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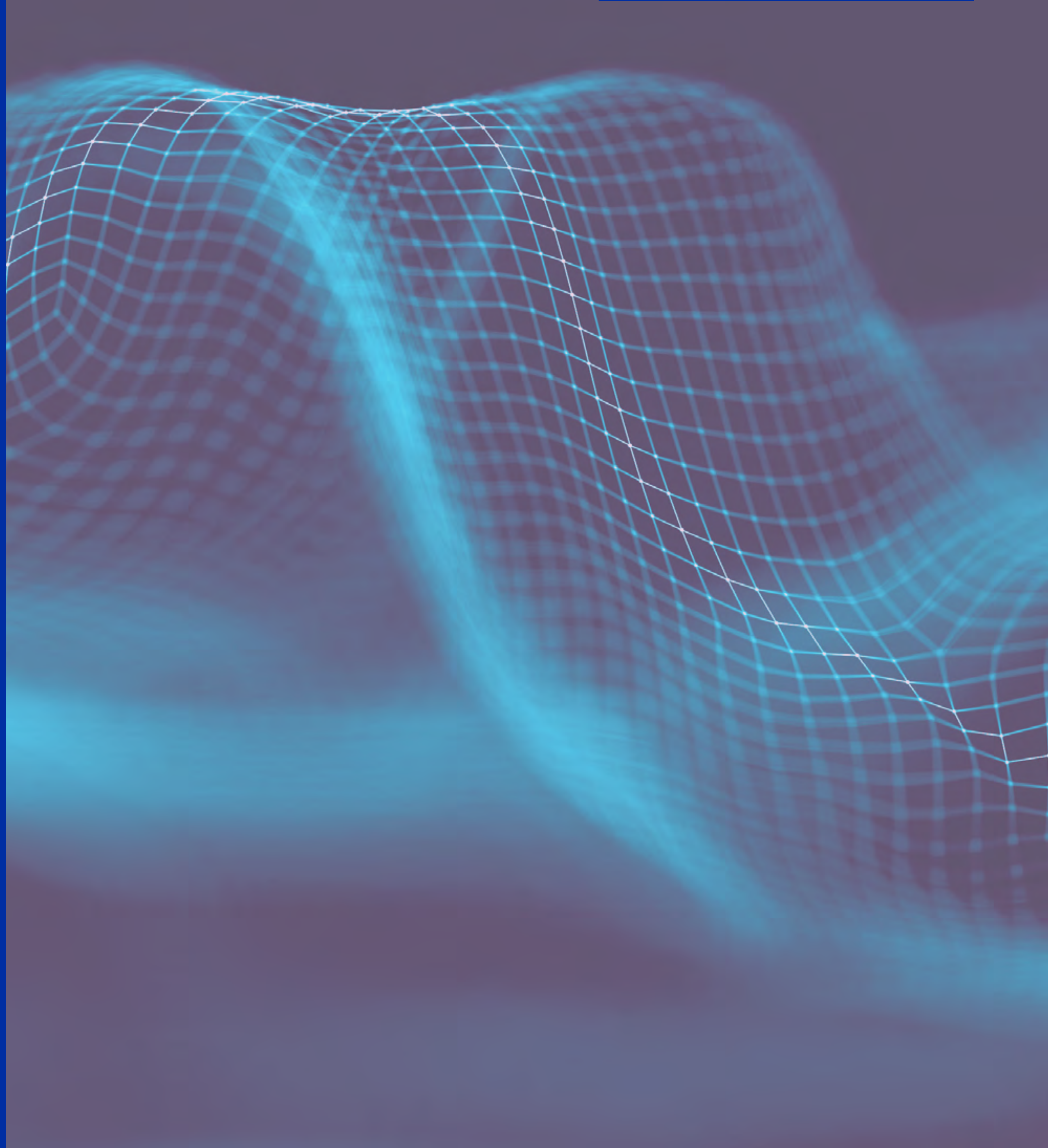

EVALUATION OF TEKES R&D FUNDING FOR THE EUROPEAN COMMISSION

Impact Study

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We believe in the power of ideas. That’s why we fund and help Finnish companies grow quicker and develop their innovations to become global success stories.

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FOREWORD

This Tekes R&D funding evaluation report is based on the evaluation plan, which has been carried out by the request of the European Commission. The aid scheme is for research and development projects. R&D scheme is planned to projects that shall contribute to the improvement in the capabilities (behavioural additionality) or renewal of the beneficiary (output additionality), national or international networking of undertakings (behavioural additionality) or increase in employment, turnover or export of the beneficiary (output additionality). According to European Commission, "State aid evaluation can explain whether and to what extent the original objectives of an aid scheme have been fulfilled (i.e. assessing the positive effects) and determine the impact of the scheme on markets and competition (i.e. possible negative effects)."

According to the Government Decree (Art.3), funding for R&D projects in the R&D scheme is either in the form of grants or loans. Choice of the funding instrument depends on the stage of the project. Grants are mainly used for more challenging R&D (industrial research, experimental development with longer time-to-market) and loans for closer to market experimental development (such as pilots and demonstrations).

This final report estimates first the direct effects. Input additionality of Tekes funding is measured as how funding has increased investments in R&D activities (R&D intensity, number of R&D workers) Then output additionality is estimated by using labor productivity as an indicator of economic performance of Tekes funding. Indirect effects of R&D subsidies have been tested by using employee flows from Tekes customers to other firms to measure spillovers. Impacts on competition has been evaluated by using exit probabilities of subsidized and nonsubsidized firms as a proxy of structural change.

The economist team of ETLA carried out this evaluation study. Business Finland wishes to thank the evaluators for their thorough and systematic approach. Business Finland expresses its gratitude to the steering group and all others who have contributed to the study.

Helsinki, November 2020

Business Finland

TIIVISTELMÄ

Tutkimushankkeen tavoitteena oli tuottaa arvio Tekesin t&k-rahoituksen vaikuttavuudesta Euroopan komissiolle. Vaikuttavuutta tutkittiin seuraavien kysymysten osalta: 1) Ovatko tukea saaneet yritykset lisänneet t&k-panoksiaan tuen seurauksena? (panosadditionaliteetti), 2) Ovatko yritykset tuottaneet saamansa tuen seurauksena enemmän innovaatioita ja onko niiden tuottavuus parantunut tuen saamisen seurauksena? (tuotosadditionaliteetti), 3) Tukiohjelman epäsuorat vaikutukset. Saatavilla oleva tilastollinen aineisto ei mahdollistanut t&k-tukien kausaalivaikutusten tutkimusta innovaatiotuotosten ja yritysten t&k-yhteistyön osalta (ts. behavioraalisen additionaliteetin arviointia).

Tutkimuksessa käytettiin Tilastokeskuksen yritystukitietokantaa täydennettynä Business Finlandilta saaduilla tiedoilla yrityksistä, jotka olivat saaneet t&k-tukea vuosina 2010–2014 päättyneisiin Tekes-projekteihin (ns. ”treated”-ryhmä). Aineisto yhdistettiin Tilastokeskuksen tutkimus- ja kehittämistoimintatilastoon, yritysrekisteriaineistoihin, yhdistettyihin työntekijä-työnantaja-aineistoihin sekä innovaatiotoiminnan tilastoihin. Kontrolliryhmä muodostettiin CEM-vertaistamismenetelmän avulla taustatekijöiltään samankaltaisista t&k-toimintaa harjoittavista yrityksistä, joilla ei ollut Tekes-rahoitteisia projekteja vuosina 2004–2018.

Tekes-tukien suoria ja epäsuoria vaikutuksia arvioitiin estimoimalla erotukset-erotuksissa -yhtälö kiinteiden vaikutusten mallilla (engl. fixed effects model) käyttäen CEM-painoja. Estimoitu malli vertaa tukia saaneiden yritysten tulemia ennen ja jälkeen tukia muiden, tukia saamattomien yritysten tulemien erotukseen samana ajanjaksona.

T&K-TUET LISÄÄVÄT YRITYSTEN T&K-PANOSTUKSIA

Tekesin t&k-tukien suorien vaikutusten osalta löysimme selvää näyttöä tukien positiivisesta vaikutuksesta tuettujen yritysten t&k-työntekijöiden määrään sekä t&k-intensiteettiin. T&K-tuet lisäsivät yritysten t&k-työntekijöiden määrää keskimäärin 16 prosenttia. Tämä vastaa noin 0,8 lisätyöntekijän palkkaamista per tukea saanut yritys. On huomattava, että otoksen yrityksissä oli verrattain vähän t&k-työntekijöitä, Tekes-tuen saantia edeltävinä vuosina vain keskimäärin noin viisi t&k-työntekijää tukea saa-

nutta yritystä kohden. Yhden prosentin korotus t&k-tuen määrässä kasvatti yrityksen työllistämien t&k-työntekijöiden määrää keskimäärin 1,4 prosenttia. Tuen positiivinen (tilastollisesti merkittävä) vaikutus yrityksen palkkaamien t&k-työntekijöiden määrään säilyi kuuden vuoden ajan.

T&K-tukea saaneet yritykset olivat tilastollisesti merkittävästi t&k-intensiivisempiä kuin tukea saamattomat yritykset jo vuoden ennen Tekes-rahoitteisen projektin aloittamistaan. Tätä edeltävinä kahtena vuotena ei ollut havaittavissa selvää eroa t&k-tukea saaneiden ja tukea saamattomien yritysten välillä. Tekes-tuilla oli huomattava positiivinen vaikutus yritysten t&k-intensiteettiin. Tukia saaneiden yritysten t&k-intensiteetti nousi keskimäärin noin 30 prosenttia t&k-tuen saamista seuraavina vuosina. Yhden prosentin kasvu t&k-tukieuroissa nosti otoksen yritysten t&k-intensiteettiä noin 2,5 prosenttia. Tukea saaneiden yritysten t&k-intensiteetti säilyi selvästi tukea saamattomien t&k-intensiteettiä korkeammalla tasolla jopa kahdeksan vuotta tuen saamisen jälkeen.

Tutkimuksessa ei löydetty näyttöä tuotosadditionaliteetista työn tuottavuuden suhteen. Tuotosadditionaliteettia yritysten innovaatiotuotosten ja behavioraalista additionaliteettia yrityksen ulkopuolisten tahojen kanssa tekemän t&k-yhteistyön suhteen ei ollut mahdollista tutkia luotettavasti käytettävissä olevilla aineistoilla.

TUET HIDASTAVAT TEHOTTOMIEN YRITYSTEN POISTUMISTA MARKKINOILTA

T&K-tukien epäsuoria vaikutuksia tutkittiin kahdella tavalla: i) analysoimalla ulkoisvaikutuksia tuetuista yrityksistä tukea saamattomiin ja ii) analysoimalla t&k-tukien vaikutusta yritysten markkinoilta poistumisen todennäköisyyteen ja sitä kautta markkinadynamiikkaan.

Arvioimme ensin ulkoisvaikutuksia Tekesin asiakasyrityksistä muihin yrityksiin. Organisaatioissa syntyvä tieto ja osaaminen ovat usein organisaatio- ja henkilösidonnaisia ja siirtyvät esimerkiksi organisaatioiden välisessä tutkimus- ja kehitysyhteistyössä tai työntekijöiden vaihtaessa työpaikkaa organisaatiosta toiseen. Jos työntekijä vaihtaa työpaikkaa osaamistaan t&k-tuen avulla lisänneestä yrityksestä, myös työntekijän palkkaavan yrityksen tuloksellisuus voi parantua uutta osaamista organisaatioon tuovan henkilön myötä.

Estimoimme mallin, jonka avulla voimme arvioida, kasvoiko uuden työntekijän Tekes-tukea saaneesta yrityksestä palkanneiden t&k-tukea saamattomien yritysten t&k-työntekijöiden lukumäärä, t&k-intensiteetti tai tuottavuus enemmän kuin muiden t&k-tukea saamattomien yritysten. Emme löytäneet tilastollisesti merkitsevää näyttöä positiivisista ulkoisvaikutuksista tukea saaneista yrityksistä tukea saamattomiin yrityksiin työntekijävirtojen kautta tapahtuvan tiedon ”läikkymisen” kautta.

