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The Design of R&D Tax Incentive Schemes and Firm Innovation

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Abstract

Research and development (R&D) tax credits are widely employed among the OECD countries to promote business sector investments in innovation. The implementation of R&D tax credit schemes, however, varies across countries. The empirical research on the effectiveness of R&D tax incentives suggests that the strength of company responses (in R&D expenditures) to more generous tax incentives substantially differ across countries. We use data from 25 OECD countries, collected from 2010 to 2018, to explore the relationship between a set of R&D tax scheme features and innovation performance. Our estimation results show that the business sector R&D expenditure is higher among those countries that have implemented either an R&D tax credit scheme with an incremental deduction basis or a hybrid scheme with both volume-based and incremental tax relief components. The input additionality is highest when the R&D tax incentives are based on the incremental deduction. Further, the hybrid tax credit scheme positively relates to innovation output. The business sector R&D investment are higher in the countries with an R&D tax credit scheme that provides favorable treatment for SMEs or option to carry forward unclaimed R&D tax credits.

Tiivistelmä

T&k-verokannustinmallin ominaisuudet ja yritysten innovaatiotoiminta

T&k-verotukia käytetään OECD-maissa laajalti lisäämään yritysten kannustimia investoida tutkimus- ja kehitystoimintaan. T&k-verohuojennusjärjestelmissä on kuitenkin suuria maakohtaisia eroja verotuen asteen ja verotukimallien ominaisuuksien suhteen. Aiempi tutkimus t&k-verokannustimien vaikuttavuudesta viittaa siihen, että se, miten yritysten t&k-investoinnit reagoivat anteliaampiin verokannustimiin, vaihtelee huomattavasti maittain. T&k-verotukimallien ominaisuuksien vaikuttavuudesta on kuitenkin saatavilla varsin vähän tutkimustietoa.

Kokosimme tietoja OECD-maiden t&k-verotukikäytännöistä ja analysoimme niiden yhteyttä yrityssektorin t&k-investointeihin ja patentointiin vuosina 2000–2018. Aineistoanalyysimme osoittaa, että yrityssektorin t&k-panostukset ovat suuremmat maissa, joissa vähennysperuste on ollut inkrementaalinen eli yrityksen t&k-menojen lisäykseen perustuva tai hybridimalli perustuen osin yrityksen t&k-menojen kokonaisvolyymiin ja osin niiden lisäykseen. Panosadditionaliteetti on suurin hybridiverohuojennusmallia käyttävissä maissa. Hybridimallin käyttö liittyy myös positiivisesti innovaatiotuotokseen. Maissa, joissa on otettu käyttöön erityisesti pk-yrityksiä suosivia t&k-verohelpotuskäytäntöjä, yrityssektorin innovaatiopanostukset ovat selvästi korkeammat, ja niissä on tuotettu myös enemmän patentoitavia innovaatiota. Lisäksi yrityssektori investoi enemmän t&k:hon maissa, joissa käyttämättä jäänyt verovähennys voidaan siirtää myöhemmille vuosille.

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Keywords: R&D tax incentives, R&D investments, Innovation policy, Patents

Avainsanat: T&k-verokannustimet, T&k-investoinnit, Innovaatiopolitiikka, Patentit

JEL: K34, L5, O3, O31

Contents

Yhteenveto

T&k-verotukia käytetään OECD-maissa laajalti lisäämään yritysten kannustimia investoida tutkimus- ja kehitystoimintaan. Vuonna 2020 t&k-toiminnan verokannustimia tarjosi 32 OECD-maata 37:sta. Verotuet kattoivat yli puolet tutkimus- ja kehitystoimintaan allokoitujen tukien kokonaismäärästä OECD-alueella.

T&k-verokannustimien etuna on markkinaehtoisuus: verotuki vähentää yritysten t&k-toiminnan kustannuksia ja luo teknologianeutraalin kannustimen innovaatiotoiminnalle. Hallinnolliset kustannukset ovat tyypillisesti pienemmät kuin suorien t&k-tukien. Verotuki tarjoaa ennustettavuutta tulevan t&k-tuen määrän suhteen, mikä on tärkeää erityisesti pienille ja aloittaville yrityksille. Huoliakin t&k-verotukien osalta on esitetty kuten muiden kustannusten kirjaaminen t&k-kuluiksi, tukien saaminen t&k-toimintaan, joka olisi tehty muutoinkin tai josta on korkeat tuotot yritykselle, muttei merkittäviä yhteiskunnallisia tuottoja, kilpailun vääristyminen tukien kohdentamisen (esim. alueellisesti) takia, t&k-toiminnan sijoittuminen tehottomasti veroetujen takia sekä maiden välinen verokilpailu.

T&k-verohuojennusjärjestelmissä on kuitenkin suuria maakohtaisia eroja verotuen asteen ja verotukimallien ominaisuuksien suhteen. Vähennys voi perustua t&k-toiminnan kokonaisvolyymiin huojennuksen perusteena olevien kustannusten osalta tai olla inkrementaalinen, eli yritys voi tehdä verovähennyksen huojennukseen oikeuttavista kustannuksista sen aiemmat tutkimus- ja kehitysmenot ylittävältä osalta määrättynä viiteajanjaksona. Joissakin maissa käytössä on hybridimalli: verohuojennus perustuu tietyiltä osin t&k-kustannusten kokonaisvolyymiin ja osin inkrementaaliseen vähennysmahdollisuuteen. Vuosittaiselle vähennykselle on useissa maissa asetettu ala- tai yläraja.

Vähennys voidaan antaa yrityksen verotettavasta tulosta (tax allowance) tai tuloverosta (tax credit). Joissakin maissa t&k-verovähennyksen voi tehdä yrityksen sosiaaliturvamaksuista tai muista työnantajamaksuista. Vähennyksen voi tällöin saada myös tappiollinen yritys. T&k-verokannustimena tappiollisille yrityksille käytetään myös verohyvitystä t&k-kustannuksista ja mahdollisuutta siirtää käyttämättä jäänyt verovähennys myöhemmille vuosille.

T&k-verovähennys voi perustua joko t&k-toiminnan panostuksiin (esim. t&k-palkat tai -alihankinnat) tai siitä syntyviin tuotoksiin. Tuotokseen perustuvassa ns. patenttilaatikko (patent box) -sääntelymallissa mekanismina toimii verokannan alennus aineettomasta omaisuudesta saataville tuloille.

T&k-verotukimallien ominaisuuksien vaikuttavuudesta on saatavilla varsin vähän tutkimustietoa. Ei ole selvää, minkälainen t&k-verotukimalli antaa parhaat kannustimet yritysten tutkimus- ja kehityspanostuksille sekä tuottaa eniten innovaatiotuotoksia. Analysoimme t&k-verotukiasteen ja verotukijärjestelmän ominaisuuksien yhteyttä yrityssektorin omiin t&k-panostuksiin ja innovaatiotuotoksiin 25 t&k-verotukia käyttäneen maan joukossa vuosina 2000–2018.

Aineistoanalyysimme osoittaa, että yrityssektorin t&k-panostukset ovat suuremmat maissa, joissa vähennysperuste on ollut inkrementaalinen eli yrityksen t&k-menojen lisäykseen perustuva tai hybridimalli perustuen osin yrityksen t&k-menojen kokonaisvolyymiin ja osin niiden lisäykseen. Panosadditionaliteetti on suurin hybridiverohuojennusmallia käyttävissä maissa; yhden euron lisäys t&k-verotuessa liittyy huomattavasti suurempaan lisäykseen yrityssektorin omissa t&k-panostuksissa. Hybridimallin käyttö liittyy myös positiivisesti innovaatiotuotokseen.

