Cross-Border Effects of R&D Tax Incentives

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Abstract

Existing evidence shows that R&D tax incentives boost countries' private sector R&D. As multinational enterprises (MNEs) account for nearly all private sector innovations, 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 show that R&D tax incentives serve as beggar-thy-neighbor instruments: 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 respond to changed R&D tax incentives.

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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 expenditures, 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, OECD, 2019b, OECD, 2019c). Several countries without R&D tax incentive schemes, moreover, 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). 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).

In this paper, we make use of rich panel data on the R&D activities of multinational enterprises (MNEs) to 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. Theoretical considerations suggest they do. On the one hand, R&D is internationally mobile (e.g., Abramovsky et al., 2008) and expanded R&D tax incentives at one group location might attract investments from abroad and lower R&D activity at entities of the same MNE group in other locations. In this scenario, global investment responses are smaller than investment responses in the policy-changing country because of a cross-border subsitution 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 positively affect foreign R&D activity and trigger global investment responses that exceed the responses in the policy-changing jurisdiction. As MNEs account for nearly all private innovation investment (e.g., see Criscuolo et al., 2010, National Science Board, 2014, Bilir and Morales, 2020), related cross-border relocation of R&D for tax purposes may be a significant driver of aggregate R&D investment patterns.[1]

To empirically determine the sign and size of the cross-border effect, we make use of rich panel data on MNEs in Europe. Our empirical analysis spans the years 2000

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

to 2012 and proxies innovative activity of MNEs by the number of granted patents owned at the location and invented locally.[2] As the innovativeness of technologies varies across patents (see e.g., Hall et al., 2010) and related differences plausibly reflect variation in the size of the underlying R&D activity, we construct our R&D measure as a quality-adjusted patent count (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 the B-index in each location of the MNE (McFetridge and Warda, 1983) that captures the tax costs related to corporate R&D investments.

Methodologically, we estimate fixed effects Poisson Pseudo-Maximum Likelihood (PPML) models that express the number of quality-adjusted patents per multinational group location and year as a function of the B-index of an MNE group affiliate's host country 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 -1.03 (see, e.g., the literature review in Guceri and Liu, 2019).[3] The analysis, moreover, points to a positive and statistically significant cross-border tax effect, suggesting that lower R&D tax costs at one group location are associated with intra-firm R&D relocations and 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 and the cross-country tax effect – is zero. 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, furthermore, 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 estimate is, moreover, robust to

[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.

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. Placebo tests where we rerun the baseline model but randomly reassign MNE group structures across multinational affiliates yield no significant tax effect.

Finally, we present evidence for effect heterogeneity across firms. Our results suggest that the size of the cross-country R&D tax effect inversely correlates with the distance between group affiliates, which is consistent with the notion that firms have regional R&D location preferences or that transaction costs increase in geographic distance. Our findings hence support prior macro data studies which *assume* that cross-border tax effects decline in space (e.g., Wilson, 2009). On top of that, we show that entities with larger R&D activities tend to respond more elastically to changes in R&D tax incentives than smaller multinational firms, which might root in fixed costs of R&D tax planning and R&D relocations.

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 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, Wilson, 2009, Moretti and Wilson, 2017), R&D information drawn from firm surveys (e.g., Lokshin and Mohnen, 2012, Mulkay and Mairesse, 2013) and, more recently, also administrative corporate tax return data (e.g., Rao, 2016, Dechezleprêtre et al., 2017, Agrawal et al., 2020, Guceri and Liu, 2019, Chen et al., 2019b) to quantify this effect. As the latter studies commonly draw on data for individual countries, cross-border tax effects can, by definition, not be assessed.[4]

Evaluations of the economic and welfare consequences of R&D tax incentives, nevertheless, require a thorough understanding of their impact across borders. If more

[4] 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 and Knoll and Riedel, 2019). In general, empirical studies on patent boxes also largely ignore cross-country effects. An exception is Schwab and Todtenhaupt (2019) who show that profit shifting opportunities and tax cost reductions related to patent box regimes spur R&D investments in non-patent box countries.

generous R&D tax incentives – as suggested by the findings – do attract mobile R&D from abroad rather than triggering new research and development activities, neighboring countries may lose welfare. The latter might counter the policy move by expanding the generosity of their own R&D tax incentives, in turn, to retain mobile R&D investment within their borders. From a global perspective, the granted R&D tax incentives are then set inefficiently high.

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. multinational companies.[5] Beyond these, we are aware of only three prior studies that consider 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) use information on private sector R&D spending in eight OECD countries for 1979 to 1997, Wilson (2009) data on company-performed R&D spending in U.S. states between 1981 and 2004, and Akcigit et al. (2018) 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) and Wilson (2009) 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 tax effects. These differences in prior evidence might be attributed to the different modeling approaches pursued. In particular, testing for cross-border spillovers requires making assumptions on where tax spillovers arise. Prior studies presume 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). With micro data, spillover routes at the group-level can be identified in a non-adhoc way based on information on multinational group structures. The data, moreover, allows for empirical identification strategies that compare changes of R&D activities 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. This ensures that the estimates are unconfounded by country-level shocks. Drawing on micro data also comes

[5] 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.

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 data studies, we can obtain an unbiased estimate of the average corporate response to R&D tax incentives.[6]

Finally, note that the more recent studies (Wilson, 2009, and Akcigit et al., 2018) assess R&D allocation 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 6 concludes.

2 Theoretical Considerations

Before embarking on the empirical analysis, we sketch channels through which R&D tax incentives may impact MNEs' R&D location choice: Consider an MNE that engages in R&D and operates in several countries, which may serve as a location for R&D investment. If one jurisdiction expands the scope of its R&D tax support, the MNE has incentives to increase its R&D investments in the policy-changing country (e.g., Bloom et al., 2002). If and how this alters R&D levels at other group locations depends on whether R&D investments at different locations act as substitutes or complements (or are uncorrelated).

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 substitu-

[6] 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 a serious upward bias in the estimates of real wage elasticities obtained from aggregated data. Dharmapala (2014) finds that estimates of profit shifting elasticities are substantially smaller if they are based on microeconomic data compared to estimates from aggregate data. Aggregate estimation approaches also perform worse than microeconomic estimation approaches in predicting aggregate variables (Pesaran et al., 1989).

tion of R&D activity between various locations: MNE groups respond to expanded R&D tax incentives by shifting R&D investments from other group locations to the policy-changing jurisdiction. R&D tax incentives, in this scenario, serve as beggar-thy-neighbor instruments that lower foreign R&D activity and may reduce foreign welfare.[7] The global R&D tax response is smaller than the observed response in the policy-changing country.

