland; this difference manifests itself throughout the distribution. Notice that we report and use R&D investments that are accepted by the government agency, "accepted" meaning those costs that the firm has announced and which are eligible for R&D support by the government.[5] The relationship between project level R&D investments and the subsidy rate is not monotonic as shown in Figure 2; neither is it clear that R&D investments are increasing in the subsidy rate. A simple explanation for this is that SMEs may receive higher subsidy rates than larger firms.

ADD FIGURE 2 HERE

[5] All monetary amounts are in 2005 euros. We use Eurostat country-specific consumer price indices in deflating. TTT (2013a) used R&D investments proposed by the firm, and TTT (2014) actual R&D investments. All these differ, with proposed R&D investments usually being the highest and actual the lowest. The accepted R&D costs are the only measure of R&D investment that we have available in all countries.

3 A structural model of the R&D subsidy process

3.1 The theoretical model

The TTT (2014) model seeks to encompass what we see as the key decisions of the R&D subsidy process.[6] The model builds on each firm having an idea for an R&D project, the quality of the which varies. Ideas have two dimensions: How good they are in generating profits to the firm, and how large spillovers the project generates per euro of R&D. Firms maximize expected discounted profits and have access to potentially three types of government support: First, in all countries, to subsidies that are tailored to each project conditional on the firm applying for support. Second, in some countries (e.g. Finland and Spain), to subsidized loans. And third (e.g. Belgium, the Netherlands and Spain), to R&D tax credits. Any firm conducting R&D is eligible for the latter type of support. In stage zero of the game, the shocks determining the quality of the idea in the two dimensions (denoted ϵ for the profitability, η for the spillovers), as well as the shock to costs of applying for a subsidy (ν) are revealed. We expand the TTT (2014) model to allow for tax credits, in line with what is observed in our data. Building on TTT (2014), we convert subsidized loans into equivalent units of support as subsidies.[7]

[6] The current section builds on TTT (2014) and we refer the reader to that paper for modeling details.

[7] Our discussions with Finnish civil servants administering the subsidy program, and our Finnish data, suggest that firms almost always apply for subsidies, but may be granted a mixture of subsidies and loans. The approach taken in TTT (2014) and here allows us to circumvent the (agency) decision of whether to grant loans or subsidies; we leave that question for future research.

In the first stage, the firm decides whether or not to apply for a subsidy. The key assumption is that while the firm knows the distribution of the spillover shock η , it does not know the exact value of it. This assumption generates, in line with our data, outcomes where a firm applies for a subsidy only to get turned down by the government agency.

In the second stage the government decides on the subsidy rate for a project if the firm applied for a subsidy. The government completely internalizes firm profits, but in addition values spillovers and takes the opportunity costs of government resources into account. We use the term "spillovers" to capture all those effects of R&D that the government internalizes but the firm does not. This definition is wider than informational spillovers which is the one usually considered: ours includes e.g. also negative effects on the profits of other (domestic) firms (e.g. Bloom, Schankerman and van Reenen 2013), (domestic) consumer surplus, and so on.

In the third stage the firm negotiates funding with private sector financiers. For simplicity, we assume that the firm has not internal funds. The set-up of the finance part of the model follows Holmstrom and Tirole (1997). The firm has the choice between the good (R&D) project that succeeds with a known probability $P^{\gamma} \in (0, 1)$, and a bad project that fails with certainty but generates large private benefits $b > 0$ per unit of investment to the firm. The financiers have access to a costly monitoring technology (with a cost that is proportional to R&D investment) that allows them to ensure that the firm chooses the good project. We assume that financiers are competitive to the extent of making no profits. The result is that they offer funding to the firm at a cost that allows them to monitor the firm and to (just) break even.

After having found out the cost of finance for the project the firm finally decides whether or not to execute the project, and if so, at what level.

A firm needs to incur both a variable cost $R>1$ and a fixed cost $F \geq 0$ to undertake an innovation project in period four (unless otherwise indicated all variables are project specific). Investing in the project yields a verifiable financial return equaling either zero in case of failure, or[8]

$$\pi = A^{\gamma}\frac{R^{1-\gamma}-1}{1-\gamma}. \tag{1}$$

In (1), A^{γ} is a measure of the profitability of the project, and it is a function of the profitability shock ϵ, as will be made clear below. The adopted functional form nests profit functions that are linear ($\gamma = 0$) and logarithmic ($\gamma \to 1$; as used by TTT 2013a) as special cases. The γ parameter is important e.g. for the much studied additionality: for example, TTT (2013b) show that with positive cost of finance ($\rho > 1$), there will necessarily be partial crowding out if profits are logarithmic in R&D.

TTT (2014) show that the negotiations with the financier lead to the following objective function for the firm:[9]

$$\Pi^{E}(R,s) = (1-\tau)[(PA)^{\gamma}\frac{R^{1-\gamma}-1}{1-\gamma} - (\rho - s(1-\tau_w) - \tau_w)\,R - \rho F]. \tag{2}$$

[8]TTT (2013b, 2014) work with a more general R&D production technology than the logarithmic assumed here. We impose the assumption because we cannot reject the hypothesis that returns to R&D are logarithmic; we thereby gain in simplicity of the model.

[9]TTT (2014) appeal to a law of large numbers type of argument by which the financiers with large loan portfolios can offset profits from successful projects against losses from unsuccessful projects and therefore do not pay taxes. For details, see either TTT (2014).

where ρ is the marginal cost of funds for the financier, consisting both of the cost of raising funding and the cost of monitoring; τ is the corporate tax rate, and τ_w is the R&D tax credit. We assume that the tax credit takes the form it has e.g. in Belgium and the Netherlands as well as in Norway, i.e., as a deduction of the R&D employment costs for which the firm is reimbursed even if it generates no taxable profits. This tax credit is rewarded on the non-subsidized part of the R&D investment R. The optimal level of R&D is, conditional on investment, then given by

$$R^{**}(s) := \arg\max_{R \geq 0} \Pi^E(R, s) = \alpha^\gamma[\rho - s(1-\tau_w) - \tau_w]^{-1/\gamma} \tag{3}$$

where $\alpha = PA$. For the firm to execute the project, the profits generated by this investment have to satisfy the firm's participation constraint:

$$\Pi^E\left(R^{**}(s), s\right) = \frac{\alpha\gamma}{1-\gamma}(\rho - s(1-\tau_w) - \tau_w)^{\frac{\gamma-1}{\gamma}} - \alpha^\gamma/(1-\gamma) - \rho F \geq 0. \tag{4}$$

Turning to the public agency, its objective function for a given R&D project is given by

$$U\left(R(s), s\right) = vR\left(s\right) + \Pi^E\left(R(s), s\right) + \Pi^B - g[s(1-\tau_w) + \tau_w]R\left(s\right) \tag{5}$$

where $g > 1$ is the constant opportunity cost of the public funds (which is the same for all projects). As the second and third term on the right-hand side of equation (5) show, the firm's and investor's profits enter the agency's objective function. As is clear from the equation, we assume that spillovers are linear in R&D. Maximizing this function with respect to the subsidy rate s and assuming an interior solution for the time being yields

$$s^{**} := \arg\max_{s\in\mathbb{R}} U(R^{**}(s), s) = \frac{v - \rho\gamma(g-1) - \tau_w[g - \gamma(g-1)]}{g - \gamma(g-1)}. \qquad (6)$$

