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Cross-border effects of R&D tax incentives[☆]

Bodo Knoll[a], Nadine Riedel[b,c], Thomas Schwab[d], Maximilian Todtenhaupt[e,c,g,*], Johannes Voget[f,g]

[a] Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany
[b] Unversity of Münster, Schlossplatz 2, 48149 Münster, Germany
[c] CESifo Munich, Poschingerstraße 5, 81679 München, Germany
[d] University of Munich, Geschwister-Scholl-Platz 1, 80539 München, Germany
[e] Norwegian School of Economics, Helleveien 30, 5045 Bergen, Norway
[f] University of Mannheim, 68131 Mannheim, Germany
[g] ZEW, L7 1, 68161 Mannheim, Germany

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ABSTRACT

Existing evidence shows that R&D tax incentives boost countries' private sector R&D. Given the importance of multinational enterprises (MNEs) for private sector innovation, it is unclear, however, whether firms engage in genuinely new R&D or whether R&D is reallocated across borders. Drawing on data on unconsolidated R&D activity of MNEs in Europe, we provide evidence that responses are dominated by cross-border relocations: More generous tax incentives in one country increase MNEs' R&D investments in affiliates located there, while lowering R&D investments in affiliates of the same MNE group located in other countries. Globally, firms hardly raise their R&D activities when tax incentives become more generous.

1. Introduction

Recent years have seen an unprecedented increase in the prevalence and generosity of tax incentives for research and development (R&D). Today, 30 out of the 36 OECD countries offer preferential tax treatment for R&D expenditure, while less than half of these countries had implemented R&D tax incentive schemes 25 years ago (OECD, 2017). The U.S. currently spends almost $11.7 billion on R&D tax support, France and the UK around $6.7 billion and $3.8 billion, respectively (see OECD, 2019a,b,c). Several countries without R&D tax incentive schemes debate their introduction.

Theory suggests that granting R&D tax subsidies to private sector firms internalizes positive externalities of corporate R&D and increases inefficiently low R&D investment levels (Arrow, 1962; Hall and Van Reenen, 2000). In line with this notion, evidence shows that the social returns to R&D investments outweigh their private returns (see e.g., Hall et al., 2010; Bloom et al., 2013) and that countries can increase R&D activity within their borders by lowering R&D tax costs (see the literature review below). Despite the growing globalization of corporate R&D (Florida, 1997), surprisingly little is known about the *cross-border* effects of R&D tax incentives. In this paper, we fill this gap and assess whether changes of R&D tax incentives in one country do not only impact R&D investment there but also affect R&D activity in *other* jurisdictions. To this end, we make use of rich micro-level panel data on R&D activities of multinational enterprises (MNEs).

From a theoretical perspective, there are various ways in which R&D tax incentives may generate cross-border effects. On the one hand, R&D is internationally mobile (e.g., Abramovsky et al., 2008) and expanded R&D tax incentives at one MNE location might attract investments from abroad and lower R&D activity at entities of the same MNE in other locations. Global investment responses are then smaller than investment responses in the policy-changing country because of a cross-border substitution effect. On the other hand, if R&D production chains span several MNE locations, investments at different locations might also be complements. Expanded R&D tax support would then increase

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* Corresponding author at: Norwegian School of Economics, Helleveien 30, 5045 Bergen, Norway.
E-mail addresses: Bodo.Knoll@ruhr-uni-bochum.de (B. Knoll), Nadine.Riedel@wiwi.uni-muenster.de (N. Riedel), thomas.schwab@econ.lmu.de (T. Schwab), maximilian.todtenhaupt@nhh.no (M. Todtenhaupt), voget@uni-mannheim.de (J. Voget).

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foreign R&D activity and trigger global investment responses that exceed the responses in the policy-changing jurisdiction. As MNEs account for a substantial share of private innovation investment (e.g., see Criscuolo et al., 2010; National Science Board, 2014; Bilir and Morales, 2020), cross-border relocation of R&D for tax purposes may be a significant driver of aggregate R&D investment patterns. [1]

To empirically identify the sign and size of the cross-border effect of R&D tax incentives, we analyze panel data on European MNEs. Our empirical analysis spans the years 2000 to 2012 and measures unconsolidated innovative activity of MNEs by the number of granted patents filed at MNE group locations and invented locally.[2] The innovativeness of technologies varies across patents (see e.g., Hall et al., 2010) and plausibly reflects variation in the size of the underlying R&D activity. Hence, we construct our R&D measure as a quality-adjusted count of granted patent applications (where quality differences are modeled by patents' family size, forward citations and the number of industry classes on the patent). This data is linked to information on tax costs related to corporate R&D investments in each location of the MNE as measured by the B-index (McFetridge and Warda, 1983).

We estimate fixed effects Poisson Pseudo-Maximum Likelihood (PPML) models that express the number of quality-adjusted patents per MNE group location and year as a function of the host country's B-index and the average B-index at other locations of the same MNE group. The models condition on a rich set of control variables that absorb observed and time-constant unobserved heterogeneity across firms and host countries. In line with prior studies, we find that lower R&D tax costs positively impact corporate R&D investments in the policy-changing country. The estimated elasticity of R&D output with respect to the B-index is -1.02 and hence in the range of prior estimates in the domestic context (see e.g., the literature review in Guceri and Liu, 2019).[3] The analysis points to a positive and statistically significant cross-border relocation effect: Lower R&D tax costs at one group location are associated with diminished R&D investments at entities in other locations that belong to the same MNE group. In absolute terms, the estimated cross-border and host country tax effects do not differ, implying that we cannot reject that the aggregate tax elasticity – i.e., the sum of the host country tax effect and the cross-country tax effect – is zero. On average, R&D tax incentives are hence suggested to serve as beggar-thy-neighbor instruments rather than policies to expand the global R&D investment of MNEs.

The estimated cross-country tax effect prevails in specifications where we augment the vector of regressors by country-year-fixed effects and hence compare changes in the R&D activity of affiliates of different MNE groups in the same country that do and do not experience tax cost shocks at other locations of the MNE group (or experience shocks of different size). The estimates are also robust to augmenting the model by subnational-region-year-fixed effects and industry-year-fixed effects respectively and to controlling for economic and technological changes at the host locations of other MNE affiliates. Furthermore, we complement the analysis by estimating distributed lag models. In line with intuition, the results indicate that responses of corporate R&D activity, as measured by granted patent applications, emerge with a time lag. The estimates also support the common trend assumption: Group locations that do and do not experience changes in foreign entities' R&D tax environments exhibit similar R&D trends prior to the reform. Placebo tests, where we reestimate our empirical model after randomly reassigning group structures across MNE affiliates, yield no significant cross-border relocation effect.

Finally, we present evidence for effect heterogeneity. Our results suggest that the size of the cross-country R&D tax effect is larger for low-distance firms than for high-distance firms. This finding is consistent with the notion that firms have regional R&D location preferences or that transaction costs increase in geographic distance. Our findings hence lend some support to prior macro-level studies which assume that cross-border tax effects decline in space (e.g., Wilson, 2009; Akcigit et al., 2018).[4] On top of that, we show that MNEs with large R&D activities tend to respond stronger to changes in R&D tax incentives than smaller MNEs. This potentially reflects that benefits from R&D tax planning increase in firm size, while implementation costs tend to be fixed.

Our paper relates to a growing empirical literature that estimates the impact of R&D tax subsidies on corporate R&D investment. The large majority of studies is concerned with determining the effect of *host country* R&D tax cost on R&D investments. This informs policymakers on how adjustments of R&D tax incentives affect R&D activity in their own country, ignoring contemporary tax policy measures in other countries. The literature relies on aggregate information on R&D spending at the country or state level (see e.g., Bloom et al., 2002; Athukorala and Kohpaiboon, 2010; Moretti and Wilson, 2017; Brown et al., 2017), R&D information drawn from firm surveys (e.g., Czarnitzki et al., 2011; Cappelen et al., 2012; Lokshin and Mohnen, 2013; Mulkay and Mairesse, 2013), annual reports of listed firms (e.g. Yang et al., 2012; Ivus et al., 2021) and, more recently, also administrative corporate tax return data (e.g., Rao, 2016; Dechezleprêtre et al., 2017; Guceri and Liu, 2019; Agrawal et al., 2020; Chen et al., 2021) to quantify this effect. As the latter studies commonly draw on data for individual countries, cross-border relocation of R&D for tax purposes can, by definition, not be assessed.[5]

Evaluations of the economic and welfare consequences of R&D tax incentives, nevertheless, require a thorough understanding of their impact across borders. If more generous R&D tax incentives – as suggested by our findings – do attract mobile R&D from abroad, neighboring countries suffer a loss in R&D activity. The global response of R&D investment is then smaller than the R&D response in the policy-changing country. To the best of our knowledge, we are the first to present micro-level evidence on the cross-border impact of input-related R&D tax incentives in a large number of countries. Our analysis relates to early work by Hines (1995) and Hines and Jaffe (2001) who study the effect of the international tax system (i.e., withholding taxes on royalty payments and the interaction of U.S. foreign tax credits with domestic tax incentives) on the R&D activity of a limited number of U.S. MNEs.[6] Beyond these contributions, there are few prior studies that consider

[1] According to National Science Board (2014), MNEs performed around 90% of the overall U.S. business R&D in 2010.

[2] Patent counts at the location of the technology inventor(s) are a widely used proxy for R&D investment (see Section 4 for details). Note that papers on corporate patent shifting, in contrast, study (tax) determinants of the location of patent *ownership*, conditional on the inventor location (e.g., Alstadsæter et al., 2018).

[3] We also show that omitting the foreign tax costs regressor biases the estimate for the host country tax coefficient — albeit in a quantitatively moderate way.

[4] Note that our binary measure of intra-firm distance cannot speak on the functional form of the relationship between effect size and absolute distance between alternative locations.

[5] This is acknowledged as a shortcoming in prior work, see e.g., Guceri and Liu (2019). Note, moreover, that analogous to the cited research, we focus on input-related R&D tax incentives, e.g., incentives granted in the form of special tax deductions for R&D costs or R&D tax credits. Output-related incentives, namely special low tax rates on patent income (patent boxes), are disregarded as they tend to be instruments to attract mobile profits rather than to spur R&D investment (see e.g., Bösenberg and Egger, 2017; Alstadsæter et al., 2018; Koethenbuerger et al., 2018; Knoll and Riedel, 2019 and Gaessler et al., 2021). In general, empirical studies on patent boxes also largely ignore cross-country effects. An exception is Schwab and Todtenhaupt (2021) who show that profit shifting opportunities and tax cost reductions related to patent box regimes spur R&D investments in non-patent box countries.

[6] Using data aggregated at 42 foreign subsidiary locations, they find substitution effects, while a first-difference analysis of patenting data from 378 U.S. firms reveals complementary effects.

cross-border effects of R&D taxation on foreign country R&D — and all of these studies are based on aggregate data. Bloom and Griffith (2001) and Montmartin and Herrera (2015) use information on private sector R&D spending in individual OECD countries, Wilson (2009) uses data on corporate R&D spending in U.S. states between 1981 and 2004, and Akcigit et al. (2018) use historic data on patent filings in U.S. counties and states during the 20th century.

The results in these papers are mixed: Bloom and Griffith (2001), Wilson (2009) and Montmartin and Herrera (2015) find large and positive cross-border effects of R&D tax costs on other jurisdictions' R&D activity. Akcigit et al. (2018) report a positive but more moderate tax impact. For corporate R&D, proxied by corporate patents, the latter study even fails to find any indication of cross-border relocation of R&D for tax purposes. These contrasting findings might, in part, be attributed to differences in the modeling approaches pursued. In particular, testing for cross-border spillovers requires making assumptions on where tax spillovers arise. Prior studies assume that they emerge in border counties of reform states (Akcigit et al., 2018), in adjacent or geographically close states (Wilson, 2009), or economically connected jurisdictions as measured by FDI flows (Bloom and Griffith, 2001) or international trade (Montmartin and Herrera, 2015). With micro-level data, as the one used in our study, spillover routes at the group-level can be identified explicitly in a non-adhoc way based on information on MNE group structures. Micro-level data, moreover, allows for empirical identification strategies that compare changes in the R&D activity of affiliates of different MNE groups located in the *same country* that do and do not experience R&D tax cost shocks in other locations of their MNE group. We thus control non-parametrically for potential unobserved time-varying host country confounders, like changes in countries' regulatory framework, technology base or patenting system. Drawing on micro-level data, furthermore, comes with the advantage that it allows us to test for effect heterogeneity across firms and that aggregation bias is avoided — that is, contrary to macro-level studies, we can obtain an unbiased estimate of the average corporate response to R&D tax incentives.[7]

Finally, note that recent related work (Wilson, 2009, and Akcigit et al., 2018), contrary to our study, assesses cross-border R&D tax effects in subnational rather than international contexts. Wilson (2009) acknowledges that insights from his U.S. state-level analysis may not carry over to federal-level R&D tax policy settings but hypothesizes that "large foreign and U.S. multinationals, which are responsible for the bulk of U.S. R&D spending, may fairly easily reallocate R&D activity to (from) the U.S. in response to favorable (unfavorable) changes in U.S. policy vis-à-vis foreign policy" (Wilson, 2009; p. 436). Our findings support this presumption.

The remainder of the paper is structured as follows: Section 2 presents theoretical considerations. Sections 3 and 4 describe the estimation approach and the dataset used. The empirical results are presented in Section 5. Section 7 concludes.