Tutkimustuloksemme t&k-tukien vaikutuksesta kilpailuun ovat samansuuntaiset kuin aiemmat suomalaisella aineistolla tehdyt löydökset (Koski ja Pajarinen, 2013). Yritysten viivästetty tuottavuus liittyy negatiivisesti ja tilastollisesti merkittävästi niiden todennäköisyyteen poistua markkinoilta viipeillä t-1,...,t-3. Tukea saaneiden yritysten joukossa tuottavuuden lasku ennustaa selvästi heikommin yrityksen markkinoilta poistumista. Tämä tarkoittaa sitä, että t&k-tuet vaikuttavat mahdollisesti haitallisesti kilpailuun. Ne vähentävät tehottomien yritysten poistumista markkinoilta ja hidastavat rakennemuutosta.

Analysoimme erikseen t&k-tukien vaikutusta yritysten markkinoilta poistumisen todennäköisyyteen nuorten, alle 6-vuotiaiden ja vanhempien yritysten joukossa. Vaikutukset ovat samansuuntaiset molemmissa ikäryhmissä, eivätkä ne poikkea tilastollisesti merkittävästi toisistaan. Tulosten perusteella ei voi päätellä, onko sillä, että t&k-tuet auttavat myös nuoria yrityksiä säilymään hengissä kilpailullisesti negatiivisia vaikutuksia, vai tarjoavatko tuet ennemminkin nuorille, tulevaisuudessa korkean tuottavuuden yrityksille mahdollisuuden säilyä hengissä vähän arvonlisää tuottavan alun tutkimus- ja kehitysintensiivisen vaiheen yli.

EXECUTIVE SUMMARY

This report presents an assessment of the impacts of Tekes R&D funding on firm performance regarding input, output and behavioral additivity as well as indirect impacts of R&D subsidies. We use a descriptive analysis and advanced econometric methods to explore both the direct and indirect effects of R&D subsidies. To evaluate the direct impacts of Tekes funding, we empirically explore the following questions: i) Have subsidized firms increased their investments in R&D activities as measured by the firm's R&D intensity and the number of R&D workers (i.e., input additionality) due to Tekes funding? ii) Have subsidized firms improved their economic performance measured by labor productivity (i.e., output additionality) due to Tekes funding?, iii) Indirect impacts of R&D subsidies. Unfortunately, the available statistical data do not allow us to empirically estimate the causal impacts of R&D subsidies either on innovation output or on firms' R&D collaboration with other companies and research organizations (i.e., behavioral additionality).

We use statistics from a business subsidies database combined with data obtained from Business Finland concerning companies that completed Tekes-funded R&D projects from 2010-2014. These data are merged with the following databases of Statistics Finland: the business register of firms that operate in Finland and the databases concerning firms' financial information, R&D activities, and patents. The data are further combined with the Community Innovation Survey (CIS) database. The control group of nonsubsidized firms is formed from firms that had R&D expenditures during at least one of the sample years and that did not obtain any Tekes funding from 2004 to 2018.

To explore direct and indirect effects of Tekes subsidies, we employed a two-stage method with Coarsened Exact Matching (i.e., CEM) followed by estimations of the difference-in-differences (i.e., DID) model.

R&D SUBSIDIES INCREASE FIRMS' R&D INPUTS

We find clear input additionality with respect to R&D job creation and R&D intensity. Our estimations suggest that R&D subsidies increase a firm's R&D intensity for up to eight years and R&D job creation for up to six years after the firm's receipt of an R&D subsidy.

There was a notable increase in R&D employment between the years prior to and after subsidy receipt among the subsidized firms compared to nonsubsidized companies. Tekes subsidies increased firms' R&D job creation by, on average, approximately 16%, or generated approximately 0.8 additional R&D workers. The estimations using the R&D subsidy-intensity measures show that a 1% increase in subsidy amount caused an increase of approximately 1.4% in the number of R&D workers. Our data further indicate that public R&D funding's contribution to R&D job creation tends to last for up to six years after the beginning of R&D funding.

The estimation results suggest that subsidized firms were statistically significantly more R&D-intensive than nonsubsidized firms before the receipt of R&D subsidies. The difference is not statistically significant during the two preceding years. Tekes subsidies generated growth of approximately 30% in firms' R&D intensity, and a 1% increase in the subsidy amount increased the sample firms' R&D intensity by approximately 2.5%. The impact lasted up to eight years after subsidy receipt.

The estimation results do not provide any support for output additionality in terms of labor productivity. The descriptive statistical analysis shows that the firms that obtain Tekes R&D subsidies collaborate more often than nonsubsidized firms with competitors, customers and research institutions. Although our data do not allow us to conclude whether the collaboration patterns differ between subsidized and nonsubsidized firms due to Tekes R&D funding, the wide external collaboration of subsidized companies may potentially provide an advantageous environment for spreading the new knowledge generated in R&D projects.

R&D SUBSIDIES HINDER EXIT OF INEFFICIENT FIRMS

We assessed the indirect effects of R&D subsides by exploring: i) whether there exist positive spillovers via employee flows from Tekes customers to other firms that enhance the performance of the latter (i.e., increasing input or output additionality among nonsubsidized firms and ii) whether the allocation of R&D subsidies affects market dynamics via an influence on firm exit probabilities.

Knowledge and competence generated in organizations are often sticky and tacit, absorbed by and linked to organizations and employees (or organization- and individual-specific). Such knowledge can be transferred, e.g., through interorganizational R&D collaboration or job-switching by employees from one organization to another. It seems credible that persons who are employed by firms that obtain Business Finland's R&D support may, when they switch jobs, take their enhanced capabilities and/or knowledge with them and also improve the performance of the new employer. We estimate a model that sheds light on the question of whether firms that hired new employees from recipients of Tekes R&D subsidies but that did not receive R&D subsidies themselves grew more than other nonsubsidized firms in terms of their R&D intensity, R&D employment and productivity. We do not find any statistically significant spillover effects on any of the dependent variables analyzed.

Our analysis suggests that R&D subsidies enhance the propensity of relatively inefficient companies to stay in business. We find that lagged labor productivity levels are not as strongly negatively related to firm exit among subsidized firms as among other firms. This finding hints that R&D subsidies may hinder the structural change and market exit of less productive firms and may thus have adverse effects on competition. Our empirical findings further show that Tekes R&D funding enhances the survival probabilities of both relatively inefficient incumbents and younger companies (those less than six years old) compared to the survival likelihood of their nonsubsidized counterparts. It is not clear whether such impact implies a distortion of competition among young firms or a positive effect of R&D subsidies enabling the continuation of newly established companies that strongly focus on R&D activities and do not yet generate much value added but that will become high-productivity companies in the future. Our empirical findings concerning market exit may further relate to and be partly explained by the signaling effect of public subsidies found by earlier studies. Tekes R&D funding may increase a firm's propensity to obtain private funding and thus increase its cash flow, which helps it survive through a relatively unproductive period with little value added.

1 INTRODUCTION

This report presents an assessment of the impacts of Tekes R&D funding on firm performance regarding input, output and behavioral additivity as well as indirect impacts of R&D subsidies. We use a descriptive analysis and advanced econometric methods to explore both the direct and indirect effects of R&D subsidies. To evaluate the direct impacts of Tekes funding, we empirically explore the following questions: i) Have subsidized firms increased their investments in R&D activities as measured by the firm's R&D intensity and the number of R&D workers (i.e., input additionality) due to Tekes funding? ii) Have subsidized firms improved their economic performance measured by labor productivity (i.e., output additionality) due to Tekes funding? Unfortunately, the available statistical data do not allow us to empirically estimate the causal impacts of R&D subsidies either on innovation output or on firms' R&D collaboration with other companies and research organizations (i.e., behavioral additionality).

The primary economic rationale for allocating R&D subsidies to firms' innovation activities relates to the presence of externalities. State-of-the-art econometric analyses do not offer much guidance, however, on the estimations of the indirect effects of R&D subsidies. Studying such effects is not straightforward, and those few previous studies that have attempted to explore broader welfare effects of R&D subsidies have built rather elaborate and complex models that are beyond the limits of the work undertaken in this project (see, e.g., Acemoglu et al., 2018). We use two rather narrow approaches to explore the indirect effects of R&D subsidies. First, we empirically analyze whether there exist positive spillovers via employee flows from Tekes customers to other firms that enhance the performance of the latter (i.e., increasing input or output additionality among nonsubsidized firms). Second, we evaluate the impacts of Tekes subsidies on competition: we empirically assess whether the allocation of R&D subsidies affects the structural change or exit probabilities of subsidized and nonsubsidized firms.

Randomized controlled trials would be the optimal way to study whether policy interventions such as R&D subsidies produce the desired outcome. Given the absence of such trials and research data, we use the best state-of-the-art statistical methods and available data to assess the causal impacts of Tekes R&D subsidies. We employ a two-stage method with Coarsened Exact Matching (i.e., CEM) matching followed by estimations of the difference-in-differences (i.e., DID) model. We use various firm-level databases from Statistics Finland combined with data obtained from Business Finland concerning the companies that completed Tekes-funded R&D projects from 2010-2014 (see Section 3 for details of the data).

Section 2 presents a literature survey that sheds light on the major findings of previous empirical studies concerning the impacts of R&D subsidies. Section 3 first describes the various datasets used in the study and explains how the samples used in the reported empirical analysis are generated from these data. It then provides a descriptive analysis of the measures used for input, output, and behavioral additionality. Section 4 discusses the econometric model used in the empirical analysis, i.e., conditional differences-in-differences (CDID) with a CEM weight-generation process. Section 5.1 presents the estimation results of these models for input, output and behavioral additionality. Section 5.2 examines the indirect impacts of R&D subsidies on nonsubsidized firms by econometrically analyzing the presence of spillovers and whether R&D subsidies affect market dynamics via their effect on firm exit probabilities. Section 6 concludes with a discussion.

2 LITERATURE SURVEY

In the following review of the literature, we cover recent academic research on the effects of R&D subsidies by focusing on both international and Finnish research. In the case of international studies, we mainly rely on recently published papers in top academic journals. In the case of Finnish studies, we also draw on the findings of working papers, books, and other reports. The previous literature that analyzes the effects of R&D subsidies is extensive; in this review, we attempt to focus on the studies that utilize innovative study designs and address the issue of causality in plausible ways. The problem of evaluating the treatment effects of policy interventions is indeed complicated because the alternative outcome – what would have happened in the absence of the intervention – cannot be observed. The issue is further complicated by the fact that the potential subsidy applicants are heterogeneous and choose whether to apply for subsidies or not. Addressing this selection problem in a reliable way – in the spirit of randomized experiments that are the gold standard of the treatment evaluation literature – remains the ever-challenging issue.

The key rationales for public R&D subsidies arise from the externalities related to knowledge spillovers and from financial-market imperfections (Hall and Lerner, 2010). According to economic theory, innovation activity is vulnerable to market failures because innovations have similar properties to public goods and because financial constraints may impede innovation activity (Griliches, 1992; Hall and Lerner, 2010). As a result, there is too little innovation activity in the economy, and public intervention could be required to overcome the underinvestment problem.

Based on the earlier literature, we address the effects of R&D subsidies from various points of view, including input and output additionality, economic performance, behavioral additionality, and welfare effects. In the concluding section, we also briefly consider alternative policy instruments other than direct R&D subsidies.

Recently, Ylhäinen et al. (2016) have analyzed the Finnish and international literature on the effects of R&D subsidies. These authors find that overall, the view of the previous literature is more positive than negative, even if the results are somewhat inconsistent and often in the undetermined area of being statistically nonsignificant.

The authors also note that with very few exceptions, the studies address neither the overall success of innovation policy nor some key issues on policymakers' agenda, including determination of the optimal level of support. Therefore, there remains room for further studies that analyze the effectiveness of R&D policy instruments.

INPUT ADDITIONALITY – DO R&D SUBSIDIES INCREASE PRIVATE R&D INVESTMENTS?

Many studies find that R&D subsidies stimulate private R&D investments, while simultaneously, there remains significant heterogeneity in the results. Below, we discuss some of the more recent individual studies and then summarize the findings from the previous literature reviews and meta-analyses.

Bronzini and Iachini (2014) study the effects of an R&D subsidy program implemented in northern Italy. They utilize a regression discontinuity design that exploits the subsidy-assignment mechanism and compares firms just below and just above the threshold score for obtaining subsidies. This quasi-experimental empirical strategy could – under some general assumptions, including the assumption that firms cannot precisely control their scores – result in a study setup where the assignment of treatment approximates randomization. Such a setup could therefore allow for a more robust analysis of the policy effects. Overall, based on their analysis, Bronzini and Iachini (2014) find no significant effects on investment when analyzing the entire sample. However, these authors document that the overall effect masks notable heterogeneity in the program effects; unlike large firms, small firms increased their investments by approximately the same amount as that of the subsidy. The finding that smaller firms respond to R&D subsidies more strongly than larger firms appears to be consistent with earlier evidence (Gonzalez et al., 2005; González and Pazó, 2008; Lach, 2002).

