# How Effective Are R&D Tax Incentives? Reconciling the Micro and Macro Evidence

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**Abstract**

Recent firm-level studies find R&D tax incentives to be much more effective at stimulating firms' R&D investment than what aggregate analyses indicate. Based on a distributed analysis of official R&D survey and administrative tax relief microdata for 19 OECD countries, we show that two factors can reconcile these contrasting results. Firstly, a limited uptake of R&D tax incentives in most countries makes aggregate studies underestimate the effectiveness of R&D tax incentives. Secondly, R&D tax incentives are (much) less effective for large and R&D-intensive firms, which account for a small share of R&D-performing firms but most aggregate R&D tax relief.

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# 1 Introduction

Investment in research and experimental development (R&D) lies at the heart of modern theories explaining economic growth (Romer, 1990; Aghion and Howitt, 1992). Activities of business enterprises play a central role in this endeavour, with over two thirds of R&D in OECD countries performed within private firms (OECD, 2023). However, knowledge spillovers from R&D mean that, on their own, private firms will invest in R&D less than what is socially optimal.[1] To correct for the positive externality, governments subsidise business R&D. Across countries, the number one policy tool to do so is R&D tax incentives, which accounted for around 55% of the total government support for business R&D in the OECD area in 2021 (OECD, 2024).

How effective are R&D tax incentives at stimulating firms' R&D investment? Over time, several aggregate cross-country studies and many firm-level studies have attempted to answer this question.[2] Both types of studies agree that R&D tax incentives are able to boost R&D expenditure, but they differ rather dramatically in the magnitude of the estimated effects. While aggregate and industry-level cross-country studies consistently find elasticities of R&D expenditure with respect to the tax price of R&D around -0.5,[3] several recent well-identified firm-level studies find much larger elasticities between -1.5 and -4.[4] Such pronounced differences are both puzzling and important. To translate them into monetary terms, assume that a firm spending 1 dollar on R&D gets 20 cents back through reduced taxes. Then an elasticity of -0.5 implies that 1 dollar of foregone government revenue results in approximately 0.6 dollar of additional R&D expenditure.[5] In contrast, an elasticity of -2 (-4) implies that 1 dollar of foregone government revenue translates into roughly 1.70 dollars (2.5 dollars) of additional R&D. The effects of such different magnitudes carry starkly different implications both for policy and for macroeconomic

[1]For example, Bloom et al. (2013) estimate private returns to R&D of 21% but social returns of 55%. See also a review by Hall et al. (2010).

[2]See recent reviews by Castellacci and Lie (2015), Appelt et al. (2016) and Hall (2019).

[3]This is specifically true for estimates from static specifications. Specifications that allow for a dynamic adjustment of R&D expenditure are sensitive to the particular specification and the estimated coefficient on the lagged dependent variable and produce short-run elasticities between -0.1 and -0.5 and long-term elasticites between -0.3 and -1. See Bloom et al. (2002), Guellec and Van Pottelsberghe De La Potterie (2003), Thomson (2017) and Appelt et al. (2019).

[4]Rao (2016) estimates the impact of the federal R&D tax credit in the US using an IV approach that exploits changes in the tax law over time, finding an elasticity of -2. Two studies estimate the impact of R&D tax incentives in the UK by analysing a 2008 change that raised the size threshold under which firms qualified for a more generous tax relief. In a difference-in-differences framework, Guceri and Liu (2019) find an elasticity of -1.6, and a regression discontinuity design analysis by Dechezleprêtre et al. (2023) finds an even greater elasticity of -4.1. Agrawal et al. (2020) study a 2004 change in the Canadian R&D tax credit, in which some firms became eligible for more generous and fully refundable tax relief on a larger amount of qualifying R&D expenditures, and their difference-in-difference estimates imply an elasticity between -0.7 and -4.6.

[5]See subsection 5.3 for details of the calculation.

models of endogenous growth.

In this paper, we attempt to bridge the gap between aggregate and firm-level studies and explain their contrasting findings. To this end, we leverage a unique new dataset covering 19 OECD countries over years 2000-2021, which we have constructed directly from representative R&D microdata following the "distributed microdata approach" pioneered by Bartelsman et al. (2005). The microdata combines, at the firm level, rich information on R&D expenditure and employment with administrative records on R&D tax relief. As the underlying firm-level data cannot be pooled across countries, we estimate the effect of R&D tax incentives on R&D expenditure at the level of firm groupings defined by a country, a 2-digit industry and a size class (small/medium/large). We control for country-industry-size class fixed effects and industry-size class-year fixed effects. Thus, we identify the effects of R&D tax incentives purely from a time variation in the tax price of R&D faced by firms in a particular country, industry and size class, relative to broad trends for firms of a given size in a given industry. To account for the fact that each firm's tax price of R&D depends on the value and structure of its R&D expenditure, we instrument the tax price with a synthetic tax price that captures only time-variation due to policy changes, keeping the set of firms and their R&D expenditure fixed between periods.

One potential explanation for the different results of aggregate as compared to firm-level studies is that aggregate studies model R&D tax incentives for a representative firm and, as a result, do not accurately reflect all features of R&D tax incentives available in each country. For example, many countries offer preferential rates for small and medium enterprises (SMEs) or impose ceilings on eligible R&D expenditure. This leads to substantial differences between the marginal subsidy rates available to SMEs and large firms and to firms below and above the ceiling. Modelling the tax price of R&D for a representative firm does not capture these differences and results in a measurement error in the key explanatory variable, which could bias the estimated elasticity.[6]

The advantage of the distributed microdata approach is that we can model R&D tax incentives at the firm level, taking into account the detailed features of each incentive. This allows us to explore the importance of the measurement error by comparing elasticities obtained when we model R&D tax incentives at the firm level and when we instead model them for a representative firm, as earlier aggregate studies do. We find that inaccurate modelling of R&D tax incentives in aggregate studies explains, at most, a small part of the gap between the elasticities found in aggregate and firm-level studies.

Another potential explanation, largely neglected in the literature so far, is that not all eligible firms benefit from R&D tax relief, and studies that do not take this into account

[6]If the measurement error is uncorrelated with other relevant variables, the bias will be towards zero.

overestimate the actual tax relief used and consequently underestimate the effectiveness of R&D tax incentives. Existing aggregate and industry-level studies implicitly assume that all eligible firms use the tax relief. In contrast, firm-level studies often use administrative tax records and specifically focus on those firms that do benefit from R&D tax relief.[7] This could explain the weaker effects found in aggregate studies.

Since the firm-level data underlying our distributed analysis combines R&D survey data, representative of the population of R&D-performing firms in each country, with administrative data on R&D tax relief, we are able to test this explanation, and we find strong evidence in its favour. We document that, in an average country and industry in our sample, fewer than half of R&D-performing firms receive R&D tax relief.[8] When we take into account whether firms actually receive the R&D tax relief for which they are eligible, the estimated elasticities increase by about 60%, becoming more similar to those found in firm-level studies.

Yet another potential explanation concerns the role of heterogeneous effects of R&D tax incentives. In particular, smaller firms might be more responsive to R&D tax incentives, for example, due to being more credit constrained, and several studies suggest that this is indeed the case.[9] Most R&D-performing firms are small or medium-sized enterprises (SMEs), but most R&D is undertaken by large firms (Appelt et al., 2022).[10] Firm-level studies either implicitly assign equal weight to all firms in the sample, most of which tend to be small (Rao, 2016), or specifically study firms of some (moderate) size.[11] In contrast, the results of aggregate studies are, to an important extent, driven by large firms, which account for the bulk of the aggregate R&D. If small firms are more responsive to R&D tax incentives than large firms, this will then translate into larger effects in firm-level studies compared to aggregate studies. Similarly, the effects of R&D tax incentives might depend on firms' R&D intensity. In particular, R&D-intensive firms,

[7] That said, firm-level studies based on R&D survey data, which typically do not contain information on R&D tax relief, could underestimate the effect of R&D tax incentives for the same reason as aggregate studies. Guceri (2018) uses R&D survey data to study the same policy reform in the UK that Guceri and Liu (2019) and Dechezleprêtre et al. (2023) explore using administrative tax data and finds a substantially smaller elasticity of firm R&D with respect to its tax price than these studies.

[8] Not focusing specifically on R&D tax incentives, Zwick (2021) similarly finds that only 37% eligible US firms claimed refunds for tax losses. In the context of general investment incentives, Cui et al. (2022) document that Chinese firms failed to claim accelerated depreciation on over 80% of eligible investments.

[9] Hægeland and Møen (2007), Baghana and Mohnen (2009), Lokshin and Mohnen (2012), Labeaga et al. (2014) and Kasahara et al. (2014).

[10] In 2020, the share of firms with 250 or more employees in the total business expenditure on R&D was, for example, 88% in the US, 68% in Italy and in the Netherlands, and 48% in Norway (OECD, 2023).

[11] By the virtue of identifying causal effects from a change in an SME definition, the UK studies (Guceri and Liu, 2019; Dechezleprêtre et al., 2023) analyse firms around the boundary between SMEs and large firms. Agrawal et al. (2020) focus on firms with taxable profits between 200 thousand and 500 thousand Canadian dollars.

for which R&D represents a core part of their business, might be less responsive to the tax price of R&D than less R&D-intensive firms, which can, for example, substitute their own R&D with purchases of technology embedded in capital goods.[12] If a small number of R&D-intensive industries or firms account for a disproportionate share of aggregate R&D, this could again explain elasticities found in aggregate studies being smaller than those found in firm-level studies.

The fact that we can accurately model R&D tax incentives at the firm level and, at the same time, explore the rich variation in R&D tax incentives across countries over time means that we can estimate R&D tax price elasticities for firms of different size and R&D intensity. When we do so, we find strong heterogeneity in the effects of R&D tax incentives. For small and medium firms with relatively low R&D intensity, we estimate elasticities greater in absolute value than -1.5, but we find that elasticities for large firms and for R&D-intensive firms are smaller (in absolute value) by 1.1 and by 0.8, respectively. This implies an elasticity of essentially zero for firms that are large *and* R&D-intensive — a striking result given that such firms account for a large part of R&D tax relief in most countries.

We find that the effect heterogeneity can be at least partly explained by a greater importance of credit constraints among smaller firms. Firstly, the stronger effects of R&D tax incentives for smaller firms are driven by R&D-related labour and material costs, while the effects for expenditure on R&D-related machinery and buildings — which is easier to use as a collateral or sell — do not differ by firm size. Secondly, the effects of R&D tax incentives appear especially strong for younger firms, which are particularly likely to face financing constraints.

An alternative explanation for the stronger estimated effects for smaller firms could be that larger firms take longer to adjust their R&D in response to changes in R&D tax incentives, and our static baseline specification fails to account for this. When we estimate a dynamic specification, we indeed find evidence of slower adjustment for larger firms, but the resulting long-term elasticities are again much larger for smaller firms and similar to the elasticities found in the static specification. Another concern could be that direct support, such as R&D grants, is an omitted variable biasing the results, especially for small firms, which tend to rely on direct support more heavily (Appelt et al., 2022). However, we find that controlling for direct support intensity has only a minor impact on the estimated elasticities and does not affect the heterogeneity in the results.

Spillovers across firms could, in theory, also account for the differences in the findings of aggregate and firm-level studies, as estimates at a more aggregate level include

[12] Hægeland and Møen (2007), Castellacci and Lie (2015) and Acconcia and Cantabene (2018) provide evidence suggesting R&D tax incentives have weaker effects in R&D intensive or high-tech industries. Bodas Freitas et al. (2017) find the opposite result.

spillovers across firms within that level (e.g. industry, country). However, explaining the much stronger effects of R&D tax incentives found in firm-level studies would require strong strategic substitutability between R&D expenditure of different firms, which is not supported by existing evidence. Even if firms' R&D expenditure has important spillover effects on other firms' market value, patenting or productivity,[13] the direction of spillover effects on other firms' R&D expenditure is theoretically ambiguous and, empirically, such spillovers have been found to be weak and, if anything, positive (Cockburn and Henderson, 1994; Bloom et al., 2013). For this reason, spillovers are unlikely to explain the differences in the effects found by firm-level and aggregate studies.

Our findings have important implications for policy and economic modeling. In terms of aggregate effects, they imply that 1 dollar of R&D tax relief is, on average, associated with 60 cents of additional R&D expenditure, and the aggregate elasticity of R&D with respect to its tax price — an important parameter in many models of endogenous growth[14] — is -0.5. This suggests that the effectiveness of R&D tax incentives in boosting aggregate R&D expenditure is somewhat weaker than what recent firm-level studies would indicate. In addition, the results imply that R&D tax incentive design features ensuring that more of the support goes to smaller and less R&D-intensive firms can substantially increase the overall effectiveness of the incentives. Such features include ceilings, thresholds, preferential rates, payroll withholding tax credits and refundability provisions. Limiting the administrative and compliance costs associated with claiming R&D tax incentives is also important to ensure that smaller and less R&D-intensive firms actually use the incentives.

The paper is organised as follows. The remainder of the introduction contains a brief literature review. Section 2 provides an overview of the main design features that feed into the modelling of R&D tax incentives, introduces our data and describes how variables are constructed. Section 3 investigates the limited uptake of R&D tax incentives and describes how R&D tax relief is distributed across firms of different size and R&D intensity. Section 4 explains the empirical specification for estimating the effects of R&D tax incentives, and Sections 5 and 6 present the results. Section 7 concludes.

**Related Literature.** Our study contributes to the literature examining the effectiveness of R&D tax incentives, reviewed by Hall and Van Reenen (2000), Castellacci and Lie (2015), Appelt et al. (2016) and Hall (2019). Our paper is closely related to studies investigating the impact of R&D tax incentives at the level of some aggregate units,

[13] Dechezleprêtre et al. (2023) document positive spillovers of additional R&D expenditure induced by R&D tax credit on patenting by technologically related firms.

[14] See, for example, Acemoglu et al. (2018), Akcigit and Kerr (2018), De Ridder (2024) and Aghion et al. (2024).

such as US states (Wilson, 2009), industries (Thomson, 2017) and countries (Bloom et al., 2002; Guellec and Van Pottelsberghe De La Potterie, 2003; Appelt et al., 2019). However, unlike these studies, we are able to model R&D tax incentives at the firm level, taking into account the cost composition of each firm's R&D expenditure and detailed incentive design features such as preferential rates and expenditure ceilings and thresholds. Additionally, we are able to measure the uptake of R&D tax incentives — something not previously undertaken on a cross-country basis — and take it into account in the econometric analysis. Finally, unlike existing aggregate studies, we are able to investigate the heterogeneous effects of R&D tax incentives across firms with different characteristics.

