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 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, and an EU-wide policy where within-EU spillovers are internalized. 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 national 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 the 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 50 billion USD annually for the OECD countries.[1] With some notable exceptions such as EU's Horizon 2020 and Eurostars,[2] innovation policy is still largely conducted within national borders even though it is well established and understood that both knowledge spillovers and other benefits (such as consumer surplus from new goods) spread internationally. We make three contributions to further our understanding of the efficiency of the existing alternative policies and the benefits of alternative ones: First, using comparable data from 3 European countries (Belgium, Finland, Germany), we estimate the parameters of a structural model of R&D investment and governmental 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.

The two widely cited motivations for supporting private sector R&D are

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[1] We arrive at this figure by multiplying Business Enterprise R&D (BERD) measures in 2010 PPP US$ by the percentage of BERD financed by government, obtained from OECD Main Science and Tech-nology Indicators www-site (accessed Sept 16th 2015).

[2] Horizon 2020 is the EU's "flagship" R&D scheme which funds both private sector and academic research. Eurostars is an EU-level R&D support scheme for SMEs.

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 see fixed costs of R&D as a large potential impediment to firms starting to invest in R&D. We use the model developed by Takalo, Tanayama and Toivanen (2013a,b, 2015, TTT henceforth) that encompasses these effects and extend it 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 three decisions: whether or not to apply for a subsidy; whether or not to invest in R&D, and conditional on investing, how much to invest. 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 at all 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, including knowledge spillovers, but also e.g. consumer surplus) 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, and Peters et al. 2015 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 the closest paper to ours is perhaps 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 start by following TTT (2015) and first evaluate policies at the national level. We calculate model outcomes (R&D decisions, subsidy rates when applicable, 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 (2015) 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 industr-level data on patent citations, to calculate the degree of spillovers from a project in industry i of country j 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 increases in national welfare, if any, compared to the laissez-faire case of no government support. Third, the optimal tax credit varies between 36% 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.

In the next section, we briefly explain the government support policies in place in the countries we study, using the Netherlands and Spain as points of comparison. Section 3 is devoted to an exposition of the TTT model, building on Takalo, Tanayama and Toivanen (2015). 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 support 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.[3] Belgium has both targeted (subsidies) and untargeted (tax incentives) support. 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 and also in not having an R&D tax incentive.[4] 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

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[3] These have since been discontinued.

[4] Finland introduced and withdrew an R&D tax credit after our observation period.

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 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. While for Belgium and Finland we observe all R&D subsidy applications, for Germany we only have data on the successful ones.

ADD TABLE 2 HERE

Finnish firms are more likely to apply for subsidies than Belgian and German ones, but even in Finland, the probability of applying for a subsidy in our data is less than 20% despite free government funds being available. Thus, even if only those firms that end up investing in R&D were to apply, only one in three actually apply.[5] Clearly, one needs to understand the selection of firms into applying for subsidies in order to understand the effects of government support.

The probability of doing R&D varies from 40% in Belgium and Germany to 50% in Finland for non-applicants. Applicants invest in R&D with a higher probability: 73% in Finland, 89% in Belgium, and 100% in Germany. This heterogeneity will be reflected in our estimates later on.

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 lower in Finland than in Belgium even though the probability of applying is

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

higher. [6] 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 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 project-level 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.[7] 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.

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[6] Here, one should note that our German data is truncated as we only observe successful applications. 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. We take this into account in our econometric model for Germany.

[7] 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.

ADD FIGURE 2 HERE

3 A structural model of the R&D subsidy process

3.1 The theoretical model

The model seeks to encompass what we see as the key decisions of the R&D subsidy process and 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.[8] 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. The third form of support available in some countries (e.g. Belgium, the Netherlands and Spain) is 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 (2015) model to allow for simultaneous use of R&D tax credits and R&D subsidies, in line with what is observed in our data. .[9]

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[8] The current section builds on and extends TTT (2015) and we refer the reader to that paper for modeling details.

[9] Some countries, Finland in our case, also give soft loans. Building on TTT (2015), we convert subsidized loans into equivalent units of support as subsidiesOur discussions with

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 (see Figure 1 and Table 2), 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 $P \in (0, 1)$, 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

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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 circumvents the (agency) decision of whether to grant loans or subsidies; we leave that question for future research.

ensure that the firm chooses the good project. We assume that financiers are competitive to the extent of making no (expected) 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

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

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 ($\rho > 1$; see below), there will necessarily be partial crowding out if profits are logarithmic in R&D.

The negotiations with the financier lead to the following objective function for the firm:[10]

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[10] We 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 (2015).

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

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

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

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

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

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). The first term on the right-hand side measures the spillovers from the project: v is the spillover rate, i.e., the spillovers per euro of R&D. As is clear from the equation, we assume that spillovers are linear in R&D. 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. The last term measures the government's cost of R&D support. 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

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

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 possibility 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

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

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. 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).