Given that there are fixed costs of R&D it may be that the interior solution is not the optimal one, but the goverment wants to give a higher subsidy to induce the firm to do R&D. The subsidy rate that just satisfies the firm's participation constraint is given by

$$\widehat{s} := \frac{1}{1-\tau_w}\{\rho - \tau_w - [\frac{\alpha\gamma}{\alpha^{\gamma} + \rho(1-\gamma)F}]^{\frac{\gamma-1}{\gamma}}\} \qquad (7)$$

If the subsidy rate given by the interior optimum does not induce R&D investment by the firm, the government needs to decide whether to grant the higher subsidy rate $\widehat{s}$ in order to induce investment. As this higher subsidy rate entails higher costs to the government, it may or may not be optimal from the government's point of view to grant the subsidy rate. Thus the possiblity of helping a firm to cross the participation threshold may lead to higher or lower subsidy rates compared to a firm that is not at the threshold.

In period one the firm has to decide whether or not to apply for a subsidy. If the firm does not apply, its profits in period five are

$$\Pi_0^E = max\left\{0, \Pi^E\left(R^{**}\left(0\right), 0\right)\right\}. \qquad (8)$$

The subscript 0 indicates that the firm does not apply for a subsidy. The right-hand side of equation (8) shows how the firm has an option to invest even without a subsidy: the investment is made only if the firm's participation constraint (4) holds for $s = 0$.

The firm's expected profits in case it applies for a subsidy are given by

$$\Pi_1^E = \mathbb{E}_v \left[max \left\{ 0, \Pi^E \left(R^{**} \left(s^* \right), s^* \right) \right\} \right] - K, \tag{9}$$

where the subscript 1 indicates that the firm has applied for a subsidy. TTT (2014) show that the model has a unique Perfect Bayesian equilibrium where firm firm only applies for a subsidy if its expected discounted profits from applying are higher than from not applying; the government, given an application, grants the subsidy rate that maximizes government utility; and the firm executes the project at the profit maximizing level if an only if the competitive cost of funding that solves the moral hazard problem yields (at the optimal level of R&D) to non-negative expected discounted profits.

3.2 Estimation of the model

The estimation proceeds in four steps:

1. Estimation of the R&D investment equation (3) (after taking logs): this reveals how the observables shift the marginal return to R&D, and the variance of the profit shock ϵ (see below).

2. Estimation of the R&D participation decision (4), utilizing the estimated parameters from (3) : this reveals how the observables affect the fixed costs of R&D.

3. Estimation of the agency subsidy rate decision (6): this equation reveals how the observables affect the spillover rate per euro of R&D, and the variance of the spillover shock η.

4. Estimation of the firm's application decision, utilizing equations (8) and (9): this equation reveals how the observables shift the cost of applying for subsidies, and the correlation between the profit and application cost shocks (ξ). In a departure from TTT (2014), we normalize the variance of the uncorrelated part of the application shock to be one (see below).[10]

Throughout the estimations we use a third order polynomial in $\ln(age)$, $\ln(emp)$ and $sales/employee$ as our key explanatory variables. We add 10 industry dummies and year dummies to most specifications. We assume we can directly measure the cost of finance by adding an interest rate margin on the annually measured market interest rate.[11] A key identifying assumption is that the SME status of the firm affects the subsidy rate, but none of the firm's decisions directly. We assume all shocks (ϵ, η, ν) to be (joint) normally distributed, and impose the following restrictions: $\sigma_{\epsilon\eta} = \sigma_{\eta\nu} = \sigma_{\epsilon\nu_0} = 0$; $\nu = \xi\epsilon + \nu_0$; and $\sigma_{\nu_0} = 1$. Our assumptions, in particular the assumption $\sigma_{\epsilon\eta} = 0$, and the assumption that spillovers are linear in R&D, imply that spillovers ($= vR(s, \epsilon)$) are a direct function of the profitability shock ϵ, but spillovers *per euro of R&D* (v) are uncorrelated with the R&D profitability shock. We estimate the model using a sequential

[10] The reason for this normalization is computational. In this paper, we need to work with harmonized data from several countries and apply a coherent model to all data sets. This limits our ability to tailor the solutions to data from individual countries.

[11] We perform robustness checks on this.

pseudo-likelihood approach following the above steps. To obtain standard errors, we bootstrap the whole estimation procedure.

The R&D investment equation is estimated using a sample selection model. We first estimate a (reduced form) probit where the dependent variable takes the value one if we observe the project level R&D of the firm and zero otherwise.[12] We then estimate the R&D equation by taking natural logs of equation (3) and specifying that $PA = \alpha = \exp(\mathbf{X^{R}}'\alpha + \epsilon)$ where $\mathbf{X^R}$ are the variables explained above, α the associated parameter vector and ϵ is the shock to the profitability of the project. We include the Mills' ratio estimated from the first stage to correct for selection; the exclusion restriction we utilize is to include the SME dummy only in the first stage probit. The justification for this is that the SME criterion is an administrative one and should only affect R&D through subsidies: As can be seen from Table 1, SMEs are allowed higher maximum subsidies than non-SMEs. The second stage estimation equation then takes the form

$$\ln R_i = \mathbf{X^{R}}'\alpha - \frac{1}{\gamma}\ln(\rho_i - s_i(1-\tau_{iw}) - \tau_{iw}) + \lambda Mills_i + \epsilon_i \qquad (10)$$

where we have added firm subscripts i. Notice that given our assumptions, s_i is orthogonal to ϵ_i, but the shock to application costs is potentially correlated with ϵ_i. We therefore need not instrument s_i, but employ a sample selection model where the first stage models the zero-one outcome of a firm obtaining a non-negative subsidy rate.[13] We use an observable measure of

[12] We observe project level so-called accepted R&D investments for all those firms that 1) apply for a subsidy and 2) are granted one.

[13] This first stage is reduced form. The outcome of it is determined by the firm's application decision and the agency's subsidy rate decision, both estimated structurally.

ρ_i explained below. For Belgium (where R&D tax credits are in place) we deal with the fact that many firms who invest in R&D as follows: First, we compute the value of τ_{iw} which the firm would be eligible to were it to claim R&D tax credits. We then, using the auxiliary data (see Appendix) to estimate a probit where the dependent variable takes value one if the firm claims R&D tax credits, and zero otherwise. Based on the estimated probability, we assign all Belgian firms to be in one of two categories: either they claim or don't claim R&D tax credits.