Recent firm-level studies estimating the impact of R&D tax incentives include Rao (2016) for the US, Agrawal et al. (2020) for Canada, Guceri (2018), Guceri and Liu (2019) and Dechezleprêtre et al. (2023) for the UK, Mulkay and Mairesse (2013) for France, Acconcia and Cantabene (2018) for Italy, Kasahara et al. (2014) for Japan, Lokshin and Mohnen (2012) for the Netherlands and Bøler et al. (2015) for Norway. Like these studies, we can model R&D tax incentives at the firm level and explore firm heterogeneity, but we are also able to explore rich cross-country variation in the availability, design and generosity of R&D tax incentives that is not available to studies focusing on a single country. This allows us to robustly estimate the heterogeneous effects of R&D tax incentives by firm size and R&D intensity, something difficult to do in firm-level studies that often have relatively few large firms in the sample, and, more fundamentally, either have to rely on strong identifying assumptions[15] or, in the rare cases where a suitable natural experiment presents itself, are constrained by the specific nature of the treated firms, which limits their ability to extrapolate the results to the entire economy or to test for heterogeneous effects across different types of firms.[16]

Our paper is also related to studies that explore the role of financial constraints in driving the heterogeneous response of firms to innovation support policies. Small firms are more likely to be credit constrained, and hence they might show stronger effects of public support that alleviates such constraints (Hall and Lerner, 2010). In the context of R&D tax incentives, Kasahara et al. (2014), Rao (2016), Acconcia and Cantabene (2018) and Dechezleprêtre et al. (2023) all document stronger effects for firms that are more likely to be financially constrained. Recent regression discontinuity design studies have arrived at similar results also for R&D grants (Bronzini and Iachini, 2014; Howell, 2017; Santoleri et al., 2024) and subsidised R&D loans (Zhao and Ziedonis, 2020).

[15] For example, Hægeland and Møen (2007) and Labeaga et al. (2014) compare firms using and not using R&D tax relief, but, as they acknowledge, whether a firm uses R&D tax relief is largely its decision, which can be correlated with its R&D performance.

[16] An important exception in the form of a well-identified study that explicitly compares effects for firms of different sizes is Rao (2016).

Last but not least, our paper contributes to the growing number of studies that analyse firm-related economic phenomena using the distributed microdata approach. This approach is motivated by the fact that confidentiality concerns make it virtually impossible to analyse firm-level data for more than one country at a time, severely limiting the scope for cross-country work and confining it to the use of the much less flexible aggregate data,[17] or commercial cross-country company data that are not representative of the firm population (Bajgar et al., 2020). The distributed microdata approach addresses this challenge by means of a harmonised data-preparation protocol, and a statistical code that is applied to confidential firm-level data in each country and produces statistical output that is not itself confidential and can be pooled across countries and further analysed. The approach was pioneered by Eric Bartelsman and colleagues in the early 2000s (Bartelsman et al., 2005, 2013) and has since been applied to topics ranging from start-up dynamics (Criscuolo et al., 2017) to technology diffusion (Hagsten and Kotnik, 2017) to industry concentration (Bajgar et al., 2023). To the best of our knowledge, the present paper represents the first application of the distributed microdata methodology to analysing the impact of a specific type of business innovation support policy, or industrial policy more generally.

# 2 Data and Measurement

## 2.1 Design of R&D Tax Incentives

R&D tax incentives are intended to promote R&D activity by reducing the user cost of R&D to firms. Unlike direct funding (e.g. through R&D grants and government procurement of R&D services), which involves discretionary choices on the part of governments as to which R&D projects and firms to support, R&D tax incentives are market-based instruments that provide broader-based R&D support. Over the last two decades, R&D tax incentives have increasingly become a common feature of the innovation policy toolbox of policy makers. In 2023, 33 out of 38 OECD countries offered R&D tax incentive support at the central or subnational government level, up from 19 countries in 2000 (OECD, 2024).

There are important differences in how the tax incentive programmes are designed in different countries. To begin with, some countries offer R&D tax credits (e.g. France, Japan, the United States), while others offer enhanced tax allowances (e.g. Czechia, the United Kingdom for SMEs). Despite the general trend towards volume-based programmes

[17] In particular, aggregate data inadequately capture firm heterogeneity, which has been the focal point of the analysis of firms in economics over the past three decades (Bartelsman and Doms, 2000).

that subsidise firms' R&D from the first euro or dollar spent, several countries support the increment in R&D over past levels, either alone (e.g. Italy, the United States) or in combination with a volume-based tax relief component (e.g. Japan, Spain). Differences also exist in the way governments define qualifying R&D expenditure, particularly with regard to how they treat R&D-related capital investments and outsourced R&D. While in some cases only current in-house R&D expenditure is eligible (e.g. the United States), in others firms can additionally deduct expenditure on R&D related machinery (e.g. Italy), buildings (e.g. France) or outsourced R&D (e.g. France).

In some countries (e.g. Czechia, Belgium), corporate R&D performers receive the same rate of R&D tax subsidy irrespective of their size or the amount of R&D spending, while other countries support R&D only up to a certain ceiling (e.g. Norway) or support R&D over a certain threshold at a lower rate (e.g. Canada). If this ceiling or threshold binds, the rate of tax support is effectively higher for firms that perform less R&D (which are, on average, also of smaller size). Some countries also directly offer preferential tax incentive rates to small and medium enterprises (e.g. Australia) or start-ups (e.g. the Netherlands). Programmes also differ in the provisions that apply to loss-making firms. Most countries allow loss-making firms to carry unused tax relief over to subsequent years, but several offer to pay it out in cash, either for small and medium enterprises (e.g. Australia) or all firms (e.g. Sweden).

As a result, R&D tax subsidy rates differ not only across countries, but also within countries according to features such as size, R&D intensity and R&D cost composition. This means that previous cross-country analyses of R&D tax incentives, which computed R&D tax subsidy rates for a representative firm in each country (Bloom et al., 2002) or country-industry (Thomson, 2017) could not accurately capture the actual R&D tax subsidy rates available to firms engaging in R&D. Capturing the full heterogeneity in available tax support is particularly important if one wishes to estimate how the effects of tax incentives vary across different types of firms. Otherwise, one could mistakenly interpret heterogeneity in tax subsidy rates available to different firms as differences in the responsiveness of these firms to the tax incentives. In this paper, we address this issue by calculating notional R&D tax subsidy rates directly at the firm-level, taking into account each firm's situation (e.g. total R&D expenditure, cost structure of R&D, firm size etc.) and modelling all key design features, such as ceilings, thresholds and preferential rates.

## 2.2 Source Firm-Level Data

The primary microdata underlying the analysis consist of firm-level records of business R&D expenditure, which are collected through national business R&D surveys in line with international standards for measuring and reporting R&D (OECD, 2015) and serve as a basis for producing official aggregate R&D statistics in each country. For each R&D-performing firm, they contain basic demographic information such as employment and industry of the main activity along with detailed information on the firm's R&D. This includes, most importantly, information on R&D performed (intramural R&D) and outsourced (extramural R&D), the type of R&D costs (e.g. labour, current consumption of goods and services, capital), R&D employment (expressed in headcount and full-time equivalents) and sources of R&D funding (e.g. own, other business, government). Business R&D surveys are generally designed to be representative of the population of R&D-performing firms in each country. To ensure the harmonisation of data across countries, we only keep firms that actually responded to the R&D survey, dropping imputed observations and reweighting the remaining observations accordingly. We also drop micro-firms with fewer than 10 employees, which several countries do not cover in their R&D surveys.

The second data source we rely on is firm-level information on R&D tax relief from tax record data. A unique feature of our study is that we are able to link the R&D survey responses with the R&D tax relief records at the firm level. The tax relief records provide information on the amount of R&D tax benefits received by corporate tax relief recipients and, in some countries, also on firm status with respect to preferential tax treatment (e.g. as SME). By matching business R&D and tax relief microdata, we are able to identify the subset of R&D-performing firms that actually use the R&D tax relief available to them and observe the amount of support they receive.

In total, the microdata underlying our analysis cover about 35,000 R&D-performing firms per year, located in 19 different countries.

## 2.3 Constructing a Micro-Aggregated Dataset

Both the R&D microdata and the tax relief records are confidential, which makes them very difficult to access and analyse for more than one country at a time. We tackle this challenge by relying on distributed microdata analysis — a method of studying microdata held in separate enclaves by means of a common, centrally designed routine.[18] This routine is automated and flexible enough to run on different data sources in different countries and to take into account their idiosyncrasies. The work, undertaken within the OECD microBeRD project,[19] relies on the collaboration of an international expert network, with each national team having legal access to their respective national microdata.

[18] The distributed approach to the analysis of business microdata was pioneered in the beginning of the 2000s in a series of cross-country projects on firm demographics and productivity (Bartelsman et al., 2005).

[19] See http://oe.cd/microberd and OECD (2020).

The harmonised cleaning and statistical routines produce micro-aggregated statistics that are comparable across countries and represent statistical moments – count, mean, standard deviation and percentiles – of distributions of firm-level variables across various sets of firms.

The distributed analysis represents a hybrid between a firm-level and more aggregate analysis. We calculate statistics directly on firm-level data in each country, which allows us, for example, to model R&D tax incentives available to each individual firm (as discussed in more detail below). At the same time, the firm-level records cannot be pooled across countries and, as a result, we cannot run pooled cross-country regressions directly at the firm level.

We perform the analysis at the level of data cells defined by country, 2-digit industry, size class and year.[20] The data used for the analysis then consist of means and totals calculated across all R&D-performing firms within each cell. We use three size classes defined by firm employment: small (10-49 employees), medium (50-249 employees) and large (250 or more employees).[21] The R&D data are available at an annual frequency for a majority of countries, and at a bi-annual frequency or a mix of annual and bi-annual frequency for most others.[22]

The baseline sample represents an unbalanced panel covering 14 countries over the period of 2000-2021. It consists of 11 countries that had an R&D tax incentive in place at some point during the sample period and for which administrative R&D tax relief records are available (Australia, Belgium, Czechia, France, Italy, the Netherlands, New Zealand, Norway, Portugal, Slovakia and Sweden). It additionally covers 3 countries that did not offer any R&D tax incentives during the sample period but which are included because they help to pin down the industry-size class-year fixed effects (see Section 4 below) and, thus, reduce the standard errors in the estimated regressions (Germany, Israel and Switzerland). There are an additional 5 countries that had an R&D tax incentive in place at some point but for which we only have information based on R&D microdata and not on the administrative R&D tax relief records (Austria, Chile, Japan, Spain and the United Kingdom). For these countries, we are not able to construct measures of the

[20]We use A38 industries, which are derived from ISIC rev. 4 2-digit industries by combining certain 2-digit industries into a single A38 industry (see EC (2010)). The data cover all industries except 3 industries with no or very limited business R&D activity: 84 (*Public administration and defence; compulsory social security*), 97-98 (*Activities of households as employers*) and 99 (*Activities of extraterritorial organisations and bodies*).

[21]As noted above, firms with fewer than 10 employees are dropped from the analysis because information on them is not available in some countries.

[22]The data are available at a bi-annual frequency for Belgium, Germany and Sweden. Australia, Austria, New Zealand and Portugal switch between an annual and a bi-annual frequency at some point during the sample period. In the case of Spain and Switzerland, the gaps between survey years are longer and irregular. Data for all other countries are available at an annual frequency. Online Appendix Table B.1 lists sample years for each country.

cost of R&D investment that take into account the actual use of the tax incentives — one of the key contributions of this paper. For this reason, we exclude these countries from our baseline sample but test the robustness of the results to using a broader sample in which they are included (using a specification that does not require availability of the tax relief data).

To ensure that the results are not driven by outliers, we drop the 1% country-industry-size classes with the largest proportional difference between the years with the largest and smallest intramural R&D expenditure. There are 8 such country-industry-size classes, representing 107 observations, and all of them have seen at least a 60-fold increase or decrease in R&D expenditure. We show in robustness checks that keeping these observations would have little effect on the results.

The resulting baseline sample counts 7,273 country-industry-size class-year observations with non-missing values of the key variables.[23] All financial variables are converted into 2005 USD using purchasing power parity (PPP) exchange rates. R&D expenditure is deflated using GDP-PPP deflators.

## 2.4 Measuring the Cost of R&D Investment

Our main explanatory variable is the B-Index, the tax component of Jorgenson's (1963) user cost of (R&D) capital. The B-Index, sometimes referred to as the tax price of R&D, is defined as the pre-tax return required for a firm to financially break even on one additional monetary unit on R&D (McFetridge and Warda, 1983; Warda, 2001; OECD, 2013). The implied marginal R&D tax subsidy rate is then given by 1 minus the B-Index. The advantage of the B-Index is that it summarises, in one indicator that can be compared across different tax regimes, the pre-tax notional generosity of R&D tax incentives available to firms with defined characteristics. It can also be computed both for countries that offer R&D tax incentives and for those that do not. For these reasons, it is commonly used in cross-country studies of R&D tax incentives.[24]

We calculate the B-Index for each firm j as the weighted average of tax prices $c_j^C$ applicable to several R&D cost components $C$: R&D labour expenditure, other current R&D expenditure (materials and other consumables, intellectual services), expenditure on R&D-related machinery and expenditure on R&D-related buildings. The B-Index for firm j is given as

$$BIndex_j^{the} \equiv \sum_c w_j^c c_j^c \ , \tag{1}$$

[23]The broader 19-country sample that includes countries for which administrative R&D tax relief records are not available counts 10,053 observations.

[24]See Bloom et al. (2002); Guellec and Van Pottelsberghe De La Potterie (2003); Wilson (2009); Thomson (2017) and Appelt et al. (2019).

where $C \in \{$*labour, other current expenditure, machinery, buildings*$\}$ and weights $w_j^C$ are given by the share of each type of R&D expenditure in the total R&D expenditure of firm j. We use the superscript "*the*" to mark that this is a theoretical B-Index that captures tax relief for which a firm is in theory eligible but it does not take into account whether the firm actually uses the tax relief. The tax price $c_j^C$ is computed as the after-tax cost ($ATC_j^C$) of one additional unit of R&D input, normalised by the share of revenue left over after paying tax:

$$c_j^C = \frac{ATC_j^C}{(1-\tau_j)} \ . \tag{2}$$

In the expression, $\tau_j$ is the corporate income tax rate that applies to firm $j$, and the normalisation converts the after-tax numerator into pre-tax terms, allowing the comparison across countries with different tax rates. For each R&D cost component, $ATC_j^C$ can be calculated as one minus the combined net present value of allowances and credits applying to R&D outlays.[25] In the case of current R&D expenditures, which are fully deductible in most countries (i.e. the net present value equals 1), the after-tax cost is derived as

$$ATC_j^{current} = 1 - \tau_j * (1 + TA_j^{current}) - TC_j^{current} \ , \tag{3}$$

where $TA_j^{current}$ and $TC_j^{current}$, respectively, denote the enhanced tax allowance rate and tax credit rate applicable to a marginal unit of current R&D expenditure incurred by firm j. Importantly, the after-tax cost is calculated using the rates that apply to a marginal unit of R&D of a given firm. This matters, for example, if a tax incentive involves a ceiling on eligible R&D expenditure, or in the case of incremental incentives that apply only to R&D expenditure in excess of a pre-defined base amount (e.g. firm's average R&D expenditure in the previous 2 years).[26] The modelling also accounts for the taxability of R&D tax benefits in some OECD economies and the interaction of wage tax-related incentives and corporate tax offsets, where applicable.[27]

Calculating the B-Index requires detailed information on tax incentive design and applicable rates in each country and their evolution over time. To this end, we rely on information collected by the OECD and validated by experts from each country. In Online Appendix Table A.1, we report the key features and parameters of the modelled

[25] For machinery, equipment and buildings used in the context of R&D projects, the net present value and adjustment factor $\theta$ depends on the depreciation method and rate applicable in each country.