In a study that focuses on Finnish R&D subsidies, Einiö (2014) exploits the geographical variations in government funding and finds that R&D subsidies have positive effects on the R&D investments of treated firms in Finland. In Germany, Hussinger (2008) observes that R&D subsidies have a positive effect on the R&D intensity of subsidized firms and appear to generate new sales as productively as private R&D investments.

The recent literature has also considered the role of the international financial crisis in the effectiveness of R&D subsidies. Hud and Hussinger (2015) study the effects of R&D subsidies on the R&D investments of SMEs in Germany during the financial crisis years. They find that R&D subsidies have a positive overall effect on R&D investments. However, they also observe crowding-out during 2009, the worst year of the crisis. Since the start of economic recovery, the effect of R&D subsidies has been positive and significant but smaller than before the crisis. The crowding-out observed during the crisis years appears to be due to an unwillingness to invest rather than to the countercyclical innovation policy conducted during the crisis period.

A substantial body of previous literature on additionality has specifically analyzed whether public R&D funding complements or crowds out privately financed R&D activity. These individual studies have been summarized in various literature reviews and meta-analyses; some of the more recent of these literature reviews are discussed below.

Zuniga-Vicente et al. (2014) review the previous literature by analyzing the additionality effects of R&D subsidies. They observe notable heterogeneity in the results of earlier studies and cannot explain these findings as being driven by methodological issues alone. The existing empirical results appear to be conflicting and inconclusive; although the studies that support additionality are predominant, other studies indicate negligible effects or substitution instead.

Becker (2015) reviews the earlier literature that analyzes the effects of R&D subsidies on R&D investments. She observes that much of the recent literature appears to be consistent with the prediction that R&D subsidies stimulate private R&D investments. This observation contrasts with earlier studies that suggest that R&D subsidies tend to crowd out private R&D activity.

Dimos and Pugh (2016) provide a meta-regression analysis of the microlevel studies that analyze the input or output additionality of R&D subsidies. They reject the hypothesis that public subsidies crowd out private investments. However, they do not find evidence of significant additionality. They also note that the treatment of firm-specific unobserved heterogeneity is an important factor in explaining the heterogeneous effects observed in the literature.

Notably, although the literature has largely focused on analyzing the additionality effects of R&D subsidies, there are theoretical arguments that suggest that such an approach could result in misleading conclusions in terms of welfare effects. Takalo et al. (2013b) show that additionality may not be observed in projects that have the largest externalities. Therefore, their theoretical analysis suggests that there may not exist an unambiguous relationship between additionality and welfare effects.

OUTPUT ADDITIONALITY – R&D SUBSIDIES AND PATENTED INNOVATION

In addition to the argument related to externalities, a key rationale for R&D subsidies originates from financial-market imperfections that could lead to underinvestment in R&D (Hall and Lerner, 2010). Lerner (1999) suggests that public R&D subsidies could provide a signal to private financiers regarding the quality of the project. Consequently, they could overcome potential financial constraints related to innovation projects that arise due to asymmetric information. This certification hypothesis provides a rationale for public interventions, particularly those targeting young and small firms. Takalo and Tanayama (2010) formalize this idea and provide a theoretical analysis of the interaction between public and private financiers; in the presence of asymmetric information, collateral-poor firms may face financial constraints when there is a nonnegligible proportion of nonviable projects in the economy. These authors show that R&D subsidies could relax problems of asymmetric information. First, the subsidy itself reduces the cost of capital by lowering the need for private capital. Second, the subsidy could provide a signal of project quality to market-based financiers; this, in turn, could reduce the cost of external capital. The authors also predict that the screening conducted by the public agency is more effective when accompanied by subsidy allocation.

Howell (2017) compares new ventures around the award cutoff by using a large-sample regression discontinuity design that allows her to draw conclusions on more confident ground than many other study designs under the general assumption that firms cannot precisely manipulate their ranks at the cutoff. She shows that the early-stage R&D subsidies granted to new ventures in the U.S. almost double the firms' probability of receiving venture capital and have significant positive effects on the citation-weighted patenting of subsidized firms. The positive effects of subsidies are larger for more financially constrained firms. However, the study suggests that these effects are unlikely to be driven by certification. Instead, the paper suggests that the positive effects arise because the subsidies allow the testing of technology prototypes that could not be financed otherwise.

In another paper based on a quasi-experimental analysis, Bronzini and Piselli (2016) use a regression discontinuity design to analyze the effects of an R&D subsidy program on innovation by using a sample of small and medium-sized firms from northern Italy. The authors document that the program had a positive effect on the number of patent applications, particularly those made by smaller firms. They also find that the program helped to increase firms' likelihood of applying for patents, but this effect only occurred among smaller firms.

Azoulay et al. (2019) study the effects of publicly funded R&D on the patenting activity of private pharmaceutical and biotechnical firms. These authors use data that allow them to link grants and private innovations and exploit discontinuities in the grant allocation process for identification of the effects. The findings of the study indicate that public funding has a positive effect on private-sector patenting.

OUTPUT ADDITIONALITY – R&D SUBSIDIES AND ECONOMIC PERFORMANCE

OUTPUT

Hyytinen and Toivanen (2005) find evidence that imperfections in the capital markets impede innovation and growth based on their analysis of small and medium-sized firms from Finland. These authors provide evidence that firms that are more dependent on external finance invest more in R&D and appear to be more growth-oriented when there is more government funding available to them. Autio and Rannikko (2016) study the effects of the NIY program of Tekes, which targets young and innovative growth-oriented firms in Finland. By using difference-in-differences matching that attempts to find a group of similar nontreated control firms based on observable characteristics and controls for fixed unobserved differences between the treated and control firms, they find that the program more than doubled the growth rates of the targeted firms. Howell (2017) documents the positive output effects – not only on patents but also on finance, revenue, survival, and successful exits – of early-stage SBIR awards granted to U.S. high-tech energy startups. The findings indeed suggest that such firms face financial constraints that could have a detrimental effect on their innovation activity. Further evidence on the financial effects is provided by Meuleman and De Maeseneire (2012), who document that R&D subsidies granted to small and medium-sized firms are associated with better access to long-term debt. They suggest that their findings provide evidence of certification; obtaining an R&D subsidy could serve as a positive signal to investors regarding the quality of the firm.

EMPLOYMENT

Several studies have addressed the employment effects of R&D subsidies – in both the Finnish and international contexts. Koski and Pajarinen (2013) study the effects of business subsidies on the employment growth of Finnish firms. These authors find that R&D subsidies in general appear to have a positive contemporaneous effect on the employment growth of subsidized firms but no significant employment effect afterwards. They also find that there is even a negative relation between subsidies and employment growth among newly established firms. Einiö (2014) and Karhunen and Huovari (2015) also find positive employment effects from Tekes subsidies in Finland. Furthermore, Karhunen and Huovari (2015) document that R&D subsidies increase the human-capital level among firms with low-skilled labor. Ali-Yrkkö (2005) finds that public R&D funding has a positive effect on the number of domestic R&D personnel but has no effect on foreign R&D personnel. The study finds no effect on the number of other personnel. However, the analysis does not rule out the possibility that such effects could occur over a longer time interval.

Czarnitzki and Lopes-Bento (2013) document a positive relation between R&D subsidies and employment in Belgium. Colombo et al. (2012) document that selective support schemes have a larger effect on the employment growth of Italian technology-based startups than automatic support schemes, but this effect is observed only if the subsidies are awarded to firms very early in their life. However, the authors also note that such subsidies are rarely provided to young technology-based startups, which casts doubt on the capability of Italian industrial policies to promote the sustainable growth of young high-tech firms. Afcha and Garcia-Quevedo (2016) utilize Spanish data and find that R&D subsidies have a positive effect on the number of R&D employees. They find no contemporaneous effect on the qualification level of R&D personnel but observe a positive effect on Ph.D. recruitment in subsequent years. Hunermund and Czarnitzki (2019) find that, on average, R&D subsidies have no effect on the job creation (or sales growth) of European SMEs. However, the effects are heterogeneous and positive for projects deemed to be of higher quality.

Howell and Brown (2020) utilize a regression discontinuity design to analyze the effects of cash-flow shocks provided by R&D grants on the earnings of employees of small, privately held high-tech firms in the United States. The study provides evidence that R&D grants have a positive effect on the earnings of incumbent employees, for whom the effect increases with tenure. There is also evidence of positive employment and revenue effects, but the findings cannot be fully explained by productivity growth. The study instead suggests that the findings could be explained by backloaded wage contracts adopted by financially constrained firms.

PRODUCTIVITY

Pajarinen and Rouvinen (2014) analyze the effects of Tekes funding on firm-level labor productivity. These authors find no statistically significant positive labor productivity effects from Tekes funding. The authors also emphasize the methodological issues faced by studies that attempt to analyze the effectiveness of public R&D funding; these studies do not measure the actual or stated mission of Tekes. In empirical implementation, firm-level labor productivity often serves as a candidate proxy for the objective of Tekes, but this measure also falls short of the objective of measuring the economy-wide impact. Likewise, the key economic mission of Tekes – generating externalities related to knowledge spillovers – is not generally addressed in statistical analyses.

Karhunen and Huovari (2015) study the effects of R&D subsidies on the labor productivity of Finnish SMEs. They find no evidence of significant and positive labor-productivity effects at the five-year horizon. Instead, they document a negative short-term productivity effect. Koski and Pajarinen (2015) study the labor-productivity effects of business subsidies, including R&D subsidies, by using the data of Finnish firms. They find no significant positive productivity effects over either the short or the long run. Einiö (2014) finds no immediate productivity effects from R&D subsidies in Finland but suggests that there are positive long-term productivity effects. Pajarinen et al. (2016) utilize state-of-the-art coarsened exact matching and analyze the effects of early-stage Tekes funding. They document a positive association between subsidies and labor productivity among young and small subsidized firms compared to control firms. Finally, in another Finnish study, Piekkola (2007) finds that public subsidies increase productivity growth only in small and medium-sized firms and among firms that are close to the productivity frontier of their industry.

There are a limited number of published international studies that have analyzed the productivity effects of R&D subsidies in other countries. Colombo et al. (2011) provide evidence from Italy that selective subsidies have a positive effect on the total factor productivity of firms. They do not find a similar effect from automatic subsidies. Cin et al. (2017) find that R&D subsidies increase the labor productivity of Korean small and medium-sized enterprises. Kaiser and Kuhn (2012) analyze subsidized joint ventures between public research institutions and industry in Denmark and do not find statistically significant effects on either value added or labor productivity. They also note that large firms are overrepresented in the program and call for a rethinking of the support policies based on their observations.

R&D SUBSIDIES AND BEHAVIORAL ADDITIONALITY

Behavioral additionality, in contrast to input and output additionality, refers to changes made to innovation processes inside firms. However, representative econometric studies on this outcome are rather scarce. Czarnitzki et al. (2007) find that the Finnish firms that receive R&D subsidies or that collaborate would increase their R&D spending and patenting by combining subsidies and collaboration. Wanzenböck et al. (2013) consider the various forms of behavioral additionality – project additionality, scale additionality, and cooperation additionality – stimulated by the Austrian R&D funding scheme, and they analyze which firm characteristics are associated with the realization of such forms of additionality. They suggest that R&D-intensive firms are less likely to exhibit behavioral additionality. However, they find that young, small, and technologically specialized firms are more likely to exhibit behavioral additionality.

Based on Spanish data, Busom and Fernández-Ribas (2008) find evidence that R&D subsidies result in behavioral changes in subsidized firms' involvement in R&D partnerships. First, they find that subsidies increase the probability that firms cooperate with public research organizations. Second, they document a positive, albeit smaller, increase in the probability of establishing private partnerships, but this effect is only observed among firms that own intangible assets. Chapman et al. (2018) find evidence from Spain that R&D subsidies stimulate the expansion of subsidized firms' collaboration breadth. The authors also find evidence of heterogeneity in the estimated effects because only approximately half of the treated firms show positive collaboration effects from R&D subsidies. Finally, they suggest that more extensive and more recent collaborations increase R&D subsidies' effect on the breadth of external collaboration.

WELFARE EFFECTS AND EXTERNALITIES

The key justification for R&D subsidies originates from the externalities related to knowledge spillovers. However, such effects are difficult to trace in empirical analyses. Nevertheless, there exist several contributions – in both published and ongoing work – that address or mention the welfare effects of R&D subsidies.