2. Theoretical considerations

Before embarking on the empirical analysis, we sketch channels through which R&D tax incentives may impact MNEs' R&D investment choice. Consider an MNE that engages in R&D and operates in two countries, denoted by $i \in \{A, B\}$, each of which can potentially serve as a location for R&D investment. To simplify notation, we denote by g^i the firm's net-of-tax profit from R&D, that is the difference between the net-of-tax value of R&D output and R&D input costs in i. g^i is a function of the firm's R&D investment at location i, x^i, as well as R&D investment at the other location, x^{-i}. After-tax profits in i, moreover, directly depend on the effective R&D tax costs in i, denoted by t^i: $g^i = g(x^i, x^{-i}, t^i)$. While g^i declines in the host location tax, $\frac{\partial g^i}{\partial t^i} < 0$, it increases in the R&D investment at i and $-i$: $\frac{\partial g^i}{\partial x^i} > 0$, $\frac{\partial g^i}{\partial x^{-i}} > 0$. The marginal product of R&D investment is, moreover, assumed to decline in the level of R&D: $\frac{\partial^2 g^i}{\partial (x^i)^2} < 0$, $\frac{\partial^2 g^i}{\partial (x^{-i})^2} < 0$. Cross-border effects of R&D investments on the profit contribution of R&D investment at the other group location may be positive or negative, as will be discussed in detail below: $\frac{\partial^2 g^i}{\partial x^i \partial x^{-i}} \lesseqgtr 0$, $\frac{\partial^2 g^i}{\partial x^{-i} \partial x^i} \lesseqgtr 0$. The MNE's global after-tax profit reads: $\Pi = \sum_{i \in \{A,B\}} g^i$. The MNE maximizes Π by choosing R&D investment levels x^i at the two locations. The first order conditions (FOCs) are given by

$$g_A^A + g_A^B = 0, \tag{1}$$

$$g_B^A + g_B^B = 0 \tag{2}$$

where the subscript denotes the first derivative of the g^i function with respect to R&D investment in countries A and B, respectively (e.g. $g_A^A = \frac{\partial g^A}{\partial x^A}$). Without loss of generality, we determine the impact of changes in the tax rate of country A, t^A, on R&D investment at the two locations. Symmetric effects can be derived for changes in t^B. Comparative statics with respect to t^A read:

$$g_{AA}^A \frac{dx^A}{dt^A} + g_{AB}^A \frac{dx^B}{dt^A} + \frac{\partial g_A^A}{\partial t^A} + g_{AA}^B \frac{dx^A}{dt^A} + g_{AB}^B \frac{dx^B}{dt^A} = 0 \tag{3}$$

$$g_{BA}^A \frac{dx^A}{dt^A} + g_{BB}^A \frac{dx^B}{dt^A} + g_{BA}^B \frac{dx^A}{dt^A} + g_{BB}^B \frac{dx^B}{dt^A} = 0 \tag{4}$$

where the second subscript denotes the second derivative of g^i with regard to x^A and x^B respectively (e.g. $g_{AA}^A = \frac{\partial^2 g^A}{\partial x_A^2}$). Cramer's rule yields that the own-country tax effect on R&D investment is negative, $\frac{dx^A}{dt^A} < 0$, as $-\frac{\partial g_A^A}{\partial t^A} \cdot (g_{BB}^A + g_{BB}^B) < 0$.

Analogously, it can be shown that the cross-border effect of the effective tax burden in country A on R&D investment in country B, $\frac{dx^B}{dt^A}$, is ambiguous and depends on the sign of $\frac{\partial g_A^A}{\partial t^A} \cdot (g_{BA}^A + g_{BA}^B)$. While $\frac{\partial g_A^A}{\partial t^A} < 0$, the sign of g_{BA}^A and g_{BA}^B is a priori unclear. If $g_{BA}^A, g_{BA}^B < 0$, R&D investment in country A lowers the marginal profit contribution of R&D investment in country B and R&D investments in countries A and B act as substitutes. Higher R&D tax costs in A then increase R&D investment in B, $\frac{dx^B}{dt^A} > 0$. Vice versa, if $g_{BA}^A, g_{BA}^B > 0$, R&D investments in countries A and B act as complements and higher R&D tax costs in A decrease R&D investment in B, $\frac{dx^B}{dt^A} < 0$. Below we discuss potential mechanisms that may establish a substitutionary or complementary link between R&D investment at MNE group locations in different countries.

Note that analogous predictions can be derived for the general case, where the MNE operates R&D activities in a set $\mathcal{I}$ of more than two countries, with $i \in \{A, B, C, \ldots\}$. The MNE's after tax profits then reads: $\Pi = \sum_{\mathcal{I}} g(x^i, x^{-i}, t^i)$, where x^{-i} denotes the vector of the MNE's R&D investment in all countries other than i. The FOC for x^A reads: $\sum_{\mathcal{I}} g_A^i = 0$ (where $g_A^i = \frac{\partial g^i}{\partial x^A}$). Analogous FOCs are derived for R&D in all other countries. As the choice of R&D investment in a particular country affects the MNE's profits in *all* locations, it depends on the full tax rate vector $(t^A, t^B, t^C, \ldots)$. In the empirical analysis to come, we therefore model R&D activity at a given MNE group location as a function of the effective host country tax rate and the tax rates at all other affiliates that serve as potential R&D locations.

R&D Investments as Substitutes

Cross-border mobility of R&D investments (documented, e.g., in Bloom and Griffith, 2001; Abramovsky et al., 2008; OECD, 2008; Iversen et al., 2016) predicts a substitutionary relationship of R&D activity at different group locations: MNEs respond to increased R&D tax incentives by shifting R&D investments from other group locations to the policy-changing jurisdiction. In the framing of our theoretical

[7] If firms react heterogeneously to R&D incentives, aggregate estimates can differ substantially from the average microeconomic response (see e.g., Gupta, 1971; Sasaki, 1978; Pesaran et al., 1989). Pesaran et al. (1989) find an upward bias in the estimates of real wage elasticities obtained from aggregated data. In their study, aggregate estimation approaches also perform worse than microeconomic estimation approaches in predicting aggregate variables.

model: If R&D tax costs decline in country A, it is optimal for the MNE to expand R&D investments in A. This lowers the marginal product of R&D investments at other locations B ($g^A_{BA}, g^B_{BA} < 0$) and renders it optimal to decrease R&D investment there ($\frac{dx^B}{dt^A} > 0$). Note that the firm's global R&D response may still be positive but the aggregate response is then smaller than the observed response in the policy-changing country. Put differently, the positive link between R&D investments and host country tax incentives documented in prior empirical research may root in cross-border relocations or reflect genuinely new R&D undertaken by the firm. If cross-border relocations are quantitatively relevant, R&D tax subsidies decrease R&D activity at foreign group locations and, in that sense, act as beggar-thy-neighbor instruments. The impact on foreign *welfare* is ambiguous though: On the one hand, a reduction in foreign R&D may lower foreign knowledge production, foreign productivity and income. Such negative cross-border effects are particularly likely to emerge if innovation mainly serves as an input to the MNE's *local* value creation — that is, if R&D increases the productivity of group affiliates located in the same country. On the contrary, foreign affiliates' productivity and income might increase if tax incentives raise MNEs' global R&D and if innovation serves as an input into MNEs' *global* value creation (i.e., R&D conducted in one country raises the productivity of MNE affiliates in other countries).

Also note that response rates may be heterogeneous across firms. Cross-border R&D mobility – and, therefore, the tax responsiveness of corporate R&D investment – may vary across firms. Firms may be more willing to reallocate R&D activity if group affiliates are geographically close, reflecting regional location preferences or transaction costs that rise with geographic distance (e.g., Thisse, 2011; Hutzschenreuter et al., 2016). R&D investments might also be more tax sensitive in large firms, consistent with the notion that benefits from R&D tax planning increase in firm size, while implementation costs are largely fixed. The opposite might also be true, however: If large firms can easily circumvent high statutory tax burdens by shifting income to low-tax countries (as, e.g., suggested by Dharmapala, 2014 and Davies et al., 2018), their R&D investments might be unresponsive to tax incentives.

R&D Investments as Complements

R&D investments at different MNE group locations might also be complements. New R&D investments at one group location may, for example, yield knowledge output that generates MNE-internal knowledge spillovers and increases the yields from R&D investments at other group locations (see e.g., Bilir and Morales, 2020). Increased tax incentives then raise R&D investments in the policy-changing country and abroad. In the framing of our theoretical model: If R&D tax costs decline in country A, it is optimal for the MNE to expand R&D investments in A. This increases the marginal product of R&D investments at other locations B ($g^A_{BA}, g^B_{BA} > 0$) and renders it optimal to increase R&D investment there ($\frac{dx^B}{dt^A} < 0$). A complementary link between domestic and foreign investment might also emerge if firms are credit constrained and need to rely on internal resources to finance R&D investments (see e.g., Hall et al., 2016).[8] When tax costs fall at one location, the induced cash increase can be used to finance new R&D investments in the policy-changing country and at other locations of the MNE group. Irrespective of the mechanism at work: If R&D activities at different group locations act as complements, the global R&D tax response exceeds the observed response in the policy-changing country. R&D tax incentives then raise foreign R&D activity and welfare.

Whether R&D tax incentives increase or decrease R&D activity in foreign countries thus remains an empirical question. Given that MNEs are responsible for a large share of private sector innovations, the sign and size of this cross-border effect is decisive for understanding the global welfare consequences of R&D tax incentives. In the following, we present firm-level estimates for this effect.

3. Estimation methodology

Our empirical analysis models the R&D investment $y_{i,c,t}$ of MNE group i in country c in year t, where an MNE's activity in a given country is referred to as an MNE group location. Prior studies focused on quantifying the effect of lagged host country R&D tax costs $T_{c,t-s}$ on firms' R&D investment $y_{i,c,t}$. Following this research, we estimate a fixed effects PPML model with the following parametrization:

$$E\left(y_{i,c,t}|T_{c,t-s}, X_{c,t-s}\right) = \exp\left(\alpha_1 T_{c,t-s} + \alpha_2 X_{c,t-s} + \lambda_{i,c} + \delta_t\right) \quad (5)$$

where $\lambda_{i,c}$ and δ_t denote full sets of MNE group location-fixed effects and year-fixed effects, respectively. The tax regressor $T_{c,t-s}$ enters with a lag to account for the time gap between R&D investments and patentable results. We use lags of one, two and three years ($s \in \{1,2,3\}$). Correspondingly, the vector $X_{c,t-s}$ comprises lagged host country control variables (country size, economic development, governance characteristics, FDI inflows and direct government support for business R&D not granted through the tax system; see Section 4 for variable definitions). R&D investments are proxied by the number of granted patent applications filed by MNE i in country c, dated by year of application t. An advantage of the PPML model that makes it particularly well-suited for estimations involving patent applications is its broad applicability to non-linear relationships (Silva and Tenreyro, 2006). It is also consistent when using dependent variables with many zeros such as corporate patent applications where not all firms apply for a patent every year (Silva and Tenreyro, 2011). The MNE-location-fixed effects $\lambda_{i,c}$ absorb time-constant heterogeneity across group locations and the time-varying control variables hedge against potential correlations of host country R&D tax costs and multinational R&D activity with other time-varying economic or institutional characteristics.

Following our considerations in Section 2, we modify this specification to test for cross-border effects of R&D tax incentives. This requires modeling where cross-border effects accrue. Prior macro-level studies assume them to emerge in geographically close and economically connected jurisdictions. Our micro-level data, in turn, allows for a more direct and accurate modeling based on observed MNE group structures. This follows the theoretical considerations in Section 2 that cross-border relocations of R&D for tax purposes, no matter if positive or negative, arise within the MNE group. We thus add regressors for the average R&D tax costs levied by the host countries of MNE i's other locations $-c$ in year t, $\bar{T}_{i,-c,t-s}$; corresponding averages for the other foreign host country characteristics (country size, economic development, governance characteristics, FDI inflows and direct government spending for R&D) are subsumed in $\bar{X}_{i,-c,t-s}$. Our model now reads

$$\begin{aligned} &E\left(y_{i,c,t}|T_{c,t-s}, \bar{T}_{i,-c,t-s}, X_{c,t-s}, \bar{X}_{i,-c,t-s}\right) \\ &= \exp\left(\beta_1 T_{c,t-s} + \beta_2 \bar{T}_{i,-c,t-s} + \beta_3 X_{c,t-s} + \beta_4 \bar{X}_{i,-c,t-s} + \lambda_{i,c} + \delta_t\right) \end{aligned} \quad (6)$$

The theoretical considerations in Section 2 predict a negative sign for β_1. For the sign of β_2, predictions are ambiguous. While estimating β_2 is at the heart of our paper, omitting $\bar{T}_{i,-c,t-s}$ may bias the estimate of β_1 with the sign of this bias being a priori unclear.[9]

[8] R&D is more difficult to finance than other investments as collateralization is difficult or even impossible. Furthermore, problems of opportunistic behavior, adverse selection and moral hazard affecting the financing of capital investments in general are exacerbated in the case of R&D as issues related to contract incompleteness, opaqueness and information asymmetries between firms and investors are more pervasive (Hall and Lerner, 2010). Raising external funds for R&D investments hence tends to be difficult, implying that firms often have to rely on internal finance for this type of investment (Myers and Majluf, 1984). See also Hall et al. (2016).

[9] In the presence of cross-border tax cost effects, control units in foreign countries are affected by the treatment: The β_1-estimate is too large (too small), in absolute terms, if the cross-border tax cost effect on foreign firms' R&D is

Eq. (6) identifies cross-border effects of R&D tax incentives by comparing changes in $y_{i,c,t}$ for cases where foreign affiliates within the same MNE group do and do not experience changes in their host country R&D tax costs (or experience changes of different size). Importantly, treatment and control firms may be located in different countries, implying that country-specific R&D time trends (not rooted in control variable trends) may confound the estimates. Our micro panel data allows us to augment the estimation model by a full set of country-year-fixed effects $\rho_{c,t}$. The modified model parametrization reads

$$E\left(y_{i,c,t}|\bar{T}_{i,-c,t-s}, \bar{X}_{i,-c,t-s}\right) = \exp\left(\gamma_1 \bar{T}_{i,-c,t-s} + \gamma_2 \bar{X}_{i,-c,t-s} + \lambda_{i,c} + \rho_{c,t}\right) \quad (7)$$

The cross-border relocation effect γ_2 is now estimated by comparing changes in the R&D investment of MNE group locations in the *same* country that belong to MNEs with and without group locations in foreign jurisdictions that change their R&D tax treatment (or change it to a different degree). Contrary to prior macro-level research, country-specific R&D trends are hence absorbed in our analysis.[10] In robustness tests, we, moreover, estimate models that include region-year-fixed effects at the subnational level to allow for divergence of R&D time trends at an even more refined geographical level and specify models that control for industry-specific R&D time trends.[11] The specifications thus non-parametrically account for potential time-varying non-tax determinants of firms' R&D and patenting activity at given locations, like changes in the country's technology base or patenting system.