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. As a measure of the interest rate we use the annually measured market interest rate.[11] A key identifying assumption that helps us deal with a sample selection problem regarding the R&D investment equation is that the SME status of the

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[11] We perform robustness checks on this.

firm affects the subsidy rate, but none of the firm's decisions directly.[12] 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 pseudo-likelihood approach following the above steps. To obtain standard errors, we bootstrap the whole estimation procedure.[13]

The R&D investment equation is estimated using a sample selection model because we only observe the R&D investment (plans) of the successful applicants. 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. We then estimate the R&D equation by taking natural logs of equation (3) and specifying that $PA = \alpha = \exp\gamma(\mathbf{X^{R}}'\beta^R + \epsilon) = \exp\Phi(\mathbf{X}^{\gamma\prime}\beta^{\gamma})(\mathbf{X^{R}}'\beta^R + \epsilon)$ 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 allow the parameter $\gamma = \Phi(\mathbf{X}^{\gamma\prime}\beta^{\gamma})$, where Φ is the cdf of the standard normal,[14] to be firm specific by making it a function of observables. The second stage estimation equation then takes the form

$$\ln R_i = \mathbf{X_i^{R}}'\beta^{\mathbf{R}} - \frac{1}{\Phi(\mathbf{X}^{\gamma\prime}\beta^{\gamma})}\ln(\rho_i - s_i(1-\tau_{iw}) - \tau_{iw}) + \lambda Mills_i + \epsilon_i \quad (10)$$

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[12] As can be seen from Table 1, SMEs are allowed higher maximum subsidies than non-SMEs.

[13] Bootstrapping the standard errors is on our to-do list. The reported standard errors for the R&D participation and the application decisions are therefore biased.

[14] In other words, we assume $\gamma \in (0,1)$.

where we have added firm subscripts i; $Mills_i$ is the Mills ratio estimated in the first stage. 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.[15] For Belgium (where R&D tax credits are in place) we deal with the fact that many firms who invest in R&D do not, despite being eligible, apply for R&D tax credits, 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.[16]

In the second estimation step, the R&D participation equation is estimated using simulated maximum likelihood because the profit shock ϵ enters the R&D participation equation (4) 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 $\hat{P}A_m = \hat{\alpha}_m = \exp(\mathbf{X}^{\mathbf{R}\prime}\hat{\beta}^{\mathbf{R}} + \epsilon_m)$ 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

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[15] 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.

[16] Currently, we assign an exogenous probability to Belgian firms to claim R&D tax credit. Adding the above described estimation procedure is on our to-do list.

observables: $F = \exp(\mathbf{X_i^F}'\beta^F)$ where $\mathbf{X_i^F}$ are the observables affecting fixed costs and $\beta^{\mathbf{F}}$ is the associated vector of parameters. By rearranging equation (4) and taking logs we arrive at the estimation equation

$$\mathbb{I}_{[0,\infty)}\left(\ln\frac{\hat{\alpha}_i}{1-\hat{\gamma}_i}\left[\hat{\gamma}_i\left(\frac{\hat{\alpha}_i}{\rho-s_i}\right)^{\frac{1-\hat{\gamma}_i}{\hat{\gamma}_i}}-1\right]-\ln\rho-\mathbf{X}_i^F\beta^F\right), \qquad (11)$$

where $\hat{\alpha}_i = \exp(\mathbf{X}_i^R\hat{\beta}^R + \varepsilon_{mi})$. Estimation of this equation identifies the fixed cost parameters $\beta^{\mathbf{F}}$. 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 $v_i = \mathbf{Z_i'}\beta^\nu + \eta_i$, 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:

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

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.[17] The agency decision rule is estimated

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

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 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 $\mathbf{X_i^K}$ as $K_i = \exp(\mathbf{X_i^K}'\beta^{\mathbf{K}} + \xi\epsilon_i + \nu_{0i})$, 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). We simulate ϵ as we did in the R&D participation equation. 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. We deflate all monetary amounts to be measured in 2005 euros.

The descriptive statistics of the explanatory variables can be found in Table 3. German firms are oldest irrespective of whether we condition on subsidies or not; Finnish firms are similarly youngest on average. The only notable difference between applicants and non-applicants is in Finland where they applicants are, at 13 years, younger on average than the non-applicants (mean 17 years). German firms are on average also the largest, with the difference being particulary noticeable among the applicants (notice that differences in medians are much smaller); Belgian non-applicants and Finnish applicants are smallest. Notice that the proportion of SMEs is higher in Germany than in either Belgium of Finland among non-applicants, and lowest among applicants. Sales per employee are the lowest in Germany and highest in Belgium with applicants having on average somewhat smaller sales per employee. In addition to these variables, we include 10 industry dummies and year dummies in most regressions.

ADD TABLE 3 HERE

4.2 Estimation results

It turns out that our data supports the view that profits are logarithmic in R&D in all three countries, i.e., that we can write equation (1) as

$$\pi = A \ln R \tag{13}$$

and consequently also simplify all other equations.[18]

4.2.1 R&D investment

We display the estimation results in the order of estimation and start with the R&D investment equation.[19] We find that firm age has a very similar impact on R&D investment in Belgium and Finland; even in Germany the impact is quite close in that the different polynomial terms have the same signs as in and Finland, but absolute values are further apart.[20] Firm size in contrast has differential impacts in Belgium where the first and third order terms carry a positive and the second order term a negative coefficient; in Finland and Germany the first and third order terms obtain positive and the

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[18] We estimated the R&D equation (10), but found for all countries that the estimated $\gamma = 1$. Imposing the simpler functional form brings a major computational saving.

[19] We use a third order polynomial of the continuous firm characteristics in the R&D investment and subsidy rate equations. In the fixed cost of R&D equation we drop the third order and in the application equation, with the exception of Germany, both higher order terms to aid computation.