[26] In the case of incremental R&D tax incentives, the formulas also consider the impact that current decisions have on future baseline R&D levels. For the calculation of adjustment factors in this case, see http://www.oecd.org/sti/rd-tax-stats-design-subsidy.pdf.

[27] One limitation that our paper shares with previous studies is that, for most countries, we do not know which firms generate profit. Unless tax incentives are fully refundable, they represent a weaker stimulus for loss-making firms. We take the standard approach of assuming that all firms generate sufficient profit to use tax relief available to them.

R&D tax incentives in the last sample year for each country. In Online Appendix Table A.2, we describe key changes in R&D tax incentives available in each country over the sample period.

Previous cross-country studies relied on a B-Index for a representative firm. For comparison purposes, we also compute a representative-firm B-Index, $\log BIndex_{cit}^{repr}$, as $BIndex_j$ computed for a firm that has the same expenditure weights $w_j^C$ as its industry does in aggregate,[28] exceeds any minimum expenditure floor, is not affected by any expenditure ceiling or threshold and does not benefit from any preferential treatment.

In our baseline approach, however, we calculate B-Index for each individual firm covered in the R&D microdata. B-Index can vary among firms subject to the same tax regime for several reasons. Firstly, cost shares $w_j^C$ are firm-specific, and eligibility and incentive rates often differ across cost components C. Secondly, tax allowance rates $TA_j^C$, tax credit rates $TC_j^C$ and corporate income tax rates $\tau_j$ may vary across firms as a result of a preferential tax treatment of certain groups of firms (e.g. SMEs, young firms). Thirdly, incremental incentives and thresholds, ceilings and floors on eligible R&D expenditure mean that each firm's B-Index depends on the level of its R&D expenditure.

These factors can lead not only to differences between the marginal subsidy rates of individual firms, but also to sizeable systematic differences between firms of different size or in different industries. For example, in 2017, the tax credit offered to firms in Sweden was the same for both small and large firms, at 10%. However, an annual ceiling of 2.76 million Swedish krona (about 270,000 euro) on eligible R&D expenditure, which is much more likely to bind for larger firms, meant that the implied marginal R&D tax subsidy rate (i.e. 1 - B-Index) was about 7% for an average small firm (10-49 employees) but only about 4% for an average large firm (250 or more employees).

The $BIndex_j^{the}$ defined above measures the theoretical rate of R&D tax subsidy to which a firm j is, in principle, entitled given its characteristics, but it does not take into account whether the firm actually applies for and receives R&D tax relief. This matters because, as we document in subsection 3.1 below, a large share of eligible R&D performers do not actually benefit from R&D tax support. For such firms, $BIndex_j^{the}$ underestimates the marginal cost of investing in R&D, as it reflects tax incentives the firms are not using. The incomplete uptake of R&D tax incentives means that estimated elasticities of R&D expenditure with respect to $BIndex_j^{the}$ can be understood as intention-to-treat estimates and, as such, generally underestimate the effect of actually using R&D tax relief.

To go beyond the intention-to-treat estimates, we exploit the R&D tax relief microdata and calculate a B-Index based on the actual use of R&D tax support, $BIndex_j$. To do

[28] We first calculate the share of each expenditure type $c$ in the total R&D expenditure of each country-industry-year and then take the average across all countries and years to obtain time-invariant, industry-specific expenditure shares $w_j^C$.

so, we first calculate $BIndex_j^{norelief}$ using the same formula as $BIndex_j^{the}$, but setting all enhanced tax allowance rates and tax credit rates to zero, such that only baseline tax deductions apply. We then define our preferred B-Index measure, i.e., $BIndex_j$, as equal to $BIndex_j^{the}$ for firms that benefit from R&D tax relief and as $BIndex_j^{norelief}$ for firms that do not:

$$BIndex_j = \begin{cases} BIndex_j^{the}, & \text{if using tax relief,} \\ BIndex_j^{norelief}, & \text{if not using tax relief.} \end{cases} \tag{4}$$

Online Appendix Figure B.1 documents the evolution of average $BIndex_j^{the}$ and average $BIndex_j$ in each country, separately for SMEs and large firms. It reveals several important points. Firstly, most countries in our sample experienced one or more important policy changes during the sample period (e.g. introduction of R&D tax incentives, subsidy rate change, change in the official SME definition...), and these changes led to strong variation in the tax price of R&D faced by firms over time, which we exploit to estimate the effects of R&D tax incentives. Secondly, in many countries, there is a substantial wedge between the theoretical B-Index and our baseline B-Index that accounts for tax incentive uptake. Thirdly, the theoretical B-Index is either similar for SMEs and large firms in countries where R&D tax incentives do not involve features such as ceilings or preferential rates for SMEs (e.g. Austria, the Czechia, Slovakia, Spain) or lower for SMEs where such features are present (e.g. Australia, the United Kingdom, Norway). Fourth, the B-Index accounting for uptake can actually be, on average, lower for large firms than for SMEs if the uptake is stronger among large firms (e.g. Belgium, Czechia, Portugal).

## 2.5 Variable Construction and Summary Statistics

Here we introduce variables used in the analysis, which are listed in Table 1. Reflecting the level of the analysis, the variables are defined for each country $c$, industry $i$, size class $s$ and year $t$.[29]

The first set of variables describes firms' R&D performance. Our main outcome variable is the natural logarithm of the total intramural (in-house) R&D performance of firms in a given country-industry-size class data cell. We also separately explore current R&D expenditure (labour costs and current consumption of goods and services) and R&D-related capital expenditure (buildings and machinery). When investigating the uptake of R&D tax incentives, we also use the logarithm of average R&D expenditure across firms in a given country, industry, size class and year.

[29] We also report some specifications estimated at the country-industry-year level. Variables in these specifications are constructed in an analogous way to those described below but aggregating across size

Table 1: **Variable Definitions**

| Variable | Definition |
|---|---|
| log R&D expenditure | log total intramural R&D expenditure of firms in a data cell |
| log current R&D expenditure | log current intramural R&D exp. of firms in a data cell |
| log capital R&D expenditure | log intramural R&D exp. of firms in a data cell on R&D-related machinery and buildings |
| log mean R&D expenditure | log average R&D expenditure across firms in a data cell |
| log B-Index (baseline) | average log B-Index (accounting for uptake) across firms in a data cell ($\overline{\log BIndex}_{cist}$) |
| log B-Index (theoretical) | average log theoretical B-Index (not accounting for uptake) across firms in a data cell ($\overline{\log BIndex^{the}}_{cist}$) |
| log B-Index (represent. firm) | log B-Index for a representative firm in a data cell ($\log BIndex^{repr}_{cit}$) |
| marginal tax subsidy rate | average of (1 - theoretical B-Index) across firms in a data cell ($\overline{1 - BIndex^{the}}_{cist}$) |
| share receiving R&D tax relief | share of firms in a data cell receiving R&D tax relief |
| small | 10-49 employees (1/0) |
| medium | 50-249 employees (1/0) |
| large | 250+ employees (1/0) |
| R&D intensive (baseline) | a data cell with an above-median ratio of R&D employment to the total employment in the first year in the sample (1/0) |
| R&D intensive (OECD) | industry classified as having high or medium-high R&D intensity by Galindo-Rueda and Verger (2016) (1/0) |
| low mean age | a data cell with below-median average firm age (1/0) |
| young firm share | the industry share of firms of <5 years (source: OECD DynEmp) |
| log value added (t-2) | log industry value added lagged by 2 years (source: OECD STAN) |
| intensity of direct support | total direct R&D support received by firms in a data cell relative to their mean intramural R&D expenditure over the sample period |
| year 1-4 since introduction | year 1-4 since the first introduction of R&D tax incentives (1/0) |
| incremental | incremental R&D tax incentive (1/0) |
| refundable | refundable R&D tax incentive (1/0) |
| payroll withholding | payroll withholding R&D tax incentive (1/0) |
| innovation authorities | innovation ministry or agency involved in administration of R&D tax incentives (1/0, source: OECD Innotax) |
| mandatory pre-registration | mandatory pre-registration (1/0, source: OECD Innotax) |

*Notes*: The source of the data is the OECD microBeRD project, unless otherwise stated. Data cells are defined by a country, industry and size class, unless otherwise stated.

The second set of variables consists of different measures of the tax price of R&D. To be able to interpret our estimates as elasticities, we enter them into our specifications as natural logarithms, and to obtain variables at the level of the analysis, we take averages across R&D-performing firms in each data cell. Our baseline explanatory variable represents an average logarithm of $BIndex_j$ across firms in a given country, industry, size class and year, $\overline{\log BIndex}_{cist}$.[30] In an analogous way, we also calculate the average

classes.

[30]We calculate the variable as an average of logarithms. However, using instead a logarithm of an average B-Index would make almost no difference as the correlation between the two measures is 0.998. This is because B-Index tends to have values close to 1, where a logarithm is relatively well approximated by a linear function.

logarithm of the theoretical B-Index that does not account for the actual uptake of R&D tax incentives, $\overline{\log BIndex^{the}}_{cist}$. In addition, for comparison with earlier studies, we also calculate a B-Index for a representative firm in each country-industry, $\log BIndex^{repr}_{cit}$. Finally, for the analysis of uptake in subsection 3.1, we calculate the marginal (theoretical) tax subsidy rate, $\overline{1 - BIndex^{the}}_{cist}$, as the average of (1 - theoretical B-Index) across firms in each data cell.

The third set of variables includes characteristics of firms in each data cell that are used to construct interaction terms designed to explore heterogeneity in the effects of R&D tax incentives. Most importantly, it includes dummies for small firms (10-49 employees), medium firms (50-249 employees) and large firms (250 or more employees). It also includes two dummies for R&D-intensive firms. The baseline measure is defined as data cells with an above-median ratio of R&D employment to the total employment in the first year in the sample.[31] Alternatively, we use an external measure, defined at the industry-level and based on the *OECD Taxonomy of Economic Activities Based on R&D Intensity* (Galindo-Rueda and Verger, 2016).[32] It marks 2-digit NACE industries as R&D-intensive if they are classified as having *high* or *medium-high* R&D intensity according to the taxonomy.[33] Finally, when exploring the role of credit constraints, we use two different indicators related to firm age.[34] The first one is a dummy variable for data cells with a below-median average age of R&D-performing firms, as observed directly in the microdata underlying our analysis. The second one measures the share of firms younger than 5 years in all firms in a given country and industry (R&D performers or not) and comes from the OECD DynEmp database.[35]

Two more variables serve as control variables in some specifications. The first one — industry-level value added — comes from the OECD STAN database[36] and is deflated using industry-specific deflators from the same source. The second one — the intensity of direct support — is defined as the ratio of the total direct R&D support received by firms in a data cell to the mean intramural R&D expenditure of these firms over the sample

[31]We measure R&D intensity by the R&D employment share rather than the ratio of R&D expenditure and sales because the R&D microdata for some of our sample countries do not include information on sales. The median is defined within each country and size class.

[32]In contrast to the baseline indicator, the classification is defined at the industry level, based on R&D expenditure and industry value added, rather than R&D and overall employment, and the denominator corresponds to all firms in each industry, not just the R&D performers.

[33]We classify the following A38 industries as R&D intensive: *Manufacture of chemicals and chemical products*; *Manufacture of basic pharmaceutical products and pharmaceutical preparations*; *Manufacture of computer, electronic and optical products*; *Manufacture of electrical equipment*; *Manufacture of machinery and equipment*; *Manufacture of transport equipment*; *Computer programming, consultancy and related activities - information service activities*; and *Scientific research and development*.

[34]For countries where a given age indicator is not available, we impute it using cross-country industry-size class-specific means.

[35]See `http://oe.cd/dynemp`.

[36]See `http://oe.cd/stan`.

period.

Finally, we use several binary indicators describing the implementation and design of R&D tax incentives in a given country. They include indicators for incentives newly introduced in the past 4 years, incremental incentives, refundable incentives, payroll withholding incentives, incentives where an innovation ministry or agency is involved in their administration (either alone or together with tax authorities) and incentives requiring that R&D projects be pre-registered or pre-approved in order to be eligible for tax relief.[37]

Table 2 presents summary statistics for our baseline estimation sample. As explained above, observations correspond to data cells defined by a country, industry, size class and year. In an average (median) cell, there are 65 (29) R&D-performing firms with a combined R&D expenditure of USD 157 million (USD 24 million), of which current expenditure on labour and materials accounts for about 90% and R&D-related capital expenditure for the rest. In an average (median) cell, R&D expenditure of an average firm is USD 3.6 million (USD 600 thousand). Firms in an average cell have a theoretical B-Index of 0.80, which corresponds to a marginal tax subsidy rate of 0.20. As expected, our baseline B-Index measure, which accounts for the uptake of R&D tax incentives, tends to be higher, at 0.89 for firms in an average cell. This is related to the fact that, in an average data cell with an R&D tax incentive in place, just below half of eligible firms actually receive R&D tax relief. For an average cell, the average age of R&D-performing firms is 18 years, and the share of young firms among all firms in an industry is 29%. The intensity of direct R&D support is 8% (4%) in an average (median) cell. Overall, about three quarters of the data cells have an R&D tax incentive in place. Among those, the incentives have been first introduced in the past 4 years in 19% of data cells, and they are incremental in 40% of data cells, refundable in 57%, payroll withholding in 13%, partly or fully managed by an innovation authority or ministry in 69% and requiring a mandatory pre-registration in 48%.

# 3 Uptake and Distribution of R&D Tax Relief

In this section, we present descriptive results that provide important context to the subsequent analysis of the effects of R&D tax incentives. First, we investigate the uptake of the incentives. Second, we show how R&D expenditure and R&D tax relief are distributed across firms of different size and R&D intensity.

[37] The last two design indicators are based on the OECD Innotax database and are only available for year 2022. See `https://stip-pp.oecd.org/innotax/`.