Maissa, joissa on otettu käyttöön pk-yrityksiä suosivia t&k-verohelpotuskäytäntöjä, ovat yrityssektorin innovaatiopanostukset olleet selvästi korkeammat, ja niissä on tuotettu myös enemmän patentoitavia innovaatiota. Lisäksi yrityssektori investoi t&k:een enemmän maissa, joissa käyttämättä jäänyt verovähennys voidaan siirtää myöhemmille vuosille. Verovähennyksen siirtomahdollisuus myöhemmille vuosille suosii tyypillisesti nuoria ja pieniä yrityksiä. Nämä empiiriset havainnot ovat yhdenmukaisia näkemyksen kanssa, että nuoret ja pienet yritykset reagoivat voimakkaammin t&k-verokannustimiin niiden kohtaamien rahoitusrajoitteiden takia. Analyysimme viittaa myös siihen, että t&k-vähennykselle asetettava yläraja ei heikennä verohuojennusmallin tehokkuutta.

Aiempi tutkimus antaa myös viitettä t&k-verotukien ja suorien tukien yhteisvaikutuksesta. Niiden perusteella näyttäisi siltä, että pk-yritysten kohdalla verotuet täydentävät suoria tukia, ts. kaksi kannustinjärjestelmää lisää toistensa tehokkuutta. Isojen yritysten kohdalla t&k-ve-

rotuet ja suorat tuet näyttävät sen sijaan korvaavan toisiaan, ja niiden yhteiskäyttö ei tuota parasta tulosta. Tämän lisäksi Einiön ym. (2022) tutkimus viittaa siihen, että suorien tukien kohdentaminen korkean innovaatiokyvykkyyden yrityksille tuottaa huomattavia hyvinvointivaikutuksia erityisesti isojen yritysten osalta verrattuna kohdentamattomiin t&k-verotukiin. Pienten yritysten kohdalla innovaatiokyvykkyyden mukaan kohdennetun suoran tukipolitiikan hyvinvointivaikutukset verrattuna verotukiin ovat pienemmät.

Aineistoanalyysiimme perustuvat havaintomme ja aiempien tutkimuksen viesti on yhdensuuntainen: t&k-verokannustinmalli kannattaisi rakentaa niin, että se painottuu pk-yrityksiin tai suosii niitä ja luo myös nuorille, tappiollisille yrityksille kannusteita tutkimus- ja kehitysinvestointeihin. Suurten yritysten innovaatiotoiminnan kannusteet kannattaisi keskittää suoriin, tarkasti kohdennettuihin t&k-tukiin. Tehokkaamman tukiallokaation lisäksi t&k-verohuojennusmalli, joka tarjoaisi isoille yrityksille vähemmän verotukia kuin pk-yrityksille tai ei lainkaan, vähentäisi huomattavasti verotukimallin rasitusta julkiselle taloudelle.

Taloustieteellinen aineistoanalyysiin perustuva tutkimus tarjoaa hyvin vähän tietoa monien verotukimallien ominaisuuksien vaikuttavuudesta. Esimerkiksi siitä, miten verohuojennukseen oikeuttavien kustannuslajien rajaaminen vaikuttaa yritysten t&k-kannustimiin, ei ole lainkaan aineistoanalyysiin perustuvaa tutkittua tietoa. Myös yritystason aineistoja hyödyntäviä tutkimuksia maakohtaisten verotukimallien ominaisuuksien kannustinvaikutuksista t&k-panostusten suhteen ja niiden vaikutuksesta innovaatiotuotoksiin tarvitaan vankempien johtopäätösten tekemiseen erilaisten t&k-verotukimallien vaikuttavuudesta.

Tässä tutkimuksessa ei ole pyritty arvioimaan t&k-verotukien pitkän aikavälin hyvinvointivaikutuksia tai vaikutuksia tuottavuuden kasvuun. Pysyvän t&k-verotukimallin käyttöönotto edellyttää myös kokonaistaloudellisten vaikutusten arviointia vaihtoehtoisten mallien välillä.

1 Introduction

Research and development (R&D) tax credits, along with direct R&D subsidies, are widely employed among the OECD countries to promote business sector investments in innovation. The justification for these government interventions arises from market imperfections. The primary motivation for publicly subsidizing business sector R&D arises from positive externalities—new knowledge generated in companies' innovation projects that spreads over the company borders and can thus be utilized by other economic actors. Companies base their R&D investment decisions on the expected private benefits and costs of R&D projects, and ignore the benefits for society at large. Private actors thus tend to underinvest in R&D, and the overall level of innovation would be suboptimal in the absence of government intervention (Warda, 2001). Moreover, the uncertain outcome of R&D investments can lead to asymmetric information problems between firms and funders, especially for smaller and younger companies. This can lead to a lack of access to private funds, even for beneficial R&D ventures.

Our review of the recent empirical literature strongly indicates that R&D tax deductions efficiently promote business sector R&D. The implementation of R&D tax credit schemes, however, varies widely across countries. It seems possible that these design features have a role in the effectiveness of the R&D tax credit schemes. The empirical research on the effectiveness of R&D tax incentives suggests that the strength of company responses (in terms of R&D expenditures) to more generous tax incentives substantially differ across countries and among different firm populations (e.g., small vs. large companies).

This report aims at shedding light on the role of the R&D tax scheme features in promoting business sector innovation. We first survey recent literature on the effects of R&D tax incentives on R&D input and output, and further, we draw insights from other economic literature to shed light on the preferability of certain R&D tax scheme features. Secondly, we undertake a cross-country analysis among 25 OECD countries, covering 2010–2018, in order to explore the relationship between a set of R&D tax scheme features and innovation performance. The results in our analysis indicate significant input additionality, i.e., R&D tax incentives relate to a disproportional increase in business R&D, especially for countries adopting an incremental tax relief. The business sector R&D investment seems to be higher in the countries with an R&D tax credit scheme that provides favorable treatment for SMEs or option to carry forward unclaimed R&D tax credits. Further, the hybrid tax credit scheme positively relates to innovation output.

The closest work to our empirical work is the meta-analysis of Blandinieres and Steinbrenner (2021) that aimed to explain the heterogeneity found in studies assessing the effects of R&D tax incentives on firms' R&D investments by using a set of features of tax credit schemes. Their meta-analysis has the clear advantage of integrating the empirical estimates of a large set of previous firm-level studies concerning various countries. However, their estimations are bound to the limited set of countries and R&D incentive schemes considered in the prior studies. Unlike their estimations, our empirical estimations cover a more representative set of OECD countries and their incentive schemes, and concern both innovation inputs and outputs. Further, our analysis concerns a long time period compared with the relatively short-term estimates of the previous empirical studies available for the meta-analysis. Even though we cannot establish causal inferences based on our estimation results, they enhance our understanding of the relationship between R&D tax scheme features and business sector R&D incentives and output.

The rest of the report is organized as follows. Section 2 discusses the main features of R&D tax schemes employed by the OECD countries. Section 3 presents a review of recent literature, focusing on the effects of R&D tax incentives on innovation inputs and outputs (Subsection 3.1) and on what can be learned from the previous economic literature concerning the effectiveness of the R&D tax scheme features (Subsection 3.2). Section 4 introduces the data of our empirical analysis. Section 5 presents the estimation results. Section 6 summarizes our findings with a practical policy discussion on the preferred features of R&D tax credit schemes.

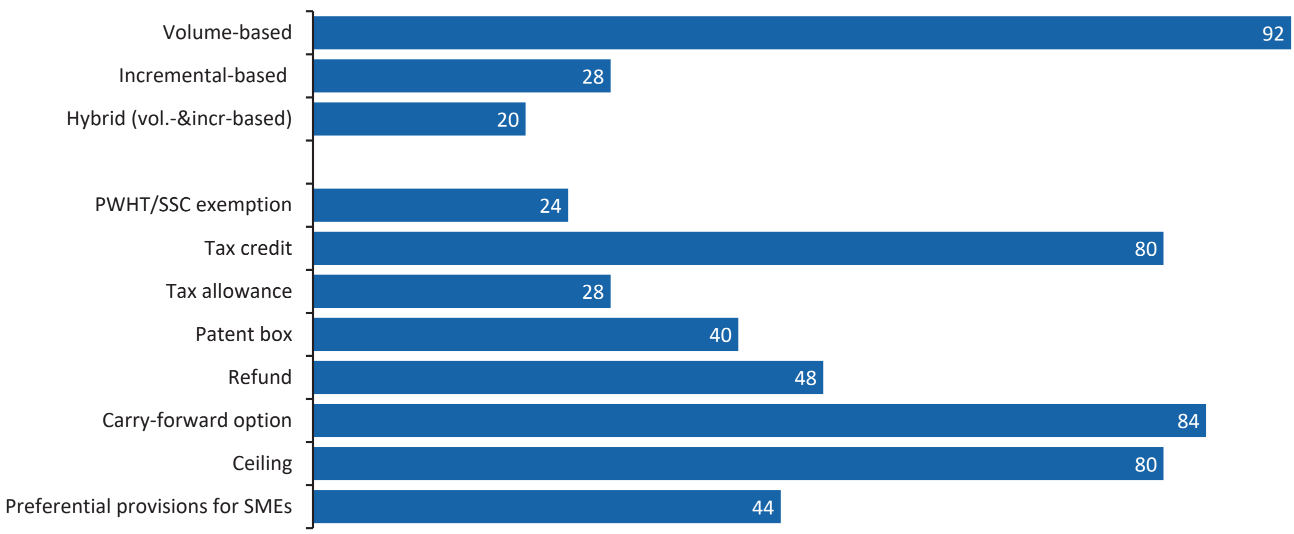
2 R&D tax scheme features

This section discusses the features of R&D incentive schemes in light of the practices of the sample OECD countries used in our empirical analysis[1] in the last year of observation, 2018. R&D tax incentives have various advantages over direct R&D subsidies. They are, by and large, market-based instruments that are neutral with respect to the firm's decisions concerning the types of R&D projects they undertake or the technology they develop. Neutrality generally also concerns firm characteristics, such as industry and location, though some countries provide preferential treatment for certain types of firms (e.g., small start-ups). R&D tax incentives are also more transparent in their prerequisites for a firm to obtain public support, and they offer predictability for a firm regarding its future R&D support, unlike direct R&D subsidies allocated for R&D projects. Further, the administrative costs of R&D tax incentives for the government and firms' compliance costs are typically smaller as R&D tax credits do not require the processing and assessment of project applications.

However, R&D tax incentives also have weaknesses. Firms may exploit the deductions for R&D they had conducted irrespective of tax support, and they may use R&D tax benefits for R&D projects that have high private returns but do not have high social returns. Also, direct R&D subsidies that require project-level decision-making provide, at least in principle, possibilities for the more efficient targeting of public R&D support (see Einiö et al., 2022). Moreover, differences in the generosity of R&D tax schemes across countries may distort competition and further constitute harmful tax competition between countries.

There are considerable differences between the countries in terms of the design of R&D tax relief schemes. The basis of R&D tax deduction can be the total volume of a firm's qualifying R&D costs, or it can be incremental, that is to say, a company can claim a tax deduction for the excess of its past R&D expenditures over a specified period. The volume-based scheme is the most common scheme among the OECD countries. In 2018, close to 30 percent of the sample countries used incremental R&D tax deduction. For example, in the United States, the deduction applied to R&D costs that exceed 50 percent of the company's average R&D costs over the previous three years. About one fifth of the countries applied a hybrid model in which the R&D tax deduction is partly based on the total volume of R&D costs and partly on in-

Figure 1 The prevalence of the characteristics of R&D tax support schemes in 2018 (as a percentage of sample countries providing R&D tax incentives)



Source: Author's own calculations.

cremental R&D deduction. Typically, a company's direct R&D subsidies reduce its R&D tax deductions on other subsidies received.

The R&D tax deduction is based on either the R&D expenditures or innovation outputs. Typically, a company may deduct a certain extra percentage of its qualifying costs from income tax (i.e., tax credit), the taxable income (i.e., tax allowance), payroll withholding tax (PWHT), or its social security contribution (SSC). In OECD countries, the most common practice is to use tax credits. A patent box scheme provides tax relief for a company's innovation output. It means that a company's income from intangible assets is taxed at a rate below the statutory corporate income tax rate. Forty percent of the sample OECD countries had introduced a patent box scheme.

In many countries, loss-making companies with an insufficient tax liability can also benefit from an R&D tax scheme. The idea is to provide R&D incentives, particularly for the small, newly established companies that often make a loss in their first years. A commonly employed means allows a firm to carry forward the amount (or part) of the current year's deduction to later years. For example, unused R&D claims can be carried forward without restriction in the UK and Ireland. However, setting a maximum time limit for carrying forward reductions to future years (e.g., the limit is eight years in Portugal) is more common. In 2018, more than 80 percent of countries provided firms with a possibility to carry forward their unclaimed tax deductions to later years. Another way to favor financially constrained companies is to provide an immediate refund from the R&D investments for the loss-making companies (e.g., this is provided in Denmark) or to enable them to claim an R&D tax deduction to their SSCs up to a specific limit (e.g., this is provided in Sweden) or from PWHT (e.g., this is provided in the Netherlands). Over 40 percent of the sample countries further provided preferential R&D tax relief provisions for SMEs.

Also, many countries have set a cap defining the maximum amount of eligible R&D expenditure that qualifies for relief or the amount of tax benefits that can be granted. The company-specific ceiling for the maximum tax relief, especially when it is relatively low, does not directly discriminate between small and large firms, but it tends to favor SMEs. The scheme may also set a floor defining a minimum amount of eligible R&D expenditure to qualify for relief.

In some countries, R&D tax aid is also directly targeted according to other firm attributes (e.g., age or sector) or targeted to the R&D activities related to specific technologies, such as the development of technologie promoting green innovation. We do not have access to such features in the time-series data.

The R&D tax incentive schemes further vary regarding the eligibility of current and capital expenditures for R&D tax relief. Many countries use the *Frascati Manual*, which sets the benchmark for identifying R&D activities. R&D personnel costs account for the largest share of firms' intramural costs (OECD, 2020), and most countries implementing R&D tax schemes consider current R&D labor expenses to be eligible for tax relief. The eligible costs for R&D tax deduction may involve other current costs (payments for R&D services provided by consultants and other third parties; payments for other services; contributions to R&D carried out with third parties such as collaboration agreements; materials and other consumables; or overheads) or capital R&D expenditures (the acquisition of plants and machinery used for R&D; the acquisition of software, licenses, and IP rights used for R&D; the acquisition of land and buildings used for R&D; or the depreciation/amortization of assets used for R&D).

3 The effectiveness of R&D tax incentives

The academic literature regarding the impact of tax incentives on R&D is considerably voluminous, and we do not attempt to cover it completely in this short review.[2] Instead, we focus on recent empirical studies. From the many extended reviews of the early literature on this subject, we refer the reader to Castellacci and Lie (2015), Straathof et al. (2014), and Kuusi et al. (2016). Our main interest here is in the empirical work that sheds light on the effects of R&D tax incentives on R&D input and output (see Section 3.1) and on the effectiveness of different features of R&D tax incentive schemes (see Section 3.2).

3.1 R&D investments and innovation

Various recent econometric studies have relied on sound identification strategies to obtain causal estimates of the impact of tax incentives on R&D expenditures and innovation. Dechezleprêtre et al. (2016) used administrative data on UK firms to study the link between R&D tax credits, R&D investments, patenting, and productivity. Their identification strategy is based on a regression discontinuity design that leverages the raising of the firm-size threshold to determine whether an SME is eligible for tax subsidies for R&D (a reform implemented in 2008). The authors highlighted the fact that this change in policy was isolated to R&D tax incentives, therefore rendering it distinguishable from the effects of other factors. They found a strong effect of R&D tax subsidies on firms that were just below the new size threshold, with an almost 100 percent increase in R&D expenditures and a 60 percent increase in patenting when compared with the control firms. The authors note that the resulting elasticity of R&D with respect to tax incentives is substantially higher than that found in the previous literature and provide evidence that this is due to their sample consisting of smaller firms (which face tighter funding constraints) than those typically used in prior studies. The resulting cost-effectiveness of the reform is estimated to be a £1.7 increase in BERD for each £1 of taxes foregone. An additional interesting result of the study is the presence of substantial innovation spillovers due to the change in policy.

The same policy change studied in the work of Dechezleprêtre et al. (2016) has been exploited in other papers regarding the impacts of R&D tax incentives (e.g., Guceri, 2018; Guceri and Liu, 2019). The first of these studies looked at the effect of the 2008 UK tax reform on R&D expenditures and employment using a difference-in-differences approach. They found a significant increase in BERD due to tax incentives, which is mostly explained by the new hiring of R&D personnel (without a significant increase in salaries). The effect on R&D expenditures is somewhat lower than that found in the work of Dechezleprêtre et al. (2016), but the author highlighted that the reform has been cost-effective for the government (with between £0.8 and £1.2 additional R&D for each £1 of taxes foregone). The analysis of Guceri and Liu (2019) was fairly similar to that of Guceri (2018), but they relied on a larger data source (administrative data instead of surveys). They again found a strong response (in terms of R&D expenditure) to a more generous tax incentive and estimated a £1 to £1.5 increase in private R&D expenditures for £1 of taxes lost.

Rao (2016) studied the effect of US tax credit on R&D intensity between 1981 and 1991, relying on corporate tax return data, which allows for an accurate measurement of the marginal tax credit rates, and relying on instrumental variables techniques to avoid potential simultaneity biases. Denoting the year of interest by t, the main idea of the instrumental variable strategy used in the paper is to rely on the t-2 R&D spending and compute the change in the marginal user cost of R&D capital due to the tax credit change between t and t-1. In this way, the author obtained the exogenous change in the cost of R&D due to different tax regimes. He found a substantial impact of tax credits, with an almost 2 percent increase in R&D intensity, a 1 percent increase in tax subsidies (on average), and a $1.8 increase in R&D spending for each dollar of tax credit.

Holt et al. (2016) looked at the Australian R&D tax policy reform, adopted in 2011, to estimate the impact of tax incentives on private R&D investments. Their identification strategy relies on a difference-in-differences approach, and they find a substantial effect of tax incentives on BERD. However, the different techniques and specifications they use give a fairly wide range of estimates of the additionality (how many US dollars of R&D investments are generated by one US dollar of tax foregone), ranging from 0.8 to 1.9 dollars.

Thomson (2017) did not rely on specific exogenous variation (for example, a change in policy) but rather exploited differences in cross-country and cross-industry capital—labor ratios in order to determine the impact of tax credits on R&D expenditures. One of the key aspects of the analysis is that different measures of tax incentives are computed separately for different components of R&D expenditures (labor and capital expenditure). The main finding of the paper is that R&D expenditures respond more strongly to tax credits compared with what is found in many previous cross-country studies (but they fall in the range of the results of previous firm-level studies), with the tax price elasticity of BERD being around -0.5 in the short run. In other words, in the short run a 10 percent reduction in tax expenditures leads to a 5 percent increase in BERD or one dollar of tax forgone leads to 60 cents of additional R&D expenditure. The estimates considerably increase in the long run (to about -4) even though the author urges caution regarding this result.

The analysis contained in the work of Chang (2018) is focused on estimating the endogeneity bias driven by the timing of tax policies, estimated using US state-level data and relying on federal tax incentive changes as a source of exogenous variation. The resulting elasticity of R&D expenditures to tax incentives is large, namely Chang (2018) found that a 1 percent increase in tax incentives leads to a 2.8 to 3.8 percent increase in BERD, substantially more than the increase found in many previous works. The author argued that this discrepancy of the results is due to the endogeneity bias of many previous works, which do not take into account the endogenous timing of a tax reform and thus underestimate the impact of tax incentives.

The tax credit reform implemented in California in 1987 is the subject of the work of Balsmaier et al. (2018). Specifically, the analysis investigated the private and public value creation that stemmed from R&D tax incentives. They found that the introduction of tax credits led to an increase in patenting within the technological domains where benefitting firms were already strong and led to significant private value creation (measured by stock market performance). The effects on competing firms depended on how close they were at the technological level, with positive externalities, on average, for firms in similar industries, but negative value effects for firms in a similar technology space. Moreover, an important finding of the study is that benefitting firms tended to have a more defensive patenting strategy.

Both Schwab and Todtenhaupt (2018) and Knoll et al. (2021) studied the cross-border effects of tax cuts on R&D outputs. The former paper considered the impacts of "patent boxes," tax cuts on income derived from intangible assets such as patents, and how they lead multinational enterprises (MNEs) to shift profits toward low-tax locations. Their findings indicate that MNEs that have subsidiaries in countries that introduce patent boxes without nexus requirements (i.e., tax cuts on patent income are granted even though R&D activity is not carried out in the territory) significantly produce more patents (around 15 percent more per year). If there are requirements for local innovation, the effect becomes statistically insignificant, highlighting a strong profit-shifting tendency. For a smaller sample of German firms, they found positive cross-border effects on R&D expenditures, derived from the introduction of patent boxes without nexus requirements. The topic of the cross-border externalities of tax incentives is also discussed in the work of Knoll et al. (2021). Using a panel of MNEs, the authors estimated the impact of changes in R&D tax incentives (measured by changes in the B-index) in the host country on the production of patents, while taking into account changes in subsidiaries that operate in other locations. The main finding of the paper is that R&D tax incentives increase innovation in the policy-changing country, but lead to a decrease in innovations performed in other locations, making the MNEs aggregate innovations not statistically different from zero. In other words, MNEs shift resources to countries with more beneficial tax regimes, rather than increase overall innovation.

Moretti et al. (2021) looked at the more general question of whether public-funded R&D impacts on BERD and whether there is a crowding-in effect or a crowding-out effect. They use the industry-level data of OECD countries and exploit the exogenous variation derived from government spending in defense-related R&D in order to establish causality. The results of the analysis indicate the presence of a crowding-in effect, which means that government-funded R&D leads to additional private R&D investments. Moreover, they found that publicly funded R&D has almost double the effect of tax credits when evaluated on a dollar-for-dollar basis (they estimate a $6 increase in privately funded R&D for each dollar invested in public-funded R&D). Finally, they observed the presence of international spillovers, with firms within the same industries benefitting from increasing public-funded R&D in another country.

Studies on Finland

Kuusi et al. (2016) relied on business register data when analyzing the impact of a Finnish R&D tax credit experiment that was implemented in the years 2013–2014; they found a limited effect of tax incentives on R&D activity while observing a stronger response of firms to direct subsidies. While the authors suggest that the proposed tax incentives are ineffective overall, they underline the uncertainty surrounding their estimates due to limited data and the somewhat lackluster design of the scheme (for example, a large number of firms were unaware of the possibility to apply for tax credit).

The tax credit experiment of 2013–2014 is also the subject of the analysis found in the work of Takalo and Toivanen (2018). This study is focused on the analysis of the welfare effects of innovation policies, especially in a small open economy context, utilizing the model formulated in the work of Takalo et al. (2017). Their scenario analysis highlighted that the introduction of tax credits does not lead to more firms investing in R&D (extensive margin) compared with a no-intervention scenario but that the quantity of R&D increases substantially along the intensive margin. Moreover, they found that the simultaneous use of tax credits and subsidies increases R&D spillovers relatively more than R&D expenditures, while the effect on welfare is minor. The overall small improvement in welfare is due to the increasing fiscal and shadow costs of public funds.

Other economic impacts

We next discuss recent empirical research concerning the other economic impacts of R&D tax reliefs. Minniti and Venturini (2017) used industry-level data from the US to examine the effect of R&D policies, including tax credits and direct government funding, on productivity growth. They found a substantial positive impact of tax credit on long-run productivity while the impact of direct funding was negligible.

Chen et al. (2021) looks at the effects of the InnoCom program, a large fiscal reform designed to boost R&D investments in China. The tax incentives devised in the reform consist of lowering the R&D expenditures threshold for qualifying a firm as *high-tech*. Firms that are classified as *high-tech* benefit from a lower corporate income tax rate. The analysis is aimed at determining the effects of the fiscal reform on both R&D investments and productivity growth. To identify causal effects, the authors rely on a bunching estimator, where the distribution of firm-level R&D intensities concentrate right above the thresholds that determine a more favorable tax rate. The results indicate a strong response in R&D investments – even though a substantial part of the increase is due to relabeling expenses – productivity, and profitability.

For the Norwegian economy, Nilsen et al. (2020) studied the impact of both direct government subsidies (grants) and tax credits on firm-level indicators, such as labor productivity and employment. The findings of the paper pointed toward a positive effect of tax incentives on employment growth and value added, but not on productivity.

Another policy-relevant question is whether R&D tax incentives spur additional innovation through the creation of new businesses. Two interesting works regarding this question are those of Babina and Howell (2018) and Fazio et al. (2019). The former study looks at the more general issue of the effect of R&D investments on workers mobility using US data. To gauge causality, the authors relied on an instrumental variable approach, using the introduction of R&D tax credits as instruments. While the analysis does not show any significant effects of R&D investments on employees' retention and mobility to other firms, there is a strong positive effect on the share of employees who leave the firm to start their own company.

Fazio et al. (2019) investigated this question by looking at the effects of tax credits on the formation of new enterprises (and their growth potential) using US data. They found that the introduction of R&D tax credits has a strong effect on the establishment of new businesses, including the creation of high-growth firms. The effect in the long run (in this case, 10 years) is an increase of around 20 percent both in the quantity of entrepreneurship and the quality-adjusted quantity of entrepreneurship. However, this strong effect takes multiple years to materialize, thus policymakers cannot rely on tax credits as a quick way of boosting business formation.

3.2 The design of a R&D tax credit scheme and incentives to invest in R&D

Empirical studies explicitly tackling how the features of R&D tax credit schemes affect a firm's incentives to invest in R&D are scarce. Blandinieres and Steinbrenner's (2021) meta-regression approach, analyzing the effects of a set of tax incentive scheme features on R&D input additionality, provided an exemption. Their findings indicated that, generally, R&D incentives stimulate R&D investments but that the underlying reason for the empirical results' heterogeneity in regard to the impacts of R&D tax incentives arises from the design of R&D tax incentive schemes. One of their main empirical results is that *clear and stable schemes are the most effective*. *Uncertainties regarding the amount of financial returns from tax claims* (e.g., in the case of super deductions) and *changes in the scheme decrease effectiveness, at least in the short run*. They further find that an *incremental R&D tax deduction basis enhances the effectiveness* of R&D tax reliefs, while volume-based tax deduction basis does not seem to have any notable impact on firms' R&D investment incentives. Their analysis indicates that *setting up a cap in order to target SMEs does not seem to impact on the effectiveness* of an R&D tax relief scheme.

The empirical findings of Dechezleprêtre et al. (2016), which used UK data, also provided evidence that the *R&D tax credits provide more powerful incentives for small and young companies* with tighter funding constraints. Agrawal et al. (2020) presented similar findings, found among small private firms in Canada, and they further found that the increase in R&D investments due to the tax credits was larger for SMEs that took the tax credits as refunds because they had no current tax liability. This finding emphasizes that *extending R&D tax incentives to cover loss-making firms may boost innovation, particularly among potentially innovative young and small companies*. Blandinieres and Steinbrenner (2021) further suggested that more generous tax credits for SMEs provide higher R&D incentives. The empirical study of Appelt et al. (2020), using firm-level data from 20 OECD countries, also indicated that the input additionality of R&D tax credits is highest among SMEs and tends to decrease with a firm's size.[3] Straathof et al. (2014)[4] surveyed a large number of studies and concluded that the effects of R&D tax incentives are heterogeneous, depending on the country and firm-level characteristics, with some *evidence of enhanced impacts on start-ups*. It also seems credible that the R&D tax credits targeted to start-ups may promote entry.

Acemoglu et al. (2018) provided further guidelines for R&D support design: Their study suggests that an increase in the R&D subsidies of all innovative firms produces substantial welfare gains. Subsidies targeted to high R&D productivity or high innovation-capacity companies generate the highest welfare gains. When R&D subsidies are uniformly distributed to all incumbent companies, irrespective of their level of R&D productivity or innovation capacities, welfare gains are smaller but still substantial. Thus, R&D tax incentives that are available to all companies may also yield notable productivity and welfare gains. However, the gains are clearly smaller than those of the optimal policy.[5] Einiö et al. (2022) drew similar conclusions using Finnish data collected from 2010 to 2016, and their empirical findings further suggest that the benefits of creative destruction that can be obtained via an (optimal) innovation policy are greater among the large companies due to their higher innovation potential and fixed costs. In other words, the targeted R&D subsidy policy generates higher benefits among the large companies, while the difference in welfare gains obtained from the optimal policy compared with those obtained via non-targeted R&D support such as R&D tax credits is lesser when the small companies are included to the sample. Consequently, targeting R&D tax deductions at SMEs and using direct R&D subsidies for large, incumbent companies might be beneficial from the point of view of society's welfare.

Setting up upper thresholds for the firm size that is eligible for R&D tax deductions or favoring smaller firms have their downside though as they may pose a "tax on growth." Firms smaller than the size threshold, particularly those just below the threshold, may not have incentive to invest in R&D and grow beyond the threshold, which may also discourage the innovation of all firms larger than the threshold (Aghion et al., 2021). However, the empirical exploration of Aghion et al. (2021) concluded that regulation that taxes firms' profits more beyond a certain threshold deters incremental innovation; instead, in the case of firms that aim at growing, it may give them incentives to do more radical innovation (to avoid being only slightly above the threshold).[6] The literature also hints that high-growth companies grow irrespective of whether they receive public support, and business subsidies do not provide a significant additional boost for those young companies that are already growing fast (Koski and Pajarinen, 2013). In the light of these empirical findings, the R&D tax incentive thresholds for firm size may not have substantial adverse effects on the companies' growth intentions and may have potentially marginal effects on innovation.

Recent research suggests that R&D tax incentives and direct funding have a complementary, mutually reinforcing effect. However, it seems that this complementarity effect may be mainly driven by small firms (Huergo and Moreno, 2017; Pless, 2021). Using discontinuity in access to tax credits, as well as other policy changes, Pless (2021) established a solid identification strategy with which to evaluate the causal impacts of grants and tax credits, as well as their interaction. The main result of the study is that the direct and indirect subsidies are complements for small firms, while being substitutes for large companies. In other words, the effect of grants on small firms' R&D expenditures is accentuated by tax credits, while the positive effect of grants is strongly attenuated for large firms that receive tax incentives. In both directions, the economic significance of the results is strong. The author argued that financial constraints are key in explaining these results and that it might be reasonable to apply both R&D subsidies and tax credits for SMEs, but only one of these means for large companies. Huergo and Moreno (2017) further provided evidence that participation in both R&D subsidy and loan programs has a larger impact on the R&D performance of SMEs. They were not able to rule out a crowding out effect for large companies. These findings concerning the complementarity of direct R&D subsidies and R&D tax incentives hint that the R&D tax incentive scheme should be designed alongside the alignment of the guidelines for the allocation of direct R&D subsidies.

There are various other design features of R&D tax schemes, the implications of which the economic literature provides either not much or no empirical evidence. It is, for instance, not clear whether the R&D incentives provided by R&D tax credits would differ from those of an R&D tax allowance as such. There are no reported empirical studies exploring whether the type of expenditures that are eligible for R&D tax deductions affect the effectiveness of an R&D tax deduction scheme. Providing companies with greater incentives to employ skilled workers for R&D activities in particular seems reasonable in the light of various studies emphasizing that the allocation of skilled workers to R&D activities, instead of their employment in non-innovative tasks, matters for productivity growth (see, e.g., Acemoglu et al., 2018). To facilitate the employment of the most skilled persons in the R&D tasks and to further enhance knowledge spillovers across organizations, it seems reasonable to also provide R&D tax credits for R&D subcontracting.

Deciding upon such alternative features with high uncertainty as to whether such R&D tax-scheme features affect firms' incentives (and if they do so, to what extent they affect them) is one of the factors to consider, along with the fiscal costs and longer-term productivity and growth implications, involves generating a light and simple R&D tax credit scheme that minimizes bureaucracy costs for both the government and the companies.

4 Data

The primary dependent variable of our analysis is the business sector R&D expenditure (i.e., BERD) of 25 OECD countries. We also estimate models for the innovation output, measured by the total count of patent applications filed with the U.S. Patent and Trademark Office (USPTO). The standard statistical sources, however, do not offer any precise measure for R&D productivity, such as the value added generated by innovation inputs. Patents have become a conventional indicator for innovation activity even though they provide a rather rough proxy for R&D productivity. Some major shortcomings of using patent counts as a measure of innovation output are that not all innovations that generate value added are patented, and that the market value of a patented innovation tends to vary notably. We chose the patent applications filed with the USPTO for our empirical analysis due to the international importance of U.S. markets.[7] The USPTO had the highest number of patent applications filed by non-residents among the top 10 patent offices in the world.[8] Consequently, the USPTO patent activities best reflect international technological efforts in terms of patenting.

All the nominal variables are expressed in 2015 US dollars adjusted for purchasing power parity (PPP). Business enterprise expenditure on R&D (BERD) was available from 2000 and a restricted sample was available from 2006 onward; they are separated by the source of funding. This means that we were able collect information on the private R&D spending, as well as on the publicly funded R&D spending done by firms (i.e., R&D subsidies). The data is not balanced, meaning that there are fewer available years for certain countries. For R&D support, direct subsidies were separately controlled for from R&D tax credits. Finally, we collected data on the country-specific number of patent applications filed with the USPTO. These data concerning R&D expenditures, patent statistics, R&D subsidies, and GDP were extracted from the OECD statistics databases (OECD.stat).

We measure the generosity of the country's R&D tax scheme using the OECD time-series estimates of the B-index from 2000 to 2018. The B-index measures the level of before-tax profit that a "representative" company needs in order to break even on one additional monetary unit spent on R&D (Warda, 2001), taking into consideration provisions in the tax system that allow for special treatment of R&D expenditure.[9] The B-index captures the reduction in a firm's costs of conducting R&D as it measures the implied level of the R&D tax subsidy or the expected cost reduction for one additional monetary unit invested in R&D. The higher the marginal R&D tax subsidy, the lower the pre-tax breakeven profit level and B-index. The B-index takes into account immediate refunds available for unused tax credits for loss-making companies and aims to also reflect (using some simplified assumptions) the carry forward provisions. However, the index does not reflect preferential provisions for start-ups, young companies, or specific sets of SMEs (e.g., innovative SMEs). We control for the existence (though not the magnitude) of such provisions. The dummy variable "favorable treatment for SMEs" was coded 1 if a country provides a preferential R&D tax treatment for SMEs, typically in the form of enhanced tax credit or allowance rates, or other more favorable terms, such as exclusive or preferential refund options.

Table 1 Descriptive statistics

Variable name	Description	Mean	Std. dev.
Dependent variables			
ln BERD	ln business enterprise expenditures, 2015 PPP USD	36.49	1.73
USPTO patents	Count of patent applications filed with the USPTO	12842	34165
Explanatory variables			
ln B-index: large profitable	The expected cost reduction for one USD invested in R&D for large profitable companies	-0.18	0.18
ln B-index: small profitable	The expected cost reduction for one USD invested in R&D for small profitable companies	-0.21	0.81
R&D tax scheme features: Dummy variable that gets 1 value (0 otherwise) if:			
Volume-based	Volume-based R&D tax credit scheme only	0.48	0.50
Incremental	Incremental-based R&D tax credit scheme only	0.13	0.30
Inc. & volume based	Hybrid tax credit scheme with volume- and incremental-based components	0.26	0.4
Tax credit	Deduction from the income tax	0.77	0.42
Tax allowance	Deduction from the taxable income	0.21	0.46
PWHT/SSC exemption	Deduction from payroll withholding tax (PWHT) or social security contribution (SSC)	0.16	0.37
Patent box	Income from intangible assets is taxed at a rate below the statutory corporate income tax rate	0.21	0.41
Ceiling	Ceiling defining a maximum amount of R&D tax relief	0.73	0.44
Preferential treatment for SMEs	R&D tax scheme providing preferential treatment for SMEs	0.45	0.50
Refund	Immediate refund option	0.34	0.47
Carry forward	Option to carry forward unclaimed R&D tax credits	0.76	0.43
ln R&D subsidies	ln direct R&D subsidies to business sector, 2015 PPP USD	6.01	1.75
ln GDP	ln Gross domestic product, 2015 PPP USD	13.75	1.22
CIT	Corporate income tax (%)	-1.37	0.27
ln Population	ln Number of inhabitants	17.10	1.21

Further, from our estimation results we derive R&D input additionality (i.e., the amount of business sector R&D generated by one dollar of public support via the R&D tax reliefs). We calculate the input additionality, or the marginal change in the business sector R&D with respect to a marginal change in the R&D tax subsidy or government tax relief for R&D (GTARD), as follows (see also Thomson, 2017; Appelt et al., 2020):

$$\frac{\partial\, BERD}{\partial\, GTARD} = \frac{1}{1-\tau} * \frac{\hat{\beta}_{B\text{-}index}}{\hat{\beta}_{B\text{-}index}(1 - B\text{-}index) - B\text{-}index} \qquad (1)$$

where τ denotes the corporate income tax (CIT) rate and $\hat{\beta}_{B\text{-}index}$ is the estimated elasticity of business R&D expenditure to the B-index. An input additionality value below 1 means that public R&D support crowds out privately funded R&D expenditures, while the value of 1 means that a one unit increase in public R&D support converts into one unit of private R&D. A value higher than 1 indicates that there is input additionality (i.e., the public R&D support increases private R&D spending). We calculate the overall input additionality and the R&D tax incentive-specific input additionality measures for the volume-based, incremental-based, and the hybrid R&D tax incentive schemes. Our calculations employ the average B-index and CIT in the samples.

In addition to targeted R&D tax incentives, general profit taxes may also affect business sector R&D spending and innovation output (Lichter et al., 2021). We control for the levels of CIT among the sample countries extracted from the OECD database. The OECD country-specific reports were used as the primary source of information on the characteristics of R&D tax schemes from 2000 to 2018.[10] We coded these data as a set of dummy variables characterizing the tax scheme features of a country in each year. The used documents comprehensively cover the sample countries' major R&D tax incentive features during the sample years. However, to generate variables "ceiling," "preferential treatments for SMEs," and "carry forward," we didn't find information for all years. We filled the gaps with values before and after the missing data for these variables, assuming that the features had remained unchanged during the years with missing observations. Table 1 describes the variables used in the empirical analysis.

5 Empirical findings

We empirically explored how the generosity of the R&D tax subsidy rates of different R&D tax incentive schemes relate to the R&D investments of the business sector and the total number of patents applied for at the USPTO. We first estimated the following basic model (Model 1) for the business sector R&D expenditure capturing its relationship with the B-index:

$$\ln BERD_{it} = \alpha_i + \beta_1 \ln(B\text{-}index)_{it} + \beta_2 \ln R\&D\ subs_{it} + \beta_3 \ln CIT_{it} + \beta_4 \ln GDP_{it} + \textstyle\sum_j \beta_{5_j} \times 1[year_{it} = j] + \varepsilon_{it}, \qquad (2)$$

where α_i controls for unobserved country heterogeneity, i and t denote country and time, respectively, and ε_{it} is a clustered standard error. The variable BERD is the (*ln*) total business enterprise R&D minus direct R&D subsidies obtained by the business sector. The estimated coefficient of the B-index measures the percentage change in business sector R&D expenditure related to a one percent reduction in the user cost of R&D. The explanatory variables further include the (*ln*) amount of direct R&D subsidies for the business sector, the CIT, and the (In) GDP. We further control for calendar years with the dummy variables. We estimated the model with country fixed effects and clustered standard errors to allow for arbitrary correlation within observation units.

In Model 2, we replace the R&D tax subsidy rate variable of Model 1 with its interactions with the key tax incentive scheme characteristics (i.e., incremental-based, volume-based, and hybrid incentive schemes). In other words, the estimated model comprises separate slope coefficients for the three different types of R&D tax incentive schemes concerning the business sector R&D investment response with respect to the generosity of R&D tax incentive schemes. We use mutually exclusive tax scheme categories for generating the dummy variables. In other words, we measure incremental alone and volume-based alone, and a hybrid combination of both incremental and volume-based R&D tax incentives as opposed to there being no R&D tax incentive scheme available. We further include the set of other features of the R&D tax schemes as the explanatory variables of the model.

Model 3 explores the relationship between different R&D tax incentive schemes and innovation output. The dependent variable in this model is the annual number of patent applications filed with the UPSTO on the country level. As the outcome variable is non-negative count data, we estimate the fixed-effects Poisson model with clustered standard errors. We use the same set of explanatory variables as in Model 2 except that we replace the variable "GDP" with "population"— that is, with the log number of inhabitants in a country—to control for the size of the country.[11] The explanatory variables representing the public R&D tax and direct subsidies and the R&D tax scheme features are lagged (*t*-1) values to reflect a time lag between the generation of innovation output from the innovation inputs.

Table 2 presents the estimation results of Models 1 and 2 for the business sector R&D expenditure using the B-indices for the profitable companies. The estimated coefficients capture the elasticity of business sector R&D expenditure to the user cost of R&D, measured by the R&D. The estimated coefficients for the B-index are in the range of -0.7–0.8 for Model 1 that does not take into consideration the variation related to the different R&D tax incentive schemes. These user cost elasticities are somewhat similar to those obtained by Appelt et al. (2020) using firm-level data and the moderately higher than short-term elasticities of about -0.5 for industry-level data that were estimated by Thomson (2017). The estimated coefficients of the interactions of the B-index and the dummies for the types of R&D tax schemes are all statistically significant, though only marginally for the interaction of the B-index for small profitable companies and the dummy variable for the volume-based R&D tax scheme. The user cost elasticities appear to be close to those of aggregate estimations for the volume-based R&D tax scheme (the most commonly implemented R&D tax incentive model), slightly higher for the hybrid model, and over double for the incremental-based tax incentives.

Table 3 provides the calculations of the business sector's R&D input additionality. Our estimations results indicate

Table 2 The estimation results of the fixed effects model for business sector R&D expenditure

Dependent variable B-index measure for	ln BERD large	ln BERD small	ln BERD large	ln BERD small
ln B-index	-0.776*** (-2.88)	-0.696** (-2.46)		
Volume-based x B-index			-0.799** (-2.33)	-0.664* (-1.74)
Incremental x B-index			-2.118*** (-3.58)	-1.864*** (-3.24)
Incr. & volume-based x B-index			-0.851*** (-3.51)	-0.901*** (4.65)
ln CIT	-0.040 (-0.13)	0.044 (0.15)	-0.023 (-0.07)	0.058 (0.19)
ln R&D subsidies	0.212*** (3.15)	0.218*** (3.08)	0.203*** (3.04)	0.204** (2.77)
ln GPD	0.840* (1.94)	0.710 (1.70)	1.046** (2.29)	0.900* (2.04)
Observations	329	329	329	329
R-squared (within)	0.68	0.67	0.69	0.68
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

z statistics in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3 The business sector R&D input additionality

B-index	R&D input additionality large firms	R&D input additionality small firms
Total	1.09	1.00
	(0.34, 1.72)	(0.18, 1.65)
Volume-based x B-index	1.12	0.96
	(0.14, 1.90)	(-0.21, 1.83)
Incremental x B-index	2.47	2.20
	(1.24, 3.37)	(0.98, 3.04)
Hybrid: incremental & volume-based x B-index	1.18	1.25
	(0.53, 1.74)	(0.75, 1.68)

The lower and upper bounds of the 95% confidence interval are reported in the parentheses.

that, by and large, the average marginal change in the business sector R&D with respect to a marginal change in the R&D tax subsidy is higher than 1 (i.e., there is input additionality). The business sector's R&D responses to higher R&D tax subsidy rates vary substantially. The volume-based R&D tax incentives using the B-index for small companies seem to, on average, generate a modest crowding-out effect. The incremental-based R&D incentives seem to be characterized by strong input additionality. One unit increase in R&D tax subsidy rates translates into about a 2.2–2.5 unit change in business sector R&D. The estimated coefficient for the direct R&D subsidy variable also appears positive and statistically significant. The variable capturing the CIT level does not get statistically significant coefficients in the estimated equations.

Table 4 reports the estimation results for business sector R&D expenditure, including the dummy variables for a set of additional R&D tax scheme features. The estimation results concerning the interaction variables of the B-index with volume-based, incremental-based, and hybrid R&D tax incentives provide qualitatively similar conclusions to those presented in Table 2. The estimated coefficient for the dummy variable "carry forward" and the variable "preferential treatment for SMEs" are positive and statistically significant. These empirical findings imply that countries employing an option for loss-making firms to carry forward unclaimed R&D tax credits tend to have a higher BERD. Furthermore, business sector R&D expenditure tends to be higher in the countries with an R&D tax credit scheme that provides favorable treatment for small companies. The estimated coefficients of the variable "ceiling" are positive and at least marginally statistically significant. This finding hints that countries employing a cap for R&D tax reliefs have a higher business sector R&D. The business sector R&D expenditures tend to be lower in countries with tax schemes offering a deduction from income tax.

We next used Model 3 to estimate the sample countries' count of patent applications filed with the USPTO. Table 5 shows that the estimated coefficients for the interaction variables of the B-index with the different R&D deduction-basis schemes are not statistically significant, except for the interaction of the B-index for small firms and the hybrid scheme. Countries with R&D tax schemes with preferential treatment for SMEs filed statistically significantly more patent applications with the USPTO than others. The estimated coefficients for the dummy variable "tax allowance" are positive and statistically significant, implying that innovation output measured by the patent applications filed with the USPTO is higher in those countries employing an R&D tax credit scheme with a deduction from income tax. Other R&D tax-scheme features do not relate statistically significantly to the number of filed patent applications.

Table 4 **The estimation results of the fixed effects model for business sector R&D expenditure with the R&D tax scheme features**

Dependent variable B-index measure for	ln BERD large firms	ln BERD small firms
Volume-based x B-index	-0.959**	-0.728*
	(-2.46)	(-1.73)
Incremental x B-index	-2.301***	-1.888***
	(-3.63)	(-3.41)
Incr. & volume-based x B-index	-0.700**	-0.562**
	(-2.43)	(-2.37)
PWHT/SSC exemption	-0.071	-0.016
	(-0.40)	(-0.08)
Tax credit	-0.502***	-0.441***
	(-3.61)	(-3.13)
Tax allowance	0.064	0.061
	(0.55)	(0.46)
Patent box	0.041	0.022
	(0.61)	(0.31)
Refund	-0.065	-0.072
	(-0.99)	(-1.14)
Carry forward	0.170**	0.176*
	(2.11)	(1.98)
Ceiling	0.224**	0.199*
	(2.12)	(1.82)
Preferential treatment for SMEs	0.252**	0.227*
	(2.14)	(1.75)
ln CIT	-0.063	0.033
	(-0.23)	(0.13)
ln R&D subsidies	0.165**	0.174**
	(2.45)	(2.34)
ln GDP	1.157***	0.976***
	(3.12)	(2.80)
Observations	329	329
R-squared (within)	0.74	0.72
Country FE	Yes	Yes
Year FE	Yes	Yes

z statistics in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 **The estimation results of using the fixed-effects Poisson model to count the patent applications filed with the USPTO**