Cross-border R&D mobility – and the tax responsiveness of R&D – may thereby vary across firms. Firms might, for example, be more willing to relocate 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). The tax responsiveness of business R&D may, on top of that, depend on firm size. If R&D tax planning involves fixed costs, R&D activities are more tax-sensitive in large MNEs. If large firms, in turn, can more 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 also respond less sensitive to R&D tax incentives.

Conditional on the policy choice of foreign jurisdictions, cross-border R&D mobility implies that countries can boost R&D investments within their borders by granting more generous R&D tax incentives. Neighboring jurisdictions are, however, negatively affected by the policy change and may have incentives to increase the generosity of their R&D tax incentives in turn (see, e.g., Keen and Konrad, 2013 for a survey of the literature on interjurisdictional tax competition). In equilibrium, R&D tax incentives are set inefficiently high from a global perspective.

R&D Investments as Complements

The above considerations follow the notion that R&D investments at different multinational group locations are substitutes. From a theoretical perspective, they might also be complements. New R&D investments at one group location may, for example, yield knowledge output that – through MNE-internal knowledge spillovers – increases the yields from R&D investments at other group locations (see e.g., Bilir and Morales, 2020). Expanded tax incentives then raise R&D investments in the policy-changing country and abroad. A complementary link between domestic and foreign investment might, moreover, emerge if firms are credit constrained and need to rely on internal

[7]Reduced foreign R&D investments may be associated with lower foreign knowledge production, tax revenues, employment and growth; see e.g., Hassan and Tucci (2010), Bloom et al. (2013), Van Roy et al. (2015), Maradana et al. (2017).

resources to finance R&D investments (see e.g., Hall et al., 2016).[8] When tax costs fall at one location, the related 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 are complements, the global R&D tax response exceeds the observed response in the policy-changing country. R&D tax incentives, in this scenario, exert a positive externality on foreign jurisdictions and are inefficiently low from a global perspective.

Summarizing, whether input-related R&D tax incentives in one country increase or decrease R&D activity in other countries remains an empirical question. Given that MNEs are responsible for the lion's 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 micro data 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 at time t, where an MNE's activities in a given country is referred to as an MNE group location. Prior studies focused on quantifying the effect of host country R&D tax costs $T_{c,t-1}$ on firms' R&D investment $y_{i,c,t}$. Following this research, we estimate a fixed effects PPML model with the following parametrization

$$E\left(y_{i,c,t}|T_{c,t-1},X_{c,t-1}\right)=\exp\left(\alpha_1 T_{c,t-1}+\alpha_2 X_{c,t-1}+\lambda_{i,c}+\delta_t\right) \tag{1}$$

where $\lambda_{i,c}$ and δ_t denote full sets of MNE group location fixed effects and time fixed effects respectively and the vector $X_{c,t-1}$ comprises host country control variables (country size, economic development, governance characteristics, FDI inflows and direct government support for business R&D (i.e., support not granted through the tax system); see Section 4 for variable definitions). R&D investments are proxied by the number of patents filed by MNE i in country c at time t and the tax regressor, in the main specification, enters with a one-year lag to account for the time gap between R&D

[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).

investments and patentable results. An advantage of the PPML model that makes it particularly well-suited for the estimations involving patent applications is its broad applicablity to non-linear relationships and its consistency when using dependent variables with many zeros such as corporate patent applications where not all firms apply for a patent every year. 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 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 data studies assume them to emerge in geographically close and economically connected jurisdictions. Our micro data, in turn, allows for a more direct and accurate modeling based on observed multinational group structures. This follows the theoretical considerations in Section 2 that cross-border tax effects, no matter if positive or negative, arise within the multinational group. We thus add regressors for the average R&D tax costs levied by the host countries of MNE i's other locations $-c$ ($\neq c$) at time t, $\bar{T}_{i,-c,t-1}$; 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 $\bar{X}_{i,-c,t-1}$. Our model now reads

$$\begin{aligned} &E\left(y_{i,c,t}|T_{c,t-1}, \bar{T}_{i,-c,t-1}, X_{c,t-1}, \bar{X}_{i,-c,t-1}\right) \\ &= \exp\left(\beta_1 T_{c,t-1} + \beta_2 \bar{T}_{i,-c,t-1} + \beta_3 X_{c,t-1} + \beta_4 \bar{X}_{i,-c,t-1} + \lambda_{i,c} + \delta_t\right) \end{aligned} \tag{2}$$

The theoretical considerations in Section 2 predict a negative sign for β_1 and an ambiguous sign for β_2: Higher R&D tax costs at the host (foreign) group location(s) are expected to exert a negative (an ambiguous) effect on corporate R&D investment. While estimating β_2 is at the heart of our paper, omitting $\bar{T}_{i,-c,t-1}$ may bias the β_1-estimate, with the sign of this bias being a priori unclear.[9]

[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 positive (negative) and the $\bar{T}_{i,t-1}$ 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 $\bar{T}_{i,t-1}$ 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 $\bar{T}_{i,-c,t-1}$ biases the β_1-estimate if R&D tax policies are correlated across countries and taxes, simultaneously, exert cross-border R&D effects. The coefficient

Equation (2) 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 multinational 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

$$E\left(y_{i,c,t}|\bar{T}_{i,-c,t-1}, \bar{X}_{i,-c,t-1}\right) = \exp\left(\gamma_1 \bar{T}_{i,-c,t-1} + \gamma_2 \bar{X}_{i,-c,t-1} + \lambda_{i,c} + \rho_{c,t}\right) \tag{3}$$

The cross-border tax effect β_2 is now estimated by comparing changes in the R&D investment of multinational 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-data research, country-specific R&D trends are hence absorbed in our analysis. In robustness checks, 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.

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.