Table 2: **Summary Statistics**

| | count | mean | p50 | sd | min | max |
|---|---|---|---|---|---|---|
| number of R&D-performing firms | 7273 | 65.41 | 29.00 | 110.11 | 3.00 | 1249.00 |
| R&D expenditure (USD millions) | 7273 | 157.47 | 23.86 | 710.96 | 0.04 | 20644.34 |
| current R&D expenditure (USD millions) | 7042 | 148.87 | 22.60 | 667.61 | 0.04 | 19296.67 |
| capital R&D expenditure (USD millions) | 7042 | 13.30 | 1.87 | 60.65 | 0.00 | 1612.53 |
| mean R&D expenditure | 7273 | 3.63 | 0.61 | 12.05 | 0.01 | 244.49 |
| B-Index (baseline) | 7273 | 0.89 | 0.94 | 0.14 | 0.37 | 1.10 |
| B-Index (theoretical) | 7273 | 0.80 | 0.81 | 0.18 | 0.31 | 1.09 |
| B-Index (representative firm) | 7273 | 0.79 | 0.78 | 0.19 | 0.32 | 1.05 |
| marginal tax subsidy rate | 7273 | 0.20 | 0.19 | 0.18 | -0.11 | 0.69 |
| share receiving R&D tax relief | 4998 | 0.47 | 0.48 | 0.25 | 0.00 | 1.00 |
| small (10-49 employees) (0/1) | 7273 | 0.36 | 0.00 | 0.48 | 0.00 | 1.00 |
| medium (50-249 employees) (0/1) | 7273 | 0.36 | 0.00 | 0.48 | 0.00 | 1.00 |
| large (250+ employees) (0/1) | 7273 | 0.29 | 0.00 | 0.45 | 0.00 | 1.00 |
| R&D-intensive (baseline) (0/1) | 7273 | 0.48 | 0.00 | 0.50 | 0.00 | 1.00 |
| R&D-intensive (OECD) (0/1) | 7273 | 0.36 | 0.00 | 0.48 | 0.00 | 1.00 |
| mean age | 7273 | 18.36 | 17.35 | 9.91 | 2.33 | 102.50 |
| young firm share | 7273 | 0.29 | 0.28 | 0.09 | 0.10 | 0.72 |
| industry value added (USD billions) | 7273 | 21.64 | 7.44 | 35.90 | 0.08 | 296.15 |
| intensity of direct support | 7273 | 0.08 | 0.04 | 0.13 | 0.00 | 1.90 |
| R&D tax incentive in place (0/1) | 7273 | 0.74 | 1.00 | 0.44 | 0.00 | 1.00 |
| year 1-4 since introduction (0/1) | 5349 | 0.19 | 0.00 | 0.39 | 0.00 | 1.00 |
| incremental (0/1) | 5349 | 0.40 | 0.00 | 0.49 | 0.00 | 1.00 |
| refundable (0/1) | 5349 | 0.57 | 1.00 | 0.49 | 0.00 | 1.00 |
| payroll withholding R&D tax incentive (1/0) | 5349 | 0.13 | 0.00 | 0.34 | 0.00 | 1.00 |
| innovation authorities (0/1) | 5349 | 0.69 | 1.00 | 0.46 | 0.00 | 1.00 |
| mandatory pre-registration (0/1) | 5349 | 0.48 | 0.00 | 0.50 | 0.00 | 1.00 |

*Notes*: The table presents summary statistics based on micro-aggregated data, with observations defined at the country-industry-size class level. It is based on the baseline estimation sample that includes the following 14 OECD countries: Australia, Belgium, Czechia, France, Germany, Israel, Italy, the Netherlands, New Zealand, Norway, Portugal, Slovakia, Sweden and Switzerland. R&D expenditure is stated in millions of 2005 US dollars using purchasing power parity exchange rates and industry value added in billions of 2005 US dollars.

## 3.1 Uptake of R&D Tax Relief

An important fact largely neglected in the existing literature on the impact of R&D tax incentives is that R&D-performing firms might not actually use the R&D tax relief for which they are eligible. To begin with, firms may not be aware of the tax incentives or may not know how to apply for them, particularly if the incentives have been introduced only recently. Furthermore, even though lower administrative and compliance costs are a presumed benefit of R&D tax incentives as compared to R&D grants, obtaining R&D tax relief is typically not automatic. It often requires extensive paperwork, and R&D projects need to be pre-approved in some cases (e.g. Australia, New Zealand, Slovakia). It is common for firms to use specialised advisory services to assist in the process of claiming tax relief for R&D. In addition to the direct administrative costs, R&D tax incentives also carry an extra cost in the form of an increased risk of inspection by tax authorities. Such inspections can be troublesome and protracted, with tax authorities struggling to determine whether reported activities meet the relevant legal definition of research and development. In the face of uncertainty and burdens posed by these challenges, firms may decide that claiming R&D tax relief is not worth the associated costs and forego the benefits they might otherwise be eligible for.

Despite the many reasons for not claiming R&D tax incentives, existing research either implicitly assumes that all R&D-performing firms obtain R&D tax relief,[38] or only observes R&D for those firms that benefit from R&D tax relief.[39] To date, there is no cross-country evidence on the share and characteristics of eligible firms that actually benefit from R&D tax relief.

The data put together within the OECD microBeRD project allow us to fill this gap. Taking year 2019 as an example,[40] Figure 1 shows, for each country and size class, the share of R&D-performing firms that used R&D tax relief. It clearly demonstrates that the uptake of R&D tax incentives is indeed highly incomplete as in all 11 countries many R&D-performing firms do not use the R&D tax support. In an average country-size class, less than half of eligible firms used R&D tax relief, with the share ranging from 80% of medium and large firms in France to just 10% of small and medium R&D-performing firms in New Zealand.

What determines whether a firm uses an R&D tax incentive for which it is eligible?

With regard to firm size, Figure 1 does not show any clear pattern. The uptake of R&D tax incentives increases with firm size in Belgium, Czechia and Portugal, decreases with size in Australia and Italy, and exhibits a weak or non-linear relationship with size in the remaining countries.[41]

A lack of awareness of R&D tax incentives is likely to reduce uptake only in the initial years after their introduction as firms can be expected to learn about the incentives over time. Figure 2 documents the uptake of R&D tax incentives over time since the first introduction of R&D tax incentives.[42] The uptake is indeed rather low in the first year

[38]This is the case in all existing aggregate studies and also those firm-level studies that exclusively rely on R&D survey data (e.g. Kasahara et al. (2014); Guceri (2018)).

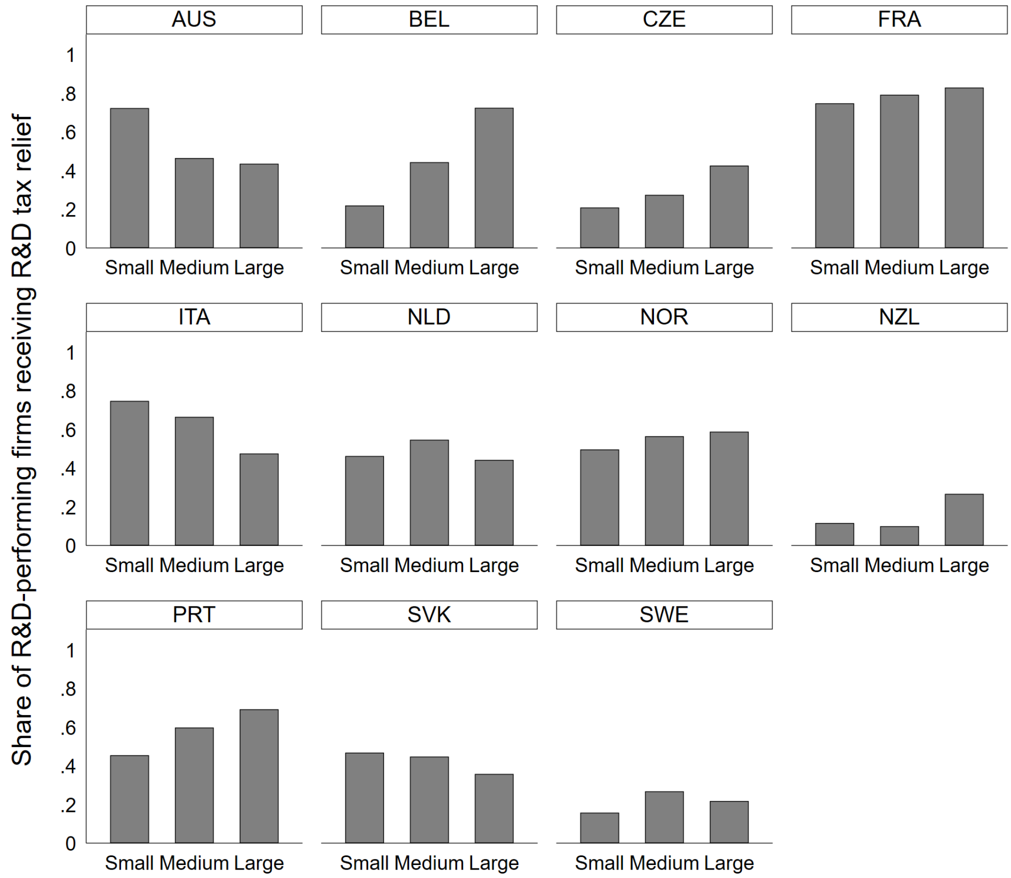
[39]This is the case in studies relying on administrative tax data (e.g. Rao (2016); Guceri and Liu (2019); Agrawal et al. (2020); Dechezleprêtre et al. (2023)).

[40]2019 is the most recent year available for the majority of countries in our data. We use year 2018 for Australia and Portugal, 2017 for Sweden and 2014 for France.

[41]In the context of tax loss refunds in the US, Zwick (2021) documents a lower uptake among smaller firms, but, similar to our results, finds that even many large firms fail to claim the refund for which they are eligible.

[42]R&D tax incentives were introduced in 1983 in France, 1985 in Australia, 1994 in the Netherlands, 1997 in Portugal, 2002 in Norway (2003 for large firms), 2005 in Belgium and Czechia, 2015 in Slovakia and Sweden and 2019 in New Zealand. In Italy they were in place between 2007-2009 and re-introduced

Figure 1: **Uptake of R&D Tax Incentives**



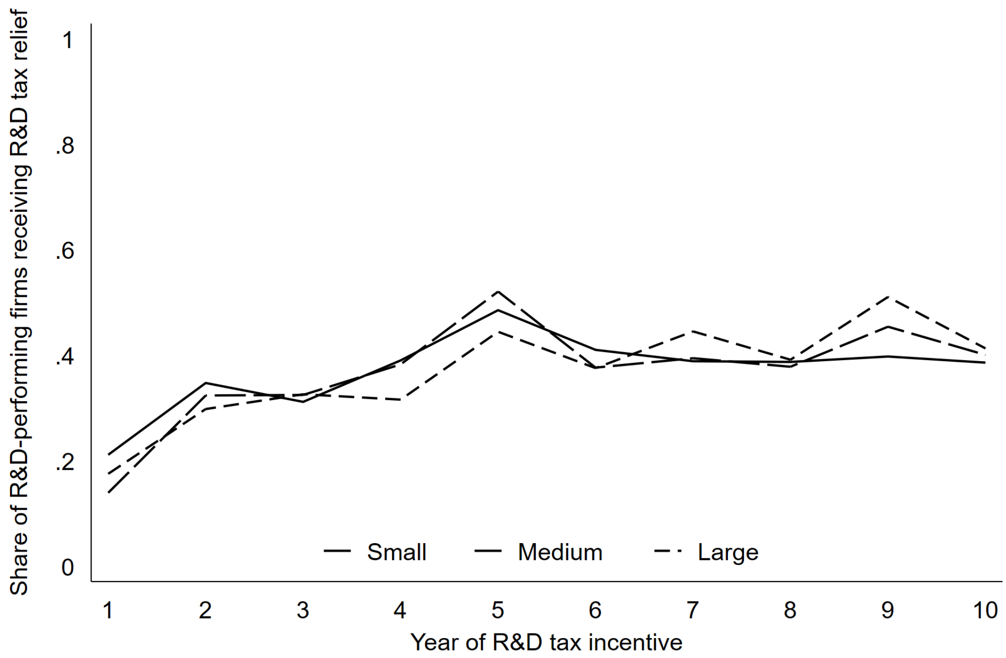

*Notes*: The figure is based on year 2019 with the exception of Australia (2018), France (2014), Portugal (2018) and Sweden (2017).

of an incentive (around 20%) and gradually increases over the next 3 or 4 years, after which it remains flat.

To investigate the potential drivers of R&D tax incentive uptake more systematically, we run descriptive regressions and report them in Table 3. The outcome variable is given by the share of R&D-performing firms in a given country, industry, size-class and year that receive R&D tax relief. For each country, we only consider years when an R&D tax incentive was in place for firms in a given size class. In regressions reported in columns 1-3, we include country dummies and year dummies. The regression reported in column 4, which investigates the role of R&D tax incentive design and administration, omits the country dummies, because the design of R&D tax incentives in individual countries does not vary much over time, and the indicators on administration of R&D tax incentives

in 2015; we count each instance separately, resetting the year count.

Figure 2: **Uptake of R&D Tax Incentives Over Time Since Their Introduction**




*Notes*: The figure shows the average (across countries) share of R&D-performing firms in each size class that benefit from R&D tax relief in years 1 to 10 since the first introduction of R&D tax incentives in a given country. For Italy, the incentives in place in years 2007-2009 and from 2015 onward are treated separately (the year count is reset). For New Zealand, the temporary incentive in place only in 2008 is ignored. For Portugal, the temporary removal of the incentives in years 2004-2005 is ignored (the year count is not reset).

from the OECD Innotax database are only available for year 2022.

If firms weigh the benefits of R&D tax incentives against the administrative and compliance costs and the increased risk of inspection associated with the them, they should be more likely to claim the R&D tax relief the greater the value of the tax relief for which they are eligible. The value of the R&D tax relief in turn depends on how much the firms invest in R&D and how generous the tax incentives are. To investigate this, we include variables measuring how much firms in a given country, industry and size class spend on average on R&D and the marginal tax subsidy rates for which they are eligible. The results indicate that the uptake of R&D tax incentives is strongly related to both variables (column 2 of Table 3). A 10% greater R&D expenditure and 10 p.p. higher marginal tax subsidy rate are associated, respectively with a 0.7 p.p. and 7 p.p. greater uptake. This implies that going from the $25^{th}$ to the $75^{th}$ percentile of average R&D expenditure and from the $25^{th}$ to the $75^{th}$ percentile of the marginal tax subsidy rate corresponds, respectively, to a 14 p.p. and 20 p.p. greater uptake. These results support the conjecture that firms are more likely to take up R&D tax incentives if the value of the benefits for which they are eligible is greater.

Table 3: **Explaining Partial Uptake of R&D Tax Incentives**

| | Outcome: Share receiving R&D tax relief | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| medium (50-249 emp.) | -0.021 | 0.079*** | 0.064** |
| | (0.031) | (0.028) | (0.029) |
| small (10-49 emp.) | -0.072* | 0.101** | 0.088** |
| | (0.041) | (0.042) | (0.043) |
| log mean R&D expenditure | | 0.074*** | 0.074*** |
| | | (0.011) | (0.010) |
| marginal tax subsidy rate | | 0.710*** | 0.565*** |
| | | (0.061) | (0.065) |
| year 1-4 since introduction | | -0.056* | -0.099*** |
| | | (0.030) | (0.035) |
| intensity of direct support | | -0.354*** | -0.359*** |
| | | (0.054) | (0.049) |
| incremental | | | -0.088*** |
| | | | (0.032) |
| refundable | | | 0.083* |
| | | | (0.041) |
| payroll withholding | | | -0.033 |
| | | | (0.031) |
| innovation authorities | | | 0.119** |
| | | | (0.048) |
| mandatory pre-registration | | | -0.055 |
| | | | (0.034) |
| Year fixed effects | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | No |
| Observations | 4998 | 4998 | 4998 |

*Notes*: *** 1%, ** 5%, * 10%. Observations are defined at the country-industry-size class-year level, and standard errors in parentheses are clustered at the country-size class level. The outcome variable is the share of R&D-performing firms that receive R&D tax relief. Only country-years with an R&D tax incentive in place (for firms in a given size class) are included.