The R&D participation equation is estimated using simulated maximum likelihood because the profit shock ϵ enters the equation nonlinearly. Here we employ the estimated values of the parameters for the firm profit function from the R&D investment equation, leaving only the parameters of the fixed costs to be identified. In other words, we insert $\hat{PA}_m = \hat{\alpha}_m = \exp(\mathbf{X^{R}}'\hat{\alpha}+\epsilon_m)$ into (4), where ϵ_m is the simulated value of the profitability shock in simulation round m. We assume that fixed costs of R&D are a deterministic function of observables:: $F = \exp(\mathbf{X_i^{F}}'\omega)$ where $\mathbf{X^F}$ are the observables affecting fixed costs and ω is the associated vector of parameters. By rearranging equation (4) and taking logs we arrive at the estimation equation

$$1[\ln[\frac{\exp(\mathbf{X_i^{R}}'\hat{\alpha}+\epsilon_{mi})\hat{\gamma}_i}{1-\hat{\gamma}_i}(\rho_i - s_i(1-\tau_{wi})-\tau_{wi})^{\frac{\hat{\gamma}_i-1}{\hat{\gamma}_i}} \tag{11}$$

$$-[\exp(\mathbf{X_i^{R}}'\hat{\alpha}+\epsilon_{mi})]^{\hat{\gamma}_i}/(1-\hat{\gamma}_i)] - \ln\rho_i - \mathbf{X_i^{F}}'\omega \geq 0].$$

Estimation of this equation identifies the fixed cost parameters ω. We draw M simulated shocks ϵ_m and average the choice probabilities over these draws that are then fed into the log-likelihood function. We utilize the smoothing function proposed by McFadden (1989) (see also Stern 1997).

Turning to the agency subsidy rate decision, the spillovers per euro of R&D are assumed to take the form $v_i = \mathbf{Z_i'}\delta + \eta_i$, where $\mathbf{Z_i}$ is the vector of observables that affect the government decision, δ the associated vector of parameters and η is the spillover shock, unobserved to the firm at the time of making the application decision. This results in the following estimation equation:

$$s_i^{**}[g - \hat{\gamma}_i(g-1)] = \mathbf{Z_i'}\delta - \rho_i\hat{\gamma}_i(g-1) - \tau_{wi}[g - \hat{\gamma}_i(g-1)] + \eta_i. \qquad (12)$$

To estimate the equation (12) we only use those observations (of applications to the agency) where $s_i^{**} > \hat{s}_i$ and we hence know that the agency decision is based on the interior solution.[14] The agency decision rule is estimated by a two-limit Tobit for all other countries but Germany. For Germany we use a left-truncated, right-censored Tobit because we don't observe an application if it is rejected. The subsidy rate is a function of the same observables as firm profits, and the SME dummy. A key identifying assumption is that η and ϵ are uncorrelated: for the agency decision rule it implies that that it is not subject to selection on unobservables.

Finally, the firm decision to (not) apply for subsidies is also estimated using simulated maximum likelihood because the profit and application shocks enter nonlinearly both equation (8) giving expected discounted profits when the firm does not apply and equation (9) that gives the expected discounted

[14] $\hat{s}_i$ is calculated by plugging the estimated parameters from the R&D investment and participation decisions into equation (7).

profits when the firm applies for subsidies. In calculating the simulated profits, we employ the estimated parameters from the R&D investment, R&D participation, and agency decision equations. The estimation necessitates that we numerically integrate the expected (discounted) profits from applying (gross of application costs) for each simulation and iteration round. We parameterize the application costs to be functions of the observables $\mathbf{X^K}$ as $K = \exp(\mathbf{X^K}'\theta + \xi\epsilon + \nu_0)$, and as explained above, allow the shock to them ($\nu = \xi\epsilon + \nu_0$) to be correlated with the shock to profitability of R&D (ϵ). Together, these four equations identify all the structural parameters of our model, including those of governing the distribution of shocks.

4 Data and estimation results

4.1 Data

To utilize as comparable data as possible across countries, we use data collected after 2000 in all countries; the years for which we have data vary from country to country. In each country, we have access to the national R&D survey data which gives us information on whether or not the firm invested in R&D in a given year, and (sometimes together with other sources) on firm characteristics. The set of firm characteristics that we can consistently measure across countries is somewhat limited: we know the sales, the number of employees and the age of each firm as well as the industry in which it operates.

The descriptive statistics of the explanatory variables can be found in

Table 3. German firms are on average the largest (the difference is mostly, and unsurprisingly, in the upper tail of the distribution); sales per employee are the lowest in Germany; Finnish firms are on average the youngest; and the proportion of SMEs is higher in Germany than in either Belgium of Finland.

ADD TABLE 3 HERE

4.2 Estimation results

In reading and interpreting the results one should bear in mind that these results are preliminary and in particular, rest on us assuming that profits are logarithmic in R&D. We are exploring the use of the more general profit function.

4.2.1 R&D investment

We display the estimation results in the order of estimation and start with the R&D investment equation.[15] We find that while in Finland firm age has a negative impact on R&D, in Belgium the relation is highly nonlinear. Firm size, measured through employment, is significantly related to R&D in all countries.[16] Our proxy for productivity, sales per employee, is also related to R&D investment. In Finland, firms in the more underdeveloped regions invest more in R&D, keeping everything else constant. Keep in mind that the interpretation of these coefficients is that they reflect how the variable in

[15] We use a third order polynomial of the continuous firm characteristics with interactions of the linear terms in all but the fixed cost equation. In that equation, we drop, due to computational problems we faced, the third order terms.

[16] When comparing our results to those in the existing literature, one has to keep in mind that we estimate **project** level R&D investment.

question affects the marginal profitability of (log) R&D.

ADD TABLE 4 HERE

4.2.2 R&D participation decision

Turning then to the discrete decision to (not) invest in R&D, we find (see Table 5) that firm age affects fixed costs in Belgium and Finland but not in Germany; that firm size (at least initially) has a negative effect on fixed costs; and that productivity has different effects on fixed costs in different countries.[17]

ADD TABLE 6 HERE

4.2.3 The agency's subsidy rate decision

The third decision we estimate is the governments subsidy rate decision. Recall that the parameters we uncover here relate to the spillovers per euro of R&D that a project generates. We can thus uncover how a particular government agency believes firm characteristics to affect spillovers. Results reported in Table 6 show that some firm characteristics affect the subsidy rate. In particular, the SME status and being in an underdeveloped region affect the subsidy rate negatively in Finland and positively in Germany. The negative SME coefficient in Finland is the opposite of what TTT (2013a) found using data for 1/2000 - 6/2002. The estimated standard deviation of the error term is of independent interest, as it tells how large the variance of the shock to spillovers is that the government observes but the econometrician

[17]NOTE: we have not yet bootstrapped the estimation, so the reported s.e.'s are biased.

does not. This variance is clearly higher in Finland than in the other two countries.

ADD TABLE 7 HERE

4.2.4 The firms' application decision

The final equation to estimate is the firm's decision to (not) apply for subsidies. The reason this is estimated last is that we need the parameters identified from the other equations to calculate the expected discounted profits of the firm. Using these allows us then to identify how firm characteristics affect the costs of applying for subsidies. As can be seen from Table 7, we find that firm age has a nonlinear effect on application costs in Belgium, a negative effect in Finland and no effect in Germany. Firm size is significantly associated with application costs in all countries. In Finland, firms in disadvantaged regions (receiving potentially higher subsidies) have higher application costs; in Germany, the reverse is true. These coefficients are used in our counterfactual exercise to calculate the costs of applying for a subsidy, and hence determine in part the decision whether or not to apply.