R&D Activity

Following prior literature (Aghion et al., 2013, Seru, 2014, Bena and Li, 2014), corporate R&D activity is proxied by the number of successful patent applications filed by a firm in a given year. The 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 European national patent offices and supranational patent offices. The drawbacks of using patent counts as a proxy for corporate R&D activity (e.g., as compared to R&D expenditure) are that it takes

estimate for 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).

some time for R&D activity to result in a patent application and that one only captures R&D that eventually becomes a successful innovation while potentially desirable externalities of R&D might also result from unsuccessful innovations. However, prior literature documents that the number of patents is highly correlated with other measures of corporate R&D activity (Hausman et al., 1984, Hagedoorn and Cloodt, 2003, Artz et al., 2010). An additional advantage of patenting as a measure for corporate R&D is that it 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. 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. In contrast, this is largely infeasible based on other R&D measures like R&D spending or the number of R&D workers which are (i) usually not reported consistently across countries and thus rarely comparable and (ii) commonly only available on a consolidated basis from company accounts. Disaggregated data on R&D expenditure must be drawn from surveys and corporate tax returns which are restricted to individual countries.

Following the existing literature, we 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.[10] If firms file for patent protection in several countries, the patented technology is, analogous to prior studies, only counted once. The analysis furthermore 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 factor analysis (e.g., Lanjouw and Schankerman, 2004).

[10]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).

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 to avoid overweighting locations with more complex affiliate structures. 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. 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 multinational groups in the data: (i) MNEs – headquartered in Europe – where information on all relevant 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. 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.

As the identifying variation is at the level of the MNE group location, we aggregate all information at the MNE-country-year level. The dependent variable is hence the quality-adjusted number of granted patent applications per multinational 'group location' and year.[11] The sample covers the years 2000 to 2012. Years after 2012 are disregarded as the dependent variable is the number of granted patents and the granting process takes five years on average (see e.g., Harhoff and Wagner, 2009 and Bösenberg and Egger, 2017). Years before 2000 are disregarded as we lack reliable information on ownership structures and tax incentives.

[11]Note that the value per patent derived from 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.

The sample is, moreover, restricted to multinational 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 1,151 MNEs and 2,938 multinational group locations hosted by 26 European countries. In Figure 1, we illustrate the intercorporate cross-border links of 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 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 multinational firms, we capture the large majority of R&D activity performed in the sample countries (e.g., Hall, 2012).[12]

R&D Tax Incentives

Countries' R&D tax treatment is modelled 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

$$T_{c,t} = \frac{1 - Z_{c,t} \cdot \tau_{c,t}}{1 - \tau_{c,t}} \tag{4}$$

where $\tau_{c,t}$ indicates the corporate tax rate of country c at time t and $Z_{c,t}$ measures the deductibility of R&D expenditures 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 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.

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

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 and Wilson, 2009) as a measure of the marginal cost of R&D inputs. An advantage of the B-index is that it 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 specifically study the tax effect on corporate R&D. To ensure that the estimated tax effect is not conditional on these factors, we also estimate regression models where we replace the B-index by the user cost of R&D capital as computed by Bloom et al. (2002) and Wilson (2009).

Our B-index information is drawn from Bösenberg and Egger (2017). Figure 2 depicts the average B-index in Europe and shows that it significantly declined during the sample frame. Figure 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. Figure A.1 in the appendix shows a graph analogous to Figure 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 largely unchanged during the sample period.

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

$$\bar{T}_{i,-c,t} = \sum_{j \neq c} W_{ij} T_{jt} \tag{5}$$

where j indicates group locations of MNE i other than c ($j \neq c$). T_{jt} stands for the host country B-index at another location j of the MNE group at time 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 larger the size of the other MNE group location that experiences the tax shock.[13] Note, moreover, that firm locations, where we only observe incidental R&D – defined as locations that

[13]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.

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 uniform weights. Furthermore, we show that the results are also robust to using the minimum B-index within the MNE group.

Control Variables and Descriptive Statistics

We augment the data by control variables for host country size (GDP), economic development (GDP per capita) and openness (FDI), all drawn from the World Development Indicator Database. The analysis, moreover, includes control variables for the quality of governance institutions as measured by the World Bank's Governance Indicators.[14] 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 multinational group locations in the dataset. Furthermore, we model economic and institutional changes in other MNE group locations by calculating the averages of these variables in the other locations of the same MNE group, analogously to Equation (5).

Descriptive statistics for the data are presented in Table 2. On average, the multinational group locations in the dataset successfully file for 2.3 quality-adjusted patents per sample year; the distribution exhibits a large standard deviation, however, and ranges from 0 to 548 quality-adjusted patents. The average host country B-index is 0.928, but we observe index variation between 0.56 (reflecting heavy subsidization of R&D investments) and 1.04 (reflecting disincentives for R&D). Descriptive statistics for the other variables are presented in Table 2.

5 Results

Baseline Findings

The baseline results are presented in Table 3. The specifications in Panel A estimate Equation (1) 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. Specification (A1) regresses the number of quality-adjusted

[14]Specifically, we account for the World Bank's political stability and rule of law indicators (that strongly correlate with other common governance indicators).

patent applications of MNE i in country c at time t on the host country's B-index at t, 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 ($\approx$ one standard deviation, cf. Table 2) is estimated to lower the number of quality-adjusted patent applications by around 11.11%.[15] Evaluated at the sample mean, this translates into an elasticity of quality-adjusted patent output with respect to the B-index of -1.03 which is in the range of prior findings (see, e.g., the literature review in Guceri and Liu, 2019).[16]

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, moreover, emerge when regressors enter with a one-year and two-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 Equation (2) of Section 3. Next 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 13% relative to the baseline models in Panel A (cf. specifications (A6) and (B6)). In line with the considerations in Section 3, the results hence suggest that the estimate for the host country tax effect is biased when $\bar{T}_{i,-c,t}$ is omitted, albeit in a quantitatively moderate way.

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

[15] Noting the exponential form of the Poisson model's conditional expectation function, the percentage change is computed as $\exp(\beta_1 \times 0.1) - 1 = \exp(-1.178 \times 0.1) - 1 = 0.1111$

[16] Evaluated at the sample mean (0.928, cf. Table 2), a drop in the B-index by 0.1 corresponds to a relative change by 10.78%. Hence, we obtain an elasticity of $\frac{-11.11}{10.78} = 1.03$. 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).

same MNE group. The coefficient estimate for the $\bar{T}_{i,-c,t}$-regressor is positive and quantitatively large in all specifications. 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 patents by 9.1%.[17] This suggests that multinational firms reallocate R&D investments across group locations when input-related 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 $T_{c,t}$ and $\bar{T}_{i,-c,t}$ 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).[18] We turn to simulations to assess this possibility and determine the adjustments in groups' aggregate global patent counts for major R&D tax reforms within the sample period (that is reforms that changed the B-index by more than 0.1). The median of affected MNEs' response to these reforms, expressed as semi-elasticity, ranges from -0.17 to 0.04, 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 multinational firms' underinvestment in R&D.