The regression reported in column 2 also confirms the lower uptake in the initial years after the introduction of an incentive, documented in Figure 2, suggesting that a lack of awareness of the incentives plays a role in the initial years.

Use of R&D tax incentives is also likely to depend on the availability of alternative sources of public support, in particular direct support in the form of grants and public procurement. To investigate this, we include a measure of intensity of direct support for business R&D, defined as the ratio of direct support received by firms in a given country, industry and size class and the total R&D expenditure by these firms. We find a strong negative relationship between the share of firms receiving R&D tax support and the availability of direct support, with 10 p.p. greater intensity of direct support associated with 4 p.p. lower uptake of R&D tax incentives. It is, however, important to interpret this finding in light of the fact that the median intensity of direct support in the sample is just 4%, and going from the 25th to the 75th percentile of the intensity of direct support corresponds to only a 3 p.p. lower uptake of R&D tax incentives.

It is also interesting to explore the role of firm size. Without conditioning on any other variables, the uptake is slightly lower among small firms (by about 7 p.p.), as compared to large ones, but similar among medium-sized and large firms (column 1 of Table 3). However, once we control for the facts that smaller firms tend to have lower R&D expenditure (and hence less to gain from R&D tax incentives) and that smaller firms tend to rely more heavily on direct support for R&D (Appelt et al., 2022), small and medium-sized firms actually become *more* likely to take up R&D tax relief than large firms (column 2).

Finally, the uptake of R&D tax incentives may depend on the specific way they are designed and implemented. We investigate this in column 3 of Table 3.[43] With respect to policy design, we investigate three features in particular. Incremental incentives, which only offer tax relief for an *increase* in R&D over expenditure in the preceding few years, are less valuable to firms — for a given marginal tax subsidy rate — and can, thus, be expected to be associated with lower uptake. This is indeed what we see in the data, which show a 9 p.p. lower uptake for incremental incentives. In contrast, the uptake should be stronger for incentives that are refundable in the case of loss-making firms. The regression supports this conjecture, showing an 8 p.p. stronger uptake for refundable incentives. Similarly, one could expect stronger uptake for payroll withholding incentives, which are deductible against employee costs and, as a result, benefit firms irrespective of whether the firms turn profit. The results, however, do not show a differential uptake for payroll withholding schemes.

The way R&D tax incentives are implemented determines the administrative and compliance costs associated with claiming the tax relief, as perceived by the firms.[44] One important question related to the implementation of R&D tax incentives is which part of public administration receives, evaluates and audits the claims for tax relief. In some countries, the tax incentives are entirely administered by the tax authorities (e.g. Czechia, Slovakia, Sweden), whereas in other countries the tasks are shared by the tax authorities and a ministry or an agency in charge of innovation policy (e.g. France, Norway) or are entirely the responsibility of an innovation ministry or agency (e.g. Belgium, Portugal). Tax authorities, whose principal mission is to *collect* taxes, may be inclined to weight trade-offs between preventing unsubstantiated claims and reducing administrative and

[43] Since the design the design of R&D tax incentives in individual countries does not vary much over time, and the indicators on administration of R&D tax incentives from the OECD Innotax database are only available for year 2022, the regression reported in column 3 does not control for country fixed effects.

[44] The results should be interpreted with caution, since the information on how R&D tax incentives are administered is only available for a single year, 2022.

compliance costs differently from innovation authorities. The staff of tax authorities may also lack the expertise required to determine whether an activity meets the legal definition of research and development, a task the personnel at innovation authorities may be better equipped for. In line with this reasoning, we find a significantly stronger uptake when innovation authorities are involved in the administration of a given incentive, by about 12 p.p..

Another important aspect of the implementation is whether an incentive requires that R&D projects be pre-registered or pre-approved in order to be subsequently eligible for R&D tax relief, as in the Netherlands and Norway. While such a requirement facilitates oversight of the supported R&D projects by relevant authorities, it also limits the presumed advantages of R&D tax incentives in terms of their flexibility and simplicity and could reduce their uptake. However, the results do not indicate a significantly lower uptake in the case of R&D tax incentives that require a mandatory pre-approval or pre-registration.

Although the regression results in Table 3 show only conditional correlations rather than causal effects, they are consistent with administrative and compliance costs, as well as a lack of awareness in the early years, contributing to the situation in which, on average, only about half of eligible R&D-performing firms actually claim R&D tax relief.

## 3.2 Distribution of R&D Activity and Tax Relief

In this paper, we argue that a potential explanation for the difference in elasticities found in aggregate and firm-level studies is heterogeneous effects of R&D tax incentives across firms of different size and R&D intensity, combined with the fact that large and R&D intensive firms represent a small share of all firms in firm-level studies (or do not appear in the sample at all), but account for a large share of aggregate R&D expenditure. We document this in Table 4, which shows, for our estimation sample and year 2019, the share of R&D activity and R&D tax relief accounted for by firms of different size and R&D intensity.[45] Specifically, the table shows the share of firms of each type in the total number of R&D-performing firms, in the total R&D expenditure and in the total R&D tax relief.

The most striking take-away from Table 4 is the disproportionate importance of large firms in aggregate R&D expenditure. Large firms account for only about 12% of all R&D-performing firms but for about 70% of the total R&D expenditure. Among them, R&D-intensive firms are particularly important, as they alone account for 6% of R&D-performing firms but over half of R&D expenditure. In contrast, less R&D-intensive small

[45]R&D intensity is defined at the level of country-industry-size class cells.

and medium firms together account for almost half of all R&D-performing firms but just 10% of the total R&D expenditure.

Table 4: **Distribution of R&D Activity and Tax Relief**

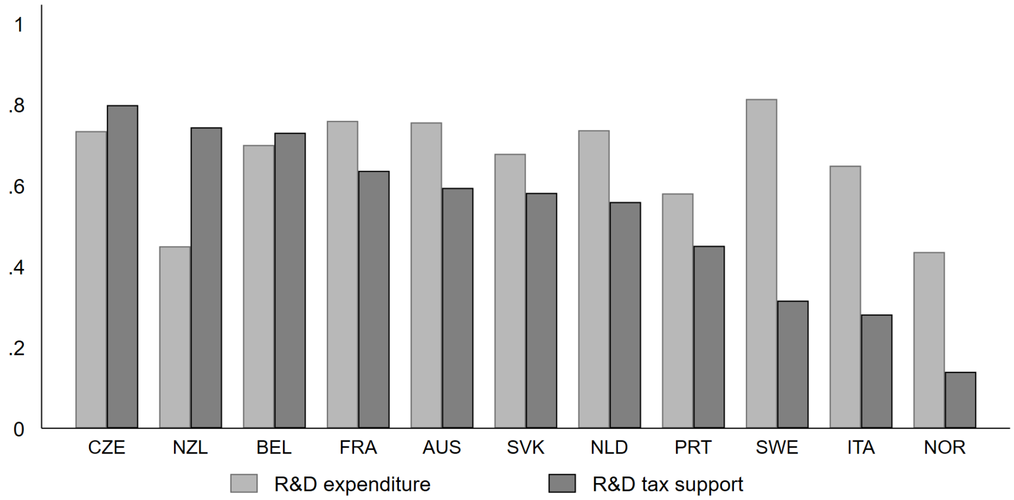
| *Size* | Small | | Medium | | Large | |
|---|---|---|---|---|---|---|
| *R&D intensity* | Low | High | Low | High | Low | High |
| Share in # of R&D-performing firms | 0.29 | 0.29 | 0.17 | 0.14 | 0.06 | 0.06 |
| Share in total R&D expenditure | 0.04 | 0.08 | 0.06 | 0.14 | 0.16 | 0.53 |
| Share in total R&D tax relief | 0.07 | 0.14 | 0.09 | 0.19 | 0.16 | 0.36 |

*Notes*: For the estimation sample, the table shows the share of country-industry-size class data cells classified as small, medium or large and as having low or high R&D intensity in the total (i) number of R&D-performing firms, (ii) R&D expenditure, and (iii) R&D tax relief. The table is based on year 2019 with the exception of Australia (2018), France (2014), Portugal (2018) and Sweden (2017).

Another take-away from Table 4 is that the share of large firms in total R&D tax relief (about 50%) is smaller than their share in the total R&D expenditure (about 70%), although still highly disproportionate with respect to their share in the number of R&D-performing firms. The share of large firms in R&D tax relief, relative to their share in R&D expenditure, depends, firstly, on the uptake of the incentives among large firms, relative to smaller ones, and, secondly, on the specific design of R&D tax incentives in each country. We illustrate this in Figure 3, where we report the share of large firms in R&D expenditure and R&D tax relief separately for each country. While large firms account for the majority of all R&D expenditure in all countries considered except New Zealand and Norway, the share of R&D tax relief going to large firms is more heterogeneous across countries. In countries with no limit on R&D eligible for the full support, such as Belgium, Czechia and Slovakia, the share of large firms in R&D tax relief is similar to, or greater than (thanks to stronger uptake), their share in R&D expenditure. In New Zealand, the share of large firms in R&D tax relief is much greater than their share in R&D expenditure, due to a very low SME uptake during the first year of the new tax incentive. In contrast, the share of large firms in R&D tax relief is lower than their share in R&D expenditure in countries that offer preferential tax subsidy rates for SMEs (Australia) and, in particular, that impose binding ceilings on eligible R&D (Norway, Sweden).[46]

[46] In the case of Italy and Portugal, the lower share of large firms in R&D tax relief, relative to their share in R&D expenditure, is likely due to the use of incremental incentives in these countries, combined with a faster growth of R&D among smaller (and, on average, younger) firms.

Figure 3: **Share of large firms in R&D expenditure and R&D tax relief**




*Notes*: The figure is based on year 2019 with the exception of Australia (2018), France (2014), Portugal (2018) and Sweden (2017).

# 4 Empirical Strategy

We estimate a model of R&D investment as proposed by Bloom et al. (2002), which relates R&D investment to the price of R&D, controlling for output and a set of fixed effects.[47] Since we cannot estimate the model at the firm level, we estimate it at the level of groups of firms defined by their country, industry and size class. The starting point for our estimation is the following specification:[48]

$$\log Y_{cist} = \beta_1 \overline{\log BIndex^{the}}_{cist} + \beta_2 \log VA_{ci(t-2)} + \gamma_{cis} + \gamma_{ist} + \epsilon_{cist} \ . \qquad (5)$$

The outcome variable $Y_{cist}$ represents R&D expenditure by firms belonging to country $c$, industry $i$ and size class $s$ in year $t$. The baseline outcome variable is the total intramural R&D expenditure, but, when exploring the potential role of credit constraints, we also separately examine effects on current R&D expenditure and R&D-related capital expenditure. The explanatory variable of interest, $\overline{\log BIndex^{the}}_{cist}$, represents an average log theoretical B-Index across firms in a given country, industry, size class and year. As both R&D investment and B-Index enter the equation in natural logarithms, the estimated coefficients on the B-Index can be interpreted as elasticities. Industry-level value added, $\log VA_{ci(t-2)}$, enters the regression as a control variable to account for in-

[47]Bloom et al. (2002) note that the model can be interpreted as a stochastic version of a demand equation for R&D capital in a steady state and under a constant-elasticity-of-scale production function.
[48]For comparison with earlier literature, we also estimate the model at the country-industry level. The specification is analogous to that described here, except for aggregating across size classes.

dustry output[49] and is lagged by 2 years to reduce the risk of endogeneity due to the simultaneous relationship with R&D investment.[50] The regressions further control for a rich set of fixed effects. The country-industry-size class fixed effects $\gamma_{cis}$ capture all characteristics of firms in a particular country, industry and size class that do not change over time. Their inclusion means that we exploit only variation within country-industry-size class units over time. We further control for industry-size class-year fixed effects ($\gamma_{ist}$). By doing so, we allow, e.g., for differential effects of industry-specific shocks on the R&D performance of firms of different size. Finally, $\epsilon_{cist}$ is a time-varying residual – a summary term for effects not captured by any of the other variables.

Previous cross-country studies based on country- or industry-level data (Bloom et al., 2002; Thomson, 2017) calculated the B-Index for a representative firm. This meant that any variation in the B-Index reflected exogenous policy variation. In contrast, we calculate the B-Index at the firm-level, which means that it depends on the level and structure of each firm's R&D expenditure (e.g., because the tax incentive rate is reduced once a certain R&D expenditure threshold is reached). This could make our main explanatory variable endogenous. We address this issue by implementing instrumental variable (IV) estimation, where we instrument for the average log B-Index with a *synthetic B-Index* that captures only time-variation due to policy changes, keeping the set of firms and their R&D expenditure fixed between periods.[51] We construct the instrument in three steps. In the first step, we calculate the synthetic log change in B-Index for each firm $j$ as

$$d\log BIndex^{syn1}_{jt} \equiv \log BIndex_t(RD_{j(t-1)}) - \log BIndex_{t-1}(RD_{j(t-1)}) \ , \tag{6}$$

where $\log BIndex_t(RD_{j(t-1)})$ is obtained by applying the R&D tax incentive design in year $t$ to the R&D performance (and other characteristics) of the firm in $t-1$, and $\log BIndex_{t-1}(RD_{j(t-1)})$ is the standard B-Index calculated for $t-1$. This ensures that R&D expenditure is kept fixed at the level and composition as of $t-1$ and only the R&D tax incentive design varies over time. In the second step, we take averages of $d\log BIndex^{syn1}_{jt}$ across firms in each country, industry, size class and year to obtain an average synthetic log change in B-Index ($\overline{d\log BIndex^{syn1}}_{cist}$). In the final step, we calculate the synthetic B-Index by cumulatively adding up the average synthetic changes:

$$\overline{\log BIndex}^{syn}_{cist} = \sum_{u=t_0+1}^{t} \overline{d\log BIndex^{syn1}}_{cisu} \ , \tag{7}$$

[49]The value added does not vary by size class, because information on value added by country, industry and size class are unfortunately not available.

[50]Using instead contemporaneous value added has no material effect on the results.

[51]Rao (2016) exploited a similar strategy in her firm-level analysis of the US R&D tax credit.

where $t_0$ is the first year a given country-industry-size class appears in the data.[52] Using this instrument, we estimate Equation 8 with two-stage least-squares (2SLS), clustering standard errors at the country-industry-size class level.

As discussed in the previous sections, the theoretical B-Index, $\overline{\log BIndex^{the}}_{cist}$, measures R&D tax incentives for which R&D-performing firms are eligible but does not take into account whether a given firm actually uses R&D tax relief. For this reason, the elasticity estimated in Equation 5 can be seen as capturing intention-to-treat effects of R&D tax incentives. To estimate the effect of R&D tax incentives while accounting for the actual tax support use, we estimate an equation where $\overline{\log BIndex^{the}}_{cist}$ is replaced with $\overline{\log BIndex}_{cist}$, the average logarithm of a B-Index accounting for the uptake:

$$\log Y_{cist} = \beta_1 \overline{\log BIndex}_{cist} + \beta_2 \log VA_{ci(t-2)} + \gamma_{cis} + \gamma_{ist} + \epsilon_{cist} \ . \tag{8}$$

We again instrument for $\overline{\log BIndex}_{cist}$ with $\overline{\log BIndex}^{syn}_{cist}$. This is particularly important as $\overline{\log BIndex}_{cist}$ depends on the share of R&D-performing firms that receive R&D tax relief, which subsection 3.1 has shown to be related to firms' R&D intensity.

An important advantage of our data and approach is that they allow us to investigate if effects of R&D tax incentives vary with different firm characteristics. We do this by interacting B-Index with indicators of firm characteristics. For example, to explore the effects of firm size, we estimate

$$\log Y_{cist} = (\beta_1^0 + \sum_z \beta_1^z D_s^z) \overline{\log BIndex}_{cist} + \beta_2 \log VA_{ci(t-2)} + \gamma_{cis} + \gamma_{ist} + \epsilon_{cist} \ . \tag{9}$$

where $z \in \{medium, large\}$ and $D_s^z$ is a dummy variable equal to 1 when firms in a given data cell are of size $z$, i.e. when $s = z$.[53] Estimates of heterogeneous effects by other firm characteristics are obtained in an analogous way.

Due to adjustment costs, firms may take time to fully reflect a change in the tax price of R&D in their R&D spending. To investigate the dynamics of the effects of R&D tax incentives and to test if allowing for only a gradual adjustment in R&D affects the results of the static model, we additionally estimate a dynamic version of Equation 8 that

[52] Where data is only available at a lower than annual frequency or contains gaps due to missing values, we use analogously computed synthetic changes over 2-year, 3-year or 4-year periods. For example, a 2-year synthetic change in B-Index for firm $j$ is calculated as $d \log BIndex^{syn2}_{jt} \equiv \log BIndex_t(RD_{j(t-2)}) - \log BIndex_{t-2}(RD_{j(t-2)})$.

[53] In IV regressions, we similarly extend the set of instruments with interactions of the synthetic B-Index with the size dummies.

includes a 2-year lag of the dependent variable among the explanatory variables:[54]

$$\log Y_{cist} = \beta_0 \log Y_{cis(t-2)} + \beta_1 \overline{\log BIndex}_{cist} + \beta_2 \log VA_{ci(t-2)} + \gamma_{cis} + \gamma_t + \epsilon_{cist} \ . \quad (10)$$

Dynamic panel estimation involving unit fixed effects leads to biased estimates unless the time dimension is long (Nickell, 1981). To avoid this bias, we estimate equation Equation 10 using the difference GMM procedure by Arellano and Bond (1991), which transforms the equation into 2-year differences and instruments changes in the lagged dependent variable with further lags of the dependent variable.[55] The GMM estimates use the two-step procedure and the standard errors reported apply the Windmeijer (2005) correction.

# 5 Main Results

In this section, we present our estimates of the relationship between the tax price of R&D, measured by B-Index, and the R&D expenditure of firms in a given country, industry and size class. Given the log-log form of our estimating equations, the estimates can be interpreted as elasticities of R&D expenditure with respect to its tax price. The elasticities can be expected to be negative, as a lower tax price should be associated with greater R&D expenditure. We then present some calculations of the aggregate effects of R&D tax incentives implied by our estimates.

## 5.1 Homogeneous R&D Tax Price Elasticities

We start by presenting the results of regressions that assume a homogeneous tax price elasticity that is the same for all firms, independently of their size or initial R&D intensity. The top panel of Table 5 shows results at the country-industry level, controlling for industry value added (lagged by 2 years), country-industry fixed effects and industry-year fixed effects and clustering standard errors at the country-industry level. The bottom panel shows results at the country-industry-size class level — our baseline level of aggregation — controlling for industry value added (lagged by 2 years), country-industry-size class and industry-size class-year fixed effects and clustering standard errors at the country-industry-size class level.

[54] We use 2-year, rather than 1-year, lags in order to keep observations for countries with only bi-annual data available.

[55] Following Roodman (2009), we reduce the instrument count by collapsing the instrument matrix and using only the 4th, 6th and 8th lags of the dependent variable (in levels) as instruments, alongside $\overline{\log BIndex}^{syn}_{cist}$.

The first column of the top panel of Table 5 shows a specification similar to those in existing cross-country studies. Like in Thomson (2017), observations are defined at the country-industry level, aggregating across firms of different size, and the B-Index is calculated for a representative (large) firm in a given country-industry and does not reflect finer design features such as expenditure floors, thresholds and ceilings ($\log BIndex^{repr}_{cit}$). The specification produces a tax price elasticity of -0.42, which is close to the elasticities around -0.5 found in the earlier studies.[56]

The corresponding specification at the country-industry-size class level is reported in column 1 of the bottom panel. The elasticity estimated at the country-industry-size class level (-.54) is about 30% larger[57] than the elasticity estimated at the country-industry level. What could explain this difference? In an average country-industry in our sample, large firms account for about 60% of the total R&D expenditure, with medium-sized firms accounting for 26% and small firms for only 14%. Variation in R&D expenditure aggregated across size classes thus largely reflects R&D by large firms. In contrast, estimation at the country-industry-size class level gives equal weight to all size classes. If smaller firms are more responsive to R&D tax incentives, estimation disaggregated by firm size will produce a greater tax price elasticity. The relative size of elasticities found in two panels is thus consistent with smaller firms being more responsive to R&D tax incentives, a hypothesis we directly test below.

Specifications shown in columns 2 and 3 of each panel replace the B-Index for a representative firm with a B-Index that is calculated directly at the firm level and then averaged across all R&D-performing firms in each country and industry or country, industry and size class ($\overline{\log BIndex^{the}}_{ci(s)t}$). Unlike the representative measures used in earlier studies, this measure reflects the detailed features of each R&D tax incentive, but like them, it does not take into account the uptake of R&D tax incentives, instead implicitly assuming that all eligible firms receive R&D tax relief. Column 2 reports OLS estimates. To account for the fact that each firm's B-Index depends on the volume and composition of its R&D expenditure, column 3 reports 2SLS estimates instrumenting $\overline{\log BIndex^{the}}_{ci(s)t}$ with the synthetic B-Index ($\overline{\log BIndex}^{syn}_{ci(s)t}$), which simulates how $\overline{\log BIndex^{the}}_{ci(s)t}$ would evolve over time if the composition and R&D expenditure of R&D-performing firms in each country and industry or country, industry and size class remained fixed.

At both levels of aggregation, elasticities found in columns 2 and 3 are rather sim-

[56]The static specifications in aggregate studies by Bloom et al. (2002); Guellec and Van Pottelsberghe De La Potterie (2003); Appelt et al. (2019) all show elasticities around -0.5. The industry-level estimates by Thomson (2017) similarly produce a short-term elasticity of -0.5.

[57]We take the liberty to refer to elasticities that are *more (less) negative* simply as "larger (smaller) elasticites", without noting that this is meant in absolute value.

Table 5: **R&D Tax Price Elasticities By Aggregation and B-Index Measure**

A: Country-industry level

| | Outcome: log R&D expenditure | | | |
|---|---|---|---|---|
| | OLS | | 2SLS | |
| | (1) | (2) | (3) | (4) |
| log B-Index (representative firm) | -0.421*** | | | |
| | (0.072) | | | |
| log B-Index (theoretical) | | -0.409*** | -0.429*** | |
| | | (0.075) | (0.078) | |
| log B-Index (baseline) | | | | -0.690*** |
| | | | | (0.126) |
| log value added (t-2) | 0.260*** | 0.252*** | 0.255*** | 0.278*** |
| | (0.087) | (0.088) | (0.088) | (0.090) |
| Observations | 3504 | 3504 | 3504 | 3504 |
| F-stat | | | 11706 | 1236 |

B: Country-industry-size class level

| | Outcome: log R&D expenditure | | | |
|---|---|---|---|---|
| | OLS | | 2SLS | |
| | (1) | (2) | (3) | (4) |
| log B-Index (representative firm) | -0.544*** | | | |
| | (0.050) | | | |
| log B-Index (theoretical) | | -0.569*** | -0.603*** | |
| | | (0.050) | (0.054) | |
| log B-Index (baseline) | | | | -0.979*** |
| | | | | (0.084) |
| log value added (t-2) | 0.220*** | 0.209*** | 0.216*** | 0.256*** |
| | (0.073) | (0.073) | (0.073) | (0.074) |
| Observations | 7273 | 7273 | 7273 | 7273 |
| F-stat | | | 13777 | 1729 |

*Notes*: *** 1%, ** 5%, * 10%. In panel A, observations are defined at the country-industry-year level, and, in panel B, observations are defined at the country-industry-size class-year level. Standard errors in parentheses are clustered at the country-industry level (panel A) or the country-industry-size class level (panel B). The outcome variable is the logarithm of the total intramural R&D expenditure by firms in a given country and industry (panel A) or country, industry and size class (panel B). In column 1 (of each panel), the main explanatory variable is a log of a B-Index calculated for a representative firm in each country-industry ($\log BIndex^{repr}_{cit}$). In columns 2-3, it is the average log theoretical B-Index (not accounting for tax incentive uptake) across all R&D-performing firms in a given country and industry or country, industry and size class ($\overline{\log BIndex^{the}}_{ci(s)t}$). In column 4, it is the average log of a B-Index accounting for tax incentive uptake ($\overline{\log BIndex}_{ci(s)t}$). Regressions in columns 1-2 are estimated by OLS, and regressions in columns 3-4 are estimated by 2SLS, instrumenting for the B-Index variables with the synthetic B-Index ($\overline{\log BIndex^{syn}_{ci(s)t}}$). All regressions control for industry value added lagged by 2 years, country-industry (panel A) or country-industry-size class (panel B) fixed effects and industry-year (panel A) or industry-size class-year (panel B) fixed effects.

ilar to each other, which suggests that the potential endogeneity of $\overline{\log BIndex^{the}}_{ci(s)t}$, while important to consider in theory, is not particularly important in practice. This reflects the first stage results (see Online Appendix Table B.2), where the elasticities of $\overline{\log BIndex^{the}}_{ci(s)t}$ with respect to $\overline{\log BIndex}^{syn}_{ci(s)t}$ are close to 1 and precisely estimated, implying that the time variation in the average log B-Index is chiefly driven by time variation in R&D tax incentive policies, not in firm R&D.[58]

At the country-industry level (the top panel), the elasticity based on a B-Index accounting for the detailed design features (column 3) is essentially the same as the elasticity based on the B-Index for a representative firm (column 1). A possible explanation is that special features such as preferential rates, floors and refunds typically do not apply to large firms, which account for the bulk of R&D expenditure at the country-industry level. In line with this explanation, at the country-industry-size class level (the bottom panel), we do see a larger elasticity when we account for the detailed design features (column 3) compared to when we do not (column 1). However, the difference is only about 10%. Overall, the results suggest that the much smaller elasticities estimated by aggregate studies, compared to the elasticities found in firm-level studies, are only to a minor extent due to the aggregate studies inaccurately measuring the tax incentives and this measurement error biasing the estimated elasticity towards zero.[59]

Finally, column 4 of each panel examines the effect of accounting for the partial uptake of R&D tax incentives, documented in subsection 3.1. It replaces the theoretical B-Index measure ($\overline{\log BIndex^{the}}_{ci(s)t}$) with a corresponding measure that reflects whether each firm actually uses R&D tax relief and sets all enhanced tax allowance rates and tax credit rates to zero if it does not ($\overline{\log BIndex}_{ci(s)t}$). Comparing columns 3 and 4 of each panel reveals that accounting for uptake further increases the size of the estimated elasticity by about 60%, to about -0.7 at the country-industry level and to about -1 at the country-industry-size class level. An important corollary of this finding is that analysis that fails to account for the incomplete uptake of the incentives, as did all previous cross-country studies, is bound to underestimate the elasticity by about 40%.

As governments may perceive R&D tax incentives and direct support for business R&D, such as R&D grants, as substitutes (or complements), an important concern might be that R&D tax incentives are negatively (or positively) correlated with the availability of direct support. If that is the case, direct support could be an omitted variable, biasing the effects of R&D tax incentives downward (upward). We test for this in Online Appendix Table B.3, which replicates Table 5 additionally controlling for the intensity of direct

[58]The strong first stages are also reflected in the tests for weak instruments, which yield Kleibergen-Paap rk Wald F-statistics of over 10,000.

[59]Accurately modelling the detailed features of R&D tax incentives is, nevertheless, important for a reliable estimation of heterogeneous effects across different size classes.

support, defined as the ratio of the total direct R&D support received by firms in a country-industry-size class to their mean intramural R&D expenditure over the sample period.[60] Controlling for the intensity of direct support only slightly reduces the estimated R&D tax price elasticities (by about 8%) and does not affect the relative size of the coefficients obtained at different levels of aggregation and using the different tax price measures.[61]

Overall, the analysis in Table 5 suggests that, while the accuracy of accounting for detailed tax incentive design features in the calculation of the B-Index does not seem to explain the large gap between elasticities estimated by aggregate and firm-level studies, disaggregating the estimation by firm size and accounting for the incomplete uptake, together, bridge a large part of the gap, as they more than double the elasticity to reach the value of -1.

## 5.2 Heterogeneous R&D Tax Price Elasticities

The analysis so far indicates that the effects of R&D tax incentives could be different for firms of different size.[62] R&D tax incentives might also be less effective for more R&D-intensive firms, e.g., in the pharmaceutical industry, for which R&D represents a core activity that is key to the future of their business and which can find it more difficult to substitute for in-house R&D with, e.g., purchases of technology embodied in capital goods and intermediate inputs. We test for the heterogeneity of the R&D tax price elasticities in Table 6, where we employ the same specification and B-Index measure as in the last column of Table 5 but additionally interact $\overline{\log BIndex}_{cist}$ with dummy variables indicating individual firm size classes and firms with high initial R&D intensity (see subsection 2.5 for variable definitions).

Column 1 of Table 6 exactly replicates column 4 of the bottom panel of Table 5. Column 2 allows the tax price elasticities to differ by firm size class. The results show a striking difference between the effects of R&D tax incentives on small and medium firms on the one hand and large firms on the other. The elasticities for small and medium firms are estimated at -1.3 and -1.0, respectively. In stark contrast, the elasticity for large

[60] We do not include direct support intensity in the baseline specification, because direct support received by firms in a certain industry or industry-size class could be endogenous to R&D-related choices of these firms, as firms that wish to invest more in R&D are also more likely to apply for direct support.

[61] Consistently across the different specifications, the results imply that a 1-percentage-point greater share of direct support in R&D expenditure corresponds to 1.8% greater R&D expenditure. Taken at face value, this could also be interpreted as implying that 1 dollar of direct support generates 1.8 additional dollars of R&D expenditure.

[62] Some existing firm-level studies also suggest larger effects of R&D tax incentives for smaller firms: Hægeland and Møen (2007); Baghana and Mohnen (2009); Lokshin and Mohnen (2012); Labeaga et al. (2014); Kasahara et al. (2014).