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

second order term a negative coefficient. Belgium and Germany share the same coefficient pattern for sales per employee, our proxy for productivity, whereas Finland has the opposite sign pattern. In Germany, firms in the more underdeveloped regions invest less in R&D, keeping everything else constant. Keep in mind that the interpretation of these coefficients is that they reflect how the variable in question affects the marginal profitability of (log) R&D. Finally, the estimated variance of the profitability shock ϵ is smaller in Germany than in either Belgium or Finland. This parameter is important as it governs the that part of distribution from which R&D ideas are drawn which determines whether a firm invests in the first place or not.

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 negatively in Belgium and Finland but not in Germany. Firm size affects fixed costs differently in Belgium and Finland as the first and second order terms obtain oppositely signed coefficients. The same applies for sales per employee.[21]

ADD TABLE 5 HERE

We display statistics on the estimated fixed costs in Table 6. Fixed costs of R&D display considerable variation across countries, with Belgium having very low fixed costs of R&D (mean 7 500€), Finland being in the middle with an average fixed cost of some 56 000€, and Germany having clearly higher

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

fixed costs, with the mean being round 7 million euros. The distributions are also quite different, with Belgium and Germany having low variances relative to the mean, and Finland having a high variance. Thus for example at the 25th percentile, the Finnish fixed cost is lower than the Belgian, but at the 75th, it is six times larger. The level of fixed costs, and the variation across firms will impact the R&D participation decision also in the counterfactuals, and of course also profitability conditional on investment.

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 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. In Belgium, we find mostly insignificant coefficients; this may partly be explained by the relatively small sample of 503 observations. It is however the case that most firm characteristics carry insignificant coefficients also with the larger Finnish and German samples. In Finland, we find that firm size obtains a negative coefficient (and the third order term of the same variable a marginally significant positive coefficient). In Finland, we find that SME status increases the subsidy rate by a full 10 percentage points and that firms that invested in R&D last year obtain a subsidy rate that is 3 percentage points lower. In Germany, size seems to have no statistically significant impact, but sales per employee affects the subsidy rate in a marginally significant way negatively. Firms in supported regions (mostly former Eastern Germany) obtain 3 percentage point higher subsidies, and SMEs almost 5 percentage points more. Notice that in all countries, the estimated variance of the spillover shock η is quite low.

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. For this equation, we adopt a more restricted specification for Belgium and Finland for computational reasons. Firm age has a negative impact on application costs in Belgium and Finland, and a nonlinear impact in Germany. Larger firms have higher application costs in the two smaller countries. In Germany, the impact seems to come mostly through the third order term of the polynomial which carries a negative coefficient. Sales per employee affects application costs in all countries, but differently: In Belgium the impact is negative, in Finland positive, and in Germany mostly positive. In Germany, where we also include the region and past R&D dummies, we find both to decrease application costs.

ADD TABLE 8 HERE

We display statistics on the (simulated) application costs in Table 9.

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.
6. EU-wide subsidy policy.

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.[22] 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

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

allowed the agency to choose the tax credit.[23] 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 calculating 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.[24]

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.

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

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[23] 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.

[24] 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.

that yield negative profits.

The last policy scenario is one where we seek to take into account the twin facts that first, some fraction of the spillovers generated by an R&D project flow beyond national borders and are therefore neglected by a benevolent social planner maximizing the welfare of the country in question; and second, that the countries we study are part of a supra-national organization, namely the EU, that exists for the purpose of coordinating policies. In the last policy scenario we keep the policy tool, R&D subsidies, unchanged, but change the utility function of the agency to take into account the spillovers that flow to other EU Member States. While in the 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.

Our measure of between-country 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. Patent citations are a widely used measure of knowledge spillovers (starting with Jaffe 1994; for international knowledge spillovers, see e.g. Eaton and Kortum 1999). Admittedly this is a partial measure as it ignores consumer surplus, possible effects on profits of rival firms, and other forms of spillovers. To take this into account, we give a weight (currently 0.8) to knowledge spillovers as a fraction of all spillovers. Our exercise should be seen as a first attempt to compare the impact of national and supranational innovation policies.

As can be seen from Table 10, the spillovers are highest from Belgian patents, where on average there are more than 4 citations from other EU countries for every Belgian citation. This high mean is however largely explained by one industry, as the quartile level values of Belgium are very close to Finland. German inventions are the least cited in other EU countries relative to domestic citations. This at least partly reflects the fact that Germany is a much larger country than either Belgium or Finland, and thus naturally has more domestic citations.

ADD TABLE 10 HERE

It is possible that the laissez-faire policy generates higher welfare than the current policy. 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.

A strength of our setting is arguably that we keep the utility function of the agency constant and can therefore compare the outcomes in different policy regimes also from the point of view of the policy maker (the agency). A weakness, tied to this, is that we are unable to attach a unique interpretation to agency utility: the agency decisions could reflect those of a benevolent social planner, but plausibly also those of a government agency operating with incentives that are not in line with those of a benevolent social planner.

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, we present averages over all firms whether or not they invest in R&D. These figures allow a comparison across countries and policies as they take both the extensive margin (whether or not to invest in R&D) and the intensive margin (how much to invest, conditional on investing) impacts of the different policies into account. For R&D investment, we also present means that condition on investment as this allows a comparison of how much R&D those firms do that invest in R&D. Finally, in most table (R&D participation being the exception) we calculate a ratio for each policy, comparing them to the laissez-faire outcome. These ratios allow one to see how much the activist policies - R&D subsidies and R&D tax credits - change things compared to there being no government support. They also allow one to see how much room there is for activist policies by showing how far apart laissez-faire and the first and second best policies are.