ADD TABLE 8 HERE

4.2.5 Variance parameters

Finally, we also identify the parameters of the (normal) shock distributions. The estimated variance of the profitability shock ϵ is clearly higher in Belgium and Finland than in Germany. This will have implications in the counterfactual analysis as it suggests that the "best" (i.e., most profitable) ideas in Belgium and Finland are better than those in Germany. We already discussed the shocks to the subsidy (spillover) rate earlier. The last parameter, ξ, reflects the degree to which the profitability of an R&D idea is correlated with application costs. The correlation is the negative in Germany and positive in the two other countries. The implication of this is that in Germany, firms with highly profitable R&D projects (ceteris paribus) are more likely to apply for subsidies, while the reverse is true in Belgium and Finland.

ADD TABLE 9 HERE

5 Counterfactual analysis

5.1 Policies

We utilize the structural parameters of our model and our data to calculate outcomes in five policy scenarios:

1. the current R&D policy
2. optimal R&D tax credits
3. laissez-faire
4. first-best
5. second best.

The simulation is carried out country by country in the standard fashion where the same simulated shocks are used in all policy scenarios. We simulate the model 100 times.[18] In the first policy scenario we simulate the current policy.

The second policy scenario involves two steps. First, we abolish both existing R&D subsidies and (if they exist) R&D tax credits. We then calculate, using a grid search, what the optimal R&D tax credit would be if we allowed the agency to choose the tax credit.[19] In other words, we keep the objective function of the government constant compared to the actual policy, but change the tool from subsidies (possibly complemented by tax credits) to tax credits. In calculatting the optimal R&D tax credit, we assume that all R&D investing firms would take advantage of it. While unrealistic in light of what we know from e.g. Belgium, the Netherlands and Spain, this assumption tilts the playing field in favor of the R&D tax credit as long as firms on average produce positive spillovers.[20]

In the third policy scenario, we abolish all government support to private R&D. Notice that this scenario, like all the others, keeps constant government R&D expenditure in other sectors of the economy, like universities and government labs. This laissez-faire policy scenario is a natural benchmark to the activist scenarios. By design, the optimal tax credit scenario must yield at least as much welfare as laissez-faire as were it the case that no strictly positive R&D tax credit raised welfare from the no tax credit level, then the optimal tax credit would be zero.

[18]For each country, we draw simulated shocks from normal distributions governed by the estimated parameters. We restrict the support of all shocks to $[-10, 10]$.

[19]We numerically maximize equation (5). The optimal tax credit rates (τ_w) can be found in Table 14. The support of our grid is $[0, 1]$, and the stepsize is 0.01.

[20]This is in line with our estimates. Obviously, were this not the case, the optimal R&D tax credit would be zero. Another complicating factor would be if firms select into using R&D tax credits as a function of the spillovers they generate; this however seems unlikely.

In the fourth and fifth scenarios we give decision-making powers to the government, assuming along the way that it has all the necessary information. These scenarios are meant to provide benchmarks for the first three. The difference between the two is that in the first-best, the government implements all projects at the level that maximizes welfare; in the second, the firms get a veto in that they can prevent those projects from being executed that yield negative profits.

It is possible that the laissez-faire policy generates higher welfare than the current policy and even second best. One may ask how the first one is possible given that we assume the government agency optimizes subsidies. The answer is that while this is true, in our model the government agency optimizes conditional on receiving a proposal. This means that it does not take into account the effects of its policy on the number, and hence also the costs of, applying for subsidies. The second possibility is explained by the fact that in the second best, the government is naïve in the sense that it does not rescale the planned R&D investments that lead to losses; an alternative way of constructing the second best would be to ask the government to maximize social welfare subject to the constraint that profits are non-negative. The benefit from our simpler approach is that it highlights the extent to which public and private incentives for R&D (spillovers and profits) lead to tensions between the government and the firms.

5.2 Results

The counterfactuals produce a large number of potentially interesting outcomes for each policy scenario. We discuss those of key interest next. Almost all outcomes are expressed as project (firm) means, making them comparable across countries. For each outcome (bar participation in R&D), we present both averages (over all firms) conditioning on R&D investment in a particular simulation run being positive (first panel), and over all simulation runs (second panel). For ease of comparison we have introduced a third panel which compares the other policies to laissez-faire, using the numbers averaged over all simulation rounds (i.e., the second panel).

R&D investment. We start from R&D investment as that is going to be driving many of the other outcomes. As can be seen from the upper panel of Table 9, R&D investment is, unsurprisingly, lowest in the laissez-faire regime in all countries, ranging from 100 000 euros or less on average/project in Germany and Belgium to about 400 000 euros in Finland, conditional on R&D being positive. The figures are naturally lower once we average over all simulation rounds (see lower panel): these latter numbers are useful for comparing the amount of R&D we would expect in a given country (scaling by the number of firms) in a particular policy regime. While Finnish firms invest (on average) more under laissez-faire than Belgian firms, the order is reversed in the other policy regimes. The relatively small differences between the figures in the two upper panels suggest that it is the large investments after large positive profitability shocks that drive the means. The activist policies indeed increase average R&D, leading to a rough doubling of R&D in

Belgium and less than a one third increase in Finland; in Germany the relative increase is between these two (see third panel). Notice however how those firms that actually get a subsidy (last row in the first panel) invest clearly more than firms on average, even after conditioning on R&D investment. The reason the figures in the second to last and last rows of the first panel differ so greatly is that only a small minority of firms gets a subsidy. The first (and second) best policies would imply clearly higher investments. The first-best investments are 3-4 times the laissez-faire investments (third panel: for example, in Belgium, the first-best R&D investment is 4.5 times the laissez-faire level). This suggests that even activist policies only close the gap to (socially) optimal R&D by a small part. [21]

ADD TABLE 10 HERE

R&D participation. Table 10 shows our counterfactual results on R&D participation. Recall that some policy makers see the main role of policy as enabling firms to start investing in R&D. Our results do not rhime with this view at all as we find that the probability of R&D investment is only marginally higher in the activist policy regimes than in laissez-faire, if at all. Indeed, in all countries the current policy does not induce any more firms to engage in R&D than would be the case under laissez-faire. Another interesting feature is that the R&D participation rates of laissez-faire and the two activist policies are very close to the first best. They are actually

[21] Notice that conditional on R&D being positive, the mean R&D is higher in second best than first best. The reason for this is that firms decide to not execute projects with small socially optimal R&D, thereby increasing the average to above that of first best investments. When we average over all projects, first best investment is higher than second best investment (as it should).

higher than the second best participation rates in Belgium and Germany.[22] This suggests that for a large part of the firms one would hope them not to engage in R&D in a given year: the costs simply outweigh the benefits. This is the case even when the spillovers are completely internalized (first-best).