Bloom et al. (2013) construct a framework for analyzing two opposite spillovers that arise from R&D that affect firm performance. The first spillovers are positive *knowledge or technology spillovers* that could benefit other firms that operate in the sector and improve their performance. The second source of spillovers arises from negative *business-stealing effects* from product-market rivals; if such effects dominate technology spillovers, they might reverse the common wisdom that there is underinvestment in R&D in welfare terms. The empirical analysis based on U.S. firms suggests that positive technology spillovers dominate in quantitative terms. These scholars estimate that the social rates of return are (at least) twice as large as private returns. They find that small firms generate smaller social returns because they are likely to operate in technological niches. In this case, if there are a few other firms in a similar field, the resulting spillovers are more limited in nature. This observation also challenges the common policy approach of subsidizing smaller firms, even if the rationale based on financial-market imperfections suggests the opposite.

Takalo et al. (2013a) study the welfare effects of R&D subsidies by using a structural model and project-level data from Finland. Their analysis framework models the subsidy application and R&D investment decisions of the firms and the subsidy decisions of the government. According to their estimates, the expected benefits of R&D subsidies are very heterogeneous. They also document that the estimated application costs are low on average. The estimates of the paper suggest that the social rate of return of targeted subsidies varies between 30% and 50%. Furthermore, the social returns appear to exceed the shadow cost of public funds –i.e., the loss caused to society by the distortion that arises from raising funds through taxation – based on typical estimates used in the literature. Regardless, the spillover effects of public subsidies remain smaller than the effects on private profits; firms capture approximately 60% of the total effect.

Takalo et al. (2017) construct a more complete structural model that considers externalities, financial market imperfections and limited R&D participation and provide a welfare analysis of R&D policies by using project-level data from Finland. They find that both tax credits and subsidies increase R&D investments compared to the state of the world where such policies are absent (*laissez-faire*). However, the policies do not significantly improve welfare in the end after the shadow cost of public funds is considered.

Akcigit et al. (2018) analyze the effects of innovation and trade policy on economic growth and welfare. They theoretically show that the effect of globalization – in the form of reduced trade barriers – is ambiguously related to welfare in a static analysis, whereas a dynamic analysis indicates that globalization increases innovation due to international competition. The empirical implementation of the framework, in the context of the U.S., indicates that R&D subsidies are an efficient policy response to international competition and generate positive long-term welfare effects. However, according to the model, there is less need for government intervention in a more globalized world because international competition stimulates innovation.

Acemoglu et al. (2018) construct a general equilibrium model to study the effects of industrial policies on long-term growth and welfare. The model emphasizes the selection between high- and low-productivity firms, which differ from each other in terms of innovation capacity. The empirical implementation of the model utilizes microdata from the United States. The results of the study indicate that the optimal policy action is to encourage the exit of low-productivity firms and free up skilled labor for the R&D activities of high-productivity firms. This objective cannot be achieved by granting R&D subsidies to incumbents because such activities encourage the survival and expansion of low-productivity firms in addition to high-productivity firms.

DIFFERENT POLICY INSTRUMENTS, SAME EFFECTS?

In many countries, R&D tax credits serve as an alternative policy instrument for direct R&D subsidies, and they have grown increasingly popular in OECD countries but are not currently utilized in Finland. Kuusi et al. (2016) analyze the R&D tax credit scheme that Finland briefly experimented with from 2013-2014. The scheme allowed firms to deduct double the amount of R&D salary payments from their corporate taxation. The empirical analysis indicates that the scheme failed to achieve the expected impact, but the paper also emphasizes numerous shortcomings in the design. First, firms utilized the scheme less than expected. Second, the tax credit did not cover the 'blind spots' of direct R&D subsidies; the participating firms were larger, older, as well as more profitable, solvent, and productive than the firms that obtained direct R&D subsidies. Moreover, most of the participating firms had obtained other subsidies in previous years, and many of them had obtained Tekes subsidies. Third, the tax credits may have had positive effects on firms, but the effect was not large or statistically significant. Fourth, the firms that obtained both Tekes subsidies and tax credits preferred Tekes subsidies. Fifth, it appeared that many firms were not informed of the scheme. Sixth, the planning of the scheme was insufficient; the resources and duration given for the scheme did not serve the objective of achieving significant economic growth. Furthermore, the design of the scheme was also insufficient from an empirical point of view and did not result in robust comparison groups for an empirical impact analysis. Seventh, the short length of the experiment and the uncertainty around the eligibility for support probably made firms less likely to participate in the scheme. Finally, the treatment of losses did not provide incentives for loss-making firms to participate in the scheme; this could be an issue for growth firms that have yet to become profitable.

Becker (2015) reviews the international literature on R&D tax credits and observes that more recent studies often find positive effects of such credits on R&D investments. Castellacci and Lie (2015) provide a meta-regression analysis of the international microeconometric R&D tax-credit literature. The analysis considers the effects of R&D tax credits on firms' innovation activities, with a particular focus on the sectoral differences in the effects of such incentives. The sectoral dimension indeed appears to matter. The meta-analysis suggests that the additionality effects appear to be larger for small and medium-sized firms and firms in the service and low-tech sectors. Taken together, the findings of the meta-analysis indicate that R&D tax credits benefit firms that have low R&D intensity more than they benefit firms with high R&D intensity in technologically advanced sectors. Thus, R&D tax credits appear to be more beneficial for helping with the catching-up process of laggard firms than for further advancing the boundaries of the technological frontier.

As noted by Ylhäinen et al. (2016), the findings from the Finnish R&D tax-credit experiment suggest that a more efficient implementation of the scheme would probably require the implementation of characteristics similar to those from the direct-subsidy schemes. Furthermore, they note that the different institutional environment in Finland from the context of international studies makes it difficult to see the additional benefits provided by R&D tax-credit schemes over direct subsidies in Finland; running two parallel systems would increase the risk of creating overlapping systems that only appear to be separate.

The literature provides limited guidance on the differences between the effects of loans and subsidies. Among the few studies that have addressed this issue, Huergo and Moreno (2017) study the effects of low interest-rate loans and subsidies for Spanish firms' R&D activities. They find that any type of public support increases the probability of conducting R&D. The largest effect comes from EU subsidies, which provide an effect that is more than three times larger than the effect of loans. However, further evidence is needed.

Finally, regarding the financing of innovation, the importance of well-functioning financial markets and a competitive business environment remains a point worth considering. Although venture capital alone may not be a panacea for spurring innovation, it appears to be more efficient in this regard in countries that have adopted a more favorable tax and regulatory environment for venture-capital investments and lower taxes on capital gains (Popov and Roosenboom, 2012). For the interaction between public and private financiers, the existing evidence suggests that the relationship between Tekes and venture capitalists is a symbiotic one: Tekes typically operates in earlier stages than private venture capitalists and could provide 'feeding traffic' to them, while its role is more limited in the context of buyout investors (Pajarinen et al., 2016).

3 DATA AND DESCRIPTIVE FINDINGS

3.1 DATA DESCRIPTION

We use statistics from a business subsidies database[1] combined with data obtained from Business Finland concerning companies that completed Tekes-funded R&D projects from 2010-2014. These data are merged with the following databases of Statistics Finland: the business register of firms that operate in Finland and the databases concerning firms' financial information, R&D activities, and patents. The data are further combined with the Community Innovation Surveys (CIS) from 2010-2012, 2012-2014 and 2014-2016. The idea is to use these data to explore whether Tekes-funded R&D projects impact subsidized firms' performance in terms of input, output, and behavioral additionality.

The treatment group of subsidized firms comprises firms that have at least one Tekes-funded R&D project completed from 2010-2014 and that did not obtain any R&D funding from Tekes during 2004-2009[2]. The firms that obtained "de minimis" subsidies are only included if the subsidy received for a completed project is over 30,000 euros since smaller subsidies are, by and large, used for planning and feasibility studies of R&D projects and do not represent actual R&D subsidies (see Koski and Pajarinen, 2015). Furthermore, firms that only received subsidies targeted to young innovation companies (NIY) are not included, as is recommended in the supplementary information sheet for the notification of an evaluation plan. We only include subsidized young innovative companies in the sample if they also obtained other Tekes R&D subsidies.

As previously reported empirical research observes (see, e.g., Koski and Pajarinen, 2015), firms with R&D activities differ from non-R&D firms in their performance. Therefore, the control group of R&D-active Tekes-funded companies needs to be constructed accordingly. The

1 See Statistics Finland (http://www.stat.fi/meta/til/yrtt_en.html) for detailed information on the business subsidies database.

2 The Tekes R&D funding comprised R&D grants and loans. Tekes loans were provided on advantageous terms (e.g., with lower interest rate) compared to those of private lenders and thus incorporated a subsidy element. It is not possible to accurately calculate the monetary value of public subsidies included in R&D loans. In the estimations involving the Tekes subsidy intensity, R&D subsidies include both grants and loans.

control group of nonsubsidized firms is formed from firms that had R&D expenditures during at least one of the sample years. We believe that this variable is a sufficiently good proxy for firms that undertake R&D. Optimally, the control group would comprise companies that applied for R&D subsidies but did not obtain them. Such a data restriction would, however, leave a very limited group of firms in the sample.[3] Furthermore, a great number of Finnish companies that engage in innovative activities obtain Tekes R&D subsidies at some point in their lifetime. We restrict the control group to companies that did not obtain any Tekes funding from 2004 to 2018.

For the calculation of the descriptive statistics, we follow a similar approach to that in the main empirical analysis and split our sample of firms into a treated and a control group. However, the way we define a firm as treated is static; i.e., if a firm has completed a Tekes-funded project between 2010 and 2014, we consider it as treated for the whole sample period (which runs from 2008 to 2017). Moreover, the sample changes slightly depending on the type of descriptive statistics we are interested in due to the different data sources considered. It is important to note that the descriptive statistics we present should not be interpreted as representative of the population of Finnish firms but rather as a preliminary analysis of how the companies in the treated group are different from those in the control group.

3.2 DESCRIPTIVE FINDINGS

We structure this section based on the different phases of the R&D process. We first look at R&D inputs, in particular R&D intensity (i.e., the ratio of R&D expenses to turnover) and the number of R&D jobs created by treated vs. control firms. We then consider R&D outputs, which include the propensity of the firms to innovate and the share of firms that have been granted patents by either the Finnish or European patent authorities. Finally, we look at some industry-level descriptive statistics that cover R&D intensity, the propensity to innovate and measures of competitiveness such as return on investment (ROI) and labor productivity.

3.2.1 R&D INPUTS

We start by looking at how firms in the treated group differ from those in the control group in terms of R&D inputs, specifically their R&D intensity and the propensity to create R&D jobs. Our main data source for this part is the R&D panel of Statistics Finland, a collection of

[3] After the CEM matching, the total number of matched treated and nontreated firms would amount to well below one hundred firms annually (e.g., 55 firms for the year 2010 treatment).

surveys in which firms are followed over time in several waves, allowing us to track aspects such as job creation. The data are available from 2008 until 2017.

The first descriptive statistic we present is R&D intensity, i.e., the ratio of R&D expenses to turnover (both in 2010 prices). We make some further adjustments to the original dataset; in particular, we remove firms with less than 50000 euros of turnover (because firms with very low turnover tend to show very high R&D intensities, which may affect the averages), and we winsorize outlier observations (specifically, observations that are larger, in absolute value, than the average R&D intensity plus twice the standard deviation, where the average and standard deviations are computed by groups). We report the descriptive results concerning R&D intensity in Table 1, where we also include the statistical significance of the t-test for the difference in means between the two groups in the last column of the table as well as the average number of firms included in the groups.

TABLE 1. Average of the share of turnover used in R&D spending; the results are in percentage points. Statistical significance obtained by the t-test for the difference in means is reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

YEAR	TREATED (%)	CONTROL (%)	STATISTICAL SIGNIFICANCE
2008	18	15	*
2009	21	12	***
2010	22	12	***
2011	22	11	***
2012	19	12	***
2013	25	11	***
2014	22	12	***
2015	21	13	***
2016	19	14	***
2017	20	18	
Avg. n. obs.	872	1005	

The results in Table 1 indicate that there is a meaningful and usually statistically significant difference in terms of R&D intensity between the treated and control groups. In particular, we find the average R&D intensity of the treated firms hovering around 20%, while for the control group, we find that R&D expenditures in relation to company turnover are lower (between 11 and 15%). Interestingly, the difference is smaller for the latest available year, but this could reflect one atypical observation rather than a persistent trend.

