# 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 the unconsolidated R&D activity of European MNEs, we show that R&D tax incentives serve as beggar-thy-neighbor instruments: More generous tax incentives at one group location increase MNEs' R&D investments in the policy-changing country, while lowering R&D investments at foreign group locations. Globally, firms hardly respond to changed R&D tax incentives.

**JEL-Codes:** H2, H7

**Keywords:** R&D tax incentives, R&D investment, multinational firms

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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 US currently spends almost 11 billion US Dollars on R&D tax support, France and the UK around 6 billion Euro and 3 billion British Pound 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 R&D tax incentives, next to impacting on R&D investment in the policy-changing country, also affect multinational R&D activity in *foreign* jurisdictions. Theoretical considerations suggest that 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 foreign group entities. In this scenario, global investment responses fall short from investment responses in the policy-changing country. 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 (see National Science Board 2014), related cross-border tax effects might be significant drivers of aggregate R&D investment patterns.[1]

To empirically determine the sign and size of the sketched cross-border effect, we make use of rich panel data on MNEs in Europe. Our empirical analysis spans the years 2000 to 2012 and proxies innovative activity of MNEs by the number of granted patents

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

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 host countries' 'B-index' (McFetridge and Warda 1983) that captures the tax costs related to corporate R&D investments.

Methodologically, we estimate fixed effects poisson models that express the number of quality-adjusted patents per multinational group location and year as a function of the host country's B-index and the average B-index at foreign group locations. 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 semi-elasticity is $-0.9$ (and hence in the range of prior estimates; see, e.g., the literature review in Guceri and Liu (2019)). 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.

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 foreign group entities. 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.[3]

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 multinational affiliates in the same country that do and do not experience tax cost shocks at foreign group locations (or experience shocks of different size). The estimate is, moreover, robust to augmenting the model by

[2] Patent counts are a widely used proxy for R&D investment in the literature (see Section 4).

[3] To be precise, the estimates reject that *simultaneous equi-sized* reductions in host country and foreign country R&D tax costs alter MNEs' R&D activity. The estimates may, nevertheless, be consistent with positive or negative group-level R&D responses if empirical variation - as in our setting - stems from isolated tax changes and tax shocks may systematically hit group locations of above or below average size respectively. We turn to simulations to assess this possibility and find small negative group-level R&D tax cost elasticities for the median firm.

subnational-region-year fixed effects and industry-year fixed effects respectively and to controlling for economic and technological changes at the host locations of foreign group affiliates. Placebo tests where we rerun our baseline model but randomly reassign foreign 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 relocation costs rise with distance. Our findings hence support prior macro data studies which *assume* that cross-border tax effects decline in space. 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 impact of *host country* R&D tax cost on R&D investments. This informs policymakers how adjustments in R&D tax incentives impact on countries' R&D activity in the absence of tax retaliations of 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. 2017, Guceri and Liu 2019, Chen et al. 2019) 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 on foreign jurisdictions. If more generous R&D tax incentives - as suggested by our findings - do attract mobile R&D from abroad rather than triggering new research and development activities, neighboring countries lose welfare. The latter may 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 set inefficiently high. 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

[4]This is acknowledged as a shortcoming in prior work, see e.g. Guceri and Liu (2019).

sector R&D spending in eight OECD countries for 1979 to 1997, Wilson (2009) data on company-performed R&D spending in US states between 1981 and 2004 and Akcigit et al. (2018) historic data on patent filings in US counties and states during the 20th century.

The results of 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, while Akcigit et al. (2018) report a positive but more moderate tax impact. For corporate patents, the latter study even fails to find any indication of cross-border tax effects. These differences may stem from different data and modeling choices of the authors. 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 multinational entities located in the *same country* that do and do not experience R&D tax cost shocks at foreign group locations. This ensures that the estimates are unconfounded by country-level shocks.

On top of that, there are four further advantages of our study relative to prior work. First, using micro data allows us to test for effect heterogeneity across firms. Second, we avoid aggregation bias. That is, contrary to macro data studies, we can obtain an unbiased estimate of the average corporate response to R&D tax incentives.[5] Third, our empirical analysis relies on more recent data than prior work. Given that firm mobility and R&D tax policies changed significantly over recent decades, our results may be better suited to guide R&D tax policies today than prior findings. Last but not least, our study complements prior evidence by assessing R&D tax policy at the national rather than the subnational level. Wilson (2009) acknowledges that insights from his US state-level analysis may not carry over to federal-level R&D tax policy settings but speculates that "large foreign and U.S. multinationals, which are responsible for

[5]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).