Policy parameters. Table 11 shows some policy parameters of interest. The optimal R&D tax credit varies from 0.36 in Finland to round 0.5 in Germany and Belgium. Under the current R&D policy, the probability to apply for subsidies varies from very low (0.03, 0.04) in Germany and Belgium to o.16 in Finland. Under the counterfactual policy of EU-wide subsidies, the application probabilities increase. The success rate (i.e., the probability of obtaining a subsidy, conditional on application) is high in all countries under the current policy, and would be clearly lower under the EU policy. The average subsidy rates are slightly below 0.5 under current policy, and somewhat lower under EU policy. The latter is partly explained by the lower success rate, and also by the fact that the probability of getting large subsidies is higher under the EU regime. Finally, we show the cost of each regime, as the out of pocket - cost to the government per potential R&D project. This is a meaningful measure in that it incorporates the extensive and intensive margins of the policy, i.e., the changes in both the probability of conducting R&D, and the levels of R&D investment, conditional on investing, and also does away with the need to adjust for the size of the country. Comparing first the current regime's costs, we find that R&D subsidies cost most to the Finnish government and least to the German government.[25] These differences are partly explained by the differences in the probability of applying for and obtaining a subsidy. The optimal tax credit would generate costs that are quite close to those of the current policy in Belgium and Finland, but in Germany the costs would be drastically higher. Switching from a national to an EU-level subsidy policy would be costly to all three countries, and more so in Belgium and Finland than in Germany. This is quite natural given that the knowledge spillovers from Belgian and Finnish R&D are higher than those from German R&D and thus the subsidies in the EU-regime are higher in the two smaller countries.

ADD TABLE 11 HERE

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[25] The Belgian figures include the costs of the existing R&D tax credits.

R&D investment. We start from R&D investment as that is going to be driving many of the other outcomes. There are two panels in Table 12: the upper one shows the means conditional on R&D investment, and the lower across all observations. The rows correspond to different policy regimes. As can be seen from the upper panel of Table 12, 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 Belgium to over a million euros in Germany, 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.

The activist policies indeed increase average R&D, almost doubling R&D in Belgium and leading to a roughly 50% increase in Finland. While in Belgium and Finland the R&D subsidy and the R&D tax credit regimes lead to about same levels of R&D investment, there is a clear difference between these regimes in Germany. In the current regime, German firms invest only maginally more than under laissez-faire, whereas the R&D tax credit regime leads to an 80% increase in R&D. The explanation for this is the low probability with which German firms apply for subsidies.

One might wonder why the counterfactual German R&D investments are higher than those in Belgium whereas in the data the mean R&D investments in these two countries are comparable. The different selection into the R&D investment estimation sample provides an explanation. In Belgium, the Mills ratio obtained a positive and highly significant coefficient implying that the projects that apply for subsidies have higher than average profitability shocks

ϵ. For Germany, the Mills ratio obtained a small negative (and insignificant) coefficient, implying that the projects for which R&D investment data is available are, if anything, slightly smaller than average. If there was an EU-wide subsidy policy, it would increase R&D substantially more than a nationally oriented one in both Belgium and Finland, but would have a rather marginal impact in Germany. This is quite in line with the differences in knowledge spillovers that the countries generate.

ADD TABLE 12 HERE

R&D participation. Table 13 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, EU policy included, 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. The R&D tax credit regime does only marginally better in this regard. 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 higher than the second best participation rates.[26] 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

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[26] 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).

when the spillovers are completely internalized (first best).

ADD TABLE 13 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, and display these per firm independently of whether the firm invests or not (to include into the policy comparison both the extensive and the intensive margins). The first thing to come out of Table 14 is profits in Germany are highest and in Belgium lowest independet of the policy regime. This was to be expected given the much larger counterfactual R&D investments. The root cause of this difference is in the observables determing the level of R&D investment rather than the estimated variance of the profitability shock ϵ which 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 - a few percentage points - compared to how much more R&D they induce. Third, first- and second-best profits are lower than laissez-faire profits 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.

ADD TABLE 14 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 15 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 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 1.02 (see Table 12; the respective numbers for Belgium and Finland are 1.79 and 1.53) and spillovers by ratio 1.03 (1.94, 1.66), i.e., only marginally more. A final thing to note is that the EU-level subsidy policy leads to a large increase in spillovers in both Belgium and Finland, but to a much more modest increase in Germany.

ADD TABLE 15 HERE

National welfare. Welfare is the sum of spillovers, profits, and government costs of support to private R&D. Our model builds on the assumption that the national government internalizes all of these, but spillovers only to the extent they stay within national borders. It is quite striking to see that the gap between laissez-faire and the first best policies is quite small, between 2

(Finland) and 5 (Belgium) 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 3-6 times higher than laissez-faire R&D). Given this very modest upside, it is not a surprise that the activist policies only improve modestly, by at most 2 per cent, on laissez-faire welfare. As to a comparison between the activist policies, in Belgium they achieve the same 1% increase in welfare. In Finland and Germany, R&D subsidies achieve no improvement in welfare, but R&D tax credits would deliver 1-2%. The EU-policy delivers national welfare that is comparable to the current regime. Regarding the EU-level subsidy policy, a better measure of welfare is the EU-level welfare as in the above numbers, we include all the costs (they are assumed to be paid by the government giving the subsidy), but not all the benefits.

ADD TABLE 16 HERE

EU-wide welfare. 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.