Next, in Table 2, we report some descriptive statistics regarding job creation. First, we report the (gross) total number of R&D jobs created by treated and control firms. To compute this measure, we consider individual firms over two consecutive years and look at the positive changes in R&D jobs for each firm. Summing the latter, we obtain the gross job creation for each year and group. This approach leads us to omit job creation stemming from entrant firms and to focus on job creation due to existing firms growing in size. In addition, we compute

TABLE 2. Gross jobs created and share of job creators for treated and control firms. Statistical significance obtained by the t-test for the difference in means reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

	JOBS CREATED		SHARE OF JOB CREATORS (%)		STATISTICAL SIGNIFICANCE
YEAR	TREATED	CONTROL	TREATED	CONTROL	
2009	1183	808	28	20	***
2010	1436	771	23	22	
2011	1760	785	28	23	***
2012	1995	922	26	20	***
2013	2095	1048	25	21	**
2014	1923	922	30	20	***
2015	1639	1007	27	18	***
2016	1773	876	30	20	***
2017	1746	975	34	24	***
Avg. n. obs.	944	1105	944	1105	

the share of job creators (i.e., firms that have created at least one R&D job between two years) for the treated and control groups. For this last measure, we further report the statistical significance of the t-test for the difference in means.

As in the case of R&D intensity, we find that treated firms tend to have higher R&D inputs, in this case R&D jobs. Firms in the treated group tend to hire more workers for R&D positions, and there is a higher proportion of firms that have created R&D jobs in the treated group for all the years considered in the sample.

3.2.2 R&D OUTPUTS

We now turn to the description of some R&D output measures. In particular, we report the proportion of firms innovating in either services, products or processes, as well as the number of patents granted. Moreover, we examine how the behavior of subsidized and nonsubsidized companies differs in terms of R&D collaboration between competitors and other external entities. The results reported in this subsection are obtained by analyzing the CIS conducted by Statistics Finland for 2010-2012, 2012-2014 and 2014-2016. The patent data are available from 2008 to 2013 and include the patents granted in Finland and the patents granted to Finnish enterprises by the European Patent Office.

We start by reporting the proportion of firms that have made product, service or process innovations for the treated and control groups in Table 3. Note that merging our original dataset with the CIS leads us to drop quite a few firms from the data, so we should expect fewer observations for the computation of these statistics. The statistical significance of the t-test for the difference in means is reported in parentheses.

TABLE 3. Proportion of firms making a product, service, or process innovation; the results are in percentages. Statistical significance obtained by the t-test for the difference in means reported in parentheses, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

2010-2012	NEW PRODUCTS (%)	NEW SERVICES (%)	NEW PROCESSES (%)	N. OBS
Treated	57	42 (**)	43 (*)	377
Control	56	34	37	309
2012-2014				
Treated	56	45 (**)	43	361
Control	54	35	42	358
2014-2016				
Treated	59	47	49	384
Control	63	44	46	311

TABLE 4. Proportion of firms collaborating with competitors, customers, or research institutions; the results are in percentages. Statistical significance obtained by the t-test for the difference in means reported in parentheses, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

2010-2012	COLLAB. WITH COMP.	COLLAB. WITH CUST.	COLLAB. WITH RESEARCH INST.	N. OBS.
Treated	44 (**)	52 (***)	53 (***)	377
Control	35	42	41	309
2012-2014				
Treated	35 (**)	48	51 (***)	361
Control	28	43	37	358
2014-2016				
Treated	32	42	48	384
Control	33	46	45	311

Table 3 gives us several insights. First, there does not seem to be a large shift between innovation activity in the period from 2010 to 2012 and the period from 2012 to 2014, while innovation propensities are slightly higher in 2014-2016. A second point is that the propensity to innovate is fairly similar between the treated and control groups, at least when we consider product innovations, where in the latest period, control firms show a higher propensity to create new products. However, the difference between the two groups is never statistically significant. For services, the propensity to innovate is markedly higher for treated firms, at least during the first two CIS waves, while the difference is statistically nonsignificant for the latest survey. The group of treated firms seems to include a significantly (albeit only at the 10% level) larger proportion of companies innovating new processes than that of the control group, while the two groups present very similar propensities to innovate in the data from the last two surveys.

We now turn to the description of how much subsidized and nonsubsidized firms differ in terms of collaborating with competitors, customers, and research institutions to conduct R&D. Again, the main data sources for this information are the CIS waves for 2010-2012, 2012-2014 and 2014-2016, and the results are presented in Table 4. As before, the statistical significance of the difference in means is reported in parentheses.

For the periods 2010-2012 and 2012-2014, treated firms display a much higher propensity to collaborate with external entities such as competitors or universities, while for the latest period, we do not find a significant difference between treated and control firms. When we examine the propensity to collaborate with customers, treated firms seem to collaborate significantly more than those in the control group in the data from the first CIS. Another aspect worth highlighting is that there is a remarkably higher propensity to collaborate with customers, research institutions and universities rather than with competitors. This consideration holds for both groups of firms.

TABLE 5. Number of patents granted and proportion of firms granted at least one patent by the Finnish or European patent authorities. Statistical significance obtained by the t-test for the difference in means reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

	NUMBER OF PATENTS		SHARE GRANTED A PATENT (%)		
YEAR	TREATED	CONTROL	TREATED	CONTROL	STATISTICAL SIGNIFICANCE
2008	1193	171	8.5	7.5	
2009	1025	173	8.3	7.5	
2010	1109	135	7.4	5.9	*
2011	993	139	6.7	6.6	
2012	1014	143	6.7	6.3	
2013	970	60	6.7	3.4	***
Avg. n. obs.	2011	1070	2011	1070	

To conclude our description of R&D outputs, we show in Table 5 the number of patents granted by the Finnish and European patent authorities to the firms in our sample as well as the share of firms that were granted at least one patent. Our figures include the patents granted by the Finnish Patent and Registration Office and by the European Patent Office. For the share of firms that have been granted a patent, we compute a t-test for the difference in means and report the statistical significance in the last column.

First, we need to highlight that our sample contains more treated firms than control firms, but this does not explain the large difference in granted patents between the two groups. Specifically, we find that companies in the treated group have many more patents granted by the authorities considered here. Moreover, we see that the proportion of firms granted at least one patent is very similar for both treated and control firms, differing significantly only in 2013, which implies that treated firms tend to be granted many more patents per firm compared to the control group.

3.2.3 COMPETITIVENESS AND INDUSTRY-LEVEL ANALYSIS

We conclude our descriptive analysis by examining how treated and control firms from the same industry differ in terms of their R&D inputs, outputs, and financial position. We group the firms into seven industries by using the TOL 2008 classification and the Eurostat definition of high- and low-tech industries. We start by looking at the R&D inputs, specifically by examining the average R&D intensity. The data are cleaned in a similar fashion to the method discussed in Section 3.2.1, and the results, reported in Table 6, are averaged over the years from 2008 to 2017.

As we can see in Table 6, treated enterprises have a higher R&D spending-to-turnover ratio for each industry examined, although the difference is particularly strong for high-tech industries, while it is smaller for medium- and low-tech manufacturing. For all industries, the difference is statistically significant. The results here confirm the observation we gathered in Table 1, i.e., that treated firms tend to have higher R&D inputs in their production process.

To measure how R&D output changes based on the Tekes subsidy and industry, we rely again on the Innovation Surveys of Statistics Finland from 2010-2012, 2012-2014 and 2014-2016, where we average the results over

TABLE 6. Average R&D intensity (in percentage) by industry. The results are computed by averaging over the years from 2008-2017. Statistical significance obtained by the t-test for the difference in means reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

INDUSTRY	R&D INTENSITY (%): TREATED	R&D INTENSITY (%): CONTROL	STATISTICAL SIGNIFICANCE
High-Tech Manufacturing	21	18	**
Medium High-Tech Man.	10	6	***
Medium Low-Tech Man.	4	3	***
Low-Tech Man.	5	2	***
Knowledge-Intensive Serv.	34	27	***
Other Services	12	6	***
Other Industries	6	5	

TABLE 7. Share of firms making product, service, or process innovations (in percentages) by industry. Statistical significance obtained by the t-test for the difference in means reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

INDUSTRY	SHARE INNOVATING NEW PRODUCTS (%)		
	TREATED	CONTROL	STATISTICAL SIGNIFICANCE
High-Tech Manufacturing	91	61	***
Medium High-Tech Man.	79	75	
Medium Low-Tech Man.	62	67	
Low-Tech Man.	62	72	*
Knowledge-Intensive Serv.	34	28	*
Other Services	40	61	**
Other Industries	46	17	**
	SHARE INNOVATING NEW SERVICES (%)		
High-Tech Manufacturing	42	32	
Medium High-Tech Man.	36	27	**
Medium Low-Tech Man.	28	27	
Low-Tech Man.	28	25	
Knowledge-Intensive Serv.	62	69	
Other Services	48	38	
Other Industries	56	41	
	SHARE INNOVATING NEW PROCESSES (%)		
High-Tech Manufacturing	51	39	
Medium High-Tech Man.	51	44	
Medium Low-Tech Man.	55	50	
Low-Tech Man.	47	45	
Knowledge-Intensive Serv.	37	39	
Other Services	26	26	
Other Industries	51	27	***

the three waves. In Table 7, we report the share of firms that have made either a product, service, or process innovation.

Table 7 indicates that treated firms do not show a systematically higher propensity to innovate than the control enterprises once we take into account the industry of operation. First, we find an inconsistency in terms of the industries considered, where we see that treated firms tend to engage in more product innovation in the high-tech manufacturing industry, while the difference becomes nonsignificant in the medium and low-tech manufacturing industries; indeed, we find that in the latter industries, companies in the control group innovate more. Moreover, we observe a different pattern when examining innovation to services and processes, where the differences between the two groups are rarely significant.

Finally, we examine how the treated and control firms differ in terms of two competitiveness indicators, i.e., their average return on investment (ROI) and their labor productivity, where both measures are at 2010 prices. As before, we separate firms by their industry of operation and average the results over the years 2008-2017. Moreover, as we did when looking at R&D intensity, we remove firms with turnover below 50000 euros and winsorize outliers.

TABLE 8. ROI (reported in percentages) and labor productivity for control and treated firms, by industry. The results are averaged over the years 2008-2017. Statistical significance obtained by the t-test for the difference in means reported in the last column, where *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels.

INDUSTRY	ROI (%)		
	TREATED	CONTROL	STATISTICAL SIGNIFICANCE
High-Tech Manufacturing	-7.28	3.63	***
Medium High-Tech Man.	-18.7	-9.93	***
Medium Low-Tech Man.	6.47	12.14	**
Low-Tech Man.	-0.63	6.57	**
Knowledge-Intensive Serv.	-49.72	23.21	***
Other Services	1.22	10.21	***
Other Industries	7.77	7.99	
LABOR PRODUCTIVITY			
High-Tech Manufacturing	58987	76735	***
Medium High-Tech Man.	58727	71889	***
Medium Low-Tech Man.	55471	65102	***
Low-Tech Man.	53561	65796	***
Knowledge-Intensive Serv.	49403	62851	***
Other Services	52289	70314	***
Other Industries	69558	143467	***
Avg. n. obs.	2627	1482	***

From Table 8, we see that firms in the treated group display significantly lower ROI and labor productivity. This holds for all industries considered, and even though we do not report the results, we have verified that this difference is not due to the inclusion of the Great Recession of 2008-2009 in the data.

The descriptive evidence reported in this section highlights some remarkable differences between treated and control firms, even though the way the companies differ depends on the part of the R&D process examined. In terms of R&D inputs, we have seen that firms in the treated group tend to have a significantly higher R&D intensity and create more R&D jobs, while we do not find such strong differences when examining patenting behavior and innovation propensities. Finally, we have found that firms in the control group have significantly higher ROI and labor productivity. While this final result might be surprising, it may be due to the fact that firms in the treated group invest more in R&D and that the positive effects of investments might appear with a longer lag than the horizon that we can observe with this simple analysis.

4 METHODOLOGY AND EMPIRICAL MODELING

The descriptive statistical measures presented above illustrate the performance differences between the groups of subsidized and nonsubsidized firms. However, these statistical measures cannot be used to draw conclusions regarding the impacts of subsidies. Because subsidies are not usually randomly distributed and since we never observe the treated firm's outcome without treatment, we need to develop a statistical model to find an answer to a counterfactual question: what would have happened to the subsidized firms without R&D subsidies? In addition, we also need the statistical model to address potential selection bias. It is possible that the firms that obtained R&D subsidies would perform differently from nonsubsidized firms even without the receipt of R&D subsidies.