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' domestic and foreign R&D investments: 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 a substitutionary relationship: MNEs respond to expanded R&D tax incentives by shifting R&D investments from foreign 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.[6] The global R&D tax response falls short from 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

[6]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).

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 in turn. New R&D investments at one group location may, for example, (be expected to) 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 2019). Expanded tax incentives then raise R&D investments in the policy-changing and in foreign countries. A complementary link between domestic and foreign investment might, moreover, emerge if firms are credit constrained and need to rely on internal resources to finance R&D investments (see e.g. Hall et al. (2016)).[7] 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 foreign group locations. 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, it is theoretically unclear whether R&D tax incentives raise or lower foreign R&D activity. 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 under-

[7]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 Hall et al. (2016).

standing the global welfare consequences of R&D tax incentives. In the following, we will present micro data estimates for this effect.

# 3 Estimation Methodology

Our empirical analysis models the R&D investment $y_{i,c,t}$ of MNE $i$ in country $c$ at time $t$, where an MNE's activities in a given country will be referred to as a multinational '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 poisson 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 $\delta_t$ denote full sets of MNE-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 investments and patentable results. 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 direct and accurate modeling based on observed multinational group structures. This follows the theoretical notion derived 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 foreign group 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 $\beta_1$ and an ambiguous sign for $\beta_2$: 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 $\beta_2$ is at the heart of our paper, omitting $\bar{T}_{i,-c,t-1}$ may bias the $\beta_1$-estimate, with the sign of this bias being a priori unclear.[8]

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 relax the common trend assumption by augmenting 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 $\beta_2$ 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.

[8] In the presence of cross-border tax cost effects, control units in foreign countries are affected by the treatment: The $\beta_1$-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, $\beta_2$ corresponds to the absolute bias in the $\beta_1$-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 $\beta_1$-estimate becomes smaller than $\beta_2$. On top of that, the omission of $\bar{T}_{i,-c,t-1}$ biases the $\beta_1$-estimate if R&D tax policies are correlated across countries and taxes, simultaneously, exert cross-border R&D effects. The coefficient estimate for $\beta_1$ 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).

# 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*

Corporate R&D activities are 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. Using patent counts as a proxy for corporate R&D activity follows a large literature (Aghion et al. 2013, Seru 2014, Bena and Li 2014), which documents that the number of patents is highly correlated with other measures of corporate R&D activity (Hagedoorn and Cloodt 2003, Artz et al. 2010). Patent data, moreover, allows identifying MNEs' *unconsolidated* R&D activities in different countries. This is largely infeasible based on other R&D measures like R&D spending or the number of R&D workers. The latter information is commonly only available from consolidated company accounts or can 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, accounting for granted patents that protect technologies 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).[9] 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

[9] 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. 2018). We disregard these patents in our 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).

classes on the patent (see, e.g., Hall et al. 2007). A composite technological quality index is derived from factor analysis (e.g. Lanjouw and Schankerman 2004).

*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 ownership 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 a multinational business and all of its affiliated firms enter our estimation sample. Also note that 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.

As the identifying variation is at the country-level, 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.[10] The sample covers the years 2000 to 2012. Years after 2012 are disregarded as our 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.

The sample is, moreover, restricted to multinational groups with positive patenting activity during our sample frame, i.e. group locations that successfully filed for at least one patent in our sample period. We, moreover, assign zeros in years without patent applications. In total, the data comprises information on 1151 MNEs and 2900 multinational group locations hosted by 26 European countries. Table 1 presents the country distribution of group locations, which broadly matches with the distribution of aggregate R&D investments and firm counts in our sample economies. Note, moreover, that by focusing on multinational firms, we capture the large majority of R&D activity

[10]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.

performed in our sample countries (e.g. Hall 2011).[11]

*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. Our B-Index information is drawn from Bösenberg and Egger (2017). Figure 1 depicts the average B-Index in Europe and shows that it significantly declined during our sample frame.