4. Data

The empirical analysis uses data on the R&D activity of MNEs in Europe that is matched to country-level information on R&D tax incentives and other economic and institutional characteristics. The sample frame comprises the years 2000 to 2012. As described in Section 3, we rely on information on *unconsolidated* R&D activity at each individual group location, i.e., information for each individual country in which the MNE is active.[12] Our sample comprises both parent and subsidiary firms. Conceptually, there are two key advantages to using unconsolidated rather than consolidated data. First, modeling individual group locations explicitly acknowledges that their behavior is not only shaped by the MNE's central management but also by local managements' decisions. Second, it allows us to isolate cross-border effects of R&D tax incentives from effects of host country tax policies.[13] Consolidated data would, in turn, only allow testing for the joint effect of the two by linking consolidated R&D activity to the average R&D tax costs at MNE group locations. Related analyses are presented in supplemental tests.[14]

Measuring R&D Activity

Our analysis thus requires modeling R&D activity per MNE group location and year. There are two common proxies for R&D investments in the literature: corporate R&D expenditure and patent output. In this paper, we follow the latter strategy and use the number of granted patent applications filed by an MNE group location in a given year as a measure for R&D activity. Following standard procedures, we use patents that are ultimately granted, dated by year of application (see e.g. Aghion et al., 2013; Seru, 2014; Bena and Li, 2014; Akcigit et al., 2018; Atanassov and Liu, 2020; Mukherjee et al., 2017).[15] There are some drawbacks of using patent counts as a proxy for corporate R&D: Patents might reflect strategic use of intellectual property and only R&D that eventually becomes a successful innovation is captured. Prior literature, however, documents that the number of patents is highly correlated with R&D expenditure and other measures of corporate R&D activity (Hausman et al., 1984; Hagedoorn and Cloodt, 2003; Artz et al., 2010). We corroborate this evidence by showing that country-level R&D expenditure and country-level patent counts are highly correlated, both in the cross-section as well as over time. Even when accounting for country- and year-specific effects, we derive a correlation coefficient of greater than 0.75 (see Table A.1). In line with this observation, existing evidence reports comparable own-country R&D tax effects when proxying R&D by patent counts and R&D expenditure (see, e.g., Dechezleprêtre et al., 2017). Also note that there are explicit advantages of using patents as a measure for corporate R&D. Notably, the measure is not subject to concerns about firms simply relabeling some expenses as R&D-related when a country increases input-related R&D tax incentives such as tax credits, super-deductions and accelerated depreciation.[16] Patent data, moreover, is particularly useful when studying international R&D activity as patents constitute a simple measure that is comparable across countries. This allows us to identify MNEs' *unconsolidated* R&D activities in different locations, which would be largely infeasible based on other R&D measures like R&D spending or the number of R&D workers. The latter information is commonly only available in consolidated company accounts. Disaggregated data on R&D expenditure must thus be drawn from surveys and corporate tax returns which are restricted to individual countries (and are thus by definition not well suited to study cross-border effects). Definitional differences, in general, limit their comparability across countries.

Proxying firms' R&D activity based on patent data, moreover, comes with the advantage that patents are a measure of R&D *output* rather than R&D input. As it is the ultimate aim of R&D policies to foster innovation (and hence R&D output; not R&D inputs per se), patent data allows for a more direct evaluation of R&D tax policies than R&D input measures like R&D spending.

Patent Data

Our patent data is drawn from the administrative patent database PATSTAT, which is operated by the European Patent Office and provides patent information from patent offices worldwide, including all

positive (negative) and the $\bar{T}_{i,t-s}$ regressor is omitted. In the words of Rubin (1978), the stable unit treatment value assumption (SUTVA) is violated. If a violation of SUTVA is the only source of bias and all control observations are affected by the treatment, β_2 corresponds to the absolute bias in the β_1-estimate when $\bar{T}_{i,t-s}$ is omitted. If only a fraction of the control observations is affected by the treatment, the absolute bias in the β_1-estimate becomes smaller than β_2. On top of that, the omission of $\bar{T}_{i,-c,t-s}$ biases the β_1-estimate if R&D tax policies are correlated across countries and taxes, simultaneously, exert cross-border R&D effects. The estimate of β_1 is too small (too large) in absolute terms if R&D tax policies are positively (negatively) correlated and cross-country tax effects on foreign R&D are positive (negative).

[10] Note that the variable of interest can equivalently be thought of as the difference in tax cost between home and foreign countries as the coefficient estimates and the fit of the regression remain the same when substituting $\bar{T}_{i,-c,t-s}$ by $(\bar{T}_{i,-c,t-s} - T_{c,t-s})$.

[11] See Table 6 in Section 5.

[12] This follows many empirical micro-level data studies on taxes and multinational firm behavior (e.g. Huizinga and Laeven, 2008; Dischinger and Riedel, 2011; Gumpert et al., 2016; Goldbach et al., 2019).

[13] Cluster-robust standard errors account for correlation of observations within the same MNE which also ensures that standard errors are not artificially deflated by giving larger groups too much weight based on the false premise that the related observations are independent.

[14] See Table 9 in Section 5.

[15] Non-granted applications are disregarded as this would distort the analysis due to strategic patenting behavior and patent trolls (Cohen et al., 2019). Harhoff and Wagner (2009) report that less than 60% of patent applications are eventually granted.

[16] Chen et al. (2021), for example, found substantial relabeling of expenditures as R&D following a change in Chinese corporate tax rules. A recent survey by Bloom et al. (2019) notes that it may therefore be a more "direct way to assess the success of the R&D tax credit [...] to look at other outcomes such as patenting" (p. 170). As patent filing at the end of R&D processes (commonly several years after initial R&D investment) is not a prerequisite for being eligible to R&D tax benefits (granted at the time of investment), "relabeling" is plausibly not an issue in our analysis.

European national patent offices and supranational patent offices. Following the existing literature, we thus construct the unconsolidated number of patent applications per firm and year, using only patents where the majority of inventors is located in the same country as the patent filing firm (see e.g., Guellec and van Pottelsberghe de la Potterie, 2001) to ensure that the number of patent applications reflects domestic R&D activity.[17] If firms file for patent protection in several countries, the patented technology is, analogous to prior studies, only counted once. Because we only consider patents linked to local R&D activity, we speak of R&D locations rather than patenting locations in our analysis in order to avoid confusion of the location of R&D activity and the patenting process. The latter also depends on the location of the chosen patent office. The analysis acknowledges that the distribution of patents' industrial value is highly skewed (see e.g., Harhoff et al., 1999 and Graevenitz et al., 2013) and that, in expectation, more R&D input is needed to produce a higher-value technological innovation. We calculate the value of each patent based on three common value correlates: the number of forward citations within a five-year period from the granting date of the patent, the patent's family size and the number of technology classes on the patent (see, e.g., Hall et al., 2007). The composite technological quality index is derived from a factor analysis (e.g., Lanjouw and Schankerman, 2004).

Using the number of granted patents as proxy for corporate R&D activity raises potential concerns about data truncation since the granting process usually takes several years (see e.g., Harhoff and Wagner, 2009 and Bösenberg and Egger, 2017). At the end of our sample frame, the measure might hence be determined by (potential differences in) the speed of patent granting decisions. To account for this issue, we end our sample frame in 2012 despite observing data on patent applications up to 2017. Fig. A.1 suggests that the large majority of patents, which are eventually granted, are indeed granted within a five year frame: The number of granted patent applications in our dataset significantly drops only in years after 2012. For patents filed in 2012, all patents granted within 5 years from their filing date are hence adequately reflected in our data.[18] To further corroborate this evidence, we present sensitivity tests showing that our baseline findings also hold in shorter sample frames.[19]

Multinational Firms and Sample Selection

The patent data is linked to firm-level information in Bureau van Dijk's AMADEUS database, which provides accounting and ownership information for firms in Europe. The link between the two databases is achieved through name and address matching implemented by Bureau von Dijk. Corporate groups are defined based on ownership connections in AMADEUS. Specifically, we identify the ultimate owner of each firm (the entity that ultimately – directly or indirectly – owns at least 50% of the firm's shares) and define all firms owned by this ultimate owner as a corporate group. If at least one firm is located in a different country than the ultimate owner, the group is defined to be an MNE group and all of its affiliated firms enter the estimation sample. We aggregate affiliates located in the same country as they are subject to the same tax regime and group structure. For instance, if an MNE group has affiliates in three different countries in a particular year, we have three observations for this MNE group in that year.[20] The definition of MNEs' group structures dynamically accounts for mergers and acquisitions (M&As) during the sample horizon, drawn from Bureau van Dijk's Zephyr database, and for new firm foundations. Also note that, while the sample firms are located in Europe, ownership connections in AMADEUS span the whole world and the sample thus comprises firms affiliated with MNEs headquartered outside Europe. In consequence, we observe two types of MNE groups in the data: (i) MNEs headquartered in Europe where information on all relevant European R&D group locations is available and (ii) MNEs headquartered outside Europe where arguably only a subset of R&D locations is observed in the data.[21] In Section 5, we discuss implications for the interpretation of the results and present robustness checks where the sample is restricted to the former set of MNEs.[22]

As information is aggregated across an MNE's affiliates in the same country and year, the dependent variable is the quality-adjusted number of granted patent applications per MNE group location and year.[23] The sample covers the years 2000 to 2012. Years before 2000 are disregarded as we lack reliable information on ownership structures and tax incentives. As mentioned above, we end the sample in 2012 to avoid data truncation.

Table 1
Country distribution.

Country	Country code	Firms	Patents
Austria	AT	109	1,634
Belgium	BE	72	1,856
Switzerland	CH	228	5,513
Czech Republic	CZ	57	576
Germany	DE	583	22,401
Denmark	DK	78	626
Spain	ES	140	1,896
Finland	FI	85	1,693
France	FR	425	14,053
United Kingdom	GB	447	7,841
Hungary	HU	11	19
Ireland	IE	17	140
Italy	IT	212	3,970
Luxembourg	LU	11	84
Netherlands	NL	136	1,185
Norway	NO	60	448
Poland	PL	48	164
Portugal	PT	13	46
Sweden	SE	136	5,274
Other		29	177
Sum		2,793	69,596

*N*otes: This table presents the distribution of MNE group locations across sample countries. The category "Other" comprises group locations in Greece, Iceland, Latvia, Romania, Slovenia, Slovakia and Turkey.

[17] While applicants may be firms or individuals, patent inventors are necessarily individuals. In case of corporate patents, usually the leading R&D workers are stated as inventors. Note, that the number of cases where the patent filing entity and the technology inventors are located in different countries is small (see e.g., Baumann et al., 2020). We disregard these patents in the empirical analysis to avoid picking up effects related to strategic shifting of patent ownership to low-tax countries (see e.g., Karkinsky and Riedel, 2012; Griffith et al., 2014).

[18] For patent applications from 2005, for which we plausibly observe all granting decisions until 2017, the large majority of granting decisions (80%) is indeed taken within 5 years (see Fig. A.2).

[19] See Table A.2

[20] Note that only group locations where MNEs file for at least one patent within our sample frame enter the data (see below). As group affiliates are aggregated at the country-level, even large MNEs enter with a limited number of observations only. The top 1% of MNEs (in terms of number of locations within the MNE where R&D is conducted) hence account for just 4.7% of the sample observations. These MNEs have on average 10.49 such locations. In a sensitivity test in Table A.2, we exclude these observations from the sample and obtain similar results as the baseline estimations.

[21] For example, if there is an MNE headquartered in the US with two subsidiaries in France and the UK, we observe all of these subsidiaries and treat them as belonging to one MNE but we do not observe subsidiaries located outside of Europe.

[22] See Table 6 in Section 5.

[23] Note that the value per patent derived from a factor analysis contains both, positive and negative values. To allow meaningful aggregation, we shift the distribution of patent quality by the absolute value of the minimum to the right. This ensures non-negative industrial values for all patents in the data, while not affecting the relative ordering of patent quality.

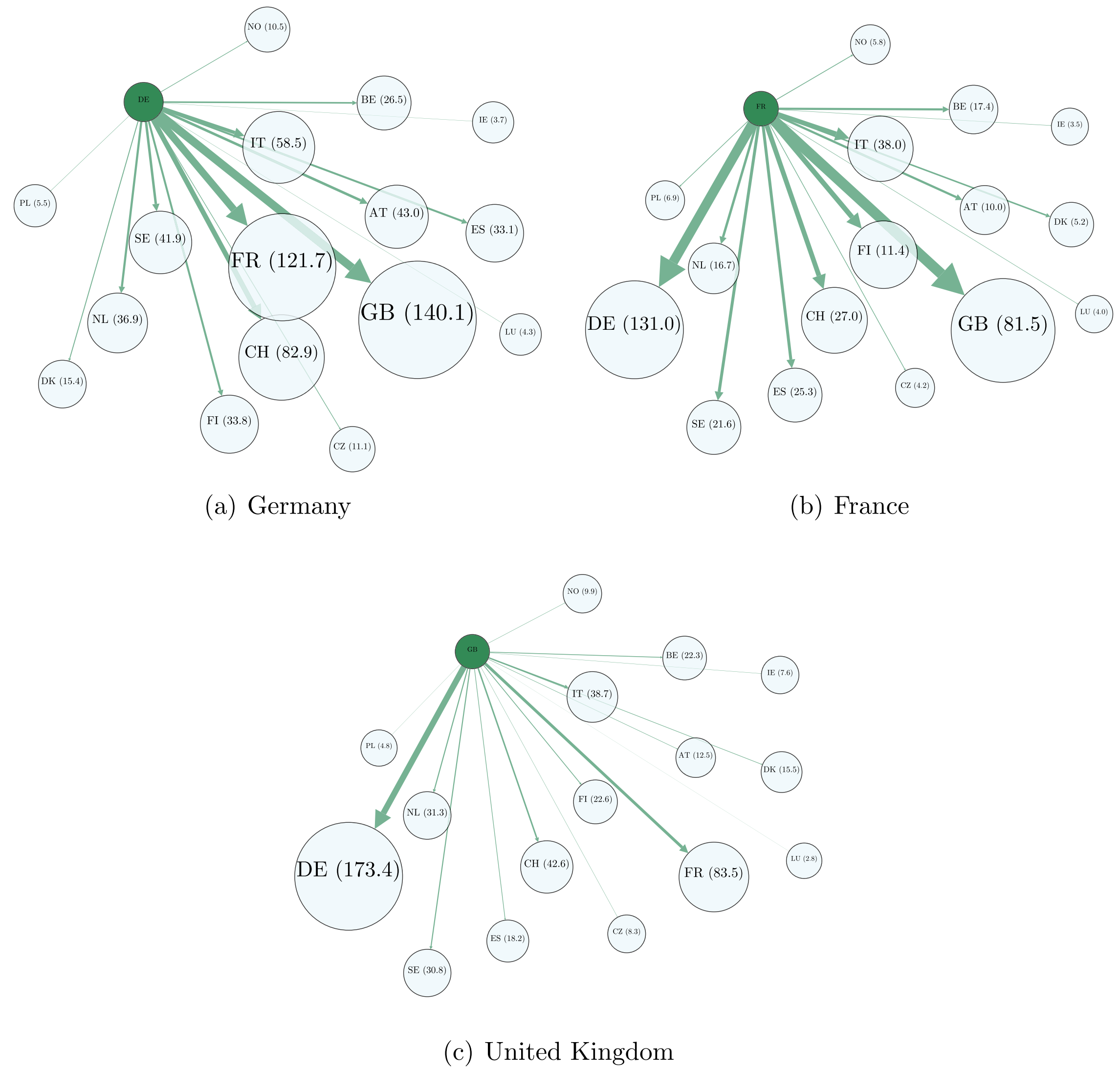

Fig. 1. Ownership Connections of Firms in Germany, France and the United Kingdom to Foreign Countries. *Notes:* This figure displays ownership connections to patenting foreign affiliates of firms in the estimation sample that are located in Germany, France and the United Kingdom. For each of the three countries, we sum the number of links to other countries (i.e., the number of foreign affiliates in individual countries that are in the same MNE group) across all firms located in that country for each year in the sample period. We then take the average of this value across time (displayed in parentheses). To simplify the presentation, we only show locations with at least 4 affiliates in the average sample year. Larger nodes around country codes indicate a higher number of cross-border links.