ADD TABLE 11 HERE

Profits. Recall that profits are a function of the R&D production technology including the fixed costs, the costs of finance, and the possible government support. Also keep in mind that we are measuring expected discounted profits. The first thing to come out of Table 11 is that R&D in Finland and Belgium seems an order of magnitude more profitable than R&D in Germany. This was to be expected given the much larger counterfactual R&D investments. The root cause of this difference is the estimated variance of the profitability shock ϵ is larger in Belgium and Finland than in Germany. The second things that one observes is that activist policies increase profits by a small margin compared to how much more R&D they induce. Third, first- and second-best profits are lower than laissez-faire profits in both Belgium and Germany despite, or actually, because of, substantially higher R&D. This makes it clear that the social planner wants to invest in R&D clearly beyond the point where marginal profits are equal to marginal costs. This difference is naturally explained mostly by the spillovers that the government takes into account.

[22] The explanation is that the social planner would like to execute some projects at a level that makes them unprofitable, and therefore the firms decline these projects. This concerns a substantial fraction of the projects that the social planner would like to execute (1/3 in Belgium).

ADD TABLE 12 HERE

Spillovers. A key assumption of our model is that spillovers are project specific and depend linearly on the amount of R&D invested. Therefore it is not surprising to see in Table 12 that Belgian and Finnish firms produce larger spillovers than German firms. Notice also that the activist policies generate clearly higher spillovers than laissez-faire, but much smaller spillovers than the first- and second-best policy scenarios. More interesting is the finding that spillovers increase by exactly the same ratio as R&D for the optimal tax credit, but more in the other policy scenarios. The explanation is twofold: on the one hand, the optimal tax credit is untargeted, and every firm and project gets it regardless of the spillovers (small, large, positive, negative) it generates. On the other hand, the other policy scenarios (first- and second-best, current policy) target R&D projects with large positive spillovers. It seems that the German R&D subsidy (= current) policy is the least effective in this regard as R&D is increased by ratio 1.37 (see Table 9; the respective numbers for Belgium and Finland are 2.16 and 1.37) and spillovers by ratio 1.38 (2.34, 1.75), i.e., only marginally more.

ADD TABLE 13 HERE

Welfare. Welfare is the sum of spillovers, profits, and government costs of support to private R&D. While we show welfare figures conditional on positive R&D for consistency, the lower panel of Table 13 is the crucial one both in terms of comparing policies and in terms of comparing countries. The reason for this is that the upper panel, as interesting as it is, neglects the external margin of increasing the number of firms doing R&D (and/or the number of projects on average per firm over a long time period) whereas the lower panel takes that also into account. It is quite striking to see that the gap between laissez-faire and the first best policies is quite small, between 2 (Finland) and 4 (Germany) per cent. This is striking given the much larger differences in the levels of R&D in these policy scenarios (recally, first-best R&D is 3-4 times higher than laissez-faire R&D; see Table 9). It is also clear that activist policies do not do a particularly good job in closing the gap between laissez-fair and first best: They close at most 1 percentage point (so up to 1/3) of the gap.

ADD TABLE 14 HERE

Other. Finally, in Table 14 we show some other outcomes of our estimations and the counterfactual exercise. Fixed costs of R&D vary between very low (we report median values) in Belgium to quite high in Germany, especially in comparison to the project level R&D estimates. Application costs are estimated to be very high - too high - the explanation most likely being that the model "uses" application costs to "deter" firms from applying when it would otherwise be profitable. Clearly some firms with highly profitable projects would find it beneficial to apply, driving up the application costs. When one looks at the estimates closer to the threshold of the application probability, the figures are much more reasonable, especially for Finland. At the first centile (10%), the estimate is 90 000 euros in Germany and 140 euros in Finland. The predicted application probabilities are well in line with what we observe in the data, as are the average subsidy rates. The optimal tax credit (τ_w) varies from country to country, but is quite high: The lowest rate was obtained for Finland (0.17), the highest for Belgium (0.51). Recall that these should be thought of as reductions in pay-roll-related costs. To compare the fiscal cost of activist policies we have calculated the average out-of-pocket expense of the current policy and of the optimal tax credit. The former is more expensive in all countries despite the fact only few firms obtain subsidies; the high costs conditional on being subsidized explain this result.

ADD TABLE 15 HERE

EU-wide R&D policy. We then turn to changing the agency to be an EU-level agency. What this means is that in assessing spillovers, the agency takes into account the spillovers that flow from country c to all other EU Member states. Our measure of these spillovers is based on industry-specific patent citation flows between countries. For each firm (project), we calculate the ratio of patent citations emanating from other Member states to the patent citations emanating from country c itself. This ratio measures how important the international, within-EU knowledge flows are compared to the national knowledge spillovers. We then give a weight (currently 0.8) to knowledge spillovers as a fraction of all spillovers. While in the data (and hence estimations), we assume the agency of country c to ignore international knowledge spillovers, in this counterfactual we assume it internalizes the knowledge spillovers to other EU Member states.

ADD TABLE 16 HERE

Table 16 summarizes the results of this exercise for Belgium.[23] By design, the EU-level policy leads to higher subsidy rates (as firms on average produce positive spillovers). This has the effect that firms are more likely to apply - 15% instead of 9%. The also receive higher subsidies - on average 0.78 instead of 0.5. Consequently, there is considerably more R&D, and spillovers to the Belgian economy go up by some 50%. Notice however that Belgian welfare goes down. The reason for this is that we place the costs of the higher subsidies on the Belgian tax-payer instead of dividing them between the 27 Member states.

ADD TABLE 17 HERE

Of more interest are the EU-level welfare figures from Belgian R&D, displayed in the second column of Table 17 (the first column repeats the Belgian figures from Table 15). These differ from Belgian figures in that we include the knowledge spillovers to other Member States. EU-level welfare is naturally always higher than Belgian welfare; more interesting is the observation that the ratio between other policies and laissez-faire are different at the EU-level. There's more room for activist policies as the gap between first best and laissez-faire is 19% instead of 3%. In line with this, activist policies improve welfare at the EU- than at the national level (5-9% instead of 1%), though relative to the size of the welfare gap between first best and laissez-faire activist policies are roughly speaking equally effective at EU and at national level.

[23] NOTE: So far, we have executed this counterfactual for Belgium only, and using a country-level measure of within-EU knowledge spillovers instead of an industry- and country-level one.

6 Conclusions

The large literature on the effects of various forms of government support to private R&D does not seek to answer the central policy question of whether those policies improve welfare or not. Also, there is little research aiming to provide results that would be comparable across countries.[24] This paper extends a new modeling framework developed by TTT (2013a,b, 2014) to provide an answer to the central policy question using data from 3 different countries (Belgiun, Finland and Germany), to compare how those countries would faire under alternative policy regimes, and finally, to provide a counterfactual analysis of what effects a European R&D policy would have.