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

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

where $j$ indicates group locations of MNE $i$ that are located in countries other than $c$ ($j \neq c$). $T_{jt}$ stands for the host country B-index at foreign group location $j$ at time $t$ and $W_{ijt}$ 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

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

larger the larger the size of the foreign group location that experiences the tax shock.[12] In robustness checks, we show results where $\bar{T}_{i,-c,t}$ is calculated based on uniform weights. Note, moreover, that firm locations, where we only observe incidental R&D - defined as locations that file for less than 10% of all of the MNE's granted patents within the sample frame - are disregarded in the calculation of $\bar{T}_{i,-c,t}$.

*Control Variables and Descriptive Statistics*

We, on top of that, 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.[13] On top of that, we account for data on direct government support for business R&D, that is R&D support not granted through the tax system. The information is drawn from the OECD's R&D tax database. These variables are included as host country controls for the multinational group locations in our dataset. Furthermore, we model economic and institutional changes at foreign group locations by calculating the averages of these variables at foreign group locations within the same multinational firm, analogously to Equation (5).

Descriptive statistics for the data are presented in Table 2. On average, the multinational group locations in our 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 550 quality-adjusted patents. The average host country B-index is 0.925, but we observe index variation between 0.5 (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. Cluster robust standard errors that allow

[12]Precisely, $W_{ijt}$ is defined as the average of total assets at foreign 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 foreign group locations to avoid losing these locations in the calculation of the size-weighted average.

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

for deviations from the Poisson distribution (see e.g. Wooldridge 2010) are depicted in brackets. 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. Specification (A1) regresses the number of quality-adjusted 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 multinational 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 12% (which translates into a tax elasticity of 1.1 and is in the range of prior findings (see e.g. the literature review in Guceri and Liu 2019)).[14]

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 other country characteristics at foreign 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 higher R&D tax costs at foreign locations within the same MNE positively impact on group locations' R&D investments. 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 at foreign group locations raises the number of quality-adjusted patents by 8.6%. This suggests

[14]Note that, 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 10.77%.

that multinational firms reallocate R&D investments across group locations when tax incentives change and that R&D activity at different locations acts 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 poisson 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).[15] 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 our 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 (at foreign group locations of the same MNE). This suggests that direct R&D subsidies, analogously to R&D tax 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

[15] 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 to host country and foreign B-index changes of -0.844 and +0.861 (as estimated in Specification (B6) of Table 3), the number of patents is predicted to drop by 8.44 patents in the policy-changing jurisdiction and to increase by 0.861 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).

group locations in the same country that belong to MNEs that are and are not subject to R&D tax cost shocks at foreign 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 our baseline findings in Table 3.[16]

*Placebo Test*

Our setting, moreover, lends itself for a placebo test, where we reestimate our baseline model after randomly reassigning group structures across firms. Specifically, for each multinational group location in our data, we determine the set of foreign group locations that belong to the same MNE. These sets of foreign group locations are randomly reassigned across MNE locations in the same country. The randomization leaves foreign group structures intact, is done without replacement and the same foreign group structure is assigned to all sample years. The average foreign B-index and all average foreign control variables are calculated based on the newly assigned foreign 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.[17]

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 2. The red line marks our coefficient estimate for $\bar{T}_{i,-c,t}$ in Specification (B6) of Table 3. While the distribution is closely centered around zero, our 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. Note that 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.

[16] To avoid multicollinearity and non-convergence of the poisson model, the specifications in Table 4 are estimated based on the subset of multinational group locations that are hosted by the 15 sample countries with more than 150 group location-year observations in our data. In the Appendix, we present estimates where we show that similar results emerge in - less demanding - specifications, where we absorb 5-year-country fixed effects but estimate the model based on the full sample (see Table A1 in the Appendix).

[17] The sampling within countries has the advantage that the foreign group locations, which are randomly assigned to a given entity, are by definition located in foreign countries. It, moreover, allows us to test whether our results are driven by common shocks to supra-national regions. Specifically, if our results were driven by such shocks (i.e. host and foreign 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.

*Further Robustness Checks*

We run a number of further robustness checks. Specifications (1) and (2) of Table 5 reestimate our 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, yielding qualitatively and quantitatively similar results as the baseline analysis. Specification (3) of Table 5, furthermore, 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.[18] The same holds true when the sample 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), moreover, 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 our baseline estimates.[19]

Moreover, while our baseline models control for economic and institutional changes at foreign 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 foreign 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 our baseline findings. Table A2 of the online appendix furthermore shows that accounting for firm productivity shocks in the host countries of foreign group entities does not alter our baseline results.