Our empirical analysis relies on a two-stage CDID estimation method. It evaluates the performance of firms before and after they completed Tekes-subsidized R&D projects compared to the performance of firms that did not complete any Tekes-funded R&D projects during the sample years (see, e.g., Imbens and Wooldridge, 2009). A project is defined to be completed when a firm has submitted the final report of the project to Tekes.

In the first stage, we performed matching analysis by using the CEM method developed by Iacus, King and Porro (2011, 2012) for each cohort (i.e., for the first year of subsidy of those firms that ended their Tekes-funded project during 2010-2014) with respect to our firm population.[4] For the exact matching analysis, the data were temporarily coarsened into discrete strata within which exact matching was performed. The variables used in the matching analysis to form the strata are firm size (measured by employment), firm age, the share of R&D

[4] As Iacus, King and Porro (2011, 2012) argue, the CEM method reduces the degree of model dependence and causal-effect estimation error resulting from ex ante user choice. The nonparametric CEM procedure has monotonic imbalance bounding, so that reducing the maximum imbalance on one variable has no effect on the other variables. It does not require a separate procedure to restrict the data to a common subsidy, is approximately invariant to measurement error, and balances nonlinearities and interactions in the data.

workers, capital intensity (fixed assets/employment) and industry (13 dummy variables).[5] The idea is to find control units that are similar or close to the subsidized companies with respect to background characteristics. The CEM stage produces weights that always have the value of 1 for subsidized firms. The weight for each nonsubsidized firm is calculated as the product of the total number of nonsubsidized firms in relation to the total number of subsidized firms (that have completed their Tekes-funded R&D project) in the sample and the number of the subsidized firms in relation to the number of nonsubsidized firms in the firm's stratum (i.e., group in which the firms are similar with respect to the selected coarsened observable characteristics). The CEM weights are utilized in the second stage, in which we perform a difference-in-differences analysis on the outcome variables.

The second-stage difference-in-differences estimation eliminates potential bias arising from the permanent (or non-time-varying) differences between the firms that received R&D subsidies and nonsubsidized firms and the aggregate factors that would affect the performance measure in question even in the absence of subsidies.

The estimated differences-in-differences model can be presented as follows (see also Aghion et al., 2018):

$$
\begin{aligned}
\ln(Y_{it}) = \alpha_i + & \sum_{\tau=-3,\ldots,11} \delta_\tau \, treated_i \, x1[\tau = t] + \\
& \sum_{\tau=-3,\ldots,11} \alpha_\tau 1[\tau = t] + \\
& \sum_{y=2005,\ldots,2018} \alpha_{year} 1[y = year] + \\
& \sum_j \beta_j C_{it} + \varepsilon_{it}
\end{aligned}
$$

where subscript i stands for the firm, the treatment time (or the first year that the firm that completed a Tekes-funded R&D project between 2010-2014 obtained Tekes funding) is denoted by t, and y is the calendar year. Vector C represents the control variables (described below) that are specific to each equation for input, output and behavioral additionality. We employed a fixed-effects model and clustered the standard errors at the firm level in all estimated equations.

5 Originally, we aimed to use the explanatory variables of each equation for the matching, but this approach produced too few matched observations. Consequently, we settled for this restricted set of background variables in the matching stage.

The advantage of the estimated model over a standard difference-in-differences model is that it controls for both the treatment years and the calendar years. Furthermore, a standard difference-in-differences specification cannot detect whether the treated firms differed from the non-treated firms with respect to the dependent variable prior to the treatment, as the fixed-effects estimations drop the treatment dummy variable due to collinearity.

We estimated the model first by employing two approaches. We constrained the treatment effect to be constant before (i.e., $\delta_\tau=\delta_{pre}$, for t=-3,...,1) and after (i.e., $\delta_\tau=\delta_{post}$, for t=0,...,11) the year the firm obtained R&D funding from Tekes. The estimated coefficients δ_{pre} and δ_{post} indicate the average difference in the dependent variable of treated and non-treated firms the years prior to and after, respectively, the treated firms began their Tekes-funded R&D project(s). We also estimated an alternative model resembling a more standard difference-in-differences approach; i.e., the estimations were undertaken without a constant pre-treatment effect.

Second, to take into consideration variation in the size of R&D subsidies, we estimated another alternative model in which the post treatment dummy variable was replaced by the intensity of R&D subsidies obtained by a firm. Here, we also measured a firm's cumulative R&D subsidy intensity after 2014, as R&D subsidy receipt is characterized by continuity, and some firms that had finished their Tekes-funded projects during 2010-2014 obtained further R&D subsidies for different projects during the subsequent years. Again, we estimated two variations of the model, one constraining the treatment effect to be constant before and after the 2010-2014 finished projects and the other without a constant pre-treatment effect.

Third, we removed the constant pre-/post-treatment constraint and estimated the treatment effect for the pre- and post-treatment years separately. The coefficients δ_τ (for t=-3,...,11) provide information on the annual differences in the performance measures of interest between the treated and non-treated firms. These estimations shed further light on the dynamics through which R&D subsidies affect input, output and behavioral additionality (e.g., in relation to the time lag and persistence of the observed effects).

5 EMPIRICAL FINDINGS

We report here the CEM-weighted estimation results of the CDID model for the equations that capture input, output and behavioral additionality. We use a fixed-effects panel data model for the estimations. The literature does not provide a single indisputable set of explanatory variables for any of these equations. Often, in the previously reported empirical studies, the availability of data strongly affects the choice of control variables. There are, however, some commonly accepted factors that arise from theory and prior empirical studies. We use prior studies published in international peer-reviewed journals to guide the choice of the set of explanatory variables for each equation.

5.1 DIRECT IMPACTS: INPUT, OUTPUT AND BEHAVIORAL ADDITIONALITY

5.1.1 INPUT ADDITIONALITY

We evaluate input additionality for a firm's R&D job creation and its R&D expenditures (minus potential R&D subsidies) relative to sales (i.e., R&D intensity). Because our R&D intensity measure comprises a firm's own investments in R&D activities excluding obtained R&D subsidies, we can use treatment dummies to capture the input additionality effect; i.e., it is not necessary to include R&D subsidy intensity as an explanatory variable. However, we also estimate an alternative model in which the post subsidy treatment dummy is multiplied by the cumulative amount of post-period R&D subsidies.

We construct the R&D job-creation equation following the empirical work of Koski and Pajarinen (2013). The set of explanatory variables includes firm size (i.e., the log of firm turnover deflated by the 2-digit industry-level production price index), R&D intensity (i.e., R&D expenditures divided by sales), dummy variables for foreign- and government-owned firms as well as for firms legally structured as groups, firm age (i.e., log number of years since the establishment of the firm), profitability (i.e., return on investment), and financial strength (i.e., equity ratio).[6] We further control for time-, industry- and location-specific variation in the firm's employment

[6] See Koski and Pajarinen (2013) for a detailed discussion on the underlying reasons for the choice of these explanatory variables.

growth with the dummy variables. The year dummies, 19 industry dummies, and 5 regional dummies are added to all estimated equations. We also include a dummy variable to control for R&D expenditure observations having a value of zero.

Becker's (2013) survey article concerning the determinants of a firm's R&D investments concludes that recent empirical literature strongly suggests that the factors that capture internal finance, particularly cash flow and sales, are positively related to a firm's R&D expenditures. We measure a firm's financial performance by its return on investment, equity ratio (i.e., total equity divided by total assets), and log of sales. Furthermore, we control for a firm's age and ownership structure – as well as time, industry, and region – similar to the above R&D job-creation equation.

Tables 9a and 9b present the estimation results of the CDID model for R&D job creation. The model is estimated first with a standard difference-in-differences model and then restricting the treatment effects to be constant three years before and (a maximum of) 11 years after a firm's receipt of the R&D subsidy (i.e., Table 9a) and further, after relaxing this restriction, for the annual pre- and post-treatment effects (i.e., Table 9b). Moreover, in Table 9a, we also report the results of "intensity" estimations in which the post subsidy treatment dummy is multiplied by the cumulative amount of post-period R&D subsidies. The estimation sample comprises 1031 companies, of which 347 are treated (i.e., received R&D subsidies) and 684 are non-treated (i.e., nonsubsidized companies).

The estimated coefficients of the PRE dummy variables suggest that subsidized firms did not generate statistically significantly more R&D jobs than nonsubsidized firms prior to the receipt of R&D subsidies. The estimated POST dummies and intensity variables display statistically significant coefficients, suggesting that there was a clear increase in R&D employment between the years prior to and after subsidy receipt among the subsidized firms compared to nonsubsidized companies. Tekes subsidies increased firms' R&D job creation by, on average, approximately 16%, or generated approximately 0.8 additional R&D workers. The estimations using the R&D subsidy-intensity measures show that a 1% increase in subsidy amount caused an increase of approximately 1.4% in the number of R&D workers. Our data further indicate that public R&D funding's contribution to R&D job creation tends to last for up to six years after the beginning of R&D funding (Table 9b).

TABLE 9a. Estimation results of the conditional differences-in-differences model with CEM weights for R&D job creation.

	LHS = LOG(COUNT OF R&D WORKERS) PRE & POST: DUMMIES				PRE & POST: INTENSITY			
	(1) BASIC		(2) PRE-POST		(3) BASIC		(4) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE			0.018	0.058			0.043	0.061
POST	0.159***	0.043	0.171***	0.059	0.014***	0.004	0.016***	0.005
Wald test for POST - PRE			10.542***				0.223	
Mean value of lhs of the treated group in the treatment year: 0.669								
Industries	Yes		Yes		Yes		Yes	
Regions	Yes		Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes		Yes	
Other controls	Yes		Yes		Yes		Yes	
Observations	7294		7294		7294		7294	
Firms	1031		1031		1031		1031	
R2 (within)	0.981		0.981		0.981		0.981	

TABLE 9b. Estimation results of the conditional differences-in-differences model with CEM weights for R&D job creation.

	LHS = LOG(COUNT OF R&D WORKERS) PRE & POST: DUMMIES			
	(1) BASIC		(2) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE_3			0.045	0.068
PRE_2			-0.051	0.071
PRE_1			0.035	0.067
POST_0	0.108**	0.047	0.115*	0.065
POST_1	0.252***	0.059	0.259***	0.074
POST_2	0.283***	0.064	0.289***	0.077
POST_3	0.201***	0.062	0.208***	0.073
POST_4	0.191***	0.063	0.197***	0.075
POST_5	0.188***	0.068	0.195**	0.077
POST_6	0.175**	0.073	0.182**	0.082
POST_7	-0.053	0.075	-0.046	0.085
POST_8	0.002	0.086	0.008	0.091
POST_9	-0.121	0.114	-0.114	0.118
POST_10	-0.117	0.138	-0.110	0.138
POST_11	-0.052	0.195	-0.046	0.197
Mean value of lhs of the treated group in the treatment year: 0.669				
Industries	Yes		Yes	
Region	Yes		Yes	
Calendar years	Yes		Yes	
Treatment years	Yes		Yes	
Other controls	Yes		Yes	
Observations	7294		7294	
Firms	1031		1031	
R2 (within)	0.981		0.981	

The estimation results of Table 10a suggest that subsidized firms were statistically significantly more R&D-intensive than nonsubsidized firms before the receipt of R&D subsidies. Table 10b indicates that the R&D intensity of Tekes subsidy recipients was over 40% higher than that of nonsubsidized firms one year prior to Tekes subsidy receipt. The difference is not statistically signifi-

TABLE 10a. Estimation results of the conditional differences-in-differences model with CEM weights for R&D intensity.

	LHS = LOG(R&D/SALES)							
	PRE & POST: DUMMIES				PRE & POST: INTENSITY			
	(1) BASIC		(2) PRE-POST		(3) BASIC		(4) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE			0.304**	0.129			0.276**	0.123
POST	0.302***	0.103	0.509***	0.150	0.025***	0.009	0.040***	0.012
Wald test for POST - PRE			4.078**				4.252**	
Mean value of lhs of the treated group in the treatment year: -4.299								
Industries	Yes		Yes		Yes		Yes	
Regions	Yes		Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes		Yes	
Other controls	Yes		Yes		Yes		Yes	
Observations	7294		7294		7294		7294	
Firms	1031		1031		1031		1031	
R2 (within)	0.985		0.985		0.985		0.985	

cant during the two preceding years. The estimated coefficient of the POST dummy variable further suggests that Tekes subsidies generated growth of approximately 30% in firms' R&D intensity, and a 1% increase in the subsidy amount increased the sample firms' R&D intensity by approximately 2.5%. The impact lasted up to eight years after subsidy receipt.