We find that fixed costs of R&D at the project level are mostly moderate (Germany being the exception); that firms perceive the costs of applying for subsidies to be high, particularly in Finland and Germany; that optimal R&D tax credits are low in comparison in Finland (0.17) and high in Belgium and Germany (round 0.5). We find considerable heterogeneity across countries in how firm characteristics affect R&D investment, R&D participation, R&D subsidy rates, and application costs. We also find that there is considerable variance in R&D profitability shocks, and more so in Belgium and Finland than in Germany.

We conduct a number of counterfactuals. Keeping first the exercises within nation states, we find that while so well laissez-faire as activist policies (optimal tax credits, subsidies) increase R&D substantially, they do not and they should not increase R&D participation, and the amount of R&D they

[24] An exception is Czarnitzki and Lopes Bento (2013),

generate falls still clearly below the socially first (or second) best. Profits are more or less on par in the different policy environments, and actually lower in first and second best scenarios than under laissez-faire for some of the countries. In the end though the interesting metric is expected welfare. There we find that the room for improvement (comparing laissez-faire to first best) is quite narrow and that activist policies only narrow the gap by very little, if at all. While activist policies - both those in place during out observation period, and the optimal tax credit we consider as an alternative - increase the levels of R&D significantly, their contribution to national welfare is so small as to be within measurement error of our model.

At the EU-level the picture is more positive. The gap between welfare produced under laissez-faire and first best is much wider (19 versus 3%) at the EU- level than at the national level, the reason being that at the EU-level knowledge spillovers between Members states are internalized. The activist policies that take within-EU knowledge spillovers into account improve welfare more (by 5-9%) than national policies (1%). Our results suggest that while at the national level activist policies in the countries we study have a large impact on R&D of those firms that receive support, but little effect on welfare, the effects of EU-level subsidies would be clearly larger.

Finally, a word of caution. These results should be viewed as preliminary in particular because we are exploring the use of the more general profit function and because the EU counterfactual is only executed for Belgium, and only in a partial way. We also hope to be able to add the Netherlands and Spain to our set of countries.

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Table 1. Description of R&D Support Policies

	Belgium/Flanders	Finland	Germany	The Netherlands	Spain
Subsidies	YES	YES	YES	YES	YES
max subsidy rate (max SME)	0.7 (0.8)	0.6 (0.7)	0.7	0.7	0.6
thematic/generic	NO/YES	YES/YES	YES/YES	YES/NO	YES/YES
basic/applied	YES/YES	YES/YES	YES/YES	NO/YES	YES/YES
soft loans	NO	YES	NO	NO	YES
interest rate	-		-	-	0
tax credits	YES	NO	NO	YES	YES
only central gov.	YES	YES	YES	YES	NO

NOTES: in the case of Flanders, "central gov." refers to the Flemish (regional) government.

In the case of "thematic/generic"and basic/applied,

the X in the entry X/Y refers to whether there are thematic grants and whether basic research is supported;

the Y to whether there are generic (unsolicited) grants and whether applied research is supported.

The policies refer to those in place during our observation period.

Table 2 Descriptive statistics - dependent variables

Prob(RD)	mean	sd	p25	p50	p75	N
Belgium/Flanders	0.409	0.492	0.000	0.000	1.000	8856
Finland	0.597	0.490	0.000	1.000	1.000	33189
Germany	0.399	0.490	0.000	0.000	1.000	49181
Prob(application)	mean	sd	p25	p50	p75	N
Belgium/Flanders	0.073	0.260	0.000	0.000	0.000	8856
Finland	0.199	0.400	0.000	0.000	0.000	33189
Germany	0.031	0.174	0.000	0.000	0.000	49181
success rate	mean	sd	p25	p50	p75	N
Belgium/Flanders	0.827	0.378	1.000	1.000	1.000	546
Finland	0.623	0.485	0.000	1.000	1.000	6620
Germany	1.000	0.000	1.000	1.000	1.000	1529
subsidy rate | subsidy rate > 0	mean	sd	p25	p50	p75	N
Belgium/Flanders	0.434	0.137	0.350	0.450	0.500	546
Finland	0.309	0.271	0.000	0.349	0.500	6620
Germany	0.479	0.094	0.410	0.500	0.500	1529
R&D investment	mean	sd	p25	p50	p75	N
Belgium/Flanders	701 100	1 435 136	91 853	297 576	600 644	545
Finland	365 941	797 115	19 628	128 332	389 510	6 364
Germany	650 910	932 631	205 992	373 191	682 982	1 529

NOTES: Years of observation are: Belgium 2004, 2006, 2008, and 2010; Finland 2000 - 2008; and Germany 2000 - 2010.

Table 3 Descriptive statistics - explanatory variables

#employees	mean	sd	p25	p50	p75	N
Belgium/Flanders	114.740	395.891	13.000	30.000	80.000	8856
Finland	124.243	633.314	9.400	25.000	78.000	33189
Germany	281.229	1502.473	12.000	35.000	130.000	49181
Sales Mio 2005 euro	**mean**	**sd**	**p25**	**p50**	**p75**	**N**
Belgium/Flanders	45.896	211.498	2.228	7.290	26.831	8856
Finland	41.898	471.508	0.858	3.337	13.755	33189
Germany	68.886	510.018	1.019	3.897	18.902	49181
Sales/emp	**mean**	**sd**	**p25**	**p50**	**p75**	**N**
Belgium/Flanders	0.494	0.789	0.106	0.186	0.383	8856
Finland	0.251	1.454	0.079	0.124	0.213	33189
Germany	0.164	0.207	0.065	0.106	0.181	49181
age	**mean**	**sd**	**p25**	**p50**	**p75**	**N**
Belgium/Flanders	28.033	22.534	13.000	22.000	36.000	8856
Finland	15.902	15.153	6.000	12.000	20.000	33189
Germany	31.458	37.129	11.000	17.000	36.000	49181
SME	**mean**	**sd**	**p25**	**p50**	**p75**	**N**
Belgium/Flanders	0.753	0.431	1.000	1.000	1.000	8856
Finland	0.752	0.432	1.000	1.000	1.000	33189
Germany	0.818	0.386	1.000	1.000	1.000	49181

Table 4 R&D investment equation - β

	Belgium/Flanders		Finland		Germany	
lnage	2.288	*	-0.229	*	0.632	
	1.064		0.110		0.457	
lnage2	-1.478	**	-0.251	**	-0.427	
	0.539		0.066		0.311	
lnage3	0.199	**	-		0.057	
	0.071				0.042	
lnemp	-1.473	**	-0.363		0.726	**
	0.531		0.216		0.217	
lnemp2	0.510	**	0.050	**	-0.092	**
	0.133		0.016		0.036	
lnemp3	-0.028	**	-		0.007	**
	0.007				0.003	
salesemp	2.728		-2.587	**	-0.864	
	1.586		0.622		1.013	
salesemp2	-2.144		-0.046		3.129	
	1.507		0.031		2.052	
salesemp3	0.383		-		-1.637	**
	0.346				0.818	
lnage_lnemp	-		0.167	**	-	
			0.046			
lnage_salesemp	-		0.467	**	-	
			0.103			
lnemp_salesemp	-		0.296	**	-	
			0.070			
region	-		0.280	*	-0.168	
			0.131		0.181	
constant	2.854		7.705	**	6.025	
	3.274		1.034		5.195	
nobs	545		5536		1529	

NOTES: **, and * denote significance at 1% and 5% level.