ADD TABLE 17 HERE

Table 17 summarize the EU-level welfare figures for all policies. The first three columns give EU-wide welfare per (potential) project; the second three compares the other policies to laissez-faire just as before; and the last three give the ratio of EU-level to national welfare. The first thing to note is that adopting an EU-wide subsidy policy increases the distance between laissez-faire and first (and second) best. This suggests that while at the national level there was only modest room for welfare improvements, this is not so at the supranational level. The reason is that now the policy maker internalizes the knowledge spillovers to other EU countries. What is also noticeable is that both the current policy and the (from a national point of view) optimal R&D tax credit lead to bigger EU-level welfare improvements than they did at the national level (the R&D subsidy regime in Germany being the exception). Again, the explanation emanates from spillovers: both activist policies increased R&D quite substantially, and those increases in R&D also increase spillovers, but more so at the EU than at the national level. The last row in the table give the EU-level welfare figures and shows that the EU-level policy does substantially better in both Belgium and Finland in terms of increasing EU-level welfare than either national policy; this is however not true for Germany. Turning to the last three columns of the table one notes that the EU-level welfare is always higher than the national one. For Germany, the difference is mostly marginal, 1-4%, but for Finland more substantial and quite large for Belgium. These figures nicely map to the differences into the EU-level spillovers the R&D of the three countries produces.

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,[27] and even less on the effects of supranational R&D policies. This paper extends a new modeling framework developed by TTT (2013a,b, 2015) 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 supranational 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 (0.36) 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 activist policies (optimal tax credits, subsidies) increase R&D substantially, they do not increase R&D participation, and the amount of R&D they 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. The large differences in

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[27] Two exceptions are Bloom, Griffith and van Reenen (2002) and Czarnitzki and Lopes Bento (2013),

R&D across policies generate large differences in spillovers. In the end though the interesting metric is expected welfare. There we find that the room for improvement (comparing laissez-faire to first best) at the national level 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 much more positive. The gap between welfare produced under laissez-faire and first best is much wider at the EU- level than at the national level for Belgium and Finland, 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 EU-level welfare more than national policies. What is more, the national policies also have a bigger impact on EU level welfare than on national welfare. 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.

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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

	Belgium			Finland			Germany		
variable	mean	sd	p50	mean	sd	p50	mean	sd	p50
application	0.07	0.26	0				0.02	0.15	0
non-applicants									
variable	mean	sd	p50	mean	sd	p50	mean	sd	p50
RD	0.37	0.48	0.00	0.49	0.50	0.00	0.39	0.49	0.00
Nobs.	8205			19120			33808		
applicants									
variable	mean	sd	p50	mean	sd	p50	mean	sd	p50
success	0.83	0.31	1	0.62	0.49	1	-	-	-
subsidy rate	0.37	0.20	0.40	0.30	0.27	0.35	0.48	0.09	0.50
RD inv.	624 455	1 419 431	226 085	392 268	825 942	151 270	662 090	805 699	398 079
RD	0.89	0.31	1.00	0.73	0.44	1.00	1.00	0.00	1.00
Nobs.	635			5718			1488		
Years	2004, 2006, 2008			2000 - 2008			2000 - 20011		

Table 3. Descriptive Statistics - explanatory variables

	Belgium			Finland			Germany		
				non-applicants					
variable	mean	sd	p50	mean	sd	p50	mean	sd	p50
SME	0.76	0.43	1.00	0.70	0.46	1.00	0.81	0.39	1.00
age	27.84	21.43	22.00	16.60	15.60	13.00	32.09	35.25	18.00
#empl.	89.83	221.70	28.00	105.14	254.71	33.00	302.50	1963.69	36.00
sales/empl.	0.55	0.88	0.20	0.26	0.38	0.14	0.16	0.18	0.11
region	0.00	0.00	0.00	0.17	0.37	0.00	0.35	0.48	0.00
interest	0.04	0.01	0.05	0.06	0.01	0.06	0.05	0.01	0.05
Nobs.	8205			19120			33808		
				applicants					
variable	mean	sd	p50	mean	sd	p50	mean	sd	p50
SME	0.65	0.48	1.00	0.74	0.44	1.00	0.58	0.49	1.00
age	27.83	26.43	20.00	12.56	13.20	9.00	31.95	38.99	15.00
#empl.	349	797	60	179	624	18	3 070	10 862	136
sales/empl.	0.38	0.62	0.20	0.21	0.35	0.11	0.17	0.14	0.13
region	0.00	0.00	0.00	0.20	0.40	0.00	0.34	0.47	0.00
interest	0.04	0.01	0.05	0.06	0.01	0.06	0.05	0.01	0.05
Nobs.	635			5718			1488		
Years	2004, 2006, 2008			2000 - 2008			2000 - 20011		

Table 4 - R&D investment equation

	Belgium	Finland	Germany
mills	2.4575**	2.5382***	-0.3175
	(1.2162)	(0.8411)	(0.4493)
lnage	1.6143*	1.9944***	0.3367
	(0.9602)	(0.6876)	(0.3621)
lnage2	-1.0519**	-1.0587***	-0.1751
	(0.4585)	(0.3352)	(0.1550)
lnage3	0.1390**	0.1433***	0.0218
	(0.0595)	(0.0449)	(0.0186)
lnemp	-1.0936**	0.7116***	0.1613
	(0.4523)	(0.1153)	(0.1758)
lnemp2	0.4229***	-0.1721***	0.0026
	(0.1131)	(0.0620)	(0.0305)
lnemp3	-0.0252***	0.0202***	-0.0010
	(0.0064)	(0.0072)	(0.0017)
salesemp	1.1875	-4.4970***	1.3119
	(1.2921)	(1.2198)	(1.0178)
salesemp2	-0.6689	7.6358***	-2.9115
	(1.2820)	(1.5646)	(2.5136)
salesemp3	0.0587	-2.8391***	1.8667
	(0.2871)	(0.5354)	(1.6443)
Observations	526	3,516	1,488