Table 6 assesses the sensitivity of our 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 other host country controls at foreign 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 our sample period. As explained in Section 3, our baseline analysis accounts

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

[19]To achieve model convergence, Specifications (1) and (4) disregard multinational group locations in NACE-industries and NUTS 2-regions with less than 150 observations (i.e. 'group location'-years) per industry/region class respectively, which triggers a moderate reduction in sample size.

for M&As and firm foundations when defining group structures at a given point in time. This adds precision to our 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. On the downside, it, however, 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 foreign group structure. Acknowledging potential endogeneity concerns related to these choices, we reran all our model specifications in a subsample of multinational group locations for which the set of foreign group entities (used for the calculation of $\bar{T}_{i,-c,t}$) remains unchanged within our 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 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.

*Response Heterogeneity*

Last but not least, 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).

We begin with testing for response heterogeneity in the distance dimension. Specifications (1) and (2) of Table 7 rerun the baseline model in subsamples of group locations with above and below median distance to foreign R&D locations. The estimated tax effects are economically and statistically more significant in the subsample of entities that are located in geographic proximity to foreign group affiliates. 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.[20] Table A3, 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. 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 our sample countries, the United Kingdom and the Netherlands, differentiated their R&D tax incentive schemes between large and small (profitable) firms during our 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 A3).[21]

[20]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 our binning strategy implies that the variables are cut at the 5th, 10th, 15th etc. percentile.

[21]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 our 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 A3).[22]

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 in space (see our 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 R&D tax incentives are associated with higher R&D investments of multinational groups in the policy-changing country. Our findings, however, also suggest that MNEs significantly lower their R&D activity at foreign multinational group locations when tax incentives are expanded. 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, R&D tax incentives are found to serve as beggar-thy-neighbor instruments, which may exert negative externalities on foreign jurisdictions. This renders decentralized R&D tax policy setting inefficient and points to welfare gains from international tax coordination. Second, our findings suggest that

[22] Bilir and Morales (2019) show that innovations at one multinational group location increase the *productivity* of foreign group entities. 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.

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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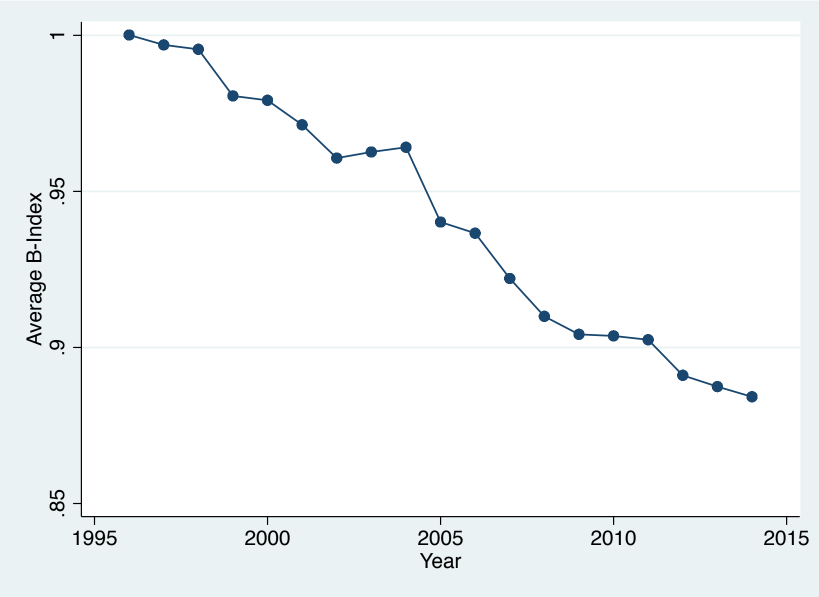
# 7 Figures and Tables

Figure 1: Average of B-Index in our Sample Countries




*Notes:* The graph plots the unweighted average of the B-index in our sample countries against time.

Figure 2: 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.