Year dummies and industry dummies are included.

ADD TABLE 5 FOR GAMMA HERE

Table 6 R&D participation equation

	Belgium/Flanders		Finland		Germany	
lnage	-1.017	**	-0.225		-0.018	
	0.338		0.167		0.043	
lnage2	0.055		-0.177	*	-0.012	
	0.062		0.037		0.007	
lnemp	-0.084		-0.127	*	-0.045	**
	0.061		0.054		0.007	
lnemp2	-		0.081	**	-	
			0.009			
salesemp	-1.253	**	-0.760		0.098	
	0.106		0.153		0.056	
salesemp2	-		0.094	*	-	
			0.023			
constant	8.183	**	7.445	**	11.928	**
	0.455		0.183		0.067	
nobs	8 582		31 461			
logL.	-5385.771		-22016.493			

NOTES: **, and * denote significance at 1% and 5% level.

Table 7 Subsidy rate equation

	Belgium/Flanders		Finland		Germany	
lnage	-0.128		0.090	**	-0.008	
	0.094		0.024		0.019	
lnage2	0.041		-0.008		0.005	
	0.037		0.006		0.008	
lnage3	-0.003		-		-0.001	
	0.005				0.001	
lnemp	0.058		0.003		-0.012	
	0.040		0.008		0.017	
lnemp2	-0.021	*	-0.002	*	0.000	
	0.010		0.001		0.004	
lnemp3	0.002	*	-		0.000	
	0.001				0.000	
salesemp	0.121		0.038		-0.044	
	0.124		0.056		0.067	
salesemp2	-0.062		0.010		-0.039	
	0.134		0.008		0.132	
salesemp3	0.010		-		0.035	
	0.034				0.059	
lnage_lnemp	-		-0.007	*	-	
			0.003			
lnage_salesemp	-		-0.019		-	
			0.019			
lnemp_salesemp	-		-0.001		-	
			0.007			
sme	-0.009		-0.041	*	0.027	**
	0.035		0.019		0.005	
region	-		-0.039	**	0.045	**
			0.011		0.010	
constant	0.879	**	0.089	**	0.733	**
	0.082		0.032		0.038	
s.e. of eta	0.192	**	0.322	**	0.083	**
	0.006		0.004		0.002	
nobs	545		5536		1528	
logL.	85.114		-2883.703		1571.028	

NOTES: **, and * denote significance at 1% and 5% level.

Year dummies and industry dummies are included.

Table 8 Application cost equation

	Belgium/Flanders		Finland		Germany	
lnage	2.663	**	-0.303	*	0.323	
	0.338		0.021		0.308	
lnage2	-1.618	**	-		-0.037	
	0.134				0.123	
lnage3	0.220	**	-		0.002	
	0.017				0.015	
lnemp	-1.609	**	0.404	**	-0.473	**
	0.142		0.010		0.171	
lnemp2	0.602	**	-		0.174	**
	0.040				0.038	
lnemp2	-0.038	**	-		-0.016	**
	0.003				0.003	
salesemp	3.089	**	-0.081	*	-2.350	**
	0.368		0.048		0.796	
salesemp2	-1.920	**			6.954	**
	0.385		-		1.435	
salesemp3	0.293	**			-2.623	**
	0.097		-		0.547	
region	-		0.138	*	-0.903	**
			0.037		0.073	
constant	2.809	**	4.618		16.541	**
	0.319		0.140		0.514	
nobs	8856		33189		49181	
logL.	-1682.009		-15033.366		-8221.7629	

NOTES: **, and * denote significance at 1% and 5% level.

Year dummies and industry dummies are included.

Table 9 Covariance terms

	Belgium/Flanders	Finland	Germany
ϵ	4.316	3.899	1.485
η	0.192	0.322	0.083
ξ	1.203	1.772	-1.896

Table 10 Counterfactual R&D investment estimates

	Belgium/Flanders	Finland	Germany
laissez-faire	288 257	402 857	71 750
1st best	1 288 042	1 138 232	209 156
2nd best	1 434 767	1 278 622	229 637
optimal tax credit	541 915	475 952	123 857
current policy	626 998	552 797	94 263
current policy, s>0	1 467 548	1 573 990	904 596
	Belgium/Flanders	**Finland**	**Germany**
laissez-faire	251 226	278 154	37 431
1st best	1 130 781	774 320	111 712
2nd best	1 120 404	768 858	109 107
optimal tax credit	476 054	329 711	66 483
current policy	542 839	380 974	51 277
	Belgium/Flanders	**Finland**	**Germany**
1st best	4.50	2.78	2.98
2nd best	4.46	2.76	2.91
optimal tax credit	1.89	1.19	1.78
current policy	2.16	1.37	1.37

Table 11 Counterfactual R&D participation estimates

	Belgium/Flanders	Finland	Germany
laissez-faire	0.40	0.57	0.40
1st best	0.43	0.59	0.43
2nd best	0.29	0.50	0.38
optimal tax credit	0.41	0.58	0.41
current policy	0.40	0.57	0.40

Table 12 Counterfactual profits estimates

	Belgium/Flanders	Finland	Germany
laissez-faire	5 576 472	7 338 900	740 284
1st best	4 815 400	6 746 752	629 256
2nd best	5 271 014	7 246 348	706 572
optimal tax credit	5 735 561	7 391 475	762 244
current policy	5 786 296	7 430 765	755 343

	Belgium/Flanders	Finland	Germany
laissez-faire	4 962 098	5 227 773	417 107
1st best	4 350 962	4 890 863	379 683
2nd best	4 352 091	4 891 434	380 587
optimal tax credit	5 135 501	5 279 194	440 239
current policy	5 152 309	5 292 571	426 351

	Belgium/Flanders	Finland	Germany
1st best	0.88	0.94	0.91
2nd best	0.88	0.94	0.91
optimal tax credit	1.03	1.01	1.06
current policy	1.04	1.01	1.02

Table 13 Counterfactual spillover estimates

	Belgium/Flanders	Finland	Germany
laissez-faire	204 911	164 150	50 253
1st best	1 084 159	802 539	151 987
2nd best	1 209 505	916 057	166 675
optimal tax credit	385 003	193 197	86 716
current policy	483 110	283 557	66 589

	Belgium/Flanders	Finland	Germany
laissez-faire	177 871	109 127	25 823
1st best	950 188	537 547	80 018
2nd best	939 818	532 090	77 927
optimal tax credit	336 944	129 409	45 870
current policy	416 536	190 582	35 742

	Belgium/Flanders	Finland	Germany
1st best	5.34	4.93	3.10
2nd best	5.28	4.88	3.02
optimal tax credit	1.89	1.19	1.78
current policy	2.34	1.75	1.38