Note, moreover, 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

[17] I.e., $\exp(0.869 \times 0.1) - 1 = 0.0907$.

[18] 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. With semi-elasticity response rates as estimated in specification (B6) of Table 3, the number of patents is predicted to drop by 8.52 patents in the policy-changing jurisdiction and to increase by 0.91 patents in the foreign country. In consequence, the MNE's aggregate group-level response to the tax reform, in this example, is a reduction by 7.6 patents or 6.9% (=7.6/110).

incentives, trigger cross-country reallocations of R&D activity.

Table 4, moreover, augments the vector of control variables by a full set of host country-year fixed effects (cf. Equation (3) of Section 3). As described above, the estimation strategy now compares changes in the R&D investment of multinational 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. Specifically, for each affiliate location of an MNE group in the data, we determine the set of other locations in which the MNE group also has affiliates. These MNE group-specific sets of foreign locations are then randomly reassigned across all MNE groups present in the same country. The randomization leaves MNE group structures intact, is done without replacement and the same MNE group structure is assigned to all sample years. The average B-index and all average control variables in the other locations of the MNE group are calculated based on the newly assigned MNE group structures. The strategy hence corresponds to a random reassignment of the $\bar{T}_{i,-c,t}$ and $\bar{X}_{i,-c,t}$ regressors across group locations.[19]

We repeat that procedure 5000 times. The distribution of the resulting coefficient estimates for the $\bar{T}_{i,-c,t}$ regressor is depicted in Figure 4. The red line marks the coefficient estimate for $\bar{T}_{i,-c,t}$ 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 $\bar{T}_{i,-c,t}$ 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, 1935 for the seminal work) is that it comes without assumptions on the correlation structure of errors.

[19] The sampling within countries has the advantage that the other MNE group locations, which are randomly assigned to a given entity, are by definition located in foreign countries. It, moreover, 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., host and other MNE group locations – located in the same region – were affected by common factors that simultaneously altered R&D investment and tax policies in the region), we would still expect to see systematically positive coefficient estimates for the $\bar{T}_{i,-c,t}$ regressor after the randomization exercise.

Robustness Checks

We run a number of robustness checks. Figure 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 $s \in \{-2, -1, ..., 2\}$. 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 patents, emerge with a time lag only.

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.[20] Specifications (1) and (2) of Table 5 reestimate the baseline models (Column (B6) of Table 3 and 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 5 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.[21] The same holds true when the sample

[20]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 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).

[21]If group locations comprise firms with different 2-digit NACE codes, we assign the most frequent

is restricted to firms that operate in a homogenous set of highly-innovative manufacturing industries, as defined by EUROSTAT, cf. specifications (4) and (5) of Table 5. 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 $\bar{X}_{i,-c,t-1}$ 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 expenditures 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 Equation (5). In both cases, the data are drawn from the World Development Indicator Database. This modification yields results similar to the baseline findings. Table A.1 of the appendix 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.

Table 6 assesses 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 are calculated based on uniform weights. Specifications (3) and (4), moreover, assess whether the estimates are driven by changes in multinational 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 reran all the model specifications in a subsample of multinational 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 lowers the number of multinational 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

industry. In case of multiple industries with the same frequency, a NACE code is randomly drawn.

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 (5) and (6) of Table 6 we use the minimum foreign B-index instead of a weighted average to account for the possibility that MNEs first and foremost distort R&D towards the location with the most favorable tax system. If that held true, R&D allocation would respond particularly sensitive to changes in the minimum foreign B-index rate. Our results reject that notion and show quantitatively even slightly weaker response rates relative to the base analysis (although not statistically different from each other). As an alternative to the B-index, we use the user cost for R&D capital as a measure of tax incentives in columns (7) and (8) of Table 6. 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.[22] This reflects that it is variation in foreign and domestic tax incentives rather than their interaction with the general economic environment that drive the results.

A final 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 depreciation). We address this concern in several analyses reported in the appendix (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 equation 4) 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.

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, over recent years, introduced patent boxes, which grant special

[22] The sample mean for the user cost of capital is 0.298 while it is 0.928 for the B-index.

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., Chen et al., 2019a, Alstadsæter et al., 2018, Koethenbuerger et al., 2018, Schwab and Todtenhaupt, 2019, and Knoll and Riedel, 2019; see also Footnote 4). 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 $\bar{T}_{i,-c,t-1}$-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 $\bar{T}_{i,-c,t-1}$-regressor of 0.903, which is statistically significant at the 5% level).

Response Heterogeneity

Next, we test for response heterogeneity. Our theoretical considerations in Section 2 suggest that the substitutionary link between R&D investments at multinational 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).

Specifications (1) and (2) of Table 7 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 (1)). 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 (3) and (4) 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 Columns (3) and (4) 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 20 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 (– using alternative binning strategies, including binning algorithms (see Iacus et al., 2012), yields comparable results); Columns (3) and (4) depict estimates from regressions on the uncoarsened data with the derived matching weights, which resemble the results obtained from regressions based on unweighted data.[23] Table A.2, moreover, shows that similar findings emerge in models with country-year fixed effects.

Specifications (5) and (6) 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 patent counts shows that tax response rates are significantly larger, in absolute terms, for MNEs with above average R&D activity. This is confirmed in specifications, where observations are reweighted using CEM weights to account for imbalances in geographic distance between group locations and the average number of forward citations (cf. specifications (7) and (8)). 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, modelling the small firm incentives instead yields comparable results (not reported). Similar results, moreover, emerge in models with country-year fixed effects (cf. Table A.2).[24]

[23]Note that Coarsened Exact Matching does not only account for imbalance in means, but also for imbalances in higher moments and interactions. Furthermore note that the binning strategy implies that the variables are cut at the 5th, 10th, 15th etc. percentile.

[24]Note that the coefficient estimates for the average B-index are marginally statistically different from each other (p-value < 0.15) in the sample split between high and low distance firms and the sample split in MNEs with small and large R&D activities.