The sample is, moreover, restricted to MNE groups with positive patenting activity during the sample frame, i.e., group locations that successfully filed for at least one patent in the sample period. We, moreover, assign zeros in years without patent applications. In total, the data comprises information on 1151 MNEs and 2793 MNE group locations hosted by 26 European countries. In Fig. 1, we illustrate the intra-group cross-border links to other R&D-active MNE affiliates for the three largest economies in the sample: Germany, France and the United Kingdom. While firms in each of these countries have strong links to other large economies, they are also connected to smaller countries indicating that there is substantial variation in the network structure of MNE groups. Table 1, moreover, presents the country distribution of all group locations which broadly matches with the distribution of aggregate R&D investments and firm counts in the sample economies. Note, moreover, that by focusing on MNEs, we capture the large majority of R&D activity performed in the sample countries (see, e.g., Hall, 2012).[24]

R&D Tax Incentives

Countries' R&D tax treatment is modeled by the B-index, initially introduced by McFetridge and Warda (1983). The B-index $T_{c,t}$ for country c in period t measures the minimum pre-tax earnings required for an R&D project to break even and serves as a measure for the R&D tax costs of a representative firm in country c. It is defined as

$$T_{c,t} = \frac{1 - Z_{c,t} \cdot \tau_{c,t}}{1 - \tau_{c,t}} \tag{8}$$

where $\tau_{c,t}$ indicates the corporate tax rate of country c in year t and $Z_{c,t}$ measures the deductibility of R&D expenditure from the corporate tax base, accounting for R&D related tax allowances and current tax expenditures as well as for R&D tax credits. The numerator of the B-index captures the marginal cost of a one-dollar-investment in R&D in

[24] Note that the sample firms are located in 26 European countries, but ownership links in AMADEUS span the whole world.

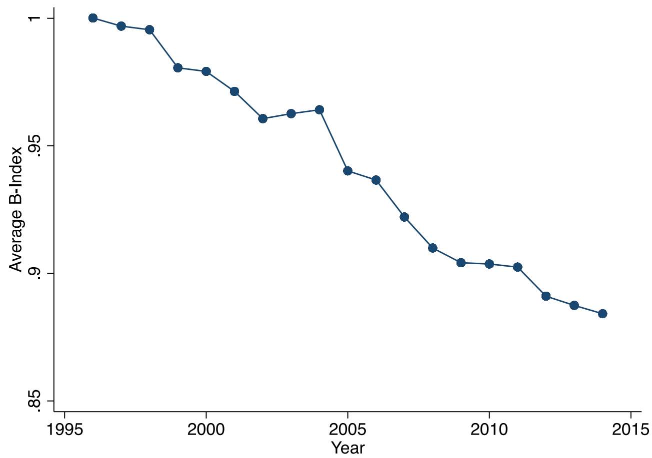

Fig. 2. Average of B-index in the Sample Countries. *Notes:* The graph plots the unweighted average of the B-index in the sample countries against time.

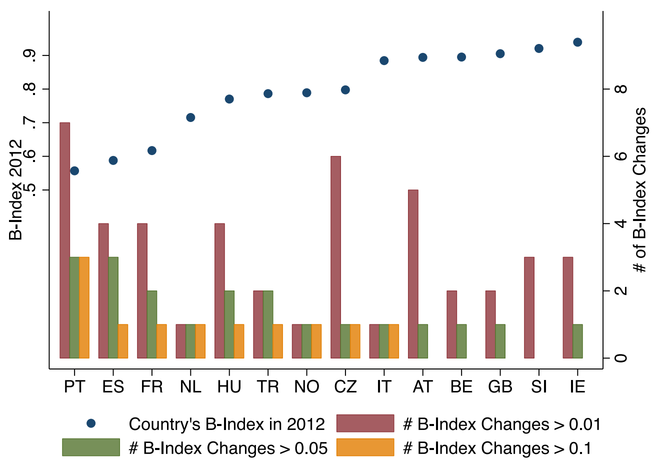

Fig. 3. B-index in 2012 (if < 0.95) and # of Changes of B-index in Sample Period. *Notes:* The graph depicts countries' B-index in 2012 as well as the number of B-index changes during the sample period (2000–2012) exceeding 0.01, 0.05 and 0.1 respectively, in absolute terms. The graph shows all sample countries with a B-index below 0.95 in 2012. The other sample countries, not depicted in this figure, experienced minor changes in the B-index only and feature a B-index of around 1 in 2012, see Fig. A.3.

a given country after taxes. The more generous the deductibility of R&D costs from the corporate tax base, the smaller the expression in the numerator. The denominator accounts for the fact that the proceeds from R&D investments are taxed at rate $\tau_{c,t}$. If the R&D investment can be fully deducted in the fiscal year, $Z_{c,t}$ and consequently also the B-index take on the value one. More generous R&D tax credits and tax allowances reduce the B-index below unity. The lower the B-index, the smaller the required pre-tax return for an R&D investment project to break even and the more attractive the tax incentive scheme.

We note that the B-index measure is closely related to the concept of the user cost of capital for R&D (e.g., see Hall and Jorgenson, 1967; Bloom et al., 2002; Wilson, 2009; Montmartin and Herrera, 2015; Brown et al., 2017) as a measure of the marginal cost of R&D inputs. Specifically, the B-index isolates the tax component from other factors that affect the user cost of capital for R&D (e.g., interest rates, depreciation rates) and thus allows us to study the tax effect on corporate R&D. To ensure that the estimated tax effect is not conditional on other user cost components, we present robustness checks where we replace the B-index by the user cost of R&D capital as computed by Bloom et al. (2002) and Wilson (2009).[25]

Our B-index information is drawn from Bösenberg and Egger (2017). Fig. 2 depicts the average B-index in Europe and shows that it significantly declined during the sample frame. Fig. 3, moreover, displays sample countries with attractive R&D tax treatment as measured by a B-index below 0.95 in 2012, showing that most of these countries experienced significant B-index changes during the sample period (in most cases reductions). Note, moreover, that these changes took place in a staggered way: B-index cuts larger than 0.1 were experienced by firms in Spain in 2001, Norway in 2002, Hungary in 2004, Czech Republic in 2005, Italy in 2007, France and Turkey in 2008 and the Netherlands in 2012. Fig. A.3 shows a graph analogous to Fig. 3 for sample countries with less attractive R&D tax treatment as measured by a B-index above 0.95 in 2012, showing that their B-index remained mostly unchanged during the sample period. Note that variation in the B-index largely reflects changes in R&D input incentives like super-deductions or R&D tax credits. While variation in statutory corporate tax rates may also trigger B-index shifts, their impact tends to be minor. All major B-index cuts observed during our sample frame relate to reforms which expanded the generosity of R&D tax credits and tax deductions.[26]

As described above, the analysis, moreover, assesses whether the R&D activity of MNE i in country c in year t is affected by R&D tax provisions in other locations. For this purpose, we define the average B-index at foreign locations as

$$\bar{T}_{i,-c,t} = \sum_{j \neq c} W_{ij} T_{jt} \tag{9}$$

where j indicates group locations of MNE i other than c. T_{jt} stands for the host country B-index at another location j of the MNE group in year t and W_{ij} depicts the weight of j in the calculation of this average. In the baseline analysis, we employ asset weights, reflecting that the cross-border tax effect is expected to be larger the size of the other MNE group location that experiences the tax shock.[27] Note, moreover, that firm locations, where we only observe incidental R&D – defined as locations that file for less than 10% of all of the MNE's granted patents within the sample frame – are disregarded in the calculation of $\bar{T}_{i,-c,t}$. In robustness checks, we show results where $\bar{T}_{i,-c,t}$ is calculated based on alternative weighting schemes.

Control Variables and Descriptive Statistics

We augment the data by control variables that capture important drivers of R&D activity such as market size (Athukorala and Kohpaiboon, 2010) and scientific capacity (Thomson, 2013). These include host country size (GDP), economic development (GDP per capita) and openness (FDI), all drawn from the World Development Indicator Database. The analysis includes control variables for the quality of

[25] See Table 7 in Section 5.

[26] In Table A.3, we show that conditioning on statutory corporate tax rates does not alter the estimated link between B-index and corporate R&D.

[27] Precisely, W_{ij} is defined as the average of total assets at MNE group location j across sample years over the sum of this variable across all foreign R&D hosts of MNE i. For group locations with missing information on total assets, we assign the average total assets of the set of other MNE group locations to avoid losing these locations in the calculation of the size-weighted average. Note, moreover, that the definition of $\bar{T}_{i,-c,t}$ implies that we disregard MNEs when 100% of the patent output is generated in one location and MNEs are, therefore, not truly multinational in their R&D activity. All other MNEs are included because even if one of the locations of an MNE conducts more than 90% of the R&D activity, there are still some locations that also conduct R&D and are potentially interesting for our analysis. For these locations, $\bar{T}_{i,-c,t}$ reflects B-index changes at the main R&D hub.

Table 2
Summary statistics.

	No. Obs.	Mean	Std.Dev.	Min	Max
Quality Weighted Patent Count	23,499	2.470	14.070	0.000	548.018
Domestic Inventors	23,593	10.418	56.816	0.000	1,358.000
B-index (t-2)	23,499	0.931	0.123	0.559	1.042
Avg. Foreign B-index (t-2)	23,499	0.946	0.106	0.559	1.042
Min. Foreign B-index (t-2)	23,499	0.915	0.131	0.559	1.042
Adj. B-index (t-2)	23,499	0.643	0.103	0.363	0.907
Avg. Foreign adj. B-index (t-2)	23,499	0.644	0.088	0.363	0.907
User Cost of Capital (t-2)	23,481	0.301	0.042	0.131	0.452
Avg. Foreign User Cost of Capital (t-2)	23,471	0.306	0.037	0.131	0.452
Corporate Tax Rate (t-2)	23,499	0.309	0.063	0.100	0.516
Avg. Foreign Corporate Tax Rate (CTR, t-2)	23,499	0.319	0.060	0.100	0.516
Effective Average Tax Rate (EATR, t-2)	23,499	0.269	0.073	0.042	0.508
Avg. Foreign EATR (t-2)	23,499	0.284	0.072	0.042	0.508
$1/(1-CTR)$ (t-2)	23,499	1.460	0.142	1.111	2.066
Avg. Foreign $1/(1-CTR)$ (t-2)	23,499	1.483	0.142	1.111	2.066
Log GDP p.c. (t-2)	23,499	10.487	0.359	8.119	11.356
Avg. Foreign Log GDP p.c. (t-2)	23,499	10.522	0.247	8.119	11.381
Log FDI (t-2)	23,499	24.261	1.219	17.348	27.322
Avg. Foreign Log FDI (t-2)	23,499	24.409	1.069	17.348	27.322
Political Stability (t-2)	23,499	0.781	0.443	−1.032	1.668
Avg. Foreign Political Stability (t-2)	23,499	0.800	0.384	−1.032	1.668
Rule of Law (t-2)	23,499	1.516	0.419	−0.269	2.000
Avg. Foreign Rule of Law (t-2)	23,499	1.564	0.331	−0.269	2.000
Direct R&D support (t-2)	23,499	8.296	3.820	0.427	21.830
Avg. Foreign Direct R&D support (t-2)	23,499	8.668	3.338	0.427	21.830
Avg. Foreign Research Expenditure (as % of GDP, t-2)	22,997	2.158	0.570	0.366	3.726
Avg. Foreign Log Patent Applications of Residents (t-2)	23,328	9.372	1.150	2.708	10.820
Avg. Foreign Pre-tax Profitability (t-2)	20,807	0.176	0.056	0.021	0.455

Notes: The observational unit is the MNE group location per year. *Quality Weighted Patent Count* is the quality-adjusted number of patents per year for the MNE group locations in the data. *Domestic Inventors* is the number of inventors cited on patent documents for the MNE group locations. *B-index (t-2)* is the second lag of the B-index ($T_{c;t-2}$ as defined in the main text) and *Avg. Foreign B-index (t-2)* is the asset-weighted average B-index in other locations of the same MNE group ($\overline{T}_{i;-c;t-2}$, lagged by two years, as defined in the main text). *Min. Foreign B-index (t-2)* is the smallest B-index within the MNE group in period $t-2$. *Adj. B-index (t-2)* denotes the second lag of the B-index multiplied by the net of corporate tax rate $(1-CTR)$. The *User Cost of Capital (t-2)* are calculated based on the lagged B-index, a depreciation rate of 30% and the long-term interest rate (see details in the main text). *Log GDP p.c. (t-2)* depicts the second lag of the log of host country GDP per capita, *Log FDI (t-2)* the second lag of the log of the host country's aggregate inward foreign direct investment. *Political Stability (t-2)* and *Rule of Law (t-2)* depict the second lags of the governance indicators for political stability and rule of law of the World Bank's Governance Data. *Direct R&D support (t-2)* is the second lag of the business enterprise expenditure for R&D that is directly financed by the government as a percentage of GDP (reported in percentage points). *Avg. Foreign Research Expenditure (as % of GDP, t-2)* is the average percentage of total research expenditures of GDP in host countries of other MNE group locations lagged by two years. *Avg. Foreign Log Patent Applications of Residents (t-2)* depicts the average log of aggregate patent applications in other locations of the same MNE group. *Avg. Foreign Pre-tax Profitability (t-2)* is the average Pre-tax profitability of national firms in other MNE group locations (see main text for details). *Avg. Foreign B-index (t-2)*, *Avg. Foreign adj. B-index (t-2)*, *Avg. Foreign User Cost of Capital (t-2)*, *Avg. Foreign Corporate Tax Rate (CTR, t-2)*, *Avg. Log GDP p.c. (t-2)*, *Avg. Foreign FDI (t-2)*, *Avg. Foreign Political Stability (t-2)*, *Avg. Foreign Rule of Law (t-2)* and *Avg. Foreign Direct R&D support (t-2)* depict the asset-weighted averages of these variables at foreign locations within the same MNE as the group location under consideration. Note, moreover, that the descriptive statistics are depicted for the sample of group location-year observations with non-missing information for the patent count variable and all depicted host and foreign country characteristics in $t-2$ that are included in the baseline results of Table 3, specifications (B4)–(B6).

governance institutions as measured by the World Bank's Governance Indicators.[28]

Descriptive statistics for the data are presented in Table 2. On average, the MNE group locations in the dataset successfully file for 2.5 quality-adjusted patents per sample year; the distribution exhibits a large standard deviation, however, and ranges from 0 to 548 quality-adjusted patent applications. The average host country B-index is 0.931, but we observe index variation between 0.56 (reflecting heavy subsidization of R&D investments) and 1.04 (reflecting disincentives for R&D).