Standard errors in parentheses,.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4 c'ed - R&D investment equation

	Belgium	Finland	Germany
region	-	0.1132	-0.3474***
		(0.1112)	(0.0777)
RD_past	-	1.9111***	0.0940
		(0.4207)	(0.3523)
Constant	5.6842**	3.7879**	10.9362***
	(2.6363)	(1.6209)	(1.7615)
σ_ϵ	1.3593***	1.4741***	1.0221***
	(0.0419)	(0.0176)	(0.0187)
Observations	526	3,516	1,488

Standard errors in parentheses,.

*** p<0.01, ** p<0.05, * p<0.1

Table 5 - R&D participation

	Belgium	Finland	Germany
lnage	-0.0858	-0.1970*	
	(0.2318)	(0.1023)	
lnage2	-0.1016**	-0.0170	0.0463***
	(0.0411)	(0.0212)	(0.0102)
lnemp	-0.2590**	0.4783***	-0.0272***
	(0.1233)	(0.0411)	(0.0058)
lnemp2	0.0600***	-0.0456***	
	(0.0150)	(0.0064)	
salesemp	0.2059	-1.9777***	0.6381***
	(0.2594)	(0.2757)	(0.0483)
salesemp2	-0.2405***	1.2598***	
	(0.0807)	(0.1553)	
RD_past		-3.4290***	-2.1560***
		(0.0523)	(0.0188)
year		-0.6412***	0.0120***
		(0.0360)	(0.0028)
year2		0.0511***	
		(0.0043)	
Constant	11.0334***	12.7819***	16.0012***
	(0.6849)	(0.1467)	(0.0381)
Observations	8,840	24,516	35,296

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6 - Fixed cost of R&D

	Belgium	Finland	Germany
mean	7 459	55 766	7 044 494
sd	8 086	113 457	5 121 868
p25	2 613	2 125	1 263 164
p50	5 108	6 204	9 836 349
p75	9 444	60 831	11 000 000

Notes: pi is the $i$the percentile.

All figures in 2005 euros.

Table 7 - Subsidy rate

	Belgium	Finland	Germany
lnage	-0.0447	0.0390	-0.0039
	(0.0906)	(0.0374)	(0.0247)
lnage2	0.0083	-0.0159	0.0059
	(0.0359)	(0.0165)	(0.0095)
lnage3	0.0006	0.0020	-0.0010
	(0.0044)	(0.0022)	(0.0011)
lnemp	0.0258	-0.0214***	-0.0225
	(0.0403)	(0.0061)	(0.0149)
lnemp2	-0.0171	-0.0017	0.0018
	(0.0109)	(0.0019)	(0.0029)
lnemp3	0.0015*	0.0003*	-0.0000
	(0.0008)	(0.0002)	(0.0002)
salesemp	-0.0736	0.0251	-0.1366*
	(0.1247)	(0.0585)	(0.0796)
salesemp2	0.0040	-0.1079	0.2190
	(0.1301)	(0.1022)	(0.1966)
salesemp3	0.0071	0.0601	-0.1054
	(0.0309)	(0.0408)	(0.1286)
Observations	503	3 516	1 488

Standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7 c'ed - Subsidy rate

	Belgium	Finland	Germany
region	-	0.0066	0.0318***
		(0.0066)	(0.0050)
RD past	-	-0.0327***	-0.0123
		(0.0071)	(0.0080)
SME	0.0059	0.1004***	0.0458***
	(0.0342)	(0.0115)	(0.0095)
Constant	0.8559***	0.7626***	0.7190***
	(0.0784)	(0.0351)	(0.0414)
σ_η	0.1808***	0.1454***	0.0799***
	(0.0058)	(0.0019)	(0.0015)
Observations	503	3 516	1 488

Standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8 - Application cost estimation

	Belgium	Finland	Germany
lnage	-0.3156***	-0.1544***	-0.2678
	(0.0615)	(0.0177)	(0.2011)
lnage2			0.1566**
			(0.0756)
lnage3			-0.0205**
			(0.0087)
lnemp	0.1807***	0.2672***	-0.0784
	(0.0376)	(0.0078)	(0.1141)
lnemp2			0.0265
			(0.0214)
lnemp3			-0.0035***
			(0.0012)
salesemp	-0.1523*	0.2496***	1.2007**
	(0.0810)	(0.0439)	(0.6010)
salesemp2			-2.4879*
			(1.4586)
salesemp3			2.0025**
			(0.9039)
Observations	8,840	24,838	35,296

Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 8 c'ed - Application cost estimation

	Belgium	Finland	Germany
region			-0.3822***
			(0.0406)
rd_past			-1.1039***
			(0.1212)
Constant	13.2530***	10.2690***	14.9162***
	(0.6228)	(0.0578)	(0.3601)
ξ	0.2106***	0.5012***	1.4828***
	(0.0337)	(0.0073)	(0.0256)
σ_{ν_0}	1.5989***	1.0843***	1
	(0.0743)	(0.0206)	-
Observations	8,840	24,838	35,296

Standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 9 - Application cost

	Belgium	Finland	Germany
mean	190469.6	62417.42	8 031 933
sd	69976.21	34274.69	5 029 581
min	34633	3716	135
p10	108669	25086.04	2475658

Table 10 - Patent citation statistics

	Belgium	Finland	Germany
mean	4.24	2.72	1.25
sd	5.02	1.11	0.11
p25	2.22	2.15	1.21
p50	2.78	2.50	1.26
p75	3.24	3.47	1.32

NOTES: the figures are ratios of patent citations from other EU-countries to the country in question.