On top of that, we determine whether a complementary link between locations' R&D investments, while rejected in the full sample, may emerge for subsets of firms. In specifications (9) and (10), 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, furthermore, confirmed in models that use CEM to account for heterogeneity in intra-firm distance and MNEs' aggregate R&D activities (cf. specifications (11) and (12)). Again, comparable results are derived in models with country-year fixed effects (cf. Table A.2).[25]

Concluding, the results in this subsection suggests 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 data studies which *assume* R&D mobility (in response to tax changes) to decline spatially (see the literature review in the Introduction). The former findings might provide a rationale for conditioning R&D tax design on the size of firms' R&D activities.

6 Conclusion

In this paper, we empirically assess the impact of R&D tax incentives on the R&D investment of multinational firms. Using rich data on MNEs' unconsolidated 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 multinational groups in the policy-changing country. Our findings, however, also suggest that R&D investments at foreign group locations decline, pointing to intra-firm R&D relocation between existing 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 exter-

[25]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.

nalities on foreign jurisdictions. This renders decentralized R&D tax policy setting inefficient and points to 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 raises doubts that the instruments are effective in correcting MNEs' underinvestment in R&D.

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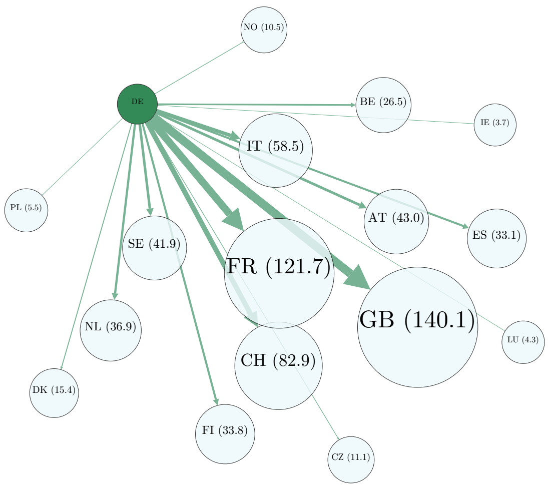
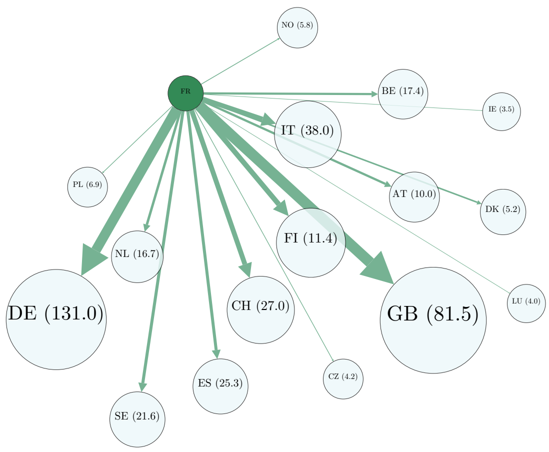
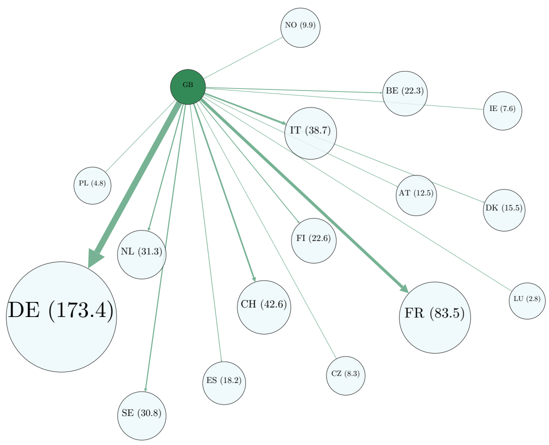
Figure 1: Ownership connections of firms in Germany, France and the United Kingdom to foreign countries



(a) Germany



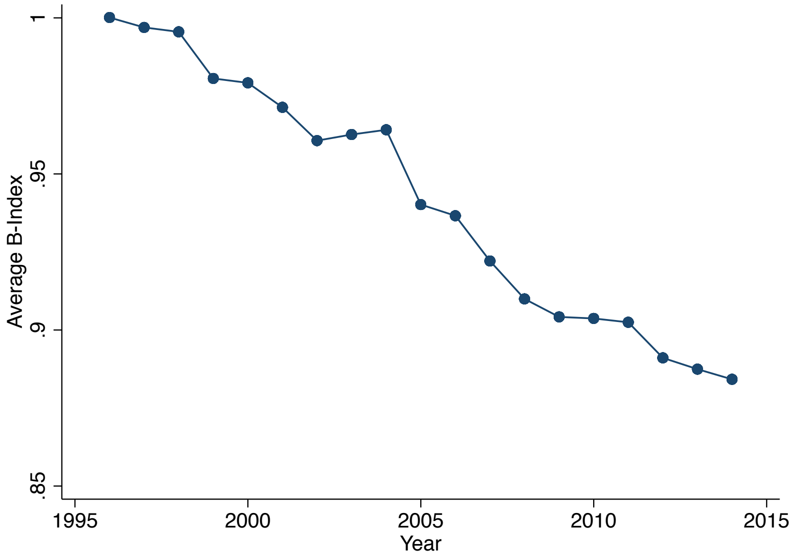
(b) France



(c) United Kingdom

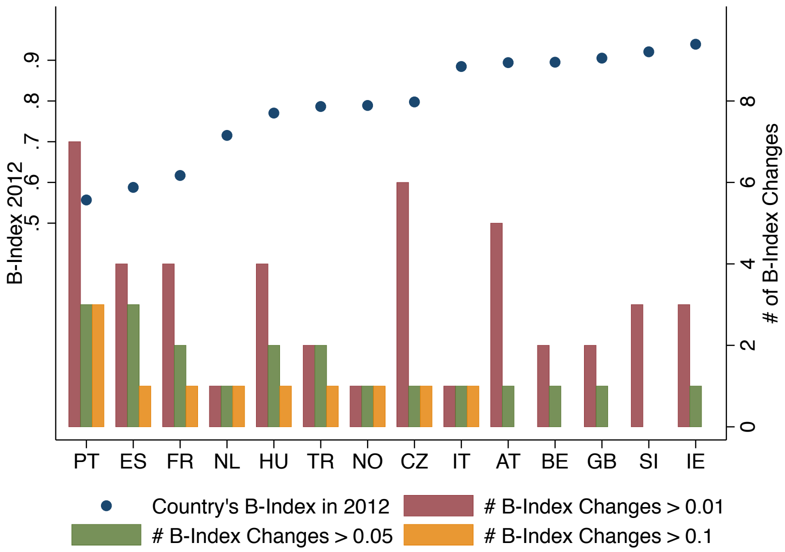
Notes: This figure displays ownership connections to patenting foreign affiliates of firms in the estimation sample that are located in Germany, France and the United Kingdom. For each of the three countries, we sum the number of links to other countries (i.e., the number of foreign affiliates in individual 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.