TABLE 10b. Estimation results of the conditional differences-in-differences model with CEM weights for R&D intensity.

	LHS = LOG(R&D/SALES)			
	PRE & POST: DUMMIES			
	(1) BASIC		(2) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE_3			0.171	0.125
PRE_2			0.281*	0.151
PRE_1			0.416**	0.161
POST_0	0.269***	0.099	0.484***	0.154
POST_1	0.278**	0.122	0.492***	0.170
POST_2	0.465***	0.133	0.677***	0.176
POST_3	0.299**	0.132	0.512***	0.175
POST_4	0.304**	0.132	0.515***	0.170
POST_5	0.277*	0.161	0.490***	0.190
POST_6	0.307*	0.173	0.521***	0.200
POST_7	0.242	0.168	0.456**	0.201
POST_8	0.289	0.180	0.507**	0.209
POST_9	0.282	0.237	0.500*	0.261
POST_10	0.167	0.295	0.390	0.312
POST_11	0.022	0.256	0.210	0.285
Mean value of lhs of the treated group in the treatment year: -4.299				
Industries	Yes		Yes	
Regions	Yes		Yes	
Calendar years	Yes		Yes	
Treatment years	Yes		Yes	
Other controls	Yes		Yes	
Observations	7294		7294	
Firms	1031		1031	
R2 (within)	0.985		0.985	

5.1.2 OUTPUT ADDITIONALITY: LABOR PRODUCTIVITY

Our research concerning output additionality first evaluates whether R&D subsidies affect firms' productivity. The impact of R&D subsidies on labor productivity is explored by using the traditional productivity framework. We follow here the work of Koski and Pajarinen (2015) by applying a Cobb-Douglas production function to derive an empirical model for labor productivity.[7] Our measure of labor productivity is the log of a firm's value added divided by the person-years of labor (i.e., full-time equivalent).[8] The control variables include capital measured by the log of fixed assets (includes both tangible and intangible assets) relative to person-years of labor, the log of a firm's person-years of labor, firm age (i.e., log number of years since the establishment of the firm), dummy variables for foreign- and government-owned firms and for firms legally structured as groups, the share of employees with a graduate-level education, the share of employees with a college-level education, the share of 25-to-34-year-old employees, the share of 35-to-44-year-old employees, the share of 45-to-54-year-old employees, the share of 55-to-70-year-old employees (the share of 18-to-24-year-old employees is the omitted group), and year, industry and regional dummies.

Tables 11a and 11b present the estimation results regarding the impacts of Tekes subsidies on labor productivity. In all models, the estimated coefficients of the PRE and POST dummies as well as the subsidy-intensity variables appear to be statistically nonsignificant. In other words, our estimation results indicate that the labor productivity of subsidized firms did not deviate statistically significantly from that of nonsubsidized firms either prior to or after the receipt of R&D subsidies.

[7] It is possible that R&D subsidies could have an impact on capital and labor, but it seems likely that this effect would occur with a time lag. Similarly, a firm's R&D expenditures are typically used as the independent variable in the labor productivity equation.

[8] All monetary variables have been deflated by a 2-digit industry-level production price index.

TABLE 11a. Estimation results of the conditional differences-in-differences model with CEM weights for labor productivity.

	LHS = LOG(VALUE ADDED/EMPLOYEES (FTE))							
	PRE & POST: DUMMIES				PRE & POST: INTENSITY			
	(1) BASIC		(2) PRE-POST		(3) BASIC		(4) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE			-0.004	0.045			0.006	0.049
POST	0.009	0.038	0.007	0.055	0.001	0.003	0.001	0.005
Wald test for POST - PRE			0.094				0.008	
Mean value of lhs of the treated group in the treatment year: 10.873								
Industries	Yes		Yes		Yes		Yes	
Regions	Yes		Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes		Yes	
Other controls	Yes		Yes		Yes		Yes	
Observations	12418		12418		12418		12418	
Firms	1034		1034		1034		1034	
R2 (within)	0.039		0.039		0.039		0.039	

TABLE 11b. The estimation results of the conditional differences-in-differences model with CEM weights for labor productivity.

	LHS = LOG(VALUE ADDED/EMPLOYEES (FTE))			
	PRE & POST: DUMMIES			
	(1) BASIC		(2) PRE-POST	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
PRE_3			0.016	0.043
PRE_2			-0.026	0.059
PRE_1			0.006	0.055
POST_0	-0.028	0.038	-0.030	0.057
POST_1	0.010	0.047	0.008	0.062
POST_2	-0.085**	0.043	-0.087	0.060
POST_3	-0.017	0.048	-0.019	0.063
POST_4	0.011	0.048	0.009	0.063
POST_5	0.049	0.051	0.048	0.064
POST_6	0.106*	0.056	0.105	0.069
POST_7	0.039	0.059	0.038	0.070
POST_8	0.093	0.059	0.091	0.070
POST_9	0.019	0.089	0.017	0.098
POST_10	0.073	0.088	0.071	0.096
POST_11	0.288	0.213	0.286	0.217
Mean value of lhs of the treated group in the treatment year: 10.873				
Industries	Yes		Yes	
Regions	Yes		Yes	
Calendar years	Yes		Yes	
Treatment years	Yes		Yes	
Other controls	Yes		Yes	
Observations	12418		12418	
Firms	1034		1034	
R2 (within)	0.042		0.042	

5.1.3 OUTPUT AND BEHAVIORAL ADDITIONALITY: INNOVATION OUTPUT AND COLLABORATION

This section analyzes whether subsidized firms produce more innovative output and whether they increase innovation collaboration with other businesses and research organizations due to R&D subsidies. We aim to assess this by first estimating three innovation output equations that capture whether a firm produced new products, new services, and new processes as the dependent variables. Furthermore, we estimate an equation for the percentage of a firm's sales that arises from the products that are new to the market. Here we follow the knowledge production-function approach adopted by, e.g., Hall et al. (2009) and consequently use a firm's R&D intensity, investment per employee, and firm size and age as the explanatory variables in the model (constructed similar to the equations for input additionality). Time-, industry- and location-specific dummy variables are used as additional control variables.

To explore behavioral additionality, our idea is to report the estimation results of the three models with dummy variables that capture whether a firm has undertaken innovation collaboration with a) competitors, b) customers, or c) universities and research institutions. We construct the set of explanatory variables following previous empirical studies concerning behavioral additionality. These studies suggest that variations in firms' innovation collaboration patterns depend on a set of general firm characteristics and R&D-related characteristics (see, e.g., Wanzenböck et al., 2013). Following this previous empirical work, we control for firm size, age, export activity (i.e., a dummy variable taking the value of 1 if a firm is active in foreign markets) and R&D intensity. In addition, we use time-, industry- and location-specific dummies as control variables.

The estimation results of all models for the innovation output measures and behavioral additionality yield no statistically significant results. However, the limitations of the dataset used in the estimations appear to be notable. A majority of the subsidized firms that responded to the CIS appear only once in the dataset because they responded to only one of the CIS 2010-2012, 2012-2014 and 2014-2016 questionnaires. Consequently, as the cross-tabulations in Table 14 show, the sample is limited to the small number of subsidized firms that reported their innovation output in more than one of the 2010-2012, 2012-2014 and 2014-2016 CIS questionnaires.

Furthermore, in many cases, there was no change in innovation output status. Consequently, due to the small number of observed changes in this status among subsidized firms, there are insufficient data to credibly econometrically explore whether R&D subsidies had an impact on innovation output. Moreover, due to an excessively

TABLE 12. Innovation patterns of subsidized and nonsubsidized R&D firms, count of firms, CIS 2010-2012, CIS 2012-2014, and CIS 2014-2016.

1) NEW PRODUCT INNOV.			4) INNOVATION COOPERATION WITH COMPETITORS		
Ended subsidized R&D projects in t = 2012 or 2014			**Ended subsidized R&D projects in t = 2012 or 2014**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	8	<4	t-2 to t: No	13	7
t-2 to t: Yes	5	32	t-2 to t: Yes	10	18
Other R&D firms, no prior R&D subsidies			**Other R&D firms, no prior R&D subsidies**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	31	<4	t-2 to t: No	42	<4
t-2 to t: Yes	6	26	t-2 to t: Yes	12	10
2) NEW PROCESS INNOV.			**5) INNOVATION COOPERATION WITH CLIENTS**		
Ended subsidized R&D projects in t = 2012 or 2014			**Ended subsidized R&D projects in t = 2012 or 2014**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	17	4	t-2 to t: No	10	<4
t-2 to t: Yes	4	23	t-2 to t: Yes	7	28
Other R&D firms, no prior R&D subsidies			**Other R&D firms, no prior R&D subsidies**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	37	5	t-2 to t: No	35	6
t-2 to t: Yes	13	11	t-2 to t: Yes	12	13
3) NEW SERVICE INNOVATIONS			**6) INNOVATION COOPERATION WITH UNIVERSITIES/RIS**		
Ended subsidized R&D projects in t = 2012 or 2014			**Ended subsidized R&D projects in t = 2012 or 2014**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	20	6	t-2 to t: No	9	4
t-2 to t: Yes	<4	19	t-2 to t: Yes	7	28
Other R&D firms, no prior R&D subsidies			**Other R&D firms, no prior R&D subsidies**		
	t to t+2: No	t to t+2: Yes		t to t+2: No	t to t+2: Yes
t-2 to t: No	35	6	t-2 to t: No	39	<4
t-2 to t: Yes	12	13	t-2 to t: Yes	12	12

small number of observations, we are unable to estimate an equation for the percentage of a firm's sales arising from the products that are new to the market.[9]

It is also noteworthy that the CIS data only allow us to distinguish whether a firm engaged in innovation collaboration with different parties, but the magnitude of collaboration or the number of parties with which the firm collaborated is not observable. Estimations with a sample with more subsidized firms could thus only detect whether a firm engaged with new types of innovation collaboration partners but not whether the magnitude of innovation collaboration in terms of euros invested in joint R&D efforts or the number of innovation collaboration partners changed due to R&D subsidies.

9 The sample after the CEM step included 41 companies, of which two had received R&D subsidies.

5.2 INDIRECT IMPACTS ON NONSUBSIDIZED FIRMS

State-of-the-art econometric analyses of the impacts of business subsidies do not offer much guidance on how R&D subsidies can indirectly impact nonsubsidized firms. This section presents an assessment of such indirect impacts by exploring i) spillovers from subsidized firms to nonsubsidized ones and ii) whether the allocation of R&D subsidies affects market dynamics via an influence on firm exit probabilities.

We first empirically assess the presence of spillovers from firms that were Tekes subsidy recipients to those that were not. The idea here is that knowledge and competence generated in organizations are often sticky and tacit, absorbed by and linked to organizations and employees (or organization- and individual-specific). Such knowledge can be transferred, e.g., through interorganizational R&D collaboration or job-switching by employees from one organization to another. It seems credible that persons who are employed by firms that obtain Business Finland's R&D support may, when they switch jobs, take their enhanced capabilities and/or knowledge with them and also improve the performance of the new employer. We estimate a model that sheds light on the question of whether firms that hired new employees from recipients of Tekes R&D subsidies but that did not receive R&D subsidies themselves grew more than other nonsubsidized firms in terms of their R&D intensity, R&D employment and productivity. In these estimations, the treated variable takes a value of 1 if the firm hired at least one person with a previous position in management, planning or research activities **and** the person's previous employer had finished the Tekes-funded R&D project during the past two years.

We estimate a standard difference-in-differences model for the indirect effects, as anticipation effects are not of great interest in this context. The results of the estimations regarding R&D job creation, R&D intensity and productivity are reported in Table 13. We do not find any statistically significant spillover effects on any of the dependent variables analyzed.

We also explore whether nonsubsidized firms active in the sectors obtaining relatively low levels of Tekes R&D subsidies differed in terms of input and output additionality spillovers from the nonsubsidized firms in relatively highly subsidized sectors. We split up the sample into industries with lower and higher than average R&D subsidy levels and then estimated separate spillover models for R&D job creation, R&D intensity and productivity for these two subsamples. Tables 14 and 15 report the estimation results. The separate estimations for relatively highly subsidized and less subsidized firms both provide conclusions of no impact on R&D employment, similar to the results for the full sample.

TABLE 13. Estimation results of the conditional differences-in-differences model with CEM weights for spillover effects.