5. Results

Baseline Findings

The baseline results are presented in Table 3. The specifications in Panel A estimate Eq. (5) of Section 3 and test whether host country R&D tax incentives impact on multinational R&D activity. Robust standard errors that allow for deviations from the Poisson distribution (see e.g., Wooldridge, 2010) and clustering on the MNE group level are depicted in brackets.[29] Specification (A1) regresses the number of quality-adjusted patent applications of MNE i in country c in year t on the host country's B-index in $t-1$, controlling for year-fixed effects and MNE group location-fixed effects. In line with intuition and with prior evidence, the results show a negative effect of host country R&D tax costs on multinational R&D investment. A rise in the B-index by 0.1 (≈ one standard deviation, cf. Table 2) is estimated to lower the number

[28] Specifically, we account for the World Bank's political stability and rule of law indicators (that strongly correlate with other common governance indicators). On top of that, we use information available from the OECD to account for the amount of direct government support for business R&D, that is R&D support not granted through the tax system. These variables are included as host country controls for the MNE group locations in the data. Furthermore, we model economic and institutional changes in other MNE group locations by calculating the averages of these variables, analogously to (9).

[29] Standard errors are generally 20% smaller with two-way clustering at the MNE and country level. We therefore report the larger standard errors with clustering at the MNE level.

of quality-adjusted patent applications by around 10.94%.[30] Evaluated at the sample mean, this translates into an elasticity of quality-adjusted patent output with respect to the B-index of −1.02 which is in the range of prior findings (see, e.g., the literature review in Guceri and Liu, 2019).[31]

This result is corroborated in specification (A2), where we augment the set of regressors by time-varying host country control variables (GDP, GDP per capita, FDI and governance institutions) and specification (A3) which, additionally, includes a control variable for governments' direct R&D support granted to the private sector. Similar findings, emerge when regressors enter with a two-year and three-year time lag, respectively, accounting for a potential time gap between MNEs' decisions to adjust their R&D investments (in the wake of R&D tax reforms) and resulting changes in patent output (cf. specifications (A4)-(A6) and (A7)-(A9)).

Panel B of Table 3 presents models that estimate Eq. (6) of Section 3. In addition to the host country regressors, the specifications include regressors for the average B-index and additional country characteristics of other MNE group locations. The organization of the specifications follows Panel A (with the modification that now both host country and foreign location regressors are included). Several insights emerge. First, the coefficient estimate for the host country B-index remains negative and statistically significant but, in absolute terms, drops by around 16% relative to the baseline models in Panel A (cf. specifications (A6) and (B6)). This suggests that estimates for the host country tax effect are biased when $\bar{T}_{i,-c,t}$ is omitted, albeit in a quantitatively moderate way (cf. our discussion in Section 3).

The results, moreover, suggest that R&D investment in a particular location of an MNE group is also affected by changes in R&D tax costs in other locations of the same MNE group. The coefficient estimate for the $\bar{T}_{i,-c,t}$ regressor is positive and quantitatively large in all specifications. We note that the standard errors for the estimated coefficient of $\bar{T}_{i,-c,t}$ decrease slightly when we increase the lag from one year to two and three years. We interpret this as indicative of a random measurement error in the dependent variable since actual R&D activity takes some time to result in R&D output such that future R&D output is a more precise measure of current R&D activity than current R&D output. The random measurement error in the dependent variable increases the share of unexplained variation in the regression and thus the magnitude of the standard errors. Column (B6) of Table 3 shows that a 0.1-increase in the average B-index in other MNE group locations raises the number of quality-adjusted patent applications by 9.3%.[32] This suggests that MNEs reallocate R&D investments across group locations when tax incentives change and that R&D activities in different locations act as substitutes. The aggregate tax effect, i.e., the sum of the estimated coefficients for the $T_{c,t-s}$ and $\bar{T}_{i,-c,t-s}$ regressors, is small and statistically indistinguishable from zero in all specifications. Equi-sized reductions in the B-index at all MNE locations are hence estimated to leave R&D investments largely unaffected.

As tax effects are modeled as semi-elasticities in PPML estimation and the identifying variation stems from unilateral tax reforms in our setting (not simultaneous tax changes at all group affiliates), the implied group-level investment response might nevertheless be non-zero. If tax reforms, for example, systematically hit group locations of above average size, the estimates are consistent with a decline (increase) in aggregate group-level investment when R&D tax costs rise (fall).[33] We draw on our estimates to simulate the effect of major R&D tax reforms within our sample period (that is reforms that changed the B-index by more than 0.1 and affected at least 50 MNEs in our sample) on the aggregate number of granted patents by the MNEs in our data. The median of affected MNEs' response to these reforms, expressed as a semi-elasticity, ranges from −0.22 to −0.03, supporting the notion that firms' overall global R&D investment hardly changes when R&D tax support at individual locations becomes more generous. R&D tax incentives are hence suggested to serve as beggar-thy-neighbor instruments rather than means to correct for MNEs' underinvestment in R&D.

Note that, although less precisely estimated, the same pattern emerges for direct government support granted for business R&D (i.e., support not granted through the tax system). MNEs' R&D investment is shown to increase (decrease) in the generosity of this support in firms' host countries (in other group locations of the same MNE group). This suggests that direct R&D subsidies, analogously to R&D tax incentives, trigger cross-country reallocations of R&D activity.

Table 4 augments the vector of control variables by a full set of host country-year-fixed effects (cf. Eq. (7) of Section 3). As described above, the estimation strategy now compares changes in the R&D investment of MNE group locations in the same country that belong to MNEs that are and are not subject to R&D tax cost shocks in other MNE group locations (or are subject to shocks of different size). This yields coefficient estimates for the foreign B-index that are qualitatively and quantitatively similar to the baseline findings in Table 3.

Placebo Test

Our setting, moreover, lends itself to a placebo test where we reestimate the baseline model after randomly reassigning group structures across firms. For each MNE group location in our data (comprising all affiliates belonging to the same MNE in a given country, cf. Section 4), we randomly reassign which other affiliates abroad are part of the same MNE in order to simulate placebo values for the $\bar{T}_{i,-c,t-2}$ and $\bar{X}_{i,-c,t-2}$ regressors. The placebo group structures abroad are drawn from all MNEs which are present in the same country. An MNE's group structure abroad is treated as a cluster which is drawn as a whole. Drawing is conducted without replacement and the drawn group structure abroad is kept constant over time for a given entity.[34]

We repeat that procedure 5000 times. The distribution of the resulting coefficient estimates for the $\bar{T}_{i,-c,t-2}$ regressor is depicted in Fig. 4. The red line marks the coefficient estimate for $\bar{T}_{i,-c,t-2}$ in specification (B6) of Table 3. While the distribution is closely centered around zero, the estimate is in the far right tail of the distribution. Note, moreover, that under the null hypothesis that the true effect of $\bar{T}_{i,-c,t-2}$ is zero, we obtain a two-sided p-value of 0.046 and hence reject the null. The advantage of this hypothesis test (randomization inference, see Fisher,

[30] Noting the exponential form of the Poisson model's conditional expectation function, the percentage change is computed as $\exp(\beta_1 \times 0.1) - 1 = \exp(-1.074 \times 0.1) - 1 = 0.1094$

[31] Evaluated at the sample mean (0.928), a drop in the B-index by 0.1 corresponds to a relative change by 10.78%. Hence, we obtain an elasticity of $\frac{-10.94}{10.78} = 1.01$. In their literature overview, Guceri and Liu (2019) report elasticities with respect to the cost of capital rather than the B-index. Note, however, that with little variation in interest and depreciation rates, the cost of capital is largely a transformation of the B-index (see also our discussion of this in Section 4).

[32] I.e., $\exp(0.887 \times 0.1) - 1 = 0.0928$.

[33] To see this, consider the example of an MNE with two R&D locations that file for 100 and 10 patents in the pre-reform period respectively. Assume that the MNE experiences a B-index increase of 0.1 at the larger group location. The semi-elasticity estimates in specification (B6) of Table 3 predict that the number of patent applications drops by 8.64 applications in the policy-changing jurisdiction and increases by 0.93 applications in the foreign country. In consequence, the MNE's aggregate group-level response to the tax reform, in this example, is a reduction by 7.71 patent applications or 7.0% (=7.71/110).

[34] Resampling group structures abroad only from MNEs, which have an affiliate in the same country, allows us to test whether the results are driven by common shocks to supra-national regions. Specifically, if the results were driven by such shocks – i.e., if domestic and foreign locations were affected by common regional factors that simultaneously altered R&D investment and tax policies for all affiliates in the region – we would still expect to see systematically positive coefficient estimates for the $\bar{T}_{i,-c,t-2}$ regressor after the randomization exercise.

Table 3
Baseline results.

Panel A	**(A1)**	**(A2)**	**(A3)**	**(A4)**	**(A5)**	**(A6)**	**(A7)**	**(A8)**	**(A9)**
B-index	−1.074***	−0.963***	−1.027***	−1.181***	−1.040***	−1.073***	−0.889***	−0.784**	−0.794**
	(0.385)	(0.332)	(0.339)	(0.330)	(0.294)	(0.300)	(0.324)	(0.308)	(0.309)
Direct R&D Support			0.018*			0.027**			0.029***
			(0.010)			(0.011)			(0.010)
Number of observations	26,919	26,919	26,919	23,499	23,499	23,499	20,151	20,151	20,151
Number of group locations	2,793	2,793	2,793	2,680	2,680	2,680	2,539	2,539	2,539
Lag structure of regressors	$t-1$	$t-1$	$t-1$	$t-2$	$t-2$	$t-2$	$t-3$	$t-3$	$t-3$
Control variables (Host)	No	Base	All	No	Base	All	No	Base	All
Panel B	**(B1)**	**(B2)**	**(B3)**	**(B4)**	**(B5)**	**(B6)**	**(B7)**	**(B8)**	**(B9)**
B-index	−0.966***	−0.875***	−0.891***	−1.069***	−0.922***	−0.904***	−0.775**	−0.646**	−0.610**
	(0.372)	(0.316)	(0.336)	(0.308)	(0.273)	(0.288)	(0.311)	(0.298)	(0.305)
Avg. Foreign B-index	0.770*	0.817**	0.869**	0.788**	0.862***	0.887***	0.771**	0.852***	0.839***
	(0.417)	(0.379)	(0.413)	(0.327)	(0.310)	(0.333)	(0.318)	(0.309)	(0.321)
Direct R&D Support			0.014			0.021*			0.022**
			(0.010)			(0.011)			(0.010)
Avg. Foreign Direct R&D Support			−0.017			−0.023*			−0.026**
			(0.016)			(0.014)			(0.011)
Number of observations	26,919	26,919	26,919	23,499	23,499	23,499	20,151	20,151	20,151
Number of group locations	2,793	2,793	2,793	2,680	2,680	2,680	2,539	2,539	2,539
Lag structure of regressors	$t-1$	$t-1$	$t-1$	$t-2$	$t-2$	$t-2$	$t-3$	$t-3$	$t-3$
Control variables (Host)	No	Base	All	No	Base	All	No	Base	All

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: the quality-adjusted patent counts. *B-index* indicates the B-index of the host country of a MNE group location in a given year. *Avg. Foreign B-index* indicates the average B-index in other MNE group locations. See the notes to Table 2 for a variable definition. All specifications account for a full set of year-fixed effects and group location-fixed effects. Specifications (A2), (B2), (A5), (B5), (A8) and (B8) furthermore include control variables for host countries' GDP, GDP per capita, FDI and governance institutions; in the models of Panel B (B2, B5 and B8), we also account for the average of these control variables at foreign MNE group locations. Specifications (A3), (B3), (A6), (B6), (A9) and (B9), on top of that, include regressors for the direct government R&D support granted to businesses in the host country and, in the models of Panel B (B3, B6 and B9) additionally for the average of this variable in other MNE group locations. In specifications (A1)–(A3) and (B1)–(B3), all regressors enter with a one-year lag ($t-1$), in specifications (A4)–(A6) and (B4)–(B6) with a two-year lag ($t-2$) and in specifications (A7)–(A9) and (B7)–(B9) with a three-year lag ($t-3$). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 4
Country-Year fixed effects.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Avg. Foreign B-index	0.776*	0.778*	0.851**	0.758**	0.779***	0.838***	0.712**	0.749**	0.792**
	(0.457)	(0.400)	(0.432)	(0.335)	(0.302)	(0.321)	(0.352)	(0.333)	(0.333)
Avg. Foreign Direct R&D Support			−0.016			−0.021			−0.028**
			(0.017)			(0.015)			(0.014)
Number of observations	26,772	26,772	26,772	23,417	23,417	23,417	20,078	20,078	20,078
Number of group locations	2,791	2,791	2,791	2,679	2,679	2,679	2,536	2,536	2,536
Lag structure of regressors	$t-1$	$t-1$	$t-1$	$t-2$	$t-2$	$t-2$	$t-3$	$t-3$	$t-3$
Control variables (Foreign)	No	Base	All	No	Base	All	No	Base	All
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. The specifications correspond to the models estimated in Panel B of Table 3, but additionally include a full set of country-year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 5
Number of domestic inventors.