Figure 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.

Figure 3: B-index in 2012 (if < 0.95) and # of Changes of B-index in Sample Period

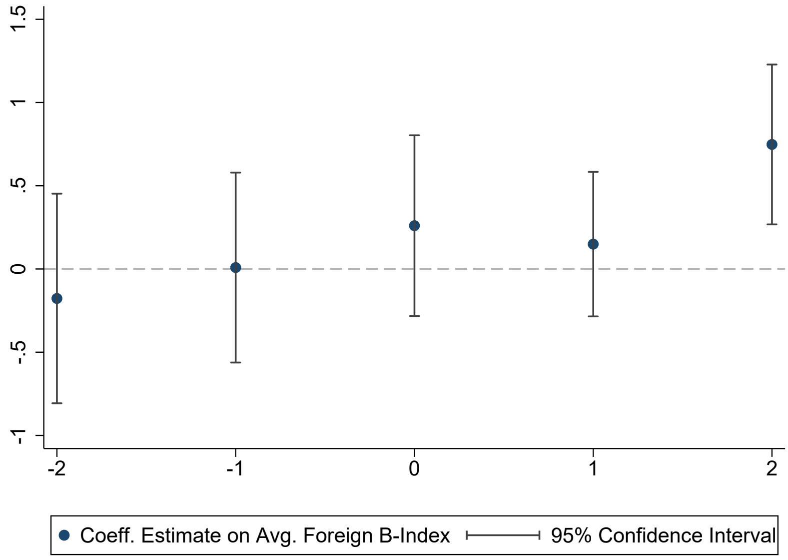


Notes: The graph depicts countries' B-index in 2012 as well as the number of B-index changes during the sample period (2000-2012) exceeding 0.01, 0.05 and 0.1 respectively, in absolute terms. The graph shows all sample countries with a B-index below 0.95 in 2012. The other sample countries, not depicted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

Figure 4: Placebo Test

Notes: The graph depicts the distribution of coefficient estimates for the 'Avg Foreign B-index'-regressor $\bar{T}_{i,-c,t}$ obtained in placebo tests where we randomly reassign foreign multinational group structures across multinational '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.

Figure 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 ("-1" and "-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 ("0", "1" and "2"). The model controls for a full set of host country-year fixed effects.

Table 1: Country Distribution

Country	Country Code	Firms	Patents
Austria	AT	116	1,745
Belgium	BE	77	1,989
Switzerland	CH	238	6,043
Czech Republic	CZ	59	616
Germany	DE	600	24,668
Denmark	DK	88	673
Spain	ES	154	2,026
Finland	FI	92	1,790
France	FR	350	15,534
United Kingdom	GB	447	8,486
Hungary	HU	12	22
Ireland	IE	25	168
Italy	IT	228	4,451
Luxembourg	LU	13	85
Netherlands	NL	145	1,296
Norway	NO	61	486
Poland	PL	50	187
Portugal	PT	13	45
Sweden	SE	136	5,780
Other		34	185
Sum		2,938	76,275

*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.

Table 2: Summary Statistics

	No. Obs.	Mean	Std.Dev.	Min	Max
Quality Weighted Patent Count	26,919	2.344	13.535	0.000	548.018
B-index (Lag)	26,919	0.928	0.125	0.559	1.042
Avg. Foreign B-index (Lag)	26,919	0.942	0.110	0.559	1.042
Min. Foreign B-index (Lag)	26,919	0.909	0.135	0.559	1.042
Adj. B-index (Lag)	26,919	0.644	0.105	0.363	0.907
Avg. Foreign adj. B-index (Lag)	26,919	0.645	0.091	0.363	0.907
User Cost of Capital (Lag)	26,895	0.298	0.043	0.131	0.452
Avg. Foreign User Cost of Capital (Lag)	26,880	0.303	0.038	0.131	0.452
Corporate Tax Rate (Lag)	26,919	0.306	0.062	0.100	0.516
Avg. Foreign Corporate Tax Rate (CTR, Lag)	26,919	0.315	0.059	0.100	0.516
$1/(1-CTR)$ (Lag)	26,919	1.453	0.139	1.111	2.066
Avg. Foreign $1/(1-CTR)$ (Lag)	26,919	1.473	0.139	1.111	2.066
Effective Average Tax Rate (EATR, Lag)	26,919	0.266	0.072	0.042	0.508
Avg. Foreign EATR (Lag)	26,919	0.279	0.071	0.042	0.508
Log GDP p.c. (Lag)	26,919	10.493	0.354	8.119	11.356
Avg. Foreign Log GDP p.c. (Lag)	26,919	10.526	0.249	8.119	11.381
Log FDI (Lag)	26,919	24.276	1.197	17.348	27.322
Avg. Foreign Log FDI (Lag)	26,919	24.401	1.062	17.348	27.322
Political Stability (Lag)	26,919	0.781	0.433	-1.032	1.668
Avg. Foreign Political Stability (Lag)	26,919	0.799	0.380	-1.032	1.668
Rule of Law (Lag)	26,919	1.515	0.416	-0.269	2.000
Avg. Foreign Rule of Law (Lag)	26,919	1.562	0.332	-0.269	2.000
Direct R&D support (Lag)	26,919	8.342	3.880	0.427	27.000
Avg. Foreign Direct R&D support (Lag)	26,919	8.658	3.384	0.427	27.000
Avg. Foreign Research Expenditure (as % of GDP, Lag)	26,393	2.176	0.575	0.366	3.726
Avg. Foreign Log Patent Applications of Residents (Lag)	26,734	9.370	1.159	2.773	10.854
Avg. Foreign Pre-tax Profitability (Lag)	24,048	0.182	0.058	0.021	0.524