	LOG(COUNT OF R&D WORKERS)		LOG(R&D/SALES)		LOG(VALUE ADDED/EMPLOYEES (FTE))	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
POST	-0.022	0.045	0.035	0.092	0.021	0.018
Industries	Yes		Yes		Yes	
Regions	Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes	
Other controls	Yes		Yes		Yes	
Observations	11812		11812		168761	
Firms	4214		4214		17650	
R2 (within)	0.974		0.987		0.003	

TABLE 14. Estimation results of the conditional differences-in-differences model with CEM weights for spillover effects in highly subsidized industries.

	LOG(COUNT OF R&D WORKERS)		LOG(R&D/SALES)		LOG(VALUE ADDED/EMPLOYEES (FTE))	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
POST	0.108	0.114	-0.161	0.173	0.002	0.030
Industries	Yes		Yes		Yes	
Regions	Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes	
Other controls	Yes		Yes		Yes	
Observations	1487		1487		19383	
Firms	517		517		2013	
R2 (within)	0.982		0.991		0.025	

TABLE 15. Estimation results of the conditional differences-in-differences model with CEM weights for spillover effects in less subsidized industries

	LOG(COUNT OF R&D WORKERS)		LOG(R&D/SALES)		LOG(VALUE ADDED/EMPLOYEES (FTE))	
	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)	COEFF.	S.E. (ROB.)
POST	-0.062	0.045	0.020	0.096	0.017	0.022
Industries	Yes		Yes		Yes	
Regions	Yes		Yes		Yes	
Calendar years	Yes		Yes		Yes	
Treatment years	Yes		Yes		Yes	
Other controls	Yes		Yes		Yes	
Observations	9059		9059		139700	
Firms	3376		3376		14579	
R2 (within)	0.982		0.988		0.067	

Second, we evaluate the effects of R&D subsidies on market dynamics. The empirical literature suggests that the productivity levels of exiting firms tend to decrease notably relative to the productivity levels of survivors several years before the former exit the market. The allocation of subsidies may affect firm exit probabilities if the subsidies are allocated to relatively inefficient firms and may enhance their likelihood of staying in business. R&D subsidies have negative effects on the rivals of subsidized firms or competition if they affect the market mechanism by weakening the relationship between firm productivity and exit, thus hindering the reallocation of market shares to more efficient firms.

We follow the empirical work of Koski and Pajarinen (2015) to explore whether R&D subsidies hinder structural change or whether declining labor productivity has a smaller impact on the probability of exit for firms that received R&D subsidies than for nonsubsidized firms. In addition, if subsidies weaken the relationship between firm exit and lagged productivity, the coefficients of the lagged labor productivity variables for subsidized firms will be less accurately estimated than these coefficients for nonsubsidized firms. To empirically assess this question, we estimate the following random-effects probit model:

$$EXIT_{it} = \alpha_0 + \beta_1 S_{it} * PROD_{it-k} + \beta_2 \left(1 - S_{it}\right) * PROD_{it-k} + \beta_3 INDUSTRY_{it} + \beta_4 YEAR_t + \upsilon_i + \varepsilon_{it}$$

where the dependent variable EXIT takes a value of 1 if a firm exits the market at year t and 0 otherwise.[10] The variable $PROD_{it-k}$ $(=(Y/L)_{it-k})$ captures firm i's lagged labor productivity for the lags k=1...4 or for the years t-1...t-4. We multiply the explanatory labor productivity variable by variable S, which takes a value of 1 if the firm has obtained R&D subsidies from Tekes. Thus, β_1 and β_2 are the coefficients for the labor productivity of the firms that had Tekes-funded R&D projects and nonsubsidized firms, respectively.

The estimation results of Table 16 suggest that a firm's lagged labor productivity from one to three years prior to the firm's exit relates negatively and statistically significantly to the firm's propensity to exit the market. The size of the estimated coefficients is increasing in the time lags, indicating that the relationship between a firm's productivity and probability of exit tends to fade over time. The coefficient for the t-4 lagged productivity level is close to zero and does not accurately forecast a firm's propensity to exit. The Wald test further shows that the estimated coefficients for one- to three-year lagged labor productivity are statistically significant and not as small for the group of R&D-subsidized companies than for other R&D-active companies. This result indicates that there is a systematic difference in how declining labor productivity affects the survival probabilities of subsidized and nonsubsidized firms. The data suggest that a 1% decline in subsidized firms' labor productivity relates to a 15 times smaller probability of exit than the exit probability of a nonsubsidized firm.

TABLE 16. Estimation results of the random-effects probit models for the shadow-of-death effect (marginal effects).

	LAG			
	K = 1	K = 2	K = 3	K = 4
RD_SUBSxPROD(t-k)	-0.006***	-0.006***	-0.004***	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)
NO_RDSUBSxPROD(t-k)	-0.093***	-0.093***	-0.060***	-0.002
	(0.006)	(0.008)	(0.010)	(0.002)
Wald test for RD_SUBSxPROD(t-k) versus NO_SUBSxPROD(t-k):				
	242.87***	127.57***	33.39***	1,24
Observations	106614	81376	58838	37788
Firms	24741	23129	21565	20073
Wald(Model)	396.7***	252.78***	125.59***	57.15***
Log likelihood	-10901,47	-8956,02	-6931,78	-4691,44

[10] Due to data limitations, our exit variable includes all types of exits, i.e., liquidations, mergers and acquisitions, etc.

TABLE 17. Estimation results of the random-effects probit models for the shadow-of-death effect (marginal effects).

	LAG			
	K = 1	K = 2	K = 3	K = 4
RD_SUBSxPRODxYoung(t-k)	-0.001***	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
RDSUBSxPRODxOld(t-k)	-0.004***	-0.005***	-0.005***	-0.004***
	(0.000)	(0.001)	(0.001)	(0.001)
NO_RD_SUBSxPRODxYoung(t-k)	-0.020***	-0.017***	-0.012***	-0.007***
	(0.001)	(0.002)	(0.002)	(0.002)
NO_RDSUBSxPRODxOld(t-k)	-0.074***	-0.075***	-0.066***	-0.059***
	(0.005)	(0.007)	(0.010)	(0.012)
Wald test for RD_SUBSxPRODxYoung(t-k) versus RD_SUBSxPRODxOld(t-k):				
	1.08	0.02	0.15	0.03
Wald test for RD_SUBSxPRODxYoung(t-k) versus NO_RD_SUBSxPRODxYoung(t-k):				
	10.17***	6.41**	5.36**	3.27*
Wald test for RD_SUBSxPRODxOld(t-k) versus NO_RD_SUBSxPRODxOld(t-k):				
	16.46***	14.68***	15.77***	11.28***
Observations	106614	81376	58838	37788
Firms	24741	23129	21565	20073
Wald(Model)	397.81***	257.33***	139.63***	96.00***
Log likelihood	-10900.84	-8953.84	-6926.88	-4691.63

Therefore, the consequences of declining labor productivity in terms of market exit are not as severe for firms receiving R&D subsidies as for firms receiving no subsidies.

We further estimate the model separating the effects for young companies (those less than six years old) and for older firms (those at least six years old) to explore whether Tekes subsidies hinder the market exit of newly established or incumbent companies (see Table 17).

We find that the lagged levels of labor productivity do not relate as strongly to market exit among younger companies as among older companies. The Wald test comparing the estimated coefficients for subsidized and non-subsidized younger/older firms suggests that the impact of subsidies on the market exit of young and incumbent firms is similar; i.e., subsidies statistically significantly hinder the market exit of both young and older companies. Indeed, according to the Wald test, the dynamics concerning the relationship between productivity and exit are not statistically significantly different between younger and older subsidized companies.

6 CONCLUSIONS

Our main empirical findings concerning the direct effects of R&D subsidies can be summarized as follows. We find clear input additionality with respect to R&D job creation and R&D intensity. Our estimations suggest that R&D subsidies increase a firm's R&D intensity for up to eight years and R&D job creation for up to six years after the firm's receipt of an R&D subsidy. The estimation results do not provide any support for output additionality in terms of labor productivity. We do not have sufficient data to undertake an econometric analysis concerning output additionality in terms of either innovation output or behavioral additionality.

The descriptive statistical analysis shows that the firms that obtain Tekes R&D subsidies collaborate more often than nonsubsidized firms with competitors, customers and research institutions. Although our data do not allow us to conclude whether the collaboration patterns differ between subsidized and nonsubsidized firms *due* to Tekes R&D funding, the wide external collaboration of subsidized companies may potentially provide an advantageous environment for spreading the new knowledge generated in R&D projects.

Furthermore, our analysis suggests that R&D subsidies enhance the propensity of relatively inefficient companies to stay in business. We find that lagged labor productivity levels are not as strongly negatively related to firm exit among subsidized firms as among other firms. This finding hints that R&D subsidies may hinder the structural change and market exit of less productive firms and may thus have adverse effects on competition. Our empirical findings further show that Tekes R&D funding enhances the survival probabilities of both relatively inefficient incumbents and younger companies (those less than six years old) compared to the survival likelihood of their nonsubsidized counterparts. It is not clear whether such impact implies a distortion of competition among young firms or a positive effect of R&D subsidies enabling the continuation of newly established companies that strongly focus on R&D activities and do not yet generate much value added but that will become high-productivity companies in the future. Our empirical findings concerning market exit may further relate to and be partly explained by the signaling effect of public subsidies found by earlier studies. Tekes R&D funding may increase a firm’s propensity to obtain private funding and thus increase its cash flow, which helps it survive through a relatively unproductive period with little value added.

We employed the difference-in-differences method with CEM weights to evaluate the direct and indirect impacts of R&D subsidies. The method is among the most advanced methods available for evaluating the effects of policy interventions when there are no data from randomized controlled trials available. However, one caveat of our empirical research arises from the characteristics of the treatment in question. In Finland, a firm’s R&D subsidies are rarely limited to a one-time treatment or to just one R&D project: many companies receive multitude R&D subsidies for different R&D projects during their lifetime. This complicates the estimation of the treatment effects and makes it difficult to precisely capture differences in the observed outcomes before and after a firm’s receipt of R&D subsidies. We used the cumulative treatment intensity as a means of alleviating this problem by capturing the variation in and impact of post-treatment (additional) R&D subsidies.

The difference-in-difference method does not entirely eliminate potential selection bias, unlike proper randomization. In Finland, randomized controlled trials have not been applied to study the impact of business subsidies. As randomized controlled trials provide the most rigorous way to explore the causal impacts of policy interventions, it would be advisable to undertake such trials in the context of R&D subsidies.

It is also noteworthy that our analysis of the impacts of Tekes R&D subsidies is limited to certain measurable direct and indirect impacts. For instance, the role of Tekes as an enabler of firms’ investment in R&D activities is not measurable. Mere knowledge of the availability of public funding for corporate R&D may encourage firms’ investment in innovation activities. R&D investment incentives that are even stronger than those arising from subsidies might be provided by R&D tax credits, the order of magnitude of which can be more predictably calculated by a firm in the future. R&D tax credits are a widely used policy instrument: the majority of OECD countries (i.e., 33 of 42 countries) provide some form of R&D tax credits. In Finland, R&D tax credits have not been used, except for during a rather short-lived experiment in 2013-2014. Some recent studies find that the net benefits of R&D tax credits may exceed those of direct R&D subsidies (see Bloom et al., 2019).

The efficient design of the R&D subsidy scheme is, however, a complex question that we cannot quantitatively explore within the scope of this project. There are currently relatively few published empirical studies that can be used to evaluate the question of whether the same effects could be obtained with differently structured innovation policy instruments. There have been some rather recent developments in economic research aimed at assessing the impacts of business subsidies on overall economic growth. In their cutting-edge research, Acemoglu et al. (2018) develop a model focusing on the reallocation of R&D inputs and investigate the growth and welfare implications of different types of industrial policies. In their model, unregulated competitive markets do not maximize the overall welfare of a society due to spillovers. The essential market failure in such markets relates to underinvestment in R&D and, consequently, lower than socially optimal demand for skilled labor. The results of Acemoglu et al. using US data suggest that R&D subsidies equivalent to 1% of GDP targeted at established companies would increase growth by only a few tenths of a percent compared to the competitive equilibrium. Their computations further show that optimal taxation of incumbent companies would increase growth more than R&D subsidies (i.e., by 4.5 %) compared to baseline growth in the unregulated competitive situation. A replication of this work using Finnish data would shed more light on the welfare implications of different industrial policies in a small open economy such as Finland. Further research along these lines could be extended to analyze different designs of R&D subsidy schemes.

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