Table 6: **R&D Tax Price Elasticities By Firm Size and R&D Intensity**

| | Outcome: log R&D expenditure | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| log B-Index | -0.979*** | -1.290*** | -1.194*** | -1.464*** | -1.317*** |
| | (0.084) | (0.119) | (0.113) | (0.140) | (0.158) |
| log B-Index x medium | | 0.261 | | 0.234 | 0.012 |
| | | (0.163) | | (0.166) | (0.244) |
| log B-Index x large | | 0.981*** | | 0.937*** | 0.586* |
| | | (0.224) | | (0.222) | (0.307) |
| log B-Index x R&D-intensive | | | 0.456*** | 0.410*** | |
| | | | (0.156) | (0.149) | |
| log B-Index x R&D-intensive x small | | | | | 0.065 |
| | | | | | (0.229) |
| log B-Index x R&D-intensive x medium | | | | | 0.563** |
| | | | | | (0.246) |
| log B-Index x R&D-intensive x large | | | | | 0.791** |
| | | | | | (0.322) |
| Observations | 7273 | 7273 | 7273 | 7273 | 7273 |
| F-stat | 1729 | 98 | 919 | 79 | 28 |

*Notes*: *** 1%, ** 5%, * 10%. Observations are defined at the country-industry-size class-year level, and standard errors in parentheses are clustered at the country-industry-size class level. The outcome variable is the logarithm of the total intramural R&D expenditure by firms in a given country, industry and size class. Explanatory variables are based on the average log of a B-Index accounting for tax incentive uptake across all R&D-performing firms in a given country, industry and size class ($\overline{\log BIndex}_{cist}$). All regressions are estimated by 2SLS, instrumenting for the B-Index-based explanatory variables with corresponding variables based on the synthetic B-Index ($\overline{\log BIndex}^{syn}_{cist}$). All regressions control for industry value added lagged by 2 years, country-industry-size class fixed effects and industry-size class-year fixed effects.

firms is rather small (-0.3) and is not statistically significantly different from zero (p-value 0.11).[63] Column 3 instead allows the elasticities to differ with firms' R&D intensity. It reports a much smaller elasticity for R&D-intensive firms. While the elasticity for less R&D-intensive firms is estimated to be -1.2, the elasticity is estimated to be only -0.7 for more R&D-intensive firms, with the difference statistically significant at the 1% level. Column 4 combines the two sources of heterogeneity. The results it reports confirm those reported in columns 2 and 3 and are even more striking. For the baseline group of less R&D-intensive small firms, they indicate a rather large elasticity of -1.5, but they indicate much smaller elasticities for large firms (by 0.9) and for R&D-intensive firms (by 0.4). Together, these interaction results imply an elasticity of essentially zero for R&D-intensive large firms.[64] Finally, column 5 reports results of a regression allowing

[63]The elasticity for medium firms is statistically significantly different from both zero and the elasticity for large firms at the 1% significance level, but it is not statistically significantly different from the elasticity for small firms (p-value 0.11).

[64]First-stage regressions corresponding to column 4 of Table 6 are reported in Online Appendix Table B.4.

the effects of R&D intensity vary by firm size. It indicates that the effects of R&D tax incentives are similarly strong for small firms of either low or high R&D intensity and for medium-sized firms of low R&D intensity, they are significantly weaker for medium-sized firms of high R&D intensity and large firms of low R&D intensity, and they are the lowest for large, R&D-intensive firms.

Overall, the results suggest that R&D tax incentives are effective at inducing R&D expenditure among SMEs and less R&D-intensive firms but have little effect on the R&D expenditure of large R&D-intensive firms, which, however, account for a large part of aggregate R&D and receive a large part of the total R&D tax relief in most countries. Importantly, the elasticities we find for SMEs, especially the less-R&D intensive ones, are much larger than those found by previous cross-country studies and rather similar to elasticities found in well-identified recent firm-level studies (Rao, 2016; Guceri and Liu, 2019; Agrawal et al., 2020; Dechezleprêtre et al., 2023). It appears that, by accounting for the imperfect uptake of R&D tax incentives and allowing for heterogeneous R&D tax price elasticities, we have been able to bridge most of the gap between cross-country and firm-level studies.

We test the robustness of the baseline results in Table 7. Column 3 replicates our baseline specification from column 4 of Table 6. In columns 1 and 2, we test the sensitivity of the results to using a broader sample that additionally includes countries for which we do not have access to the administrative tax data. First, in column 1, we use the baseline sample but use a B-Index measure that does not account for the tax incentive uptake ($\overline{\log BIndex^{the}}_{cist}$). As expected, the results are qualitatively similar to those in column 3, only with smaller estimated elasticities. Column 2 reports the results of estimating the same specification on the broader sample. The results in column 2 are similar to those in column 1, suggesting that the results are robust to using a broader country sample. In Online Appendix Table B.5, we also show that our baseline results are robust to excluding any one country from the sample and therefore are not driven by variation for a particular country. Column 4 of Table 7 tests the sensitivity of the results to keeping outliers in the sample, and column 5 the sensitivity to removing the value added control. Either modification leads to results that are similar to those in the baseline specification.

While we have shown above that controlling for direct support intensity does not significantly alter the estimated homogeneous tax price elasticities, it could still affect the estimated heterogeneous elasticities, particulary as smaller firms tend to rely more strongly on direct support (Appelt et al., 2022). However, column 6 of Table 7 shows that controlling for the intensity of direct support has little effect on the estimated heterogeneous R&D tax price elasticities, again indicating that our results for R&D tax incentives are not driven by availability and generosity of direct support.

Finally, in column 7 of Table 7, we test the robustness of our result suggesting that R&D-intensive firms respond less strongly to R&D tax incentives. Instead of the baseline measure, based on the ratio of R&D employment and total employment of firms underlying our sample, we rely on the alternative measure based on the OECD Taxonomy of Economic Activities Based on R&D Intensity (Galindo-Rueda and Verger, 2016).[65] Using this alternative measure, we again estimate a large and highly statistically significant interaction between our B-Index measure and high R&D intensity pointing towards weaker effects for more R&D-intensive firms.

## 5.3 Quantifying the Effects of R&D Tax Incentives

In this section, we quantify the aggregate effects of R&D tax incentives implied by our estimates. We start by converting the estimated elasticities into *incrementality ratios*, which state how many dollars of additional R&D expenditure are induced by 1 dollar of R&D tax relief. For a given marginal tax subsidy rate $s$, the tax price elasticity can be expressed as $e = -\frac{dR}{R}/\frac{ds}{1-s}$, where $R$ is R&D expenditure. Following Thomson (2017), the incrementality ratio can then be expressed as $IR \equiv \frac{dR}{d(sR)} = \frac{-e}{1-s(1+e)}$. We calculate separate incrementality ratios for each country, industry, size class and year, and then we aggregate them up to the country-year level based on the share of each industry-size class in the total R&D tax relief received by firms in a given country and year. We obtain $e$ for a given firm group based on elasticity estimates from column 4 of Table 6 and calculate $s$ for those groups as $1 - \overline{BIndex}_{cist}$. The incrementality ratio for country $c$, industry $i$ and size class $s$ in year $t$ is calculated as

$$IR_{cist} = \frac{-e_{cis}}{1 - (1 - \overline{BIndex}_{cist})(1 + e_{cis})} \ , \tag{11}$$

and the aggregate incrementality ratio for country $c$ in year $t$ is given by

$$IR_{ct}^{agg} = \sum_i \sum_s w_{cist}^{relief} IR_{cist} \ , \tag{12}$$

where $w_{cist}^{relief}$ is the share of R&D tax relief received by firms in country $c$, industry $i$ and size class $s$ in the total R&D tax relief received by all firms in country $c$.

For each of the 11 sample countries with R&D tax incentive in place for which tax relief microdata are available, Figure 4 reports the aggregate incrementality ratio implied by its country-specific distribution of the R&D tax relief in 2019 (or the latest available

[65] See section 2 for more detail.

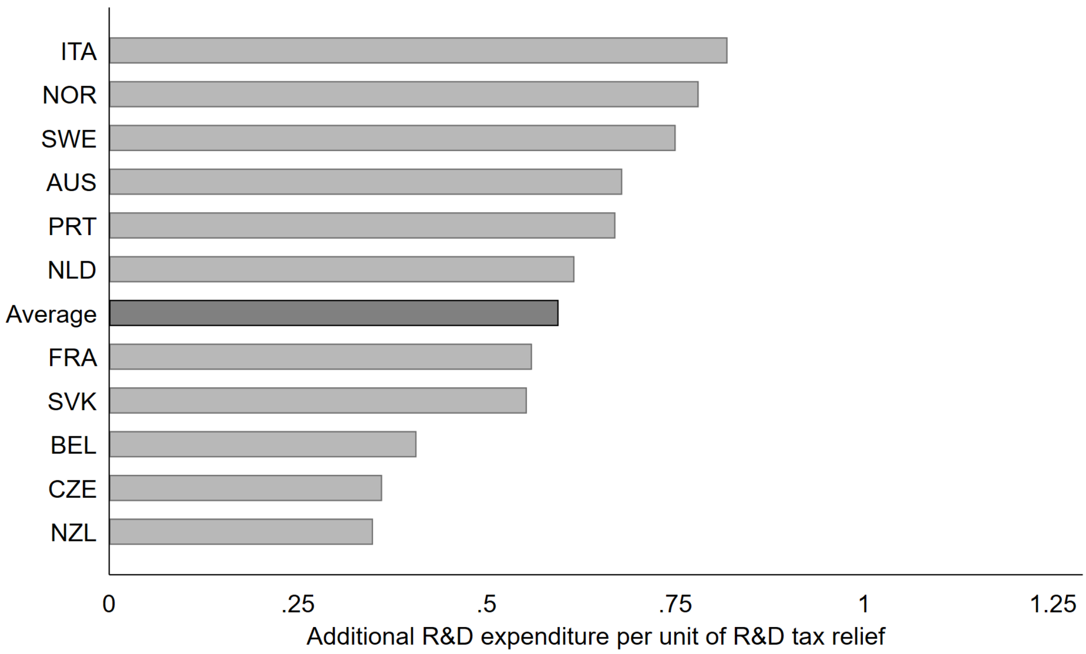
Table 7: **R&D Tax Price Elasticities by Firm Size and R&D Intensity: Robustness**

| | Outcome: log R&D expenditure | | | | | | |
|---|---|---|---|---|---|---|---|
| | Not accounting for uptake | | Accounting for uptake | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| log B-Index | -0.993*** | -1.012*** | -1.464*** | -1.455*** | -1.424*** | -1.430*** | -1.442*** |
| | (0.094) | (0.089) | (0.140) | (0.145) | (0.139) | (0.120) | (0.132) |
| log B-Index x medium | 0.226** | 0.256** | 0.234 | 0.262 | 0.244 | 0.246* | 0.244 |
| | (0.109) | (0.105) | (0.166) | (0.169) | (0.166) | (0.144) | (0.164) |
| log B-Index x large | 0.703*** | 0.629*** | 0.937*** | 0.904*** | 0.950*** | 0.885*** | 0.945*** |
| | (0.128) | (0.122) | (0.222) | (0.299) | (0.228) | (0.207) | (0.219) |
| log B-Index x R&D-intensive | 0.266*** | 0.182* | 0.410*** | 0.317* | 0.427*** | 0.502*** | |
| | (0.093) | (0.094) | (0.149) | (0.171) | (0.152) | (0.133) | |
| intensity of direct support | | | | | | 1.800*** | |
| | | | | | | (0.099) | |
| log B-Index x R&D-intensive (OECD) | | | | | | | 0.471*** |
| | | | | | | | (0.157) |
| log value added (t-2) | 0.217*** | 0.318*** | 0.256*** | 0.263*** | | 0.228*** | 0.242*** |
| | (0.073) | (0.067) | (0.074) | (0.074) | | (0.069) | (0.074) |
| Observations | 7273 | 10053 | 7273 | 7380 | 7273 | 7273 | 7273 |
| F-stat | 500 | 806 | 79 | 81 | 78 | 79 | 77 |

*Notes*: *** 1%, ** 5%, * 10%. Observations are defined at the country-industry-size class-year level, and standard errors in parentheses are clustered at the country-industry-size class level. The outcome variable is the logarithm of the total intramural R&D expenditure by firms in a given country, industry and size class. In columns 1 and 2, the principal explanatory variables are based on the average log theoretical B-Index (not accounting for tax incentive uptake) across all R&D-performing firms in a given country and industry or country, industry and size class ($\overline{\log BIndex^{the}{}_{cist}}$). In columns 3-7, they are based on the average log of a B-Index accounting for tax incentive uptake ($\overline{\log BIndex_{cist}}$). All regressions are estimated by 2SLS, instrumenting for the B-Index-based explanatory variables with corresponding variables based on the synthetic B-Index ($\overline{\log BIndex^{syn}_{cist}}$). The regressions reported in columns 2 and 4 are on broader samples that additionally include, respectively, countries for which administrative tax relief microdata could not be obtained (column 2) and outlier country-industry-size classes that are dropped in the baseline specification (column 4). All regressions control for industry value added lagged by 2 years, country-industry-size class fixed effects and industry-size class-year fixed effects.

year, if earlier).[66] It is important to emphasise that the model parameters do not vary across countries, and, as a result, cross-country variation in the incrementality ratios is driven solely by cross-country differences in the distribution of R&D tax relief over firms of different size and R&D intensity, and, to a lesser extent, by differences in the generosity of R&D tax incentives.[67] In reality, other country-specific factors that we do not model here can also influence the effectiveness of R&D tax incentives in each country. For this reason, Figure 4 should not be interpreted as comparing the overall effectiveness of R&D tax incentives in each country, but rather as documenting the joint implications of the heterogeneous elasticities that we estimate and the substantial cross-country differences in the distribution of R&D tax relief over different types of firms.

Figure 4: **Incrementality Ratios Implied by the Distribution of R&D Tax Relief**




*Notes*: For each country, the figure shows the aggregate incrementality ratio of R&D tax incentives implied by elasticity estimates in column 4 of Table 6 (which are themselves not country-specific). The incrementality ratios are defined as dollars of additional R&D induced by 1 dollar of R&D tax relief (see the main text for the details of the calculations). The figure is based on year 2019 with the exception of Australia (2018), France (2014), Portugal (2018) and Sweden (2017). "Average" corresponds to the unweighted mean across countries.

[66] In the estimation data, coverage of industry-size class cells varies across countries. To make sure this variation does not affect the aggregate incrementality ratio calculated for each country, we balance the data and impute missing observations based on non-missing observations in the same country-size class (e.g. the B-Index) or industry-size class (e.g. the R&D intensive dummy).

[67] For a given value of R&D tax price elasticity, more generous tax incentives (i.e. a smaller value of $\overline{BIndex}_{cist}$) are associated with incrementality ratios closer to 1, i.e. greater incrementality ratios for elasticities smaller than 1 and smaller incrementality ratios for elasticities greater than 1. A elasticity of exactly 1 implies an incrementality ratio of 1 for any generosity of R&D tax incentives.