Notes: The observational unit is the multinational group location per year. 'Quality Weighted Patent Count' is the quality-adjusted number of patents per year for the multinational group locations in the data. 'B-index (Lag)' is the first lag of the B-index ($T_{c;t-1}$) as defined in the main text) and 'Avg. Foreign B-index (Lag)' is the asset-weighted average B-index in other locations of the same MNE group ($\overline{T}_{i;-c;t-1}$ as defined in the main text). 'Adj. B-index (Lag)' denotes the lag of the B-index multiplied by the net of corporate tax rate ($1-CTR$). The 'User Cost of Capital (Lag)' are calculated based on the B-index, a depreciation rate of 30% and the long term interest rate (see details in the main text). 'Log GDP p.c. (lag)' depicts the first lag of the log of host country GDP per capital, 'Log FDI (Lag)' the first lag of the log of the host country's aggregate inward foreign direct investment. 'Political Stability (Lag)' and 'Rule of Law (Lag)' depict the first lag of the governance indicators for political stability and rule of law of the World Bank's Governance Data. 'Direct R&D support (Lag)' is the first 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, Lag)' is the average percentage of total research expenditures of GDP in host countries of other MNE group locations lagged by one year. 'Avg. Foreign Log Patent Applications of Residents (Lag)' depicts the average log of aggregate patent applications in other locations of the same MNE group. 'Avg. Foreign Pre-tax Profitability (Lag)' is the average Pre-tax profitability of national firms in other MNE group locations (see main text for details). 'Avg. Foreign B-index (Lag)', 'Avg. Foreign adj. B-index (Lag)', 'Avg. Foreign User Cost of Capital (Lag)', 'Avg. Foreign Corporate Tax Rate (CTR, Lag)', 'Avg. Log GDP p.c. (Lag)', 'Avg. Foreign FDI (Lag)', 'Avg. Foreign Political Stability (Lag)', 'Avg. Foreign Rule of Law (Lag)' and 'Avg. Foreign Direct R&D support (Lag)' 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 $t-1$ that are included in the baseline results of Table 3, specifications (B4)-(B6).

Table 3: Baseline Results

Panel A	**(A1)**	(A2)	**(A3)**	**(A4)**	**(A5)**	**(A6)**	**(A7)**	**(A8)**	**(A9)**
B-index	-1.178**	-1.083**	-1.174***	-1.074***	-0.963***	-1.027***	-1.181***	-1.040***	-1.073***
	(0.500)	(0.440)	(0.440)	(0.385)	(0.332)	(0.339)	(0.330)	(0.294)	(0.300)
Direct R&D Support			0.022***			0.018*			0.027**
			(0.008)			(0.010)			(0.011)
Number of Observations	31,087	31,087	31,087	26,919	26,919	26,919	23,499	23,499	23,499
Number of Group Locations	2,938	2,938	2,938	2,793	2,793	2,793	2,680	2,680	2,680
Regressors, Lag Structure	Current	Current	Current	Lag1	Lag1	Lag1	Lag2	Lag2	Lag2
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	-1.076**	-1.033**	-1.109**	-0.966***	-0.875***	-0.891***	-1.069***	-0.922***	-0.904***
	(0.500)	(0.419)	(0.431)	(0.372)	(0.316)	(0.336)	(0.308)	(0.273)	(0.288)
Avg. Foreign B-index	0.772	0.679	0.680	0.770*	0.817**	0.869**	0.788**	0.862***	0.887***
	(0.528)	(0.493)	(0.531)	(0.417)	(0.379)	(0.413)	(0.327)	(0.310)	(0.333)
Direct R&D Support			0.020**			0.014			0.021*
			(0.008)			(0.010)			(0.011)
Avg. Foreign Direct R&D Support			-0.006			-0.017			-0.023*
			(0.014)			(0.016)			(0.014)
Number of Observations	31,087	31,087	31,087	26,919	26,919	26,919	23,499	23,499	23,499
Number of Group Locations	2,938	2,938	2,938	2,793	2,793	2,793	2,680	2,680	2,680
Regressors, Lag Structure	Current	Current	Current	Lag1	Lag1	Lag1	Lag2	Lag2	Lag2
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 multinational 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 time fixed effects and group location fixed effects. Specifications (A2/B2), (A5/B5) and (A8/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 multinational group locations. Specifications (A3/B3), (A6/B6) and (A9/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/B1)-(A3/B3), all regressors, moreover, enter with their current values ('Current'), in specifications (A4/B4)-(A6/B6) with a one-year lag and in specifications (A7/B7)-(A9/B9) with a two-year lag. 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	0.754	0.672	0.719	0.776*	0.778*	0.851**	0.758**	0.779***	0.838***
	(0.565)	(0.513)	(0.542)	(0.457)	(0.400)	(0.432)	(0.335)	(0.302)	(0.321)
Avg. Foreign Direct R&D Support			-0.008			-0.016			-0.021
			(0.014)			(0.017)			(0.015)
Number of Observations	30,919	30,919	30,919	26,772	26,772	26,772	23,417	23,417	23,417
Number of Group Locations	2,937	2,937	2,937	2,791	2,791	2,791	2,679	2,679	2,679
Regressors, Lag Structure	Current	Current	Current	Lag1	Lag1	Lag1	Lag2	Lag2	Lag2
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: Further Robustness Checks I

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
B-index	-0.791**		-0.876***	-0.818**				
	(0.374)		(0.264)	(0.408)				
Avg. Foreign B-Index	1.029**	1.020**	0.747**	1.277***	1.327***	0.785**	0.745*	0.748*
	(0.453)	(0.470)	(0.301)	(0.458)	(0.507)	(0.371)	(0.391)	(0.392)
Number of Observations	17,530	17,367	26,745	13,052	12,944	32,354	26,067	25,833
Number of Group Locations	1,826	1,824	2,791	1,349	1,344	3,471	2,770	2,759
Regressors, Lag Structure	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1
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	All
							+ For. R&D	+ For. R&D
								+ For. Pat.
Sample	EU	EU	All	NACE	NACE	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 multinational group location at time t. The specifications include the full set of regressors outlined in Table 3 (see the notes to Table 3). Specification (3) and (4) additionally includes 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 multinational group locations and the average aggregate number of patent applications of residents of the host countries of the foreign multinational 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 6: Further Robustness Checks II