Table 1: Country Distribution

| Country | | |
|---|---|---|
| Austria | AT | 109 |
| Belgium | BE | 72 |
| Switzerland | CH | 228 |
| Czech Republic | CZ | 57 |
| Germany | DE | 583 |
| Denmark | DK | 78 |
| Spain | ES | 140 |
| Finland | FI | 85 |
| France | FR | 343 |
| United Kingdom | GB | 425 |
| Hungary | HU | 11 |
| Ireland | IE | 17 |
| Italy | IT | 212 |
| Luxembourg | LU | 11 |
| Netherlands | NL | 136 |
| Norway | NO | 60 |
| Poland | PL | 48 |
| Portugal | PT | 13 |
| Sweden | SE | 136 |
| Other | | 29 |
| Sum | | 2793 |

*N*otes:
This table presents the distribution of multinational '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 |
| Log GDP (Lag) | 26,919 | 27.721 | 1.012 | 23.157 | 28.780 |
| Log Avg. Foreign GDP (Lag) | 26,919 | 27.890 | 0.894 | 24.140 | 28.780 |
| Log GDP p.c. (Lag) | 26,919 | 10.493 | 0.354 | 8.119 | 11.356 |
| Avg. 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. Log Foreign 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 | 0.0834 | 0.039 | 0.004 | 0.27 |
| Avg. Foreign Direct R&D support (Lag) | 26,919 | 0.087 | 0.034 | 0.004 | 0.27 |

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 our 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 at foreign group locations within the same MNE ($\bar{T}_{i,-c,t-1}$ as defined in the main text). 'Log GDP (lag)' depicts the first lag of the log of host country GDP, 'Log GDP p.c. (lag)' the first lag of the log of GDP per capita, '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 B-Index (Lag)', 'Avg. Log Foreign GDP (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 $t-1$.

Table 3: Baseline Results

| Panel A | (A1) | (A2) | (A3) | (A4) | (A5) | (A6) | (A7) | (A8) | (A9) |
|---|---|---|---|---|---|---|---|---|---|
| **B-Index** | -1.178** | -1.080** | -1.188** | -1.074** | -0.901*** | -0.966*** | -1.181*** | -0.976*** | -1.050*** |
| | (0.547) | (0.487) | (0.488) | (0.418) | (0.348) | (0.352) | (0.336) | (0.253) | (0.256) |
| **Direct R&D support** | | | 0.023** | | | 0.014 | | | 0.025** |
| | | | (0.010) | | | (0.011) | | | (0.011) |
| Number of Observations | 31087 | 31087 | 31087 | 26919 | 26919 | 26919 | 23499 | 23499 | 23499 |
| Number of Group Locations | 2938 | 2938 | 2938 | 2793 | 2793 | 2793 | 2680 | 2680 | 2680 |
| **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** | -1.034** | -1.123** | -0.966** | -0.824** | -0.844** | -1.069*** | -0.867*** | -0.893*** |
| | (0.529) | (0.449) | (0.451) | (0.400) | (0.325) | (0.331) | (0.320) | (0.245) | (0.248) |
| **Avg. Foreign B-Index** | 0.772 | 0.688 | 0.705 | 0.770* | 0.795** | 0.861** | 0.788** | 0.850*** | 0.898*** |
| | (0.495) | (0.460) | (0.499) | (0.407) | (0.396) | (0.433) | (0.321) | (0.326) | (0.343) |
| **Direct R&D Support** | | | 0.021** | | | 0.010 | | | 0.020* |
| | | | (0.010) | | | (0.011) | | | (0.010) |
| **Avg. Foreign Direct R&D Support** | | | -0.007 | | | -0.016 | | | -0.023* |
| | | | (0.014) | | | (0.017) | | | (0.014) |
| Number of Observations | 31087 | 31087 | 31087 | 26919 | 26919 | 26919 | 23499 | 23499 | 23499 |
| Number of Group Locations | 2938 | 2938 | 2938 | 2793 | 2793 | 2793 | 2680 | 2680 | 2680 |
| **Regressors, Lag Structure** | **Current** | **Current** | **Current** | **Lag1** | **Lag1** | **Lag1** | **Lag2** | **Lag2** | **Lag2** |
| **Control Variables (Host+Foreign)** | **No** | **Base** | **All** | **No** | **Base** | **All** | **No** | **Base** | **All** |

Notes: * p<.1, ** p<.05, *** p<.01. 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 at foreign 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 at foreign 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.