	(1)	(2)	(3)	(4)	(5)	(6)
B-index	−1.197***	−1.082***		−0.921**	−0.775**	
	(0.414)	(0.396)		(0.363)	(0.382)	
Avg. Foreign B-index		0.701**	0.704**		0.760**	0.786**
		(0.326)	(0.341)		(0.333)	(0.339)
Direct R&D Support				0.035***	0.029**	
				(0.012)	(0.013)	
Avg. Foreign Direct R&D Support					−0.007	−0.003
					(0.017)	(0.018)
Number of observations	23,593	23,593	23,531	23,593	23,593	23,531
Number of group locations	2,690	2,690	2,689	2,690	2,690	2,689
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Control variables (Host)	No	No	No	All	All	All
Country-year FE	No	No	Yes	No	No	Yes

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: total number of inventors listed on the patent applications of a given group location in period t. Specifications (1) and (4) correspond to the specifications (A4) and (A6) of Table 3. Specifications (2) and (5) correspond to specifications (B4) and (B6) of Table 3, specifications account for country-year fixed effects and correspond to specifications (4) and (6) in Table 4. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 6
Further robustness checks I.

Sample	EU		All	NACE		All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
B-index	−0.816***		−0.945***	−0.751**				
	(0.306)		(0.220)	(0.310)				
Avg. Foreign B-index	1.068***	1.038***	0.568**	1.175***	1.150***	0.599*	0.838***	0.827***
	(0.348)	(0.325)	(0.268)	(0.367)	(0.355)	(0.313)	(0.321)	(0.315)
Number of observations	15,308	15,183	23,361	11,406	11,317	28,029	23,417	23,214
Number of group locations	1,752	1,751	2,677	1,300	1,297	3,298	2,679	2,671
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Industry-Year FE	No	No	Yes	Yes	No	No	No	No
Country-Year FE	No	Yes	No	No	Yes	No	Yes	Yes
NUTS2-Year FE	No	No	No	No	No	Yes	No	No
Control variables (Host+Foreign)	All	All	All	All	All	All	All + For. R&D	All + For. R&D + For. Pat.

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: the quality-adjusted patent count of a MNE group location in year t. The specifications include the full set of regressors outlined in Table 3 (see the notes to Table 3). Specifications (3) and (4) additionally include a full set of 2-digit industry-year-fixed effects. Specification (6) additionally accounts for a full set of NUTS2 region-year-fixed effects. Specifications (7) and (8) additionally include regressors for the average aggregate R&D spending (as a % of GDP) in the host countries of foreign MNE group locations and the average aggregate number of patent applications of residents of the host countries of the foreign MNE group locations. In specifications (1) and (2), the sample is restricted to group locations that belong to MNEs headquartered in Europe. In specifications (4) and (5), the sample is restricted to high-technology manufacturing industries as defined by Eurostat. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 7
Further robustness checks II.

Sample	All				No group change		All			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
B-index	−0.925***		−0.966***		−0.919***		−0.885***			
	(0.267)		(0.269)		(0.291)		(0.295)			
Avg. Foreign B-index	1.006***	0.951***			0.976***	0.891***				
	(0.331)	(0.322)			(0.340)	(0.333)				
Avg. Foreign B-index (all affil.)			0.882**	0.820**						
			(0.369)	(0.357)						
Min. Foreign B-index							0.807***	0.755***		
							(0.296)	(0.278)		
User cost of capital (UCC)									−2.450***	
									(0.890)	
Avg. Foreign UCC									3.019***	2.806***
									(1.003)	(0.974)
Number of observations	23,499	23,417	23,499	23,417	20,159	20,072	23,499	23,417	23,442	23,365
Number of group locations	2,680	2,679	2,680	2,679	2,221	2,220	2,680	2,679	2,676	2,675
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Country-Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Control variables (Host+Foreign)	All	All	All	All	All	All	All	All	All	All
Weights	Uniform	Uniform	Patents	Patents	Asset	Asset	Asset	Asset	Asset	Asset

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: quality-adjusted patent count of a MNE group location in year t. The specifications include the full set of control variables outlined in Table 3. The *Avg. Foreign B-index* and all control variables for other MNE group locations are calculated based on uniform weights in Specifications (1) and (2). In specifications (3) and (4), the weighting is based on the number of patents granted during the sample period. Here all group locations with non-zero patents obtain non-zero weights (also those with incidental R&D, which are excluded in the baseline analysis, cf. Section 4). The weighting is based on asset-weights in specifications (5) and (6). Specifications (1)–(4) and specifications (7)–(10) comprise the full sample while specifications (5) and (6) restrict the sample to MNE affiliates that did not experience a change in the set of other MNE group locations (used for the calculation of $\overline{T}_{i;-c;t}$ and $\overline{X}_{i;-c;t}$) during the sample period. Columns (7) and (8) replace the average foreign B-index with its minimum. Specifications (9) and (10) replace the B-index with a *User Cost of Capital* measure that is calculated based on the B-index, information on long-term interest rates and a depreciation rate of 30%. *Avg. Foreign UCC* is the asset-weighted average of the user cost of capital of foreign affiliates, calculated as in Eq. (9). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

1935 for the seminal work) is that it comes without assumptions on the correlation structure of errors.

Robustness Checks

We run a number of robustness checks. First, Fig. 5 presents results from a distributed lag model, which includes leads and lags of the average B-index in other MNE group locations: $\bar{T}_{i,-c,t+s}$ with $s \in \{-2,-1,\dots,2\}$. Analogously to the specifications in Table 4, the model, moreover, accounts for a full set of country-year-fixed effects. Importantly, the figure indicates that changes in the average B-index in other MNE group locations do not impact firms' R&D activity in years *prior* to the reform. In the parlance of standard difference-in-differences analysis, this suggests that the common trend assumption holds and R&D group locations that do and do not experience changes in foreign entities' R&D tax environments (or experience changes of different sign and/or size) do not systematically differ in their R&D trends prior to the reform. In line with intuition (see Section 3), the results furthermore indicate that responses of corporate R&D activity, as measured by corporate patent applications, emerge with a time lag.

A second robustness check follows up on our discussion in Section 4, where we acknowledge that R&D is commonly proxied either by output-related measures, like patent counts, or by input-related measures like R&D expenditures in the existing literature. While our baseline analysis relies on an output-related proxy, we assess the sensitivity of our findings to using an input-related measure instead, namely the number of inventors at a given MNE group location in a given year. More precisely, we calculate for each location of the MNE group in each year the number of inventor names on the patent documents who are located in the same country as the applicants of these patents. We disregard locations with incidental R&D – consistently defined as locations where less than 10% of all of the MNE's inventors are located

Table 8
Effect heterogeneity.

Panel A	Distance				Firm Size				Forward Citations			
CEM Match	Unweighted		CEM-weights		Unweighted		CEM-weights		Unweighted		CEM-weights	
Sample Split, Med.	Below (A1)	Above (A2)	Below (A3)	Above (A4)	Below (A5)	Above (A6)	Below (A7)	Above (A8)	Below (A9)	Above (A10)	Below (A11)	Above (A12)
B-index	−0.868***	−0.254	−0.872***	−0.254	−0.548	−0.910***	−0.556	−0.910***	−1.156***	−0.733*	−1.218***	−0.733*
	(0.303)	(0.504)	(0.306)	(0.504)	(0.381)	(0.302)	(0.512)	(0.302)	(0.254)	(0.401)	(0.274)	(0.401)
Avg. Foreign B-index	1.112***	0.339	1.072***	0.339	0.223	0.973***	0.495	0.973***	0.643	0.990**	0.745	0.990**
	(0.358)	(0.532)	(0.363)	(0.532)	(0.388)	(0.364)	(0.473)	(0.364)	(0.439)	(0.394)	(0.507)	(0.394)
Number of observations	11,281	11,486	11,281	11,486	11,163	11,604	11,163	11,604	11,292	11,475	11,292	11,475
Number of group locations	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1298	1,298	1,298
Control variables	All	All	All	All	All	All	All	All	All	All	All	All
Reg. Lag	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Panel B	Distance				Firm Size				Forward Citations			
CEM Match	Unweighted		CEM-weights		Unweighted		CEM-weights		Unweighted		CEM-weights	
Sample Split, Med.	Below (B1)	Above (B2)	Below (B3)	Above (B4)	Below (B5)	Above (B6)	Below (B7)	Above (B8)	Below (B9)	Above (B10)	Below (B11)	Above (B12)
Avg. Foreign B-index	1.066***	0.135	1.028***	0.135	0.047	0.890**	0.180	0.890**	0.581*	0.923**	0.657**	0.923**
	(0.354)	(0.514)	(0.352)	(0.514)	(0.401)	(0.353)	(0.502)	(0.353)	(0.313)	(0.386)	(0.324)	(0.386)
Number of observations	11,212	11,405	11,212	11,405	11,074	11,537	11,074	11,537	11,226	11,411	11226	11,411
Number of group locations	1,297	1,296	1,297	1,296	1,295	1,298	1,295	1,298	1,297	1,295	1,297	1,295
Control variables	All	All	All	All	All	All	All	All	All	All	All	All
Reg. Lag	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: the quality-adjusted patent count of a multinational group location in year t. Panel A shows models that reestimate the baseline regressions in Table 3, specification (B6) splitting the sample in group locations with a below and above median geographic distance to other MNE group locations (specifications (A1)–(A4)); that belong to MNEs with below and above median R&D activities as measured by the aggregate number of quality-adjusted patents during the sample period (specifications (A5)–(A8)); and group locations that belong to MNEs with patent forward citations below and above the median, as measured by the average number of forward citations per granted patent (specifications (A9)–(A12)). Panel B reestimates specification (B6) of Table 4 for these subsamples. The row "CEM Match" indicates if regression weights are derived by coarsened exact matching. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 9
Impact on group level patenting and tax payments.

Dependent variable	Quality weighted patents		ETR - STR	
	(1)	(2)	(3)	(4)
B-index	−0.088		0.131***	
	(0.665)		(0.047)	
Min. B-index		0.103		0.064**
		(0.300)		(0.028)
Direct R&D Support	0.075***	0.074***	−0.000	−0.000
	(0.025)	(0.024)	(0.001)	(0.001)
Number of observations	9,885	9,885	7,572	7,572
Number of group locations	1,114	1,114	1,084	1,084
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$
Control variables (Host)	All	All	All	All

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. The dependent variable in specifications (1) and (2) is the total number of quality adjusted patents filed by a given MNE in year t. In specifications (3) and (4), the dependent variable is the difference of the MNE's effective tax rate (i.e., the sum of taxes paid relative to the total pretax profits of the group) and the average statutory tax rate of the MNE. Observations are dropped if the effective tax rate is negative or above 100% or if the multinational group reports losses before taxes in any of our sample years. *B-index* denotes the average B-index of all affiliates of the MNE, lagged by two years. *Min. B-index* is the smallest B-index across all group affiliates, lagged by two years. The specifications include averages of each control variable that is included in specification (B6) in Table 3. All specifications are run with country- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Fig. 4. Placebo Test. *Notes:* The graph depicts the distribution of coefficient estimates for the "Avg Foreign B-index"-regressor $\bar{T}_{i,-c,t-2}$ obtained in placebo tests where we randomly reassign foreign MNE group structures across MNE group locations in the same country before reestimating the model in specification (B6) of Table 3. The red line indicates the actual coefficient estimate for the "Avg Foreign B-index"-regressor in specification (B6) of Table 3.

– in the computation of $\bar{T}_{i,-c,t-s}$. Reestimating our baseline model (see specification (A6) and (B6) of Table 3 and specification (6) in Table 4) with this modified R&D proxy yields qualitatively and quantitatively very similar results (cf. Table 5). This is in line with prior evidence, which finds that R&D tax elasticities are broadly similar when proxying for R&D activity based on input and output-related R&D measures (e.g., Dechezleprêtre et al., 2017).

In Table 6, we run robustness checks with respect to the sample composition and add additional fixed effects and control variables. As highlighted above, one particularity of the data is that, for global MNE groups, we do not observe R&D activities outside Europe (cf. the data description in Section 4). Changes in the tax environment at non-European R&D locations are hence disregarded in the calculation of the average B-index. This implies that the coefficient estimate on the average foreign tax regressor should be interpreted as cross-border tax effect between European group locations.[35] Specifications (1) and (2) of Table 6 reestimate the baseline models (Column (B6) of Table 3 and

[35] This interpretation relies on the assumption that R&D tax policies at non-European group locations do not act as a confounder (i.e., that these policies are uncorrelated with R&D tax environments/R&D investments at MNE group locations in Europe). As the innovation-rich economies outside Europe hardly

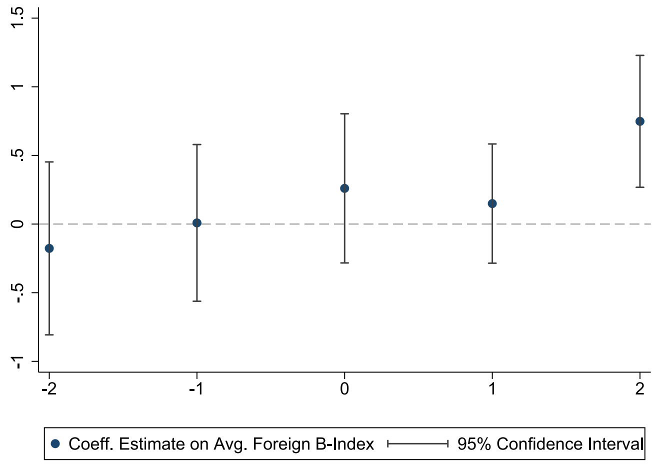

Fig. 5. Distributed Lag Model. *Notes:* The graph depicts the coefficient estimates and 95% confidence intervals from a distributed lag model. The model regressors comprise the first and second lead ($t-1$ and $t-2$) of the average B-index in other MNE group locations as well as the current period and first and second lag of this variable (t, $t+1$ and $t+2$). The model controls for a full set of host country-year-fixed effects.