Dependent variable B-index measure for	USPTO patent applications Large firms	USPTO patent applications Small firms
Volume-based x B-index	0.522	0.750
	(0.48)	(0.78)
Incremental x B-index	-1.455	-1.208
	(-0.64)	(-0.61)
Incr. & volume-based x B-index	-0.367	-1.651***
	(-0.46)	(-3.10)
PWHT/SSC exemption	-0.415	-0.322
	(-1.16)	(-0.94)
Tax credit	0.723	1.136
	(0.81)	(1.49)
Tax allowance	0.380***	0.331***
	(3.80)	(3.58)
Patent box	-0.196	-0.088
	(-1.07)	(-0.68)
Refund	-0.042	-0.028
	(-0.35)	(-0.24)
Carry forward	0.056	-0.043
	(0.35)	(-0.38)
Ceiling	-0.511	-0.890
	(-0.78)	(-1.63)
Preferential treatment for SMEs	0.367***	0.274***
	(3.28)	(3.57)
ln R&D subsidies	0.004	-0.073
	(0.03)	(-0.68)
ln Corporate Income Tax	-0.055	0.013
	(-0.14)	(0.04)
lpop	2.272	2.399**
	(1.46)	(2.24)
Observations	325	325
Country FE	Yes	Yes
Year FE	Yes	Yes

z statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Conclusions

We draw conclusions concerning the effectiveness of R&D tax scheme features based on both our estimation results using data from 25 OECD countries, collected from 2000 to 2018, and the recent economic literature. We have strong evidence that R&D tax credits incentivize companies' R&D investments and generate input additionality. Also, the R&D tax incentive features matter. Our estimation results show that the business sector R&D expenditures have been higher among the countries that have implemented either incremental-based tax incentives or a hybrid scheme with volume-based and incremental-based tax relief components. Our data indicate that the R&D input additionality is highest when the R&D tax incentives are based on incremental deduction. This finding is consistent with the meta-analysis of Blandinieres and Steinbrenner (2021), suggesting that the estimations linked to incremental-based tax incentives drive the positive results found in the literature. Our empirical estimations further provide some evidence that the hybrid tax-credit scheme relates positively to innovation output: The number of patents filed with the USPTO is higher in the countries employing both volume- and incremental-based R&D tax incentives.

Our data suggest that the countries with preferential R&D tax incentive provisions or more favorable terms for SMEs tend to have higher business enterprise expenditure on R&D as well as a higher number of patent applications filed with USPTO. Countries that have enabled loss-making firms to carry forward unclaimed R&D tax reliefs tend to have higher BERD. A carry-forward option typically favors young and small firms. These findings are thus consistent with various previous studies suggesting that young and small firms respond more strongly to R&D tax incentives due to their financial constraints. Small start-ups often suffer from financial-market imperfections arising from asymmetric information between them and potential financers, and they consequently lack access to private funds. Our analysis further hints that setting up an annual upper-ceiling threshold for the R&D tax deductions relates positively to the effectiveness of the R&D tax credit incentives scheme.

Prior empirical work exploring the joint impacts of R&D tax credits and R&D subsidies may provide further guidance for designing an R&D tax relief scheme (Pless, 2021). It seems that for SMEs, the R&D tax credits complement R&D subsidies (i.e., the two R&D incentive mechanisms boost the effectiveness of one another). However, for large companies, direct R&D support and R&D tax deductions tend to be substitutes, and thus it might be preferable to use only one of them for large firms. Furthermore, Einiö et al. (2022) suggested that there would be substantial welfare gains from targeting direct R&D subsidies to high-innovation-capacity firms rather than practicing a subsidy policy that allocates R&D support uniformly, without distinguishing between firm types, to the larger companies, whereas the welfare benefits of such a targeted R&D policy would be substantially smaller when small companies are included to the sample.[12]

Alongside our reported empirical findings, prior evidence suggests that effective R&D tax incentives can be provided by the schemes targeting SMEs and giving R&D incentives to young loss-making companies. The allocation of R&D support by primarily offering R&D tax credits to SMEs and focusing more on large companies in R&D subsidy allocation might generate higher welfare gains than an R&D tax credit scheme that treats all companies equally. In addition to the more efficient allocation of public R&D support, an R&D tax scheme offering no (or more minor) R&D deductions for the larger companies would substantially decrease the system's financial burden. For instance, in Finland, firms employing at least 500 persons cover about 55 percent of private R&D expenditure, with large companies of at least 250 persons covering over 65 percent of this expenditure. If SMEs employing less than 250 persons were granted, for instance, a 150 percent volume-based deduction (i.e., 50 percent extra deduction) of all their R&D expenses (excluding their publicly funded R&D), the fiscal cost of the R&D tax scheme would be about EUR 170 million if all the companies opt to use the deduction. The annual cost would be more than three times higher, about EUR 464 million, with a similar deduction for all companies.

These static calculations using 2020 Statistics Finland data do, however, underestimate the actual costs since they do not take into account the dynamic effects of the R&D tax credit scheme, such as boosting business sector R&D. On the other hand, the assumption of all firms opting to use available tax deduction overstates the actual cost. Assessing the longer-term welfare gains or productivity growth is also outside the scope of this study. Implementing a permanent R&D tax scheme in Finland also necessitates that the overall fiscal impacts of different R&D tax schemes are assessed.

The economic literature provides very little or no evidence of various features of the R&D tax credit scheme. Such details include the importance of expenditure eligible for a deduction in relation to the effectiveness of the R&D tax credit incentives. Also, we still lack firm-level empirical evidence of the effectiveness of different R&D tax scheme features concerning innovation output. Our aggregate data hint that the R&D tax incentive features matter for the innovation output, but they are limited to the country-level analysis of patents filed with the USPTO and do not allow us to make any causal inferences. More profound empirical explorations of the effectiveness of different R&D tax schemes using firm-level data combined with country-level R&D tax scheme features are still needed in order to better understand how different features moderate business sector R&D investment incentives and affect the generation of innovation output.

Endnotes

1 Countries include Australia, Austria, Belgium, Canada, Chile, Denmark, France, Greece, Hungary, Ireland, Italy, Japan, Korea, Lithuania, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Turkey, United Kingdom, and the United States.

2 Another important feature of this review is that it is focused on the impact of R&D tax incentives, so we omit works on the impact of R&D-related government grants and on the effects on innovation of general taxation (on this latter topic, we refer, e.g., to the interesting analysis presented in Akcigit et al., 2022).

3 Appelt et al. (2020) find that that EUR 1 of tax support stimulates an increase over EUR 1.4 of R&D for small firms employing less than 50 persons, EUR 1 of R&D for medium-sized firms employing 50–249 persons and about EUR 0.4 of R&D for large firms employing 250 persons or more.

4 Their conclusion is that tax incentives stimulate R&D investments, with a general finding that one euro of foregone taxes leads to a less than one euro of additional R&D expenditure, and that favorable tax schemes for R&D lead to more innovation, even though the evidence for this relationship is weak.

5 The underlying reason is that when subsidies or tax deductions are available to all companies, despite of their innovation capacity, low-R&D-productivity companies that are close to exit also receive public support and remain in business. They consequently retain some of the skilled workers that would move on to the R&D activities of higher innovation capacity companies if the company had exited—these higher innovation capacity companies have a higher likelihood to succeed in their innovation activities. This non-optimal allocation of resources restrains economic growth.

6 The literature exploring the determinants and patterns of firm growth finds that most firms do not grow much, but there tends to be only a handful of high-growth companies, outliers, that drive industry dynamics (Coad et al., 2017).

7 For instance, according to the PwC Global Investor Survey 2017, investors continued to view the U.S. as the most important country for companies' overall growth prospects. See: https://www.pwc.com/gx/en/ceo-survey/2017/industries/pwc-global-investor-survey-feb2017.pdf.

8 According to the World Intellectual Property Organization, WIPO, in 2018, more than half of all patent applications filed in the U.S. were non-resident applications. See: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2019-chapter1.pdf.

9 For a detailed description of the estimation methodology of the B-index, see https://www.oecd.org/sti/rd-tax-stats-bindex-notes.pdf.

10 The most recent country-specific reports that were available at https://www.oecd.org/sti/rd-tax-stats.htm (accessed June 2021). We further used various previous OECD reports, such as *OECD Science, Technology and Innovation Outlooks* and other documents in order to obtain information regarding the R&D tax scheme features of the countries (see, e.g., OECD, 2018).

11 This corresponds to the standard approach to making cross-country comparisons of innovation activities by scaling the R&D expenditures and the number of patents by country size, dividing the former by the GDP and the latter by the number of inhabitants.

12 In practice, implementing an optimal policy is hardly viable, but there are ways to develop the practical execution of an innovation policy in order to target R&D support more efficiently (see Einiö et al., 2022, for a discussion of this).

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