Table 4: Country-Year Fixed Effects

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| **Avg. Foreign B-Index** | 0.766 | 0.690 | 0.738 | 0.789* | 0.802** | 0.878** | 0.764** | 0.795*** | 0.857*** |
| | (0.520) | (0.474) | (0.504) | (0.436) | (0.391) | (0.420) | (0.326) | (0.295) | (0.310) |
| **Avg. Foreign Direct R&D Support** | | | -0.008 | | | -0.017 | | | -0.022 |
| | | | (0.0130) | | | (0.016) | | | (0.014) |
| Number of Observations | 30101 | 30101 | 30101 | 26178 | 26178 | 26178 | 22770 | 22770 | 22770 |
| Number of Group Locations | 2841 | 2841 | 2841 | 2712 | 2712 | 2712 | 2593 | 2593 | 2593 |
| **Regressors, Lag Structure** | **Current** | **Current** | **Current** | **Lag1** | **Lag1** | **Lag1** | **Lag2** | **Lag2** | **Lag2** |
| **Control Variables (Foreign)** | **No** | **Base** | **All** | **No** | **Base** | **All** | **No** | **Base** | **All** |
| **Ctry-Year FE** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

Notes: * p<.1, ** p<.05, *** p<.01. The specifications correspond to the models estimated in Panel B of Table 3, but additionally include a full set of country-year fixed effects.

Table 5: Further Robustness Checks I

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| **B-Index** | -0.755** | | - 0.7214*** | -0.7110*** | | | | |
| | (0.372) | | (0.2177) | (0.2420) | | | | |
| **Avg. Foreign B-Index** | 1.043** | 1.046** | 0.7353** | 1.2024*** | 1.3309** | 0.863** | 0.7618** | 0.7664** |
| | (0.474) | (0.455) | (0.2938) | (0.3137) | (0.5521) | (0.402) | (0.3854) | (0.3868) |
| Number of Observations | 17,530 | 17,024 | 25,565 | 12,771 | 12,834 | 24,949 | 25,484 | 25,250 |
| Number of Group Locations | 1,826 | 1,771 | 2,691 | 1,340 | 1,325 | 2,608 | 2,691 | 2,680 |
| **Regressors, Lag Structure** . | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** |
| **Industry-Year FE** | **No** | **No** | **Yes** | **No** | **No** | **No** | **No** | **No** |
| **Ctry-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: * p<.1, ** p<.05, *** p<.01. 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) 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 (5) and (6) 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. Specification (6) includes NUTS regions with more than 150 observations to achieve model convergence.

Table 6: Further Robustness Checks II

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **B-Index** | -0.866*** | | -0.8453** | |
| | (0.323) | | (0.3335) | |
| **Avg. Foreign B-Index** | 0.986** | 1.022** | 0.9060** | 0.9260** |
| | (0.459) | (0.439) | (0.4480) | (0.4318) |
| Number of Observations | 26,919 | 26,178 | 23,093 | 22,443 |
| Number of Group Locations | 2,793 | 2,712 | 2,353 | 2,284 |
| **Regressors, Lag Structure** | **Lag1** | **Lag1** | **Lag1** | **Lag1** |
| **Ctry-Year FE** | **No** | **Yes** | **No** | **Yes** |
| **Control Variables (Host+Foreign)** | **All** | **All** | **All** | **All** |
| **Weights** | Uniform | Uniform | Asset | Asset |
| **Sample** | **All** | **All** | **No Group Change** | **No Group Change** |

Notes: * p<.1, ** p<.05, *** p<.01. 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 foreign group location control variables 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 group locations that did not experience a change in the set of foreign group locations (used for the calculation of $\bar{T}_{i,-c,t}$ and $\bar{X}_{i,-c,t}$) during our sample period.