Table 11 - Policy parameters

		Belgium	Finland	Germany
τ_w		0.50	0.36	0.48
application	mean	0.04	0.16	0.03
EU		0.06	0.2	0.05
success	mean	0.98	1	0.99
EU		0.59	0.75	0.5
subsidy rate	mean	0.49	0.47	0.48
EU		0.41	0.45	0.3
cost	subsidy	45 154	90 359	11 214
	tax credit	49 683	84 479	326 240
	EU	97 799	221 080	18 447

NOTE: the EU-rows refer to the EU-wide policy, others to national policies.

Table 12 - counterfactual R&D investment

	Belgium	Finland	Germany	Belgium	Finland	Germany
Conditional on R&D > 0						
	euros			compared to laissez-faire		
laissez-faire	71 614	208 012	1 186 258	1	1	1
first best	435 972	589 829	3 828 392	6.09	2.84	3.23
second best	312 094	578 209	3 697 398	4.36	2.78	3.12
optimal R&D tax credit	135 326	312 770	2 128 832	1.89	1.5	1.79
R&D subsidies	128 297	318 446	1 198 561	1.79	1.53	1.01
EU R&D subsidies	193 123	468 540	1 206 219	2.7	2.25	1.02
Unconditional						
laissez-faire	51 779	154 910	365 193	1	1	1
first best	317 136	424 810	1 182 154	6.12	2.74	3.24
second best	184 428	394 286	1 117 439	3.56	2.55	3.06
optimal R&D tax credit	99 367	234 663	679 666	1.92	1.51	1.86
R&D subsidies	95 041	240 360	375 891	1.84	1.55	1.03
EU R&D subsidies	145 310	363 529	382 825	2.81	2.35	1.05

NOTES: the euro figures are means over all simulation draws with R&D > 0 in the upper panel, and over all simulation draws in the lower panel.

Table 13 - counterfactual: R&D participation

	Belgium	Finland	Germany
laissez-faire	0.41	0.54	0.41
first best	0.44	0.56	0.43
second best	0.28	0.5	0.41
optimal R&D tax credit	0.42	0.55	0.42
R&D subsidies	0.41	0.54	0.41
EU R&D subsidies	0.41	0.54	0.42

NOTES: the euro figures are means over all simulation draws.

Table 14 - counterfactual: profits

	Belgium	Finland	Germany	Belgium	Finland	Germany
		euros			compared to laissez-faire	
laissez-faire	755 955	2 370 133	3 740 595	1.00	1.00	1.00
first best	555 267	2 226 504	3 320 963	0.73	0.94	0.89
second best	608 504	2 233 362	3 359 456	0.80	0.94	0.90
optimal R&D tax credit	791 193	2 438 281	3 976 099	1.05	1.03	1.06
R&D subsidies	781 542	2 425 798	3 743 342	1.03	1.02	1.00
EU R&D subsidies	811 869	2 534 694	3 740 595	1.07	1.07	1.00

NOTES: the euro figures are means over all simulation draws.

Table 15 - counterfactual: Spillovers

	Belgium	Finland	Germany	Belgium	Finland	Germany
		euros			compared to laissez-faire	
laissez-faire	37 132	88 583	252 818	1.00	1.00	1.00
first best	275 907	285 094	850 968	7.43	3.22	3.37
second best	143 497	254 720	799 782	3.86	2.88	3.16
optimal R&D tax credit	71 287	134 251	470 711	1.92	1.52	1.86
R&D subsidies	71 889	147 192	260 361	1.94	1.66	1.03
EU R&D subsidies	104 841	211 717	265 191	2.82	2.39	1.05

NOTES: the euro figures are means over all simulation draws.

Table 16 - counterfactual: Welfare

	Belgium	Finland	Germany	Belgium	Finland	Germany
		euros			compared to laissez-faire	
laissez-faire	793 087	2 458 716	3 993 413	1.00	1.00	1.00
first best	831 174	2 511 598	4 171 931	1.05	1.02	1.04
second best	752 001	2 488 082	4 159 239	0.95	1.01	1.04
optimal R&D tax credit	802 859	2 471 157	4 055 322	1.01	1.01	1.02
R&D subsidies	779 711	2 408 894	3 990 246	0.98	0.98	1.00
EU R&D subsidies	749 490	2 316 554	3 983 651	0.95	0.94	1.00

NOTES: the euro figures are means over all simulation draws.

Table 17 - counterfactual: EU-level welfare

	Belgium	Finland	Germany	Belgium	Finland	Germany	Belgium	Finland	Germany
		euros			compared to laissez-faire			compared to national welfare	
laissez-faire	892 202	2 613 557	4 043 933	1.00	1.00	1.00	1.12	1.06	1.01
first best	1 661 059	2 994 569	4 337 641	1.86	1.15	1.07	2.00	1.19	1.04
second best	1 136 099	2 925 848	4 315 872	1.27	1.12	1.07	1.51	1.18	1.04
optimal R&D tax credit	993 307	2 705 803	4 149 347	1.11	1.04	1.03	1.24	1.09	1.02
R&D subsidies	975 169	2 720 686	4 042 235	1.09	1.04	1.00	1.22	1.10	1.01
EU R&D subsidies	1 054 608	2 881 554	4 036 841	1.18	1.10	1.00	1.32	1.16	1.01

NOTES: the euro figures are means over all simulation draws.