Column (6) of Table 4) in a sample of group locations that belong to MNEs headquartered in Europe, where all relevant R&D group locations are observed. This leaves the estimated tax effects largely unchanged. Specification (3) of Table 6 shows that the estimates are robust to augmenting the vector of regressors by a full set of 2-digit-NACE industry-year-fixed effects, which absorb industry-specific shocks.[36] The same holds true when the sample is restricted to firms that operate in a homogeneous set of highly-innovative manufacturing industries, as defined by Eurostat, cf. specifications (4) and (5) of Table 6. Specification (6) replaces the set of country-year-fixed effects with a set of region-year-fixed effects, where regions are defined according to subnational NUTS 2 areas. This hedges against differential R&D time trends at a refined subnational geographical level. The results resemble the baseline estimates. Moreover, while the baseline models control for economic and institutional changes in other MNE group locations (subsumed in the vector $\bar{X}_{i,-c,t-s}$ in Section 3), specifications (7) and (8) furthermore augment the vector of control variables by country-level R&D trends in the host countries of foreign MNE locations. In specification (7) (specification (8)), we add a regressor for R&D expenditure as a percentage of GDP (the number of resident-filed patent applications) in the host countries of other MNE group locations, calculated as an asset-weighted average analogously to (9). In both cases, the data are drawn from the World Development Indicators. This modification yields results similar to the baseline findings. Table A.4 furthermore shows that accounting for firm productivity shocks in the host countries of other entities of the same MNE group does not alter the baseline results either.

changed their R&D tax treatment during the sample period, we consider this assumption to hold (the B-index for the U.S. remained unchanged during the sample period; the B-index for Japan, Canada and Australia moved moderately only with standard deviations of 0.048, 0.006 and 0.012, respectively during the sample period). Note, moreover, that we present evidence for effect heterogeneity below. Specifically, we show that firms' R&D tax responsiveness negatively correlates with intra-group distance and positively with MNE size. The tax responsiveness of unobserved non-European R&D locations of the sample MNEs might hence be larger or smaller than the estimated effect for the set of European group locations (as non-European affiliates likely belong to MNEs of above average size and with above average intra-group distance).

[36] If group locations comprise firms with different 2-digit NACE codes, we assign the most frequent industry. In case of multiple industries with the same frequency, a NACE code is randomly drawn.

In Table 7, we assess the sensitivity of the results to changes in the definition of the foreign tax regressor $\bar{T}_{i,-c,t}$. Specifications (1) and (2) reestimate the baseline model with a foreign tax variable (and further host country controls in other MNE group locations) that is calculated based on uniform weights. Instead of disregarding locations with less than 10% of all of the MNE's granted patents when calculating $\bar{T}_{i,-c,t}$, specifications (3) and (4) average over all locations weighting by the locations share in all of the MNE's granted patents over the complete sample frame. Specifications (5) and (6), moreover, assess whether the estimates are driven by changes in MNE group structures within the sample period. As explained in Section 3, the baseline analysis accounts for M&As and firm foundations when defining group structures at a given point in time. This adds precision to the estimation strategy as group locations enter the data when they are founded and firms are reassigned to new owners at the time of mergers and acquisitions. However, it also implies that $\bar{T}_{i,-c,t}$ may not only vary with country-level R&D tax reforms but also with choices of the MNE that alter the MNE group structure. Acknowledging potential endogeneity concerns related to these choices, we rerun all model specifications in a subsample of MNE group locations for which the set of MNE group locations (used for the calculation of $\bar{T}_{i,-c,t}$) remains unchanged within the sample frame. This ensures that time variation in $\bar{T}_{i,-c,t}$ stems from tax reforms only. This restriction reduces the number of MNE group locations by 500 locations only, reflecting that firm foundations and acquisitions only alter group structures if the incoming/exiting firm is the only group entity in the respective country; furthermore new firms with little R&D activity do not enter the calculation of $\bar{T}_{i,-c,t}$ (cf. Section 4). Results remain largely unchanged.

In columns (7) and (8) of Table 7, we use the minimum foreign B-index instead of a weighted average as explanatory variable of interest. If R&D activities at alternative locations are perfect substitutes without any further transactions costs, MNEs might first and foremost distort R&D towards the location with the most favorable tax system. If that held true, R&D allocation would be particularly sensitive to changes in the minimum foreign B-index. However, the empirical estimates imply quantitatively slightly weaker response rates for the minimum B-index relative to the baseline analysis (although not significantly different in a statistical sense). This may reflect the presence of transaction costs, including agency costs and other frictions within the firm (e.g., see Williamson, 2000), which inhibit the emergence of corner solutions where all R&D activity is located at the affiliate with the lowest R&D costs. Transaction costs may also occur in the form of convex adjustment costs, the convexity of which decreases in the level of R&D input factors present at the alternative locations (e.g., see Bloom, 2007; Freeman and Van Reenen, 2009).

As an alternative to the B-index, we, moreover, use the user cost for R&D capital as a measure of tax incentives in columns (9) and (10) of Table 7. The user cost of R&D capital is computed as in Bloom and Griffith (2001) and Wilson (2009). Following these papers we assume a depreciation rate of 30% and use long-term interest rates (i.e., interest rates on 10-year government bonds). Reassuringly, results remain robust when using the user cost of capital as a tax incentive measure with the larger coefficient resulting from the different scaling of the explanatory variable.[37] This indicates that it is variation in foreign and domestic tax incentives rather than their interaction with the general economic environment that drives the results.

Another concern is that because the B-index formula contains the corporate income tax rate, variation in the tax incentive measure is driven by variation in the tax rate rather than by variation in the actual input incentives (e.g., tax credits, super-deductions, accelerated

[37] The sample mean for the user cost of capital is 0.301 while it is 0.931 for the B-index. Note that, evaluated at the sample mean, the estimated own-country R&D tax effect again translates into a tax elasticity well in the range of the existing literature.

depreciation). We address this concern in several analyses reported in the (Table A.3). In particular, we first add both the domestic and the average foreign statutory tax rate as additional control variables. We repeat this exercise using the effective average tax rate (EATR) for R&D as reported by Bösenberg and Egger (2017) instead of the statutory tax rate. Finally, we separate the denominator and the numerator of the B-index (see Eq. (8)) and add them separately as explanatory variables. In all specifications the main effect remains robust with estimated coefficients of similar magnitude as in the base analysis. Interestingly, the coefficient for both the domestic and the foreign EATR is insignificant. This points to MNEs adjusting R&D at the intensive margin and thus responding to measures of marginal tax costs such as the B-index rather than average tax rates such as measured by the EATR.

Also note that the analysis abstracts from so-called patent box regimes. While R&D tax incentives are commonly designed as special R&D tax deductions or R&D tax credits, a number of countries have recently introduced patent boxes which grant special low tax rates on patent income. Following the prior literature, the B-index definition does not account for related provisions (see e.g., Bösenberg and Egger, 2017) as they largely serve as instruments to attract mobile shifting income rather than to foster R&D investment (cf. e.g., Alstadsæter et al., 2018; Koethenbuerger et al., 2018; Knoll and Riedel, 2019 and Schwab and Todtenhaupt, 2021; see also footnote 5). Dropping MNEs connected to countries which introduced patent box regimes during the sample period, does not change the estimates for the B-index regressors (reestimating specification (6) of Table 4, e.g., yields a coefficient estimate for the $\bar{T}_{i,-c,t-s}$-regressor of 1.108 which is statistically significant at the 5% level). Analogously, we find results comparable to the baseline estimates when we augment the set of regressors by control variables for patent box regimes in the group location's host country and at foreign locations (reestimating specification (6) of Table 4, e.g., yields a coefficient estimate for the $\bar{T}_{i,-c,t-s}$-regressor of 0.903, which is statistically significant at the 5% level).

Response Heterogeneity

Next, we examine response heterogeneity. Our theoretical considerations in Section 2 suggest that the substitutionary link between R&D investments at MNE group locations, identified in the prior analysis, may correlate with geographic distance and the size of R&D activities. In the empirical analysis to come, the former is measured by the asset-weighted average distance of a group location to all foreign R&D hosts within the MNE; the latter is captured by the MNEs' aggregate quality-adjusted number of patent applications over the full sample period. Moreover, we test whether a complementary link between group locations' R&D investments, while rejected in the full sample, may emerge for subsets of firms. To do so, we identify MNEs that file for patents that receive many forward citations. As forward citations indicate that corporate R&D activities yield innovations that serve as basis for future R&D, R&D investments in these companies are particularly likely to be shaped by knowledge spillovers that establish a complementary R&D investment link (see Section 2).

The first two columns of Panel A in Table 8 test for response heterogeneity in the distance dimension and rerun the baseline model in subsamples of group locations with below and above median distance to foreign R&D locations, respectively. The estimated tax effects are economically and statistically more significant in the subsample of entities that are located in geographic proximity to other affiliates of the same MNE group (column (A1)). This holds true for the host country tax effect as well as for the foreign location tax effect. The aggregate tax effect, as measured by the sum of the coefficient estimates is close to zero and statistically insignificant in both subsamples. This suggests that R&D tax responses are driven by cross-border R&D relocation in both sets of firms but that effects are stronger for MNEs characterized by small geographic intra-firm distances between R&D locations. Specifications (A3) and (A4) assess whether this finding is driven by other imbalances between the subsamples of high-distance and low-distance firms. One might, for example, presume that firms with higher intra firm distance to other group affiliates belong to larger MNEs; if size determines firms' tax responsiveness, related effects might be picked up in the analysis. The models in specifications (A3) and (A4) employ Coarsened Exact Matching (CEM, see Iacus et al., 2012) to absorb heterogeneity in MNEs' aggregate R&D size and the average number of forward citations per patent. The covariates are coarsened in 5 equi-sized bins each and MNE locations with below and above median distance to foreign R&D hosts are exactly matched on the coarsened data. This provides matching weights for the subsequent regression. The estimates obtained from this specification resemble the results obtained from regressions based on unweighted data.[38]

Specifications (A5) and (A6) test for response heterogeneity between MNE groups with small and large aggregate R&D activities, respectively. Splitting the sample at the median of the MNEs' aggregate quality-adjusted count of granted patent applications shows that tax response rates are significantly larger, in absolute terms, for MNEs with above average R&D activity. This result is confirmed in specifications using CEM weights to account for imbalances of covariates in the sample split (cf. specifications (A7) and (A8)). Note, moreover, that two of the sample countries, the United Kingdom and the Netherlands, differentiated their R&D tax incentive schemes between large and small (profitable) firms during the sample period. While all specifications presented so far have accounted for large firms' tax incentives in these cases, modeling the small firm incentives instead yields comparable results (not reported).

Finally, we determine whether a complementary link between locations' R&D investments, while rejected in the full sample, may emerge for subsets of firms.[39] In specifications (A9) and (A10), we reestimate the baseline model in subsamples of group locations that belong to MNEs that, within the sample frame, file for patents with an above and below median number of patent forward citations. The results show similar coefficient estimates in the two subsamples. This finding is confirmed in CEM specifications (i.e., specifications (A11) and (A12)).

All results in our heterogeneity analysis are robust to including the full set of country-year-fixed effects (see Panel B of Table 8). Concluding, the results in this subsection suggest that it is mainly firms with large overall R&D activities and firms with small intra-firm distances between R&D locations that relocate R&D activity in response to changes in R&D tax incentives. The latter finding supports recent macro-level studies which *assume* R&D mobility (in response to tax changes) to decline in space (see the literature review in the introduction). The former finding provides a rationale for conditioning R&D tax design on the size of firms' R&D activities.

6. Implications and discussion

The evidence provided in this study indicates that MNEs reallocate R&D across borders when R&D tax incentives change, implying that R&D investments at different MNE group locations act as substitutes. It follows that the global response of MNEs' R&D activity to changes in R&D tax incentives is smaller than the response in the policy-changing country. In fact, our estimates suggest that MNEs hardly raise their global R&D activity at all when R&D tax costs fall. To further check if this is indeed the case, we reestimate the global tax effect with *consolidated* group-level data. Specifically, we aggregate the MNEs' R&D activity (as measured by quality-weighted granted patent applications)

[38] Coarsened Exact Matching does not only account for imbalance in means, but also for imbalances in higher moments and interactions. Note that the binning strategy implies that the variables' 20th, 40th, 60th, and 80th percentiles separate the bins.

[39] Bilir and Morales (2020) show that innovations at one MNE group location increase the *productivity* of entities of the same MNE group in other locations. They, however, do not test for a complementary link between R&D investments at different group locations or for effects related to R&D tax incentives.

across all locations and regress it on the average R&D tax costs of R&D active affiliates, a full set of MNE group-fixed effects as well as the average time-varying host country controls. The overall effect of the average B-index on R&D at the group level is estimated to be close to zero and turns out statistically insignificant (see specification (1) of Table 9). Similar results are obtained when using the minimum tax cost in the group (see specification (2) of Table 9). This supports the notion that R&D tax incentives are hardly instrumental in expanding aggregate group-level R&D.

R&D tax subsidies thus appear to create significant windfall gains for MNEs. To inquire if MNEs indeed benefit from a reduced tax burden, we repeat the previous two regressions but the dependent variable is substituted by the difference between the MNE's effective tax rate – i.e., the sum of taxes paid relative to total pretax profits – and the MNE's average statutory tax rate. The significant coefficient estimates in specification (3) and (4) of Table 9 imply that lower R&D tax costs, as measured by the B-index, are indeed associated with lower effective tax rates at the MNE group level. The reduced overall tax bill may ultimately benefit various stakeholders of the MNE. Prior evidence suggests that reduced tax payments lead to higher payouts (e.g., see Blouin and Krull, 2009; Dharmapala et al., 2011). Other stakeholders' compensation might adjust as well, including CEO's salaries and workers' wages. There is also evidence that firms use tax savings to supplement precautionary cash holdings (e.g. Guenther et al., 2020). If firms are credit constrained, they might, on top of that, use the free cash flow to raise capital investment and employment.[40] This is in line with the negative correlation between the average level of the B-index (lagged by two years) and the two year growth rate in the number of employees in our data (Fig. A.4).

While our evidence attenuates hopes that R&D tax incentives trigger significant expansions of MNEs' global R&D activity, this does not necessarily mean that such tax subsidies are undesirable from a social perspective. If R&D tax incentives are instrumental in raising the R&D activity of domestic firms (which are, among others, more likely to be credit-constrained than large multinational entities), their overall welfare effect may be positive. Smaller firms frequently have the largest relative demand for capital but information asymmetries and a lack of collateral – in particular in the knowledge-intensive industries – inhibit the acquisition of external funds, in particular debt financing (Brown et al., 2012; Carpenter and Petersen, 2002; Colombo and Grilli, 2007; Freel, 2007; Hsu, 2004). Consistent with more binding financial constraints, R&D investments by small firms exhibit a stronger response to tax incentives than R&D investments by large firms (Castellacci and Lie, 2015; Lokshin and Mohnen, 2012). Hence, focusing funds on smaller firms by capping the absolute value of R&D tax incentives is an attractive policy option, which curbs the "crowding out" effect for larger firms without impeding firm growth at particular size thresholds.[41] Nevertheless, R&D tax incentives for large MNEs might still be efficiency enhancing despite lacking an apparent effect on aggregate R&D. In particular, locations with a relative cost advantage in R&D tasks in the global production process may be the ones to introduce attractive tax incentives for R&D. Jointly, these benefits may then outweigh adjustment costs which may otherwise inhibit an efficient reallocation of R&D production tasks in the global production network. Similar effects might emerge through repercussions of R&D output within MNEs' global value chain. Such repercussions could depend on the geographic proximity of R&D activities to other operating entities, e.g. manufacturing sites. This may be the case if knowledge spillovers decline in space or with cultural distance. Then, R&D relocations that alter the geography of intra-firm R&D may trigger adjustments in firm productivity and income.