Table 7: Effect Heterogeneity

| | **Distance** | | | | **Firm Size** | | | | **Forward Citations** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** | **(9)** | **(10)** | **(11)** | **(12)** |
| **B-Index** | -0.8353** | -0.3027 | -0.9887*** | -0.2921 | -0.5044 | -0.8413** | -0.3790 | -0.9401*** | -1.0886*** | -0.8781* | -0.6268*** | -0.7064 |
| | (0.3590) | (0.4595) | (0.3216) | (0.4609) | (0.4038) | (0.3442) | (0.4712) | (0.3503) | (0.2994) | (0.4982) | (0.1630) | (0.5155) |
| **Avg. For. B-Index** | 1.0760** | 0.2722 | 1.0996*** | 0.3435 | -0.1919 | 0.9869** | 0.0476 | 1.0472** | 0.6875 | 0.7539 | 1.1058*** | 0.9478* |
| | (0.5236) | (0.5209) | (0.4021) | (0.5200) | (0.4041) | (0.4724) | (0.4531) | (0.4928) | (0.4969) | (0.4780) | (0.3361) | (0.5006) |
| 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 | 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. Lags** | **Lag 1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** |

Notes: * p<.1, ** p<.05, *** p<.01. 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 foreign 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 our 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)).

# Online Appendix

Table A1: Country-5 Year Fixed Effects (Full Sample)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| **Avg. Foreign B-Index** | 0.693* | 0.726** | 0.771** | 0.714** | 0.740** | 0.813*** |
| | (0.392) | (0.364) | (0.390) | (0.312) | (0.289) | (0.313) |
| Number of Observations | 26919 | 26919 | 26919 | 23499 | 23499 | 23499 |
| Number of Groups | 2793 | 2793 | 2793 | 2680 | 2680 | 2680 |
| **Regressors, Lag Structure** | **Lag1** | **Lag1** | **Lag1** | **Lag2** | **Lag2** | **Lag2** |
| **Control Variables** | **No** | **Base** | **All** | **No** | **Base** | **All** |
| **Ctry-Year FE** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

Notes: * p<.1, ** p<.05, *** p<.01. Dependent variable: the quality-adjusted patent counts of a multinational group location at time $t$. The specifications reestimate the models in Columns (B4)-(B9) of Table 3 but, instead of the country-year fixed effect, include a full set of country-5year-fixed effects. The models are, moreover, estimated on the full sample of observations (see Footnote 16).

Table A2: Controlling for Firm Productivity at Foreign Group Locations

| | (1) | (2) |
|---|---|---|
| **B-Index** | -0.8060** | |
| | (0.3270) | |
| **Avg. Foreign B-Index** | 1.0039** | 1.1041** |
| | (0.4462) | (0.4363) |
| Number of Observations | 18,861 | 18,313 |
| Number of Group Locations | 2,160 | 2,093 |
| **Regressors, Lag Structure .** | **Lag1** | **Lag1** |
| **Ctry-Year FE** | **No** | **Yes** |
| **Control Variables (Host+Foreign)** | **All** | **All** |
| | +Profitability | +Profitability |
| | Foreign Ctry | Foreign Ctry |

Notes: * p<.1, ** p<.05, *** p<.01. 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 our 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 foreign group locations that belong to the same MNE as the group location under consideration, the asset-weighted average is calculated following Equation (5).

Table A3: Effect Heterogeneity, With Country Fixed Effects

| | **Distance** | | | | **Firm Size** | | | | **Forward Citations** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** | **(9)** | **(10)** | **(11)** | **(12)** |
| **Avg. For. B-Index** | 1.1693** | 0.0372 | 1.1395*** | 0.0955 | -0.3616 | 0.9792** | -0.3678 | 1.0600** | 0.5040 | 0.7760* | 0.6557** | 1.0817** |
| | (0.5223) | (0.5353) | (0.3904) | (0.5289) | (0.4160) | (0.4618) | (0.4717) | (0.4792) | (0.4453) | (0.4699) | (0.3075) | (0.5256) |
| Observations | 12,803 | 12,660 | 12,773 | 12,604 | 12,379 | 13,084 | 9,923 | 11,655 | 12,502 | 12,961 | 10,945 | 11,318 |
| Number of group | 1,330 | 1,307 | 1,326 | 1,301 | 1,309 | 1,328 | 1,038 | 1,184 | 1,307 | 1,330 | 1,142 | 1,166 |
| **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** |
| **Ctry Year FE** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| **Reg. Lags** | **Lag 1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** | **Lag1** |

Notes: * p<.1, ** p<.05, *** p<.01. The specifications correspond to the models estimated in Table 7, but additionally include a full set of country-year fixed effects.