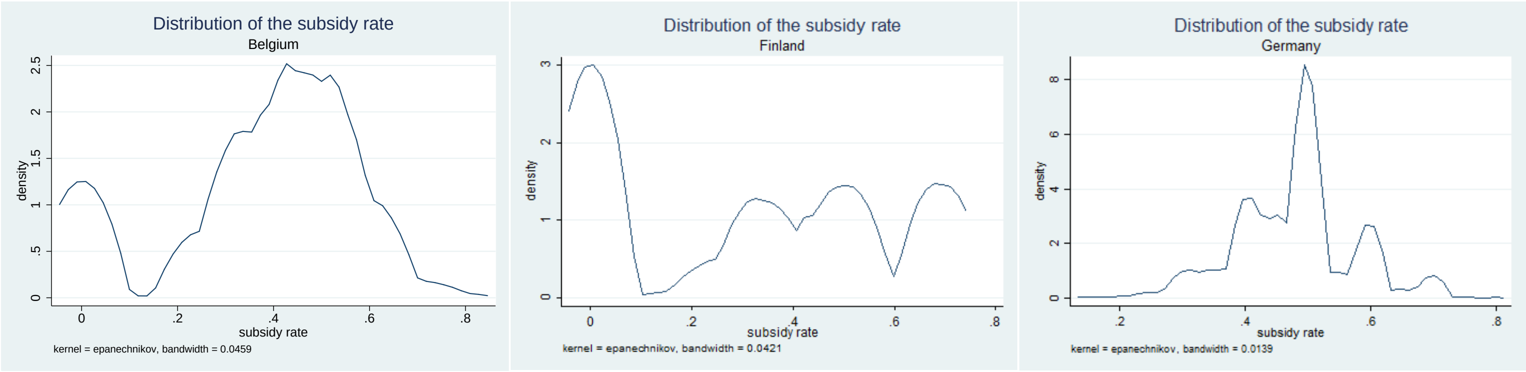
Distribution of the subsidy rate
Belgium
density
0
.5
1
1.5
2
2.5
0
.2
.4
.6
.8
subsidy rate
kernel = epanechnikov, bandwidth = 0.0459
Distribution of the subsidy rate
Finland
density
0
1
2
3
0
.2
.4
.6
.8
subsidy rate
kernel = epanechnikov, bandwidth = 0.0421
Distribution of the subsidy rate
Germany
density
0
2
4
6
8
.2
.4
.6
.8
subsidy rate
kernel = epanechnikov, bandwidth = 0.0139

Figure 1.

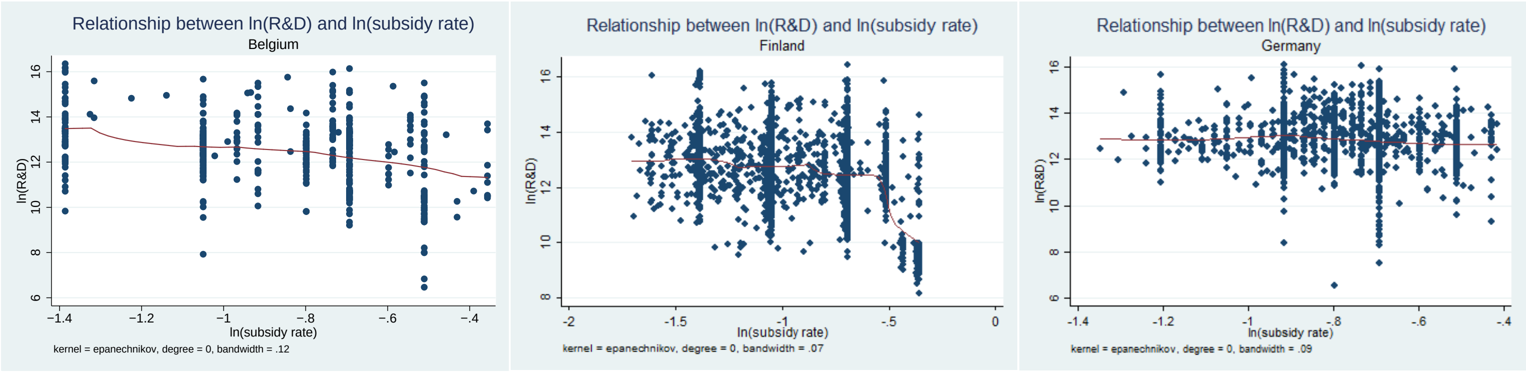
Relationship between ln(R&D) and ln(subsidy rate)
Belgium
ln(R&D)
6
8
10
12
14
16
−1.4
−1.2
−1
−.8
−.6
−.4
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .12
Relationship between ln(R&D) and ln(subsidy rate)
Finland
ln(R&D)
8
10
12
14
16
-2
-1.5
-1
-.5
0
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .07
Relationship between ln(R&D) and ln(subsidy rate)
Germany
ln(R&D)
6
8
10
12
14
16
-1.4
-1.2
-1
-.8
-.6
-.4
ln(subsidy rate)
kernel = epanechnikov, degree = 0, bandwidth = .09

Figure 2.