7. Conclusion

In this paper, we empirically assess the impact of R&D tax incentives on the R&D investment of multinational firms. Using rich unconsolidated data on MNEs' R&D activities, we replicate prior findings and show that more generous input-related R&D tax incentives such as tax credits, accelerated depreciation or super-deductions are associated with higher R&D investments of MNE groups in the policy-changing country. Our findings, however, also suggest that R&D investments at locations abroad decline, pointing to intra-firm R&D relocation between R&D hubs. The aggregate tax incentive effect, i.e., the sum of the host and foreign country tax effect, turns out to be small and not statistically different from zero. This suggests that MNEs respond to R&D tax incentives by relocating R&D activity across group locations rather than by increasing their aggregate R&D investments.

This has important policy implications. First, input-related R&D tax incentives are found to serve as beggar-thy-neighbor instruments, which may exert negative externalities on foreign jurisdictions. This renders decentralized R&D tax policy setting inefficient and points to potential welfare gains from policy coordination. Second, the findings suggest that MNEs do not significantly raise their aggregate R&D in response to more generous R&D tax support. The analysis hence casts doubts on the effectiveness of these instruments in alleviating MNEs' underinvestment in R&D.

CRediT authorship contribution statement

Bodo Knoll: Data collection, Analysis, Writing involved in creating this paper. **Nadine Riedel:** Data collection, Analysis, Writing involved in creating this paper. **Thomas Schwab:** Data collection, Analysis, Writing involved in creating this paper. **Maximilian Todtenhaupt:** Data collection, Analysis, Writing involved in creating this paper. **Johannes Voget:** Data collection, Analysis, Writing involved in creating this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A.1
Correlation between patent output and R&D expenditure.

Specification	Adjustment of Variables	ρ
(1)	None	0.889***
(2)	Scaling by GDP	0.688***
(3)	Country fixed effects	0.815***
(4)	Country-year fixed effects	0.779***

Notes: This table reports the Pearson correlation coefficient ρ between national patent output and corporate R&D expenditure in OECD countries for the years 1981 to 2012 based on official OECD data. The reported correlation coefficient in line (1) uses non-adjusted values for patent output and R&D expenditure. In line (2), both patent output and R&D expenditure are divided by GDP prior calculation of ρ. In lines (3) and (4), patent output and R&D expenditure are demeaned using fixed effects methodology to absorb country fixed effects (3) and country-year fixed effects (4), respectively. Patent output refers to the total count of patents in a country for given year. R&D expenditure refers to the sum of corporate R&D expenditures in a country for a given year. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

[40] A thorough empirical assessment of these response margins to changes in R&D tax incentives is a fruitful avenue for future research. Among other factors, the eventual use of funds will depend on the type of owners and institutional parameters like dividend tax rates and wage tax rates.

[41] Additionally, smaller firms are also found to benefit from direct R&D subsidies (Howell, 2017) and direct R&D subsidies can amplify the effect of R&D tax incentives (Bérubé and Mohnen, 2009; Neicu et al., 2016).

Table A.2
Sample restrictions.

Panel A	Less than 9 locations			Sample years 2000–2010		
	(A1)	(A2)	**(A3)**	**(A4)**	**(A5)**	**(A6)**
B-index	−1.403***	−1.273***	−1.325***	−0.999***	−0.840***	−0.759***
	(0.283)	(0.224)	(0.222)	(0.267)	(0.208)	(0.205)
Direct R&D Support			0.034***			0.032**
			(0.010)			(0.013)
Number of observations	22,282	22,282	22,282	17,547	17,547	17,547
Number of group locations	2,550	2,550	2,550	2,487	2,487	2,487
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Control variables (Host)	No	Base	All	No	Base	All
Panel B	**(B1)**	**(B2)**	**(B3)**	**(B4)**	**(B5)**	**(B6)**
B-index	−1.288***	−1.168***	−1.222***	−0.879***	−0.636***	−0.564***
	(0.274)	(0.222)	(0.220)	(0.257)	(0.206)	(0.205)
Avg. Foreign B-index	0.554**	0.701**	0.640**	0.751**	0.722**	0.641**
	(0.280)	(0.279)	(0.294)	(0.319)	(0.346)	(0.320)
Direct R&D Support			0.030***			0.026**
			(0.010)			(0.012)
Avg. Foreign Direct R&D Support			−0.003			−0.022
			(0.010)			(0.017)
Number of observations	22,282	22,282	22,282	17,547	17,547	17,547
Number of group locations	2,550	2,550	2,550	2,487	2,487	2,487
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Control variables (Host)	No	Base	All	No	Base	All

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. The specifications (A1)–(A3) and (B1)–(B3) reestimate specifications (A4)–(A6) and (B4)–(B6) in Table 3, but exclude outliers in terms of group size: only MNEs with less than nine locations are included in the sample. Columns (A4)–(A6) and (B4)–(B6) run the same regressions from Table 3 for the (restricted) sample period 2000–2010. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.3
Alternative measures of R&D Tax incentives.

	(1)	(2)	(3)	(4)	(5)	(6)
B-index	−1.030***		−0.728**			
	(0.230)		(0.326)			
Avg. Foreign B-index	0.876**	0.821**	0.971***	0.844**		
	(0.355)	(0.338)	(0.353)	(0.340)		
B-index adj.					−1.473***	
					(0.336)	
Avg. Foreign B-index adj.					1.161**	1.084**
					(0.511)	(0.497)
Corporate Tax Rate (CTR)	−1.208*					
	(0.700)					
Avg. Foreign CTR	−0.502	−0.192				
	(0.886)	(0.805)				
Effective Average Tax Rate (EATR)			−0.902			
			(0.755)			
Avg. Foreign EATR			−0.218	−0.025		
			(0.975)	(0.880)		
$1/(1-CTR)$					−1.016***	
					(0.269)	
Avg. Foreign $1/(1-CTR)$					0.118	0.198
					(0.427)	(0.392)
Number of observations	23,499	23,417	23,499	23,417	23,499	23417
Number of group locations	2,680	2,679	2,680	2,679	2,680	2,679
Lag structure of regressors	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$	$t-2$
Country-Year FE	No	Yes	No	Yes	No	Yes
Control variables (Host+Foreign)	All	All	All	All	All	All

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. Dependent variable: the quality-adjusted patent count of a MNE group location in year t. The specifications include the full set of control variables outlined in Table 3. Columns (1) and (2) (colums (3) and (4)) include the corporate tax rate (the effective average tax rate) as an additional control variable. Columns (5) and (6) decompose the B-index as follows: *B-index adjusted* denotes the B-index multiplied by the net of corporate tax rate $(1-CTR)$. The inverse of $(1-CTR)$ is also included. *Avg. Foreign CTR*, *Avg. Foreign B-index adj.*, *Avg. Foreign* $1/(1-CTR)$ are asset-weighted averages, calculated as in (9). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.4
Controlling for firm productivity at foreign group locations.

	(1)	(2)
B-index	−0.906***	
	(0.281)	
Avg. Foreign B-index	0.922***	0.910***
	(0.309)	(0.314)
Number of observations	16,396	16,361
Number of group locations	2,071	2,070
Lag structure of regressors	$t-2$	$t-2$
Country-Year FE	No	Yes
Control variables (Host+Foreign)	All + Profitability Foreign Country	All + Profitability Foreign Country

Notes: Standard errors (adjusted for clustering at the MNE group level) are presented in parentheses. The specifications in this table reestimate the baseline models in Column (A6) and (B6) of Table 3 but include an additional control variable for the average pre-tax profitability, measured as pre-tax profits over shareholders' funds, of firms in the host countries of the foreign MNE group locations. The variable is constructed based on firm-level data in Bureau van Dijk's AMADEUS database (drawing on firms with balanced unconsolidated accounting information between 2002 and 2012). Outliers are winsorized at the 5% level and the firm set for the calculation is restricted to national entities. This implies that none of the sample firms enters this calculation. We then determine firms' average pre-tax profitability in country-year cells. To absorb potential shocks to firm profitability in the host countries of the other group locations that belong to the same MNE as the group location under consideration, the asset-weighted average is calculated following Eq. (9). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

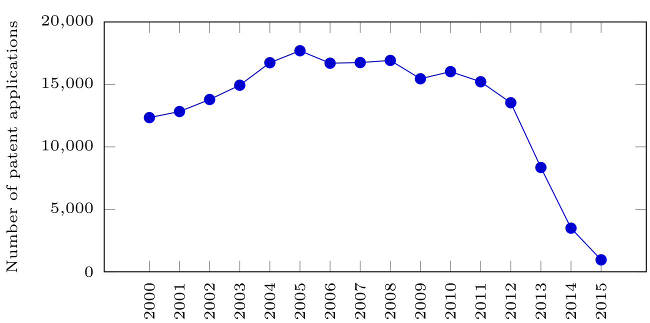

Fig. A.1. Total number of domestic patent applications in the estimation sample. *Notes:* This graph displays the evolution of the total number of patent applications filed by MNEs in the estimation sample over time.

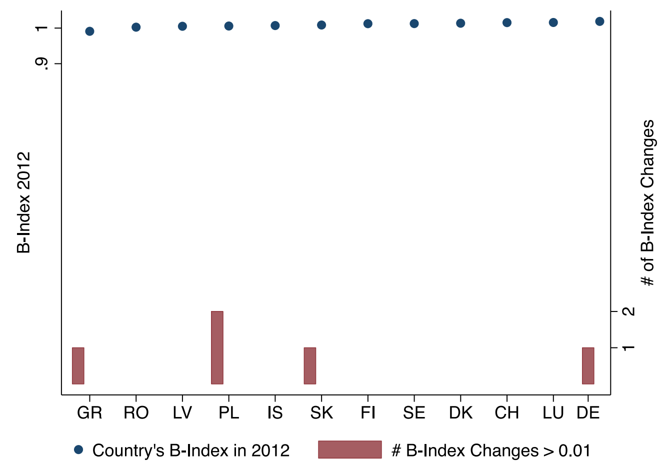

Fig. A.3. B-index in 2012 (if > 0.95) and # of B-index-Changes in Sample Period. *Notes:* The graph is an extension to Fig. 3 in the main text. It depicts the 2012-value of the B-index for countries with a B-index above 0.95 as well as the number of B-index changes during the sample period exceeding 0.01 (in absolute terms) experienced by these countries. Note that none of the depicted sample countries experienced a B-index change larger than 0.05.

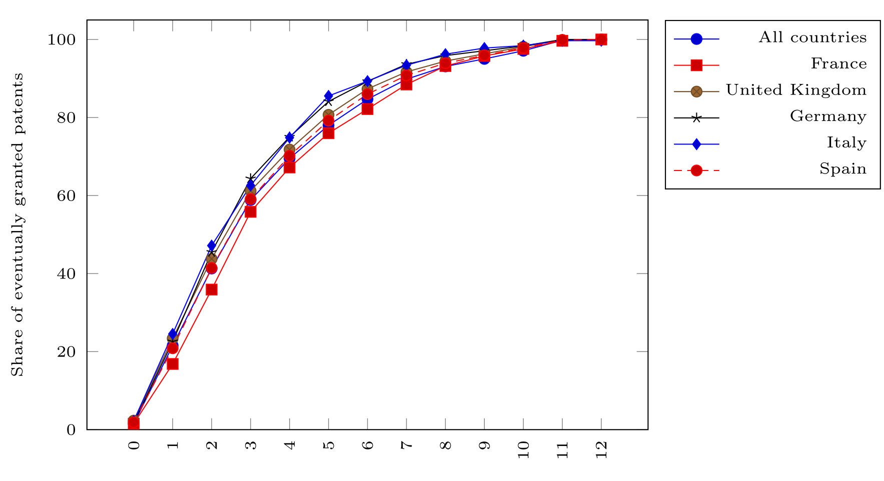

Fig. A.2. Share of patent applications from 2005 that are granted in a given year after application. *Notes:* This graph displays the percentage of eventually granted patent applications filed in 2005 that is granted in each year following the application. It does so for patents filed by applicants from all countries as well as separately for patents filed by applicants from France, the United Kingdom, Germany, Italy and Spain.

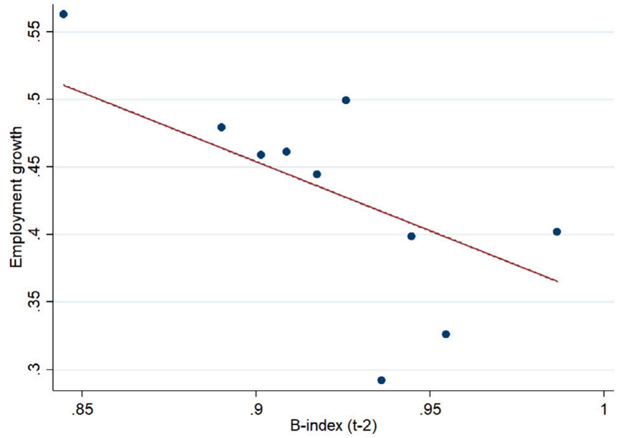

Fig. A.4. Binned Scatter Plot of Two-year Employment Growth and B-index. *Notes:* The graph displays a binned scatter plot for the relative change of average employment two years after the observed value of the B-index. We use the binscatter program published by Michael Stepner. The plot is created by first regressing the relative change of average employment in all MNE affiliates during the last two years on the B-index lagged by two years as well as year and MNE fixed effects. The sample restriction is the same as in the specifications of Table 9. We have further excluded outliers with an extreme employment growth (i.e., the top percentile). The B-index is grouped into 10 equal-sized bins and the mean of the average employment growth is computed for each bin and displayed as a scatter plot. The best fit from an OLS regression is plotted as a red line.

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