The implied aggregate incrementality ratios, shown in Figure 4, vary considerably across countries, from 0.35 to 0.8. They are the highest in countries where R&D tax relief goes disproportionately towards smaller or less R&D-intensive firms, either due to a binding ceiling on eligible R&D expenditure (Norway, Sweden) or due to the preferential treatment of SMEs (Australia).[68] They are the lowest in countries where design features favoring smaller R&D performers are not in place (Czechia, Belgium, Slovakia) or are binding for very few firms (France). The particularly low incrementality ratio for New Zealand is linked to the fact that its R&D tax credit was only introduced in 2019, and, while the uptake in the first year was generally low, 1 in 4 large R&D-performing firms used R&D tax relief but only 1 in 10 small or medium R&D performers did (see Figure 1). On average across countries, each dollar of R&D tax relief is associated with about 60 cents of additional R&D expenditure. This is broadly in line with aggregate studies but much less than what recent firm-level studies indicate.[69] Importantly, our analysis shows that this difference is largely due to the weak effects estimated for large, R&D-intensive firms, which account for a small share of firms in firm-level studies but receive about half of the total R&D tax relief.

We also compute the aggregate R&D tax price elasticity in response to a uniform proportional change in the B-index of all firms, given by

$$e_{ct}^{agg} = \sum_i \sum_s w_{cist}^R e_{cist} \ , \tag{13}$$

where $w_{cist}^R$ is the share of R&D expenditure of firms in country $c$, industry $i$ and size class $s$ in the total R&D expenditure of all firms in country $c$. We again use weights for year 2019 (or the latest year, if earlier), and we report an unweighted average of $e_{ct}^{agg}$ across countries. When we use the baseline elasticities with respect to the tax price of R&D accounting for incomplete uptake, we obtain an aggregate elasticity of -0.5 However, it also interesting to calculate the aggregate intention-to-treat elasticity of R&D with respect to the theoretical tax price of R&D for which firms are eligible if they benefit from the tax relief. This elasticity is substantially smaller in absolute value, -0.3.[70]

[68]In the case of Italy and Portugal, the relatively high incrementality ratios are related to the comparatively high subsidy rates in these countries.

[69]E.g., Thomson (2017) also reports a (short-term) incrementality ratio of 60 cents per dollar of forgone tax revenue.

[70]This is based on the sample of 11 countries with R&D tax incentive in place for which tax relief microdata are available. In the broader 16-country sample including also countries without tax relief microdata, the corresponding figure is -0.4.

# 6 Exploring the Heterogeneous Effects of R&D Tax Incentives

In this section, we analyse the main results by assessing to what extent they are driven by (i) the existence of credit constraints, and (ii) dynamic adjustment of R&D expenditure over time.

## 6.1 Role of Credit Constraints

What can explain the apparent greater responsiveness of small and medium-size firms to R&D tax incentives? As smaller firms are more likely to be credit-constrained (Hall and Lerner, 2010), credit constraints represent the most natural explanation, which we test in two different ways in Table 8.

Firstly, we explore the composition of R&D expenditure. The reason that R&D is more affected by credit constraints than other types of investment is that the costs involved mostly consist of salaries for scientists and engineers, and it entails a highly uncertain process aimed at creating intangible assets that are largely tacit and embedded in the firm's human capital (Hall and Lerner, 2010). The salaries and the intangible assets are much harder to use as collateral for obtaining a loan than traditional investment in physical capital. However, R&D expenditure also involves expenditure on R&D-related machinery and buildings, i.e. tangible assets not subject to the same collateral issues. To the extent the differential effects for firms of different size are driven by credit constraints, it seems reasonable to expect the differences to be smaller for R&D-related capital than for current expenditure on R&D labour and materials. We test this in columns 1 and 2, which split the outcome variable into current and capital R&D expenditure, respectively. The results for current expenditure, which accounts for most of the total R&D spending, largely replicate the results for R&D expenditure as a whole. In contrast, while we observe a large effect of R&D tax incentives on R&D-related capital spending, this effect is very similar for firms of all sizes, in line with the idea that firms' ability to use investment as collateral plays a role.

Secondly, we explore the widely held notion that young firms are more likely to be financially constrained, because there is less information about them and they have more limited internal resources and fewer assets to use as a collateral (Cabral and Mata, 2003; Angelini and Generale, 2008).[71] In column 5 of Table 8, we interact our baseline B-Index measure with a dummy for country-industry-size classes with below-median value of mean firm age (among R&D-performing firms). The estimated coefficient on the newly added

[71] Howell (2017), among others, similarly uses firm age to proxy for financial constraints.

Table 8: **Heterogeneous R&D Tax Price Elasticities: Role of Credit Constraints**

| | Outcome: log R&D expenditure | | | |
|---|---|---|---|---|
| | (1) Current | (2) Capital | (3) Total | (4) Total |
| log B-Index | -1.394*** | -1.725*** | -1.312*** | -0.801*** |
| | (0.131) | (0.260) | (0.145) | (0.238) |
| log B-Index x medium | 0.243 | 0.031 | 0.215 | 0.219 |
| | (0.162) | (0.326) | (0.164) | (0.161) |
| log B-Index x large | 1.019*** | -0.288 | 0.861*** | 0.897*** |
| | (0.214) | (0.449) | (0.236) | (0.218) |
| log B-Index x R&D-intensive | 0.358** | 0.832*** | 0.553*** | 0.468*** |
| | (0.144) | (0.299) | (0.162) | (0.147) |
| log B-Index x low mean age | | | -0.466*** | |
| | | | (0.167) | |
| log B-Index x young firm share | | | | -2.470*** |
| | | | | (0.742) |
| Observations | 7042 | 7042 | 7273 | 7273 |
| F-stat | 80 | 80 | 59 | 58 |

*Notes*: *** 1%, ** 5%, * 10%. Observations are defined at the country-industry-size class-year level, and standard errors in parentheses are clustered at the country-industry-size class level. The outcome variable is the logarithm of the total intramural R&D expenditure by firms in a given country, industry and size class. Explanatory variables are based on the average log of a B-Index accounting for tax incentive uptake across all R&D-performing firms in a given country, industry and size class ($\overline{\log BIndex}_{cist}$). All regressions are estimated by 2SLS, instrumenting for the B-Index-based explanatory variables with corresponding variables based on the synthetic B-Index ($\overline{\log BIndex}^{syn}_{cist}$). All regressions control for country-industry-size class fixed effects and industry-size class-year fixed effects.

interaction term is -0.5, indicating a substantially larger elasticity for industry-size class cells with younger firms. We test the robustness of this result in column 4 by instead interacting B-Index with a share of young firms (defined as firms less than 5 years old) among all firms (not only those performing R&D) in an industry.[72] The results similarly indicate a greater elasticity for data cells containing a higher share of young firms.

Overall, the evidence reported in Table 8 is supportive of the hypothesis that credit constraints play an important role in driving the heterogeneous effects of R&D tax incentives indicated by our results.[73]

## 6.2 Dynamic Adjustment

The results shown so far are based on static specifications. In the presence of adjustment costs or policy uncertainty, firms could take longer than one year to adjust their R&D expenditure when its tax price changes. If firms of different size or R&D intensity take

[72] This variable comes from the OECD DynEmp database.

[73] Our results are in line with those of Rao (2016), Acconcia and Cantabene (2018), Dechezleprêtre et al. (2023) and Kasahara et al. (2014), who also document greater responsiveness to R&D tax incentives for firms that are more likely to be credit-constrained.

longer or shorter to adjust their R&D, the estimated differences in the effectiveness of R&D tax incentives could be due to the different dynamics of adjustment for such firms. To investigate this, we examine the effect of R&D tax incentives in a dynamic setting that includes a two-year lagged dependent variable among the regressors. We estimate the equation separately for each size class, in order to allow for different adjustment paths for firms of different size. We report the results in Table 9. In columns 1-3, we estimate the dynamic specification in levels, with 2SLS and controlling for country-industry fixed effects. The estimated coefficients on the lagged dependent variable are of moderate size but precisely estimated, and, as expected, they indicate a somewhat slower adjustment for large firms (coefficient 0.30) than for medium-sized firms (0.17) and small firms (0.19). Similar to the static specifications, estimated coefficients on log B-Index, here interpreted as short-run elasticities, are quite large for medium-sized firms (-0.8) and small firms (-1), but close to zero and statistically insignificant for large firms. The corresponding long-run elasticities for medium-size and small firms are -0.9 and -1.2, respectively, which are similar to the elasticities from our baseline static specification (Table 6).[74]

Fixed effects specifications are known to give biased and inconsistent results in the presence of a lagged dependent variable (Nickell, 1981). For this reason, in column 4-6, we redo the analysis from columns 1-3 using the difference GMM estimation (Arellano and Bond, 1991), where we transform Equation 10 into two-year differences and instrument changes in the lagged dependent variable with 4th, 6th and 8th lags of the dependent variable (in levels).[75] Using this procedure, we obtain results that are broadly similar to those obtained with a fixed effects estimation in levels, but with slightly larger coefficients on the lagged dependent variable in the case of large firms (0.49) and medium-size firms (0.26). The resulting long-run elasticities for medium-sized firms (-0.8) and small firms (-1.1) are very similar to those obtained with fixed effects estimation in levels, and the elasticities for large firms are again not statistically significantly different from zero.

Overall, while the results in Table 9 show some evidence of a dynamic adjustment in R&D expenditure over time that is slower for larger firms, the dynamic adjustment does not seem to explain the large difference in the results found for large firms as compared to medium and small firms.

[74]Using parameter estimates from Equation 10, the short-run elasticity is given by $\beta_1$ and the long-run elasticity by $\frac{\beta_1}{1-\beta_0}$. In the static case, the short-run and long-run elasticities are the same.

[75]The Sargan (1958) and Hansen (1982) tests of overidentifying restrictions do not reject exogeneity of the instruments.

Table 9: **R&D Tax Price Elasticities with Dynamic Adjustment**

| | Outcome: log R&D expenditure | | | | | |
|---|---|---|---|---|---|---|
| | Fixed effects | | | Difference GMM | | |
| | (1) Small | (2) Medium | (3) Large | (4) Small | (5) Medium | (6) Large |
| log R&D exp. (t-2) | 0.193*** | 0.168*** | 0.302*** | 0.186 | 0.256** | 0.488*** |
| | (0.039) | (0.049) | (0.055) | (0.113) | (0.106) | (0.187) |
| log B-Index | -0.941*** | -0.782*** | 0.190 | -0.904*** | -0.620*** | 0.318 |
| | (0.101) | (0.138) | (0.177) | (0.144) | (0.142) | (0.217) |
| Observations | 1451 | 1482 | 1149 | 1451 | 1482 | 1149 |
| F-stat | 868 | 641 | 222 | | | |
| Sargan | | | | 0.41 | 0.93 | 0.30 |
| Hansen | | | | 0.51 | 0.95 | 0.33 |
| Long-run elasticity | -1.17 | -0.94 | 0.27 | -1.11 | -0.83 | 0.62 |

*Notes*: *** 1%, ** 5%, * 10%. Observations are defined at the country-industry-size class-year level, and standard errors in parentheses are clustered at the country-industry-size class level. The outcome variable is the logarithm of the total intramural R&D expenditure by firms in a given country, industry and size class. The main explanatory variable is the average log of a B-Index accounting for tax incentive uptake across all R&D-performing firms in a given country, industry and size class ($\overline{\log BIndex_{cist}}$). Regressions are estimated separately for each size class, marked in the column header. All regressions instrument for the average log B-Index with the synthetic B-Index ($\overline{\log BIndex^{syn}_{cist}}$). Results in columns 1-3 are based on estimation in levels, controlling for country-industry fixed effects. Results in columns 4-6 are based on a difference generalised method of moments estimation (Arellano and Bond, 1991) that transforms the estimating equation into two-year differences and instruments changes in the lagged dependent variable with its lagged levels. Following Roodman (2009), instrument count is reduced by collapsing the instrument matrix and using only the 4th, 6th and 8th lags of the dependent variable (in levels) as instruments, alongside $\overline{\log BIndex^{syn}_{cist}}$. The GMM estimates use the two-step procedure and the standard errors reported apply the Windmeijer (2005) correction. All specifications control for industry value added lagged by 2 years and year fixed effects.

# 7 Concluding Remarks

Over time, R&D tax incentives have become a primary tool through which governments encourage companies to invest more in R&D. Despite numerous studies evaluating the effectiveness of R&D tax incentives, their impact on aggregate R&D expenditure remains unclear given the large gap between the results of aggregate cross-country studies on the one hand and recent well-identified firm-level studies on the other. In addition, evidence on the heterogeneous effects of R&D tax incentives across firms with different characteristics — and in particular for large firms — is, to date, limited, and there are virtually no studies investigating why many eligible firms do not benefit from R&D tax relief.

In this paper, we attempt to address these issues with the help of a unique, newly-constructed database containing representative firm-level microdata in 19 OECD economies. We are able to model R&D tax incentives at the level of individual firms, which allows us to accurately account for the detailed design features of the incentives in place in each country. Importantly, we are also able to observe which R&D-performing firms actually receive R&D tax relief and to take this into account when modelling the incentives. We estimate a simple model of R&D investment that relates the R&D expenditure by firms in each country, industry and size class to their tax price of R&D capital, controlling for country-industry-size class and industry-size class-year fixed effects and identifying the effects of R&D tax incentives from policy variation within country-industry-size class over time.

Our results indicate that two effects, in particular, can explain the much larger R&D tax price elasticities found in recent firm-level studies relative to those found in aggregate studies. Firstly, in most countries, only about half of all R&D-performing firms benefit from R&D tax relief. As suggested by our exploratory analysis, the reasons likely involve a combination of a lack of awareness and, more importantly, administrative and compliance costs. Existing aggregate studies do not account for the partial uptake and, as a result, provide intent-to-treat estimates that underestimate the actual effects of R&D tax incentives by about 40%. Secondly, while small and medium-sized firms and less R&D-intensive firms respond strongly to R&D, the incentives appear to have much weaker effects on larger and more R&D-intensive firms. R&D-intensive large firms account for a small share of firms in the samples used in firm-level studies, or do not appear there at all, but they account for a substantial part of aggregate R&D expenditure. Consequently, the heterogeneous effects across different types of firms drive a wedge between the effects found in firm-level studies (which largely reflect the effects on smaller firms) and those found in aggregate studies (which are importantly driven by a small number of large R&D-intensive firms).

Overall, our results imply that 1 dollar of R&D tax relief is, on average, associated with 66 cents of additional R&D expenditure. This relatively modest "bang-for-the-buck" ratio is in line with existing aggregate studies but much lower than what recent firm-level studies suggest, with the difference largely due to the fact that we find virtually no effects of R&D tax incentives on large R&D-intensive firms. Importantly, the results also suggest that the way R&D tax incentives are designed and administered in a particular country can have a major impact on their overall effectiveness. In particular, the amount of R&D expenditure induced by a dollar of R&D tax relief can be expected to be much greater for incentives that channel R&D tax relief towards smaller and less R&D-intensive firms, e.g., by imposing a ceiling on eligible R&D expenditure and using the saved resources to increase the subsidy rates for firms below the ceiling, or by administering R&D tax incentives in a way that motivates smaller and less R&D-intensive firms to actually apply for the tax relief.

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