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
B-Index	-0.906***		-0.935***		-0.887**			
	(0.321)		(0.343)		(0.347)			
Avg. Foreign B-Index	1.009**	0.999**	0.908**	0.892**				
	(0.432)	(0.448)	(0.437)	(0.448)				
Min. Foreign B-Index					0.724*	0.728*		
					(0.388)	(0.390)		
User cost of capital (UCC)							-2.251**	
							(1.007)	
Avg. Foreign UCC							2.608**	2.463**
							(1.142)	(1.217)
Number of Observations	26,919	26,772	22,971	22,818	26,919	26,772	26,851	26,717
Number of Group Locations	2,793	2,791	2,299	2,298	2,793	2,791	2,789	2,787
Regressors, Lag Structure	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1
Coutry-Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Control Variables (Host+Foreign)	All	All	All	All	All	All	All	All
Weights	Uniform	Uniform	Asset	Asset	Asset	Asset	Asset	Asset
Sample	All	All	No Group Change	No Group Change	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 multinational group location at time 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) and based on asset-weights in specifications (3) and (4). Specifications (1) and (2) comprise the full sample, while specifications (3) and (4) 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 (5) and (6) 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 Equation (5). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

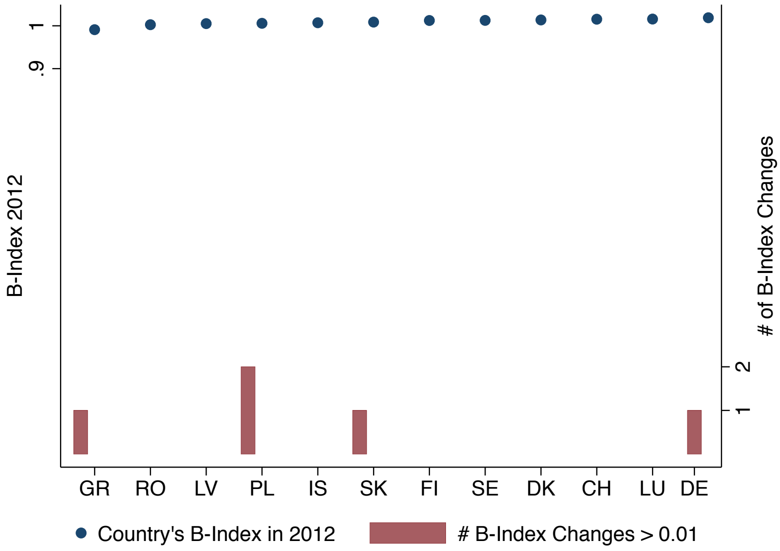
Table 7: Effect Heterogeneity

	Distance				Firm Size				Forward Citations			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
B-index	-0.877**	-0.249	-1.005**	-0.238	-0.538	-0.892**	-0.422	-0.974***	-1.187***	-0.792*	-0.693	-0.626
	(0.388)	(0.438)	(0.394)	(0.438)	(0.424)	(0.348)	(0.573)	(0.366)	(0.287)	(0.472)	(0.458)	(0.499)
Avg. Foreign B-index	1.087**	0.244	1.097**	0.315	-0.174	0.987**	0.074	1.043**	0.748	0.777*	1.403**	1.014**
	(0.457)	(0.550)	(0.472)	(0.549)	(0.400)	(0.452)	(0.609)	(0.451)	(0.563)	(0.466)	(0.654)	(0.455)
Number of Observations	13,003	13,082	12,973	13,018	12,668	13,417	10,145	11,956	12,834	13,251	11,210	11,571
Number of Group Locations	1,353	1,352	1,349	1,345	1,341	1,364	1,062	1,216	1,343	1,362	1,171	1,194
Control Variables	All	All	All	All	All	All	All	All	All	All	All	All
Sample Split, Med.	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
CEM Match	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
Reg. Lag	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1

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 at time t. The table shows models that reestimate the baseline regressions in Table 3, Column B6 in the subgroup of group locations with a below and above median geographic distance to other MNE group locations (specifications (1)-(4)); 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 (5)-(8)); 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 (9)-(12)). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Appendix

Figure A.1: B-index in 2012 (if > 0.95) and # of B-index-Changes in Sample Period



Notes: The graph is an extension to Figure 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.

Table A.1: Controlling for Firm Productivity at Foreign Group Locations

	(1)	(2)
B-index	-0.852***	
	(0.315)	
Avg. Foreign B-index	1.017**	1.085**
	(0.423)	(0.437)
Number of Observations	19,065	18,987
Number of Group Locations	2,167	2,166
Regressors, Lag Structure	Lag1	Lag1
Country-Year FE	No	Yes
Control Variables (Host+Foreign)	All	All
	+ Profitability	+ Profitability
	Foreign Country	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 multinational 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 Equation (5). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.2: Effect Heterogeneity, With Country Fixed Effects

	Distance				Firm Size				Forward Citations			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Avg. Foreign B-index	1.148**	-0.001	1.121**	0.075	-0.421	0.947**	-0.421	1.031**	0.480	0.816*	0.656	1.155**
	(0.484)	(0.547)	(0.457)	(0.535)	(0.408)	(0.474)	(0.629)	(0.471)	(0.407)	(0.474)	(0.462)	(0.503)
Number of Observations	12,921	12,950	12,891	12,886	12,554	13,322	10,025	11,857	12,760	13,143	11,137	11,483
Number of Group Locations	1,352	1,350	1,348	1,343	1,339	1,364	1,059	1,214	1,343	1,358	1,169	1,191
Control Variables	All	All	All	All	All	All	All	All	All	All	All	All
Sample Split, Med.	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
CEM Match	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
Reg. Lag	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1

Notes: The specifications correspond to the models estimated in Table 7, but additionally include a full set of country-year fixed effects. 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	-0.974***		-0.915**			
	(0.299)		(0.383)			
Avg. Foreign B-Index	0.902**	0.882*	0.764*	0.701*		
	(0.452)	(0.458)	(0.407)	(0.418)		
B-Index adj.					-1.412***	
					(0.437)	
Avg. Foreign B-Index adj.					1.187*	1.184*
					(0.642)	(0.656)
Corporate Tax Rate (CTR)	-0.447					
	(0.825)					
Avg. Foreign CTR	0.147	0.325				
	(1.020)	(0.951)				
Effective Average Tax Rate (EATR)			-0.173			
			(0.847)			
Avg. Foreign EATR			0.537	0.661		
			(1.067)	(0.985)		
$1/(1-CTR)$					-0.727**	
					(0.341)	
Avg. Foreign $1/(1-CTR)$					0.338	0.415
					(0.511)	(0.480)
Number of Observations	26919	26772	26919	26772	26919	26772
Number of Group Locations	2793	2791	2793	2791	2793	2791
Regressors, Lag Structure	Lag1	Lag1	Lag1	Lag1	Lag1	Lag1
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 multinational group location at time 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 Equation (5). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.