Table 14 Counterfactual welfare estimates

	Belgium/Flanders	Finland	Germany
laissez-faire	5 781 383	7 503 127	790 536
1st best	5 899 559	7 549 667	781 243
2nd best	6 480 519	8 162 833	873 247
optimal tax credit	5 788 912	7 488 343	779 105
current policy	5 829 705	7 519 333	792 730

	Belgium/Flanders	Finland	Germany
laissez-faire	5 139 969	5 336 900	442 930
1st best	5 301 149	5 428 410	459 701
2nd best	5 291 909	5 423 525	458 515
optimal tax credit	5 181 100	5 341 341	448 613
current policy	5 190 912	5 349 376	444 128

	Belgium/Flanders	Finland	Germany
1st best	1.03	1.02	1.04
2nd best	1.03	1.02	1.04
optimal tax credit	1.01	1.00	1.01
current policy	1.01	1.00	1.00

Table 14 Other counterfactual outcome estimates

	Belgium/Flanders	Finland	Germany
Fixed cost of R&D	204	456	111282
Prob(apply)	0.09	0.12	0.03
application cost	27 648	8 777 427	157 000 000
subsidy rate	0.57	0.34	0.49
gov. cost, subsidy	314 943	111 481	31 247
subsidy | s>0	811 762	693 544	448 647
optimal tax credit	0.51	0.17	0.47
gov. cost, tax credit	242 788	56 051	14 971

NOTES: for fixed costs of R&D and for application costs,

we report the median.Otherwise we report means

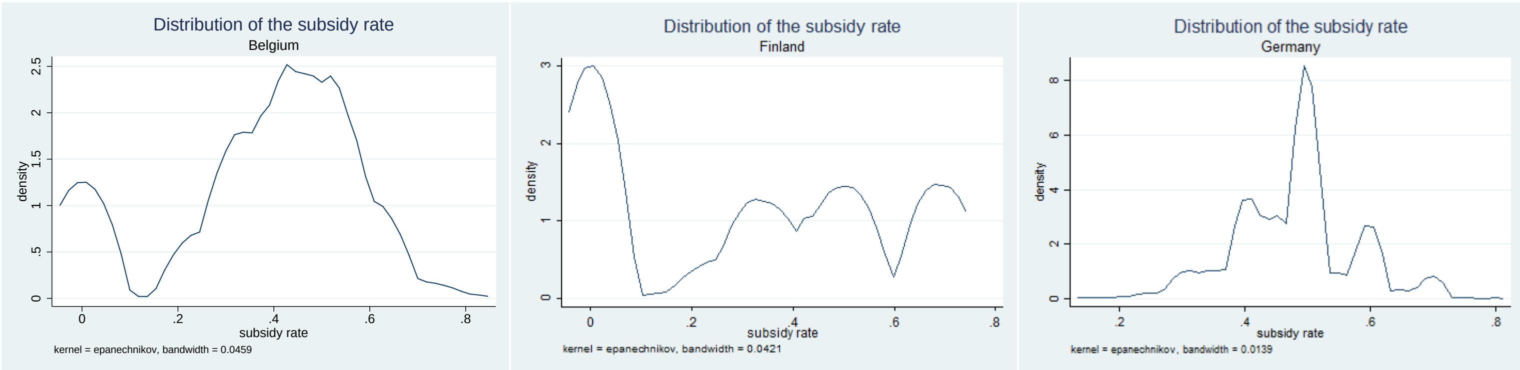
Table 16 Counterfactual welfare estimates - EU policy

	Current policy	EU
Pr(*apply*)	0.09	0.15
Pr(*get* | *apply*)	0.97	1.00
$s \mid s > 0$	0.50	0.78
R&D investment	316 000	534 000
R&D participation	0.41	0.42
R&D inv | $s > 0$	961 000	1 041 000
Spillovers	234 000	372 000
Profits	3 273 000	3 367 000
Welfare	3 314 000	3 264 000

Table 17 Counterfactual welfare estimates - EU policy

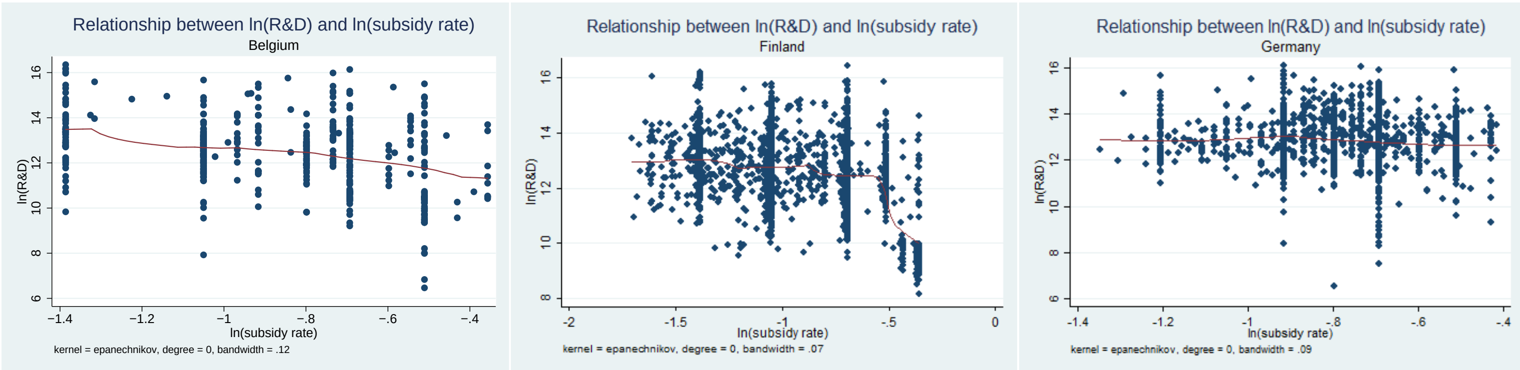
	Belgian Welfare	Relative to laissez-faire	EU Welfare	Relative to laissez-faire
laissez-faire	3 284 000	1	3 425 000	1
1st best	3 381 000	1.03	4 090 000	1.19
2nd best	3 307 000	1.03	4 066 000	1.19
optimal tax credit	3 307 000	1.01	3 534 000	1.03
current policy	3 314 000	1.01	3 604 000	1.05
EU subsidies	3 314 000	1.01	3 726 000	1.09

Figure 1.



Distribution of the subsidy rate
Belgium
density
subsidy rate
kernel = epanechnikov, bandwidth = 0.0459
Distribution of the subsidy rate
Finland
density
subsidy rate
kernel = epanechnikov, bandwidth = 0.0421
Distribution of the subsidy rate
Germany
density
subsidy rate
kernel = epanechnikov, bandwidth = 0.0139

Figure 2.



Relationship between ln(R&D) and ln(subsidy rate)
Belgium
ln(R&D)
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .12
Relationship between ln(R&D) and ln(subsidy rate)
Finland
ln(R&D)
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .07
Relationship between ln(R&D) and ln(subsidy rate)
Germany
ln(R&D)
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .09