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Spillover from the Haven: Cross-Border Externalities of Patent Box Regimes Within Multinational Firms

Paper

Thinking Outside the Box:
The Cross-border Effect of Tax Cuts on R&D*

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Abstract

We analyze the cross-border effect of tax cuts on R&D activity in the context of profit shifting. A tax cut in one location of a multinational enterprise reduces the user cost of capital for the whole group if profit shifting is possible and exerts a positive cross-border effect on R&D output. Using micro-level data, we find an increase of patent output of 15% upon the implementation of a foreign tax cut for firms with cross-border links. In addition, we find that foreign tax cuts prohibiting profit shifting generate a negative cross-border effect on average patent quality.

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1 Introduction

R&D activity is an important determinant of growth and technological progress as well as innovation and job creation in an economy. Not surprisingly, governments regularly use fiscal policy to attract R&D investment and top inventors (Akcigit *et al.*, 2016; Moretti & Wilson, 2017). With integrated economies, the implementation of such policies is likely exert cross-border effects on other locations. The direction of these cross-border effects is of high relevance in a world where jurisdictions use tax policy to compete for internationally mobile capital and talent. If nexus is required to benefit from tax cuts such that income must be collocated with the underlying real activity, it appears to be that a lower average tax rate in one location draws away operations from other locations and, hence, the cross-border effect of a tax cut is negative (Barrios *et al.*, 2012). However, this is not necessarily true if income and real activity can be separated via profit shifting. For instance, it is possible to assign the generation and ownership of output from research and development (R&D) to different locations via patent transfers. In this case an entity can transfer profits to a low-tax affiliate but leave the actual operations in the high-tax location. As profit shifting strategies become more sophisticated, the cross-border impact of tax policy is thus getting more complex. Despite the intuitive relevance of this issue, not much is known about the international effect of unilateral tax reductions on innovative activity in the context of profit shifting. In this paper, we close this gap by estimating the cross-border effect of tax cuts on R&D output. We explicitly account for the possibility of profit shifting.

Our focus on R&D activity allows us to base our analysis on two important features. First, the source of income and the underlying real activity are easily separated for R&D because the ownership rights of intellectual property are usually assigned via tradable patents. Thus, profit shifting is a particularly relevant phenomenon which allows us to study the cross-border effect of tax cuts in its full complexity. Second, there have been a large number of corporate income tax cuts specifically for income from intangible assets at different points in time in different locations. These tax regimes are often termed “patent boxes” because they are exclusively targeted at returns to intellectual property. Patent box regimes exempt a large share of profits related to intangible assets (mainly patents)[1] from taxation and, thus, reduce the effective tax rate on these profits. Furthermore, patent boxes differ substantially in their design, in particular with regard to the extent of real activity (i.e. nexus) which is required to become eligible for the lower tax rate. This makes them an interesting policy feature for our analysis. Since the R&D activity of individual firms outside of a jurisdiction are unlikely to affect this jurisdiction's fiscal policy, these reforms can be exploited as an exogenous variation for the identification of the cross-border impact of tax cuts on R&D output.[2]

We analyze the cross-border effect of tax cuts on corporate R&D activity using a difference-in-difference design which exploits firm-level variation in the exposure to foreign patent box regimes within a multinational group. The cross-border effect is identified by estimating the response of a firm in one location to the exogenous patent box implementation in another location where one of its foreign affiliates resides.[3] Following previous studies (e.g. Blundell *et al.*, 1995; Stiebale, 2016), we measure R&D output by granted patent applications. We address the potential endogeneity of firm structure in an instrumental variable research design following the approach by Gumpert *et al.* (2016). Furthermore, we provide additional evidence for R&D inputs using confidential data on R&D expenditure for German firms. For the analysis, ownership information for more than 26,000 firms is linked to administrative data on patent applications. Cross-border links are established via multinational companies which have been identified as important transmitters of macroeconomic and policy shocks (Cravino & Levchenko, 2017). Using micro-level data also allows us to avoid problems of spatial effects that arise when using aggregated data (Montmartin & Herrera, 2015).

Importantly, in our analysis we differentiate between patent box reforms with and without nexus requirement. *Nexus patent boxes* only apply the reduced tax rate if at least part of the

[1] Some patent boxes also allow for the inclusion of trademarks or other intellectual property.

[2] We verify this by testing for common trends in our empirical analysis.

[3] See Figure A.3 in the Appendix for a graphical illustration of this concept.

research activity has been carried out in the respective country (i.e. there is some nexus in this country). These regimes make it hard to separate R&D profits from underlying operations. Thus, we do not expect this incentive to raise R&D activity beyond the jurisdiction where it is implemented. The cross-border effect would be negative, if the tax cut leads to the relocation of R&D activity. One could, however, still observe some positive repercussions on domestic investment from increases in R&D activity in the foreign affiliate. A similar effect has been identified for FDI of U.S. multinationals by Desai *et al.* (2009). This is likely to mitigate or compensate a negative cross-border effect of nexus patent boxes.

Patent boxes *without* nexus requirement also tax patents at the favorable rate that have been generated elsewhere. This is usually done by including existing and acquired patents in the patent box which provides firms with the following profit shifting opportunity: They conduct R&D in the location of their choice and then transfer the resulting patent to a patent box location without nexus requirement in order to benefit from the lower tax rate there.[4] This lowers the user cost of capital for R&D activity in the group as a whole through a mechanism that is very similar to the one described in Hong & Smart (2010) for tax havens. In fact, this similarity is not surprising. Countries that implement patent boxes without nexus requirement effectively become tax havens for a particularly important asset. Below, we thus refer to these regimes as *patent havens*. Because patent havens provide an output-related tax incentive beyond the location where they are implemented, we expect them to generate a positive cross-border effect on R&D activity.

Our estimation results suggest that the implementation of a foreign patent haven (no nexus requirement) raises R&D activity in the form of patent output by about 15% on average. We capture the treatment intensity by interacting the implementation indicator with the change in the tax rate difference between firm and affiliate location and find that the patent haven implementation leads to an increase of patent output by 1.1% per percentage point of change in the tax rate differential. The cross-border effect of tax cuts on R&D output

[4]The extent to which such a profit shifting strategy is feasible depends on the design of both the patent box regime and the tax system in the high-tax country. We discuss institutional issues in more detail below.

is thus about one third of the effect estimated by Karkinsky & Riedel (2012) for domestic tax changes. Similar results are obtained when using confidential data on R&D expenditures of German firms. For patent boxes with nexus requirement, we find a cross-border effect that is close to zero and possibly negative. Furthermore, we find that nexus patent boxes reduce the average patent quality in related firms abroad. The cross-border effect of nexus boxes thus occurs with respect to the intensive rather than with respect to the extensive margin of corporate R&D location decisions. This result can be explained by the spatial sorting of patents according to their profitability: Nexus patent boxes probably lead to the relocation of the most profitable patents.

These findings are robust to controlling for domestic tax-related input incentives such as super-deductions and credits. They also pertain when we adjust the patent count for heterogeneity in the patent quality. We further ensure robustness by replicating our results using different estimation methods such as propensity score matching as well as an event study design and by conducting a number of sample checks with regard to the structure and activity of the corporate group.

Our analysis expands the large literature on tax policy and R&D activity. We explore the cross-border impact of tax cuts as a novel effect of tax policy on R&D and highlight the importance of nexus conditions in these policies. Previous studies have established a link between taxation and investment in R&D (Mamuneas & Nadiri, 1996; Bloom *et al.*, 2002; Wilson, 2009), the location choice of intangible assets (Dischinger & Riedel, 2011; Karkinsky & Riedel, 2012; Griffith *et al.*, 2014) and the quality of patents (Ernst *et al.*, 2014) within the borders of a particular location. The literature on international effects of tax policy on R&D is scarce and relies on macro data. For example, Wilson (2009) uses aggregate data on R&D spending from US states to show that a large part of the increasing effect of tax credits on R&D *inputs* is due to a reallocation of research activity between states. In contrast, we study the cross-border effect of *output*-related tax incentives in the form of tax cuts for intellectual property. This allows us to directly account for the differences in nexus requirements that drive the cross-border impact of these reforms.

More generally, we contribute to the literature on the cross-border impact of taxation on economic activity which is centered around multinational firms (e.g. Dharmapala, 2008; Slemrod & Wilson, 2009; Hong & Smart, 2010; Desai *et al.*, 2006). Our results provide important insights into the role of tax policy in determining the geographical distribution of economic activity. We show that tax incentives in one location only attract real activity from another location if they are combined with an effective nexus requirement. In contrast, if tax benefits are available without nexus, tax cuts raise economic activity across borders. Such differences in the cross-border effect of tax policy are especially relevant for high-growth industries. For instance, the sustainability of nexus rules is particularly questionable in the case of highly valued R&D activity which is associated with extremely mobile intellectual property and top scientists. Moreover, the fast-growing digital economy challenges conventional concepts of the economic nexus of a taxable activity. Our results suggest that tax policy is less likely to determine the location choice of real activity for these growing sectors. However, it remains relevant for the allocation of mobile income and tax revenue.

In addition, we enrich the growing literature on patent box regimes. In this field, more normative analyses (e.g. Evers *et al.*, 2015) have recently been complemented by empirical studies (e.g. Bradley *et al.*, 2015; Koethenbuerger *et al.*, 2016; Alstadsæter *et al.*, 2018). Even though most governments claim to implement patent boxes mainly to facilitate *domestic* R&D activity, the emergence of these regimes has raised concerns. Not surprisingly, the cross-border effect that we investigate in this paper is at the heart of several of these issues. For instance, it is not certain that patent boxes actually boost new R&D projects and, thus, increase the overall level of corporate innovation. In response to the implementation of a more favorable tax regime in one location, firms could merely relocate existing research projects. Such a beggar-thy-neighbor effect is well-known for tax credits (Wilson, 2009). In addition, the economic role of patent boxes is heavily debated. In the best case, these regimes eliminate a market failure by increasing the net return of R&D to a level that better reflects its positive externalities on knowledge generation within the economy. In the worst case, patent boxes distort the location decisions of R&D investments. To the best of our knowledge, our paper is the first to empirically analyze the cross-border effect of patent boxes on R&D activity. Our results suggest that the institutional design of patent boxes is decisive for the direction and magnitude of their international impact.

The remainder of this paper is structured as follows. Section 2 develops a stylized theoretical framework for our analysis. We explain the empirical strategy in Section 3 and describe the data collection in Section 4. Results are presented in Section 5 while Section 6 concludes.

2 The Cross-border Effect of Tax Cuts

In this section we develop a stylized theoretical framework to characterize the response of a firm's R&D activity to a tax cut in one of its foreign affiliate locations (e.g. the implementation of a patent box). From this framework we derive testable hypotheses for our empirical analysis. We consider a multinational enterprise (MNE) i that is located in country h and has an affiliate in country p. We are interested in the cross-border effect of a tax cut for patent income. Thus, our focus is on the number of successfully realized research projects (measured as patents) in h rather than the overall research activity in the MNE. The firm makes three decisions: (i) it chooses whether or not to realize projects (patents) from a given set of potential undertakings indicated by $s = 1, ..., n_i$, (ii) it decides on the location of R&D activity and (iii) it chooses the location of patent ownership. The two location decisions do not necessarily coincide and depend on the characteristics of h and p such as R&D related fixed costs and tax rates for patent income. All three choices jointly determine the number of realized research projects in h denoted by P_i.

Let us define the return to a research project s by

$$r_s = (1 - t)\,\pi_s - c \tag{1}$$

where $(1-t)\,\pi_s$ is the net profit (i.e. revenue less deductible cost after taxes) and c is some non-deductible fixed cost. The effective tax rate t and the fixed cost c may differ between location h and p and are thus functions of the ownership and activity location choices of the firm. For simplicity, we normalize tax rates to be equal initially, $t_h = t_p$. The tax cut in p lowers t_p such that $t_h > t_p$. The fixed cost c comprises items that are hard to price and usually not considered as deductible expenses such as the cost of risk-taking in R&D investments in a particular location, the cost of becoming acquainted with local patenting institutions or the cost to identify suitable researchers in different regions. To simplify the derivation, we assume that firm i incurs higher fixed costs if it relocates its research activity to country p (i.e. $c_p > c_h$). Besides the specific characteristics of the fixed costs described above, this reflects potential relocation costs which include the establishment of new organizational R&D structures in p and the effort for convincing researchers to move.

The firm either co-locates or geographically separates R&D activity and ownership. There are various ways to achieve the latter, including the direct transfer of patent rights, contract R&D and cost sharing agreements between the two affiliates (Griffith *et al.*, 2014). Effectively, all of these arrangements result in part of the profit from the research project being taxed in a location different from the one where the R&D activity was carried out and, thus, have qualitatively similar consequences. The organizational form of the geographical location of patent rights is, however, an important feature for the empirical identification of the cross-border effect of tax cuts. We discuss this in more detail below.

Depending on the location choices of the firm, the profit of a research project s is given by

$$
\begin{aligned}
r_s^{h,h} &= (1-t_h)\,\pi_s - c_h && \text{if R\&D activity and ownership in } h,\\
r_s^{h,p} &= (1-t_h+\alpha\Delta t)\,\pi_s - c_h && \text{if R\&D activity in } h \text{ and ownership in } p,\\
r_s^{p,p} &= (1-t_p)\,\pi_s - c_p && \text{if R\&D activity and ownership in } p
\end{aligned}
$$

where $\Delta t = t_h - t_p \geq 0$. Locating R&D activity in p and ownership in h is not optimal because $c_p > c_h$. α denotes the profit share of a research project conducted in h that is taxed at t_p as a consequence of the relocation of the ownership right to p. The parameter α captures the extent to which a reduction in the tax burden is inhibited both by regulations in location h (e.g. CFC rules or exit taxes) and in location p. Regulations in location h are likely to be orthogonal to the patent box implementation while regulations in location p are directly linked to the setup of the exploited patent box. For example, α is small if the patent box in p excludes R&D profits for projects conducted outside of p (nexus patent box). In contrast, α is close to 1 if the patent box regime in p includes existing and acquired patents (patent haven).

To compute the number of realized research projects, we assume the following sequence of decisions: The firm first decides on whether or not to realize a particular project s and then simultaneously determines where to optimally locate R&D activity and legal ownership. Solving this problem backwards, we begin with the location decision. If $\Delta t > 0$, legal ownership is assigned to p because there are no fixed costs for separating ownership and R&D activity[5] and hence $r_s^{h,h} < r_s^{h,p}$, $r_s^{p,p}$. To simplify notation, we assume that the ownership rights are also assigned to p if $\Delta t = 0$. The ownership location does not affect the return of a project if tax rates are equal. R&D activity is located according to the cut-off profit

$$\tilde{\pi} = \frac{c_p - c_h}{(1-\alpha)\,\Delta t}$$

Activity for all projects with $\pi_s < \tilde{\pi}$ is located to h because in this case $r_s^{h,p} > r_s^{p,p}$, while R&D activity for the remaining projects (for which $r_s^{h,p} < r_s^{p,p}$) is located to p. Next, we turn to the decision of whether or not a research project is realized. Only research projects with a positive return are completed. This implies that any project s with

[5] To make the framework more realistic, one could introduce some fixed costs to separating ownership and activity which would result in the ownership of some research projects being located in h even if $t_h > t_p$. This would make our model slightly more complicated without adding further insights with regard to the main effect of interest.

$$\pi_s > \tilde{\pi}^* = \frac{c_h}{1 - t_h + \alpha \Delta t}$$

is realized. We sort the gross profits of all available projects along the interval $(\underline{\pi}_i, \bar{\pi}_i)$ and define the corresponding cumulative distribution function F. Let us assume for illustrative purposes that $\tilde{\pi}^* < \tilde{\pi}$.[6] The overall number of finished projects is then given by $n_i (1 - F(\tilde{\pi}^*))$ with $n_i (1 - F(\tilde{\pi}))$ projects realized in p and the number of realized R&D projects of firm i in location h given by

$$P_i = n_i \left(F(\tilde{\pi}) - F(\tilde{\pi}^*) \right). \tag{2}$$

Note that $F(\tilde{\pi}) \to 1$ as $\Delta t \to 0$, that is, P_i converges to the overall number of realized projects as the tax differential shrinks.

How is P_i affected by a tax cut in p? Such a reform lowers t_p and, thus, increases the tax differential Δt. The change in the number of realized R&D projects in h as a result of an increase in the tax differential of $d\Delta t$ is given by

$$dP_i = n_i \left(-(1-\alpha) \frac{f(\tilde{\pi})(c_p - c_h)}{((1-\alpha)\Delta t)^2} + \alpha \frac{f(\tilde{\pi}^*) c_h}{(1 - t_h + \alpha \Delta t)^2} \right) d\Delta t. \tag{3}$$

The sign of the effect depends on how much the separation of ownership and real activity for tax purposes is inhibited by regulations. For example, if the patent box requires full nexus in location p, that is $\alpha = 0$, dP_i is negative. In this case, cross-border relocation of ownership (and, thus, profits) from h to p is not an option and the tax reduction in p does not affect the cost of capital in h. Rather, activity for sufficiently profitable projects is located to p, reducing the overall number of realized projects in h.[7] In contrast, a patent haven (no nexus

[6] Various orders of the threshold profits are possible but yield the less interesting case where all research activity is located to p irrespective of the change in the tax rate differential.

[7] Note that this does not necessarily imply that overall research activity of the multinational company decreases. If the tax benefits in p are large enough, the total number of patents would even increase. This occurs, however, only because the increase in research activity in p more than compensates for the decrease in h. Research activity in h always decreases.

requirement) has a positive effect on research output in h. Abstracting from inhibiting factors in the transferor location, we have $\alpha = 1$ in this case and, thus, $dP_i > 0$. As the firm is able to relocate the ownership of some projects realized in h to p, the tax cut there also reduces the user cost of R&D capital in h and increases research output.[8]

Finally, we observe that the average profit of realized projects in h decreases with the tax cut in p. A formal analysis of this result is presented in Appendix A.1. For nexus boxes (small α), the intuition for this result is that only R&D activity for the most profitable projects is relocated to p. This is consistent with an analysis by Haufler & Stähler (2013) who show in a tax competition model, that more profitable projects sort into low-tax jurisdictions. Empirical evidence by Becker *et al.* (2012) suggests that this effect contributes significantly to the overall tax base location effect of corporate taxes. In principal, the negative effect on average R&D quality can also occur when a patent haven is established in p because this allows R&D projects with lower profitability to be realized in h. In practice, this effect can, however, be compensated or even overturned by an increase in R&D profitability due to an agglomeration effect that is likely to be observed if patent havens generate a positive cross-border effect on R&D quantity.

Thus, the theoretical framework suggests two types of cross-border effects that are tested in the empirical analysis. First, the cross-border effect of a tax cut for patent income on the quantity of R&D output is positive if profit shifting is possible and absent or negative if profit shifting is limited. Second, we expect a negative cross-border effect of tax cuts on the quality of R&D output, especially if firms can only benefit from the tax cut if they establish sufficient nexus in the relevant patent box country.

[8] A graphical illustration of this formal analysis can be found in Appendix A.2.

3 Empirical Identification

3.1 Patent Output

The goal of this paper is to assess the cross-border impact of tax cuts on R&D activity. Following previous studies (e.g. Blundell *et al.*, 1995; Stiebale, 2016), R&D activity of a firm is measured by its annual registered output of granted patents.[9] We model the number of granted patent applications P_{ijct} in year t of firm i which is member of multinational group j and is located in country c as a function of foreign tax cuts on patent income and several control variables.

We begin our analysis using an event study design.[10] The general idea of the event study is to regress the number of patents on individual dummies indicating periods before and after the implementation of a foreign patent box. This approach is helpful in two ways. First, it allows us to verify the validity of our research design, which compares the response of firms with and without affiliates in particular countries to exogenous tax cuts in these locations, by establishing common pre-trends of R&D activity for the treatment and control firms. Second, since in an event study we observe the cross-border effect of foreign patent box implementations for individual periods, we are able to explore the dynamics of this effect. The setup of the event study closely follows Fuest *et al.* (2018) and is described in detail in Appendix A.5.

In order to estimate the average cross-border effect of a tax cut, we use a difference-in-difference strategy in a Poisson fixed effects model[11] (see Hausman *et al.*, 1984; Wooldridge, 1999; Cameron & Trivedi, 2015) of the following form:

[9] Granted applications are commonly used in the literature (e.g. Aghion *et al.*, 2013; Seru, 2014; Stiebale, 2016; Bena & Li, 2014) because they better capture actual research activity rather than strategic patent filing.

[10] See Hoynes *et al.* (2011), Kline (2012) and Chetty *et al.* (2014) for recent applications of event studies in public economics. Furthermore, Alpert *et al.* (forthcoming) use an event study design in a count model that closely resembles our approach.

[11] This model is equivalent to the Poisson Pseudo Maximum Likelihood estimator proposed by Silva & Tenreyro (2006). As demonstrated by Wooldridge (1999), it is the most robust choice among nonlinear count models. To verify whether over-dispersion drives our result, we have also estimated a negative binomial regression and obtained very similar results.

$$E\left(P_{ijct}\right) = exp\left(\mathbf{x'_{ijct}}\beta\right)$$

$$\text{with } \mathbf{x'_{ijct}}\beta = \alpha \cdot BOX_{jt}^{Haven} + \eta \cdot BOX_{jt}^{Nexus} + \boldsymbol{\beta X_{it}} + \boldsymbol{\gamma Z_{jt}} + \boldsymbol{\delta C_{ct}} + \boldsymbol{\phi_t} + \boldsymbol{\phi_i} \quad (4)$$

BOX_{jt}^{Haven} and BOX_{jt}^{Nexus} are binary variables that are equal to 1 if a patent box of a particular type is implemented in the country of residence of at least one of the foreign affiliates of firm i and zero otherwise. $\boldsymbol{X_{it}}$, $\boldsymbol{Z_{jt}}$ and $\boldsymbol{C_{ct}}$ are firm-, group- and location-specific characteristics. $\boldsymbol{\phi_t}$ and $\boldsymbol{\phi_i}$ capture time- and firm-specific effects. In the estimation, we differentiate between nexus patent boxes (some nexus requirement, indicated by BOX_{jt}^{Nexus}) and patent havens (no nexus requirement, indicated by BOX_{jt}^{Haven}). Patent havens are defined as patent boxes that include both acquired and existing patents and, thus, allow firms to realize tax benefits through the post-generation cross-border transfer of patent rights (see Table 2). In contrast, the nexus patent boxes apply the favorable rate mainly to profits from R&D activity conducted in the respective location.

To identify the cross-border effect of tax cuts on a particular firm, we exploit the exogenous implementation of a patent box regime in the location of a foreign affiliate of this firm. The identification relies on the assumption that, prior to the implementation of a patent box, firms with affiliates in the implementing countries are not systematically different with respect to the evolution of their R&D activity from those that do not have affiliates in these locations. We test this assumption using the event study design. A further potential source of endogeneity is the structure of the multinational group. On the one hand, MNEs that comprise firms which expect an increase in their research activity have an incentive to set up a new affiliate in a patent box location. On the other hand, firms may establish affiliates in patent box locations once they accumulated a significant stock of patents and R&D activity subsequently slows down. There are two ways in which we account for these issues and ensure that our results are not driven by firms endogenously establishing affiliates in patent box locations: We employ an instrumental variables strategy and we conduct an additional sample check where we consider only firms with no changes in their group structure.

The instrumental variable approach follows a strategy proposed by Gumpert *et al.* (2016) to account for the potential endogeneity of firm location. In this estimation, we fix the organizational structure of each firm at the beginning of our sample period and then redefine the variables that indicate the occurrence of foreign tax cuts (e.g. BOX_{jt}^{Haven}, BOX_{jt}^{Nexus}) according to this fixed structure. We use these hypothetical realizations as instruments for the actual variables. The instruments only capture foreign tax cuts on patent income that result from the exogenous implementation of patent boxes and are unrelated to the location choice of the firm during our sample period. Such an instrumental variable strategy is valid if the initial structure of the firm is not affected by the subsequent response of innovation output to foreign tax cuts. This is a plausible assumption given that both the tax changes implemented through the patent box regimes and the success of R&D activity are highly unpredictable. In an additional robustness check, we exclude all groups that changed their structure with respect to a patent box location and reestimate our benchmark specification. In this setting, the foreign tax cuts are again the ones exclusively caused by the exogenous implementation of patent box regimes.

The macroeconomic and institutional control variables include the log of GDP per capita, GDP growth, general research activity measured by R&D expenditures as a percentage of GDP and the corporate income tax rate. One concern with regard to our analysis is that those countries without a patent box have instead turned to input-related tax incentives in order to remain competitive R&D locations. If these alternative incentives are the main drivers of the observed rise in domestic patenting activity, this would still hint to a cross-border effect of patent boxes. Instead of a direct impact on the user cost of capital, the effect would then be a result of policy interactions in a fiscal competition game. To avoid capturing such spurious effects, we include the user cost of capital for R&D in our estimation which is a composite measure that includes input-related tax incentives such as tax credits and super-deductions for R&D activity.[12] We also control for several items that have been suggested to affect R&D activity on the firm level such as the number of affiliates, the age of a firm as well as the firm size measured in total assets, the working capital and the capital intensity of a firm (see Stiebale, 2016). Finally, we include firm- and time-fixed effects to capture cross-sectional differences in the level of R&D output, as well as general time trends.

We restrict our analysis to firms located in countries without a patent box implementation during our sample period. As the focus of this study is the cross-border effect of tax cuts through patent box regimes, patent box locations must be excluded to avoid distorting effects of the implementation of domestic regimes that may or may not coincide with the implementation of patent boxes abroad. However, we verified that our results also hold when we include these locations.

The number of patents is primarily measured as the count of annual granted patents per firm. To capture the intensity of domestic R&D activity, we also conduct our analysis using the quality-weighted number of new patents. Frequently cited patents registered at multiple patent offices and classified to contribute to many patenting classes are potentially more valuable (see Harhoff *et al.*, 1999). We construct patent quality using the composite quality indicator proposed by Lanjouw & Schankerman (2004) which is commonly employed in this strand of literature (see, e.g., Hall *et al.*, 2007 and Ernst *et al.*, 2014). The composite quality indicator is derived through a multiple-indicator model relying on the number of forward citations, the patent family size and the number of patent classifications resulting in a relative measure for patent quality. The procedure to derive it is described in Appendix A.3.

3.2 Patent Quality

We also estimate the cross-border effect of a patent box implementation on the average quality of new patents to test our theoretical predictions with regard to the cross-border

[12] See Appendix A.4 for a detailed derivation.

effect of patent boxes on the quality of R&D output. The latter is computed by dividing the quality-weighted patent count by the number of patents, $q_{ijct} = \frac{P^{qual.}_{ijct}}{P_{ijct}}$. To account for general quality shifts within the same industry as well as level differences across industries and countries, we then scale this measure by its 2-digit SIC industry, country- and year-specific mean $\bar{q}_{sct}$ and obtain $\tilde{q}_{ijct} = \frac{q_{ijct}}{\bar{q}_{sct}}$. We relate the logarithm of this relative measure to foreign patent box implementations in the following fixed effects regression:

$$\log\left(\tilde{q}_{ijct}\right) = \iota + \alpha \cdot BOX^{Haven}_{jt} + \eta \cdot BOX^{Nexus}_{jt} + \boldsymbol{\beta X_{it}} + \boldsymbol{\gamma Z_{jt}} + \boldsymbol{\delta C_{ct}} + \boldsymbol{\phi_t} + \boldsymbol{\phi_i} \quad (5)$$

The specification of variables is the same as for equation (4).

4 Data

4.1 Patent Data

The analysis is based on a rich panel dataset built by combining multiple data sources on administrative patent data, firm information and patent box characteristics. Patent data is taken from the PATSTAT database operated by the European Patent Office (EPO). PATSTAT is a comprehensive data source covering patent data for over 80 countries in a harmonized way (Jacob, 2013). For the econometric analysis we count the number of granted patents per firm for each year.[13]

In our analysis we focus on domestically developed patents. In principal, the country of residence of the firm applying for a patent does not necessarily constitute the place of development of the patent. As is common in the literature, we identify whether or not a patent was developed at the location of the firm using address information of the inventors (Guellec & de la Potterie, 2001). A patent is classified as domestic if the majority of its

[13] Since it can take multiple years between application and approval of a patent, we account for this time lag between generating an innovation and acceptance of the patent application using the date of first patenting application instead of the patent publication date.

inventors reside in the same country as the applicant firm.[14] We remove outliers by trimming the sample at the 99 percentile of annual domestic patent output.

Table 1 displays descriptive statistics of the firm locations we include in our sample.[15] Research activity is particularly strong in Switzerland, Austria, Finland and Germany with average annual domestically developed patents per firm of between 0.55 and 0.48. Fewer patent applications are observed in smaller locations like Croatia and Lithuania.

As pointed out above, an institutional feature that is crucial to identify the cross-border effect of a tax cut on R&D output is the way MNEs separate patent ownership and R&D activity. Previous studies that estimate the elasticity of legal ownership of a patent in a particular jurisdiction with respect to the applicable tax rate have argued that, if the separation of R&D activity and ownership occurs, this is done mainly through contract R&D and cost sharing arrangements whereby the patent applicant would also be the final owner (Karkinsky & Riedel, 2012; Griffith *et al.*, 2014). In contrast, actual transfers of patents via intra-company sales are less attractive because of their adverse tax effects. This assumption appears sensible given that these studies cover periods when many countries applied CFC rules that should substantially diminish potential tax benefits of cross-border patent transfers.[16] Under these circumstances, contract R&D or cost sharing are probably more attractive modes of cross-border ownership allocations.

However, in its seminal 2006 Cadbury-Schweppes ruling the European Court of Justice (ECJ) has effectively limited the applicability of CFC rules and the majority of countries has amended their regimes (Bräutigam *et al.*, 2017). Further ECJ rulings have mitigated the threat of exit taxes on the capital gains realized in these cross-border transfers.[17] In fact, a

[14] For those patents with no inventor information provided by PATSTAT, it is assumed that the patent was developed domestically. As a robustness check, it is also assumed that all patents without inventor information provided are non-domestic ones. The results still hold implying that these patents are not systematically different from those with inventor information.

[15] An overview of the sample selection process is displayed in Table A.2 in the Appendix.

[16] Griffith *et al.* (2014) study patent applications from 1985 to 2005, Karkinsky & Riedel (2012) observe annual patent applications of European firms from 1995 to 2003. According to Bräutigam *et al.* (2017), Germany, Denmark, Finland, France, the United Kingdom, Hungary, Norway, Portugal and Sweden had CFC rules with respect to other European countries in 2003.

[17] E.g. National Grid Indus BV v Inspecteur van de Belastingdienst Rijnmond C-371/10 (NGI) and

recent anonymized survey conducted by Heckemeyer *et al.* (2015) reveals that MNEs consider the selling of patents to foreign affiliates a feasible way to transfer ownership rights across borders.[18] A possible reason for this observation is that it is particularly difficult for tax authorities to examine the true value of recently granted patents with no revenues attached which makes it easy to set transfer prices in such a way that MNEs can realize tax benefits from cross-border transfers. At the same time, direct patent transfers avoid communication costs and uncertainty arising from cost sharing or contract R&D arrangements. Furthermore, many input-related incentives for R&D (e.g. direct subsidies, tax credits) usually do not apply to contract arrangements.

In line with Dischinger & Riedel (2011), we conclude that the post-generation transfer of intangible assets such as patents is a viable mode of ownership relocation for tax purposes. Recent findings on patent transfers suggest that such transfers are a relevant phenomenon. For instance, Gaessler *et al.* (2017) estimate that the implementation of patent boxes in the recipient country that include acquired and existing patents (i.e. no nexus requirement) significantly increases the number of annual bilateral patent transfers. It follows that it is feasible to identify the cross-border effect of patent boxes using patent application data. We further ascertain that the initial applicant is likely to be the entity that was actively involved in the research project by using information on inventor residence to isolate patents for which the underlying R&D activity has been conducted elsewhere. If anything, the measurement error induced by R&D contract arrangements would exert a downward bias on our estimates of the cross-border effect. While the patent box implementation in one affiliate actually raises R&D output in another non-patent box affiliate of an MNE, this would in some cases not be observed in the patent application data since the final applicant would be the patent box affiliate as the internal buyer of R&D services. Our estimate would then have to be interpreted as a lower bound of the true effect.

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[18]The survey also finds that cost sharing agreements are much less important which probably reflects that they are primarily a phenomenon in MNEs with US parents due to institutional reasons (Dischinger & Riedel, 2011).

4.2 Institutional Details

Before testing the empirical relevance of our analytical results, it is useful to describe to the patent boxes that exist in practice. Evers *et al.* (2015) and Alstadsæter *et al.* (2018) provide a comprehensive overview of the various regimes that have been established since 2000. In Table 2, we summarize key elements of existing patent box regimes in our sample. In general, firms enjoy substantial reductions in effective tax payments when opting for these regimes but significant differences remain. Patent boxes differ in the treatment of expenses as well as in the types of intangible assets they are applied to beyond patents (e.g. trademarks, brands). The magnitude of the tax exemption varies significantly across locations. For instance, while the tax rate on profits from patents is reduced by 35 percentage points in Cyprus, firms enjoy only a 50% exemption in Portugal which implies a decrease in the statutory tax rate of 11.25 percentage points.

For the cross-border effect of a patent box, it is relevant whether or not the regime has a nexus requirement. In the sense of our analytical framework, a nexus requirement is a regulation that restricts the lower tax rate to income from patents for which the underlying R&D activity has also been carried out in the respective country. This is done by either excluding previously existing or acquired patents from the benefits of the lower patent box tax rate (Spain, Portugal) or by requiring acquired patents to either have been further developed to a substantial degree at the patent box location (Belgium, Ireland[19], Netherlands, United Kingdom) or to have been purchased from a non-related entity (Luxembourg). Effectively, all of these patent boxes require that a substantial part of the research activity must be conducted in the respective country for the lower patent box rate to apply. As a consequence, profit shifting opportunities are limited and these regimes are thus unlikely to generate a positive cross-border effect on R&D activity.

[19] In 2008, Ireland extended the scope of its patent box to patent income resulting from R&D conducted in a EEA member state. However, the reform also imposed an upper limit of EUR 5 million for the income to which the exemption is applied. This prohibits the setup of effective prot shifting structures through holding entities.

Several patent box regimes include acquired and existing patents (France, Hungary, Malta, Cyprus) without effective restrictions.[20] Since this allows firms to conduct the actual development of the patent elsewhere and then transfer the resulting patent right to the patent box location, these regimes correspond to the patent *havens* in the theoretical analysis.

4.3 Ownership and Firm Data

We obtain PATSTAT patent data through Bureau van Dijk's Orbis database. This allows us to link patents of the applying firms to the comprehensive ownership information contained in Bureau van Dijk's Amadeus database via common identifiers. The firm level databases by Bureau van Dijk are unique in two important ways. First, they provide information on the organizational structure of multinational firms around the globe. Second, they contain firm-level balance sheet data in an internationally comparable format. Both features are crucial for the analysis of the cross-border effect within MNEs and have also been exploited to identify other types of international transmissions (e.g. Cravino & Levchenko, 2017).

Using the ownership information, we are able to identify the ultimate owner for each firm in the sample. We construct multinational groups by assigning firms with a common ultimate owner to the same group. This approach is complemented using data on firm establishment and acquisitions in order to record changes in the ownership structure over time. More precisely, we check whether the firm existed throughout the whole observation period and combine the ownership information with data on mergers and acquisitions (M&A) from Bureau van Dijk's Zephyr database to capture ownership changes. In line with previous studies (e.g. Stiebale, 2016), we restrict our sample to industries where patenting is actually relevant. We include firms active in the manufacturing sector as well as several knowledge-intensive service sectors such as information technology, telecommunications, transport, or

[20] In France, the only limitation is that acquired patents must be held for at least 2 years by the acquiring company for the resulting profits to be taxed under the patent box regime.

business-related services.[21] Table 1 provides information on the geographical distribution of firm observations over the 22 locations that remain after excluding patent box locations.

We also obtain balance sheet items as well as firm age from Amadeus. Working capital is computed by scaling the difference between current assets and current liabilities with total assets while capital intensity is defined as the ratio of tangible fixed assets and sales.[22]

Macroeconomic control variables are obtained from the World Bank's World Development Indicators (WDI) and the OECD. Tax policy indicators are collected from the IBFD tax database. When computing the user cost of capital, we follow Bloom *et al.* (2002) and incorporate the input incentives, the applicable tax rate and the fixed depreciation rate into a measure for the user cost of a domestic R&D investment. In order to isolate the effect of tax policy on R&D activity, we calculate the user cost using a fixed interest rate of 5%.[23]

Firm-level ownership and balance sheet information is available from 2000 onward. We analyze data until 2012 because for more recent years the patent data is not reliable. The process of granting patents usually takes several years, such that for more recent periods we do not yet observe the full amount of R&D output.[24]

4.4 Descriptive Statistics

Table 3 provides summary statistics for all variables used in the empirical analysis. As mentioned above, for the cross-border effect of patent boxes to be identified, we require firms with affiliates in patent box locations (treated) and those that do not have affiliates in these countries (non-treated) to be comparable. We thus complement the descriptive statistics with various characteristics of the two types of firms. In Table 4 we display the distribution across industries (NACE Rev. 2 divisions) of the two groups (Panel A) and state the within-group averages for key variables (Panel B). Treated and non-treated firms have a similar

[21] This excludes financial services. We identify relevant sectors via 2-digit NACE Rev. 2 codes and include firms with codes 10-32, 51-53, 58-63, 69-74 and 77-82.

[22] Missing entries for the necessary variables are replaced by annual industry (2-digit US SIC code) means.

[23] See Appendix A.4 for a detailed description of the calculation of user cost of capital.

[24] In a robustness check, we extended the sample to 2015 (see Table A.3). The results remain highly significant with coefficients of similar size.

distribution across industries, with the majority of patenting firms in the manufacturing and services sectors. They differ with respect to location-specific variables such as the user cost of R&D capital, the statutory corporate income tax rate and GDP per capita. However, these differences are very small in magnitude. This implies that firms with affiliates in patent box countries are not clustered in certain locations and, therefore, our results are not driven by such a clustering. The two groups differ more substantially with respect to size (measured in total assets), age and the number of affiliates within their corporate group. Firms with foreign affiliates in patent box locations are larger, older and more often part of large multinationals. This difference in levels is not surprising since a large part of the non-treated firms operates domestically. We control for this by including the respective variables in our regression model. Furthermore, we further ensure the robustness of our results using a matching analysis.

5 Results

5.1 R&D Quantity

In a first step, we present results from an event study design. Figure 1 plots the results of the event-study analysis for the implementation of patent havens and nexus boxes separately.[25] The effect is normalized to zero in the year before the patent box implementation and the coefficients have to be interpreted as the cross-border effect of a patent box on patent output relative to the year prior to the reform. Here, we present the benchmark results using a Poisson count model and report very similar results for a linear model in the Appendix. For foreign tax cuts that allow for profit shifting (patent havens), we observe a positive cross-border effect on patent income. It is strongest in year two after the reform with a significant increase of about 21.2% relative to the pre-reform. In contrast, the impact of tax cuts that require real activity in the relevant location for a firm to become eligible to the lower tax rate (nexus patent box) is initially negative. However, this trend reverses in later periods

[25] Although both effects are estimated jointly.

and is close to zero in period five.

Interestingly, neither the cross-border effect of nexus patent boxes nor the one of a patent haven implementation materializes immediately. Rather, the response is significantly pronounced only about two years after the foreign tax cut became effective. This is consistent with the observation that it takes some time for R&D activity to result in patent applications. Furthermore, we note that pre-trends are flat which implies that our difference-in-difference design is a valid approach.[26] Thus, our econometric approach identifies the cross-border effect of patent boxes correctly if it exists.

Having established the validity of our research design, we turn to the benchmark difference-in-difference setup to estimate the average cross-border effect of tax cuts on R&D activity. Table 5 contains the main estimation results. Heteroscedasticity robust standard errors adjusted for firm clusters are presented in parentheses.[27] In column (1), the cross-border effect of patent havens is captured by a dummy BOX_{Haven} that indicates a relevant patent box implementation in the residence country of a foreign affiliate of a firm. We estimate a positive cross-border effect for patent havens. The foreign tax cut for patent income leads to a significant increase of domestic patenting activity by 14 log points. This translates into a rise of annual patent output by approximately 15%.

We are also interested in the cross-border effect of nexus patent boxes on R&D activity. In columns (2) of Table 5 we present results of an estimation that relates the patent count to a dummy BOX_{Nexus} that switches to one when the residence country of one of the foreign affiliates of the firm implements a patent box with nexus requirement. The coefficient of interest is insignificant and very small. Thus, we cannot identify a significantly positive cross-border effect for nexus patent boxes. This is consistent with the notion that tax cuts for patent income only reduce the user cost of R&D capital in other countries if they do

[26] More precisely, we cannot reject the hypothesis of common trends, that is, all coefficients of the pre-implementation periods are jointly equal to zero (χ^2-test statistic 2.99 for patent havens, 1.10 for nexus boxes).

[27] We also ran the regression with standard errors clustered in the group level and found the results to be robust to this adjustment. However, clustering on a level that nests the firm-fixed effects is computationally demanding and the model did not converge when we included the full set of controls.

not inhibit profit shifting (e.g. by requiring nexus). We note from the results of the event study design, that the cross-border impact of nexus patent boxes is initially negative. This probably reflects that, consistent with the theoretical prediction, some research projects are relocated away from the observed firm to the corresponding patent box location to satisfy the nexus requirement and benefit from the tax cut. However, we also observe a reversal of this trend in later periods leading to an insignificant cross-border effect of nexus patent boxes in the long-run. We attribute this to positive repercussions on domestic investment from increased activity in the foreign affiliate. This is consistent with previous studies that have found positive effects of FDI on domestic activity (e.g. Desai *et al.*, 2009).

In column (3) we include both implementation dummies BOX_{Haven} and BOX_{Nexus} into one regression. Again, we estimate a significantly positive coefficient for BOX_{Haven} which is similar to the previous results while the coefficient for BOX_{Nexus} is insignificant and small in magnitude.

Firm-level patent output is also driven by other macroeconomic factors and policies. R&D expenditures as a share of GDP increases patent output of firms. On the contrary, an increase in the financing cost measured by the real interest rate or a higher statutory corporate income tax rate is expected to induce a decline in innovative activity. Consistent with related studies (e.g. Bloom *et al.*, 2002; Wilson, 2009), our estimates suggest that an increase in the user cost of R&D capital leads to a decline in corporate R&D investment. The fact that the coefficient for the patent box dummy is significant despite the inclusion of the user cost of R&D capital indicates that our estimates are not the result of the fiscal competition game described above.[28] The significantly positive coefficients of total assets and the firm age indicate that, consistent with previous findings, larger and also older firms conduct more R&D.

In columns (4) to (6) of Table 5 we account for treatment intensity, that is, we allow

[28] We also ran regressions restricting the set of control variables to macro-economic factors first and then excluding all control variables (keeping year-fixed and firm-fixed effects in both cases). The resulting coefficient estimates were qualitatively similar albeit somewhat larger in magnitude.

patent boxes with different magnitudes of tax exemption for patent income to have a different cross-border impact. Instead of an implementation dummy, we use the change in the tax rate difference between the location of the firm and the patent box country that is induced by the patent box implementation. More specifically, we take the change in the difference between the corporate income tax rate in the residence country of the firm and the applicable tax rate for patent profits in the relevant affiliate country upon implementation of the patent box and interact it with our implementation dummies, BOX_{Haven} and BOX_{Nexus}. We then repeat regressions (1) to (3) using our more sophisticated indicator. Again, the estimated coefficient of interest is significantly positive for the patent haven indicator. Our results suggest that a patent haven that increases the tax rate differential by 1 percentage point raises the number of patents by 1.1%. This cross-border effect of taxation on patent output is thus about one third of the effect estimated by Karkinsky & Riedel (2012) for domestic tax changes.[29] The coefficient for the nexus box indicator is insignificant and small.

In the next step, we account for the fact that patents vary strongly with regard to their quality, usefulness and applicability (see Hall *et al.*, 2010) and repeat our analysis using the quality-weighted patent count as dependent variable. Columns (7) and (8) of Table 5 present the results from replicating regressions (3) and (6) with this alternative dependent variable. Throughout the specifications, the coefficients of the patent haven implementation dummy as well as the one for the more sophisticated measure of the corresponding patent-box-induced tax difference remain significantly positive. We note that the coefficients for the nexus box indicator is slightly negative and marginally significant when interacted with the reduction in the tax rate differential. This suggests a negative cross-border effect of nexus patent boxes on R&D quality. We analyze this phenomenon in more detail below.

We also check whether the direction of our estimated effect is driven by the model choice and use a linear fixed-effects model in columns (9) and (10). In this specification, the de-

[29] Karkinsky & Riedel (2012) estimate a semi-elasticity between 3.5% and 3.8%. A comparison to Griffith *et al.* (2014) is more difficult because they allow the own-region semi-elasticity of patent applications with respect to the tax rate to vary by location. The estimated own tax semi-elasticity ranges from 0.52% in Germany to 3.9% in Luxembourg.

pendent variable is the inverse hyperbolic sine transformation[30] of the patent count. This transformation is often employed to account for the non-linearity of the relationship while not generating missing observations for firm-years without patent applications (e.g. Burbidge *et al.*, 1988). Again, the estimated coefficient for the patent haven indicator is significantly positive. Consistent with the notion that patent boxes with nexus requirement lead to relocations of R&D activity, we estimate a negative coefficient for the nexus patent box indicator. However, for our benchmark results we prefer to rely on the Poisson model as it correctly adjusts for the count nature of the patent data.

Finally, we employ an instrumental variable strategy to verify that our results are not driven by firms endogenously establishing affiliates in patent box locations. In this specification, the actual realizations of foreign tax cuts are instrumented by the hypothetical realization that we obtain when fixing the firm structure in 2000. To ensure exogeneity of the instrument we begin our estimation in 2001. Results are presented in columns (11) and (12). The size of the F-test statistic for the exclusion of the instruments in the first-stage regression is large which indicates that our instrumental variable strategy is a valid approach. Again, we find a positive cross-border effect of tax cuts if profit shifting is possible while tax cuts that require nexus exhibit negative cross-border effects. Comparing the coefficients obtained from the instrumental variable specification to the results of the linear model in columns (9) and (10), we observe that the estimated cross-border effect is slightly larger for patent havens and very similar for nexus patent boxes. This points to a slight underestimation in our benchmark model due to endogenous location choices of the treated firms. Our benchmark results can thus be interpreted as lower bounds of the actual effect.

[30] The inverse hyperbolic sine transformation of the patent count takes the following form: $\ln\left(P_{ijct} + \sqrt{P_{ijct}^2 + 1}\right)$.

5.2 R&D Quality

In Table 6, we present estimates of the cross-border effect of a patent box implementation on the average quality of patents. Column (1) contains the regression result relying on a dummy indicating that one of the affiliate countries of a firm turned into a patent haven as well as the set of control variables and fixed effects described above. We find no significant cross-border effects of this type of patent box on average R&D quality. In contrast, we find significantly negative cross-border effects for nexus patent boxes in column (2). Having an affiliate in a country with a nexus patent box significantly reduces the average quality of domestic patents. We estimate similar coefficients when including both dummies in the regression presented in column (3). Taking into account our results for the cross-border effects on the number of patents (i.e. R&D quantity), this implies that cross-border effects of nexus boxes occur with respect to the intensive rather than with respect to the extensive margin of corporate R&D location decisions.

We are only able to compute the average quality of patents for firm-year observations where the firm successfully applied for a patent. In order to not distort our estimation by potentially confounding effects of the R&D quantity decision of a firm, we restrict the sample to firms that apply for patents before and after a foreign patent box was implemented. Regression results are presented in columns (3) to (6) where we obtain similar results as in the benchmark analysis.

While it is possible in theory, that both patent havens and nexus patent boxes generate negative cross-border effects on patent quality, these effects are in practice only observed for nexus boxes. If a sufficiently large number of high-quality R&D projects is available, a decrease in the user cost of R&D does not necessarily lead to a significant decrease in R&D quality. One reason for this is that the increase in R&D quantity that results from the positive cross-border effect of patent havens is likely to lead to agglomeration effects which increase R&D quality rather than decreasing it. This compensates negative cross-border effects on the quality of R&D projects chosen for realization. In contrast, nexus patent boxes directly affect R&D related decisions of the firm on the extensive margin by providing an incentive to relocate profitable R&D projects. This observation is consistent with previous findings by Ernst *et al.* (2014).

5.3 Further Robustness Checks

The validity of our results is reassured when exposing them to various robustness checks. We discuss the three most important tests here and relegate the corresponding results to the Appendix. First, one concern is that the firms in our sample are not sufficiently comparable since we include both domestic and multinational firms. We verify that this is not the case by re-estimating our benchmark results with a sample restricted to MNEs. Results are presented in Table A.4. Reassuringly, the coefficient estimates are similar to those in our benchmark regression.

Second, the structure of an MNE may be affected by the implementation of patent box regimes which may induce an endogeneity bias to our results. For instance, if firms can foresee increases in patent output and are more likely to establish an affiliate in a patent box location if they expect such an increase, our coefficient estimate for the foreign patent box indicators in the benchmark regression would be upward biased due to reverse causality. We check empirically whether this is an issue in our data by reestimating the benchmark regressions using a restricted sample. In this specification we exclude all multinational groups that had an ownership change with respect to a patent box location after the relevant regime had been implemented there. For this specification, the foreign patent box implementation is exogenous as long as the level of patent output in particular firms does not affect the implementation of such a reform in another country. If there was an upward bias, we would expect to estimate a smaller coefficient for the patent box indicators than we do in the benchmark estimation presented in Table 5. However, this is not the case. The coefficient estimate, which is presented in Table A.6, is larger rather than smaller when we use the restricted sample. From this we infer that our estimation does not suffer from an endogeneity bias that would drive estimates upwards. If anything, our estimates are biased downwards. In principal, a downward bias in the benchmark sample is possible, e.g. firms may first pile up their patent stock and then acquire a firm in a patent box location to shift the property rights and benefit from the lower tax rate but at the same time do not further accelerate R&D activity. The results in Table A.6 are also likely to reflect that by excluding firms with ownership structure changes, we exclude many large MNEs from the sample. Since these firms often have additional opportunities to shift profits and lower their effective tax burden (e.g. through tax havens), they react much less to foreign patent box implementations. Thus, we obtain a smaller coefficient in the benchmark estimate that includes these firms.

Third, the differences in average assets, age and group size between treated and untreated firms (see Table 4) could be indicators for endogenous sorting causing a self-selection bias (Wooldridge, 2010). For example, a member of a large group is more likely to be assigned to the treatment group because of having more foreign affiliates and, thus, having a higher probability that one of these foreign affiliates obtains access to a patent box. However, if affiliates of large groups exhibit a different evolution of patent output during the sample period, comparability of treatment and control group is limited. To verify the preclusion of such a selection bias, we reestimate our benchmark model using propensity score matching to account for structural differences between treatment and control group. More precisely, we employ nearest neighbor matching on initial firm characteristics in 2000, the first year of our sample period, to find for each firm of the treatment group its most similar counterpart in the control group. The nearest neighbor for a firm is found by estimating a Probit model for being in the treatment group. This is conducted by regressing a dummy for having access to a foreign patent box at some time during our sample period on our usual firm- and group-specific characteristics. Based on this Probit regression result, a propensity score is calculated for each firm. The propensity score statistic enables comparisons in terms of similarity of firms. Single nearest neighbor matching is then conducted by assigning each firm of the treatment group to the firm in the control group with the most similar propensity score. Our benchmark regression results in Table 5 are then reestimated on the sub-sample of treatment group firms and firms of the control group which are most similar to the treatment group. The estimated average treatment effect on the treated (ATT) in various specifications as reported in Table A.8 is similar to our benchmark regression results. Therefore, we rule out endogenous sorting of firms into the treatment group.

Further untabulated robustness checks include re-estimations of the benchmark model including industry-specific and location-specific time trends as well as separate time trends for MNEs and domestic firms. We obtain virtually the same results in all specifications.

5.4 Additional Analysis

In this section, we consider several extensions to our benchmark analysis. First, we examine heterogeneity across industry sectors to further further verify the plausibility of our results. Second, we compute the elasticity of R&D output to various measures of the effective tax burden within company groups. This exercise highlights more general aspects of our results. Finally, we complement our analysis of patent output using additional information on R&D expenditures of German firms to check whether the impact of the foreign, output-related tax incentives we study is also reflected in domestic R&D spending.

Industry Heterogeneity

Previous studies have shown that the responsiveness of corporate R&D activity to domestic tax incentives varies across industry sectors (Griffith *et al.*, 2014). This is likely to be the case for cross-border effects of taxation as well. Moreover, firms in different industries probably react differently to foreign patent boxes with and without nexus requirement. To explore these heterogeneities, we focus specifically on two sectors with different types of R&D activity: the Information and Communications Technology (ICT) sector and the manufacturing sector. The ICT sector is characterized by low relocation costs, in particular for software development which, for instance, does not require specific hardware. In contrast, R&D activity in the manufacturing sector, which includes large pharmaceutical and chemical companies, is usually concentrated in one place and not easily relocated to another country because of the immobility of invested R&D capital. Researchers in this sector are often highly specialized and not easily replaceable at a new location while laboratories are hard to move across long distances.

In Table A.5 in the Appendix, we analyze how firms in these two sectors respond to foreign tax incentives. Columns (1) to (4) report the results for the sub-sample of ICT firms. We find a significantly negative cross-border effect of nexus patent boxes on patent output. This is consistent with the notion that these tax regimes generally incentivize firms to relocate R&D activity away from locations with relatively higher taxation of patent income. ICT firms are more responsive to this incentive than the overall sample because the relocation cost for R&D in this sector is lower. We do not find a significant cross-border response to the implementation of patent havens. While the ICT sector experiences strong growth in patenting (e.g. Fink *et al.*, 2016), these patents are also more likely to be held together in one location as this strengthens the position of the owner in patent litigation that frequently occurs in this sector.[31] This inhibits the relocation of patents for profit shifting and, thus, also mitigates the response to foreign tax cuts on patent income without nexus requirements (i.e. patent havens).

Results for manufacturing firms are reported in columns (5) to (8) of Table A.5. We find no significant response to foreign nexus patent boxes which is consistent with the observation that the cost to relocate R&D activity is relatively high in this sector and firms are thus less reactive to foreign tax cuts that incentivize the relocation of R&D. However, innovation in the manufacturing sector usually occurs in the form of well-specified technologies and is easily patented. The ownership rights can then be transferred to other locations to benefit from tax cuts that do not require nexus (i.e. patent havens). This explains the significantly

[31] These cases regularly result in so-called "patent wars" with large costs. For instance, in a recent case Samsung was ordered to pay US$ 120 million to Apple for patent infringements in October 2016. This case had been open since 2012.

positive coefficient for foreign patent haven indicators.

The Effective Tax Burden of R&D

We now turn to implications of our findings for the measurement of the tax burden on corporate R&D investment in the presence of cross-border effects of tax cuts. An important issue raised by the literature on tax havens and investment of MNEs (e.g. Hong & Smart, 2010) is that the domestic tax rate of a jurisdiction is not very informative with respect to the tax environment faced by such firms for investing in this jurisdiction. Since internationally operating firms are able to shift part of their profit from one location to another, their effective tax burden in one location is likely to depend on the applicable tax rates in the whole group. With sufficiently low costs of profit shifting (e.g. when locating intellectual property rights to patent havens), it is the location with the lowest tax rate in the group that determines the effective tax burden of its members.

We test this notion by replacing the main variable of interest BOX in equation (4) by several measures for the effective tax rate for profits faced by a firm. We are interested in how R&D activity reacts to each of these measures. They include the statutory corporate income tax rate and the minimum tax rate on patent profits within the whole group. For the latter, we again distinguish between nexus patent boxes and patent havens. Effectively, we extend our analysis beyond the particular incidence of a foreign patent box implementation and exploit the full variance of tax rates on patent profits in a multinational group to identify cross-border effects on patent output.

Following Hong & Smart (2010) and Slemrod & Wilson (2009), the statutory tax rate should be most relevant for firms without foreign affiliates. If we take into account tax rate reductions of patent boxes without nexus requirement (patent havens), the minimum tax rate within a group should be more informative for the whole sample. Table 7 displays the results of this exercise. In column (1), the variable of interest is the statutory corporate income tax rate. The respective coefficient is negative but small and insignificant. This implies that the statutory tax rate is not very informative with respect to the tax environment of a firm in our sample that also includes large MNEs. In column (2), we restrict the sample to firms without foreign affiliates. The coefficient for the statutory corporate income tax rate is now larger and significantly negative. Our results suggest that for domestically operating firms a one percentage point decrease in the corporate income tax rate would raise R&D activity by about 0.7%. Next, we use the minimum tax rate on patent profits within the group of affiliates of a firm as a measure of the tax burden in column (3). In doing so, we take into account tax reductions resulting from the implementation of patent havens. In contrast to the regression in column (1), the coefficient for this adjusted tax rate measure is significantly negative and implies that an effective tax rate decrease by one percentage point leads to an increase of patent output by 0.3%.

Thus, our results indicate that the effective tax burden of a firm with respect to R&D investment is better described by also taking into account tax rate changes in the whole group. The statutory corporate income tax rate is, however, informative for firms that operate in one country only. Consistent with our expectation that cross-border effects only results from the implementation of patent haven regimes that allow for profit shifting, we do not find a significant effect of the minimum group tax rate when we account for tax cuts induced by foreign nexus patent boxes. The corresponding coefficient in column (4) is negative but insignificant.

R&D Expenditures

Our analysis focuses on R&D output measured by patent applications because this captures the firm response that directly corresponds to the output-related tax incentive we study. In the following extension, we investigate how this response transmits to R&D inputs. The level of innovation in a firm is not necessarily proportional to its R&D expenditure (Hausman *et al.*, 1984). However, if the change in corporate patent output that we measure in our benchmark analysis reflects an increase in innovative activity, we are likely to observe a similar cross-border effect of tax cuts on R&D expenditure.

Unfortunately, detailed information on R&D inputs is scarce. Firms are usually not required to report them and are generally reluctant to publish related data because of the strategic information contained in these figures. In the following analysis we use confidential survey data for German firms.[32] The data is collected on a biannual basis and feeds into the Eurostat database on corporate R&D. In this confidential database, total annual R&D expenditures together with R&D expenditure for R&D personnel and R&D equipment of German firms are reported. The identifier used by the Stifterverband is identical to the one in the Bureau van Dijk databases such that we can directly link our ownership and tax policy information as well as the relevant balance sheet items to the R&D expenditure data. In total, we obtain R&D expenditure information from 2001 to 2011 on a biannual basis for 3,762 German firms of our main sample (13,006 firm-year observations). Aligning the R&D expenditure information with the benchmark estimation sample ensures consistency across data sets. Furthermore, we focus on firms that file patent applications throughout the sample period such that the R&D expenditure we observe is closely linked to the firm's innovative output which the foreign tax cuts relate to. Descriptive statistics for the R&D expenditures are reported in Table A.9 in the Appendix.

We estimate a linear model that follows the specification defined in equation (4) but replace the patent count with the logarithm of firm-level R&D expenditure.[33] Results are presented in Table 8. In column (1), we use total R&D expenditures as the dependent variable. We obtain a significantly positive coefficient for the patent haven indicator which suggests a positive cross-border effect on R&D inputs of a tax cut that allows for profit shifting. This is consistent with our benchmark findings for R&D output. According to our estimates, the patent haven implementation in a foreign affiliate of a German firm increases its overall R&D expenditure by about 18.4%. We find no cross-border effect for nexus patent

[32] We use the R&D survey of the Wissenschaftsstatistik of the Stifterverband.

[33] Since the analysis is restricted to firms residing in Germany, we capture macro-economic shifts by including year-fixed effects as in the benchmark specification and drop macro-economic control variables due to collinearity.

boxes and attribute this result to the fact that in order to benefit from this type of foreign tax cut the firm is required to relocate R&D activity. This is costly in practice and, thus, rarely observed. In a next step, we disaggregate R&D expenditure into expenditure for personnel and expenditure for equipment and report results separately in columns (2) and (3). We estimate a significantly positive response of personnel expenditure. In our sample of German firms, it increases by 17.3% once a foreign patent haven is implemented. We also estimate a positive response for equipment expenditure which is, however, not significant. In columns (4) to (6), we repeat a robustness check from the benchmark analysis, by excluding all domestic firms from the estimation sample. In these regressions, we thus compare MNEs with and without affiliates in patent box locations. Our results with regard to the cross-border effect of tax cuts which allow for profit shifting are robust to this restriction. If anything, the estimated effect is larger.

6 Conclusion

In this paper, we combine information on firm ownership, administrative patent data and output-related R&D tax incentives to identify the cross-border effect of tax cuts within multinational groups. Our results indicate that within MNEs, the patent box implementation in one location also affects R&D output at other locations of the group. It increases the research activity there by 1.1% per percentage point of change in the cross-border tax rate differential. Consistent with our theoretical analysis, we find this effect only for patent boxes *without* nexus requirement (patent havens). In contrast, patent boxes *with* nexus requirement effectively preclude tax benefits from the transfer of intangibles and, thus, do not lower the effective tax burden on R&D investment across borders. However, for these nexus patent boxes we estimate a negative cross-border effect on patent quality. This implies that the cross-border effect of nexus boxes occurs with respect to the intensive rather than with respect to the extensive margin of corporate R&D location decisions.

These results have several important implications. First, they provide empirical evidence with regard to previous theoretical analyses (e.g. Desai *et al.*, 2006; Hong & Smart, 2010), who argue that the presence of low-tax countries reduces the user cost of capital for investment in high-tax countries. It is questionable whether tax havens are beneficial from an overall welfare perspective (see Slemrod & Wilson, 2009), but our analysis shows that the proposed mechanism is a relevant phenomenon for investments in intangible assets which are particularly mobile with regard to the location of related profits.

Second, these findings inform the ongoing debate on patent boxes and tax cuts on mobile types of income in general. Some countries have argued that patent boxes are not effective in fostering domestic research activity but merely constitute an instrument for harmful tax competition. Indeed, existing empirical studies have not yet robustly identified a direct effect of patent boxes on domestic innovation. The risk that these tax regimes merely provide an opportunity for profit shifting by transferring patents is arguably high and, thus, a negative cross-border effect on tax revenue is likely. However, our results show that the possibility of profit shifting implies that the real activity underlying these profits is not necessarily relocated as well. In contrast, it may even increase because tax benefits are realized across borders. In the context of intellectual property, this means that R&D remains in the location with the relatively higher tax burden. As a consequence, this location continues to benefit from R&D industry spillovers and other effects that have been cited as positive externalities of research activity (e.g. Jones & Williams, 1998). More generally, the insight that foreign tax cuts do not necessarily draw away real activity applies to all sector where profit generation and the underlying activity can be easily separated. For instance, profits in the fast growing digital economy are often difficult to tax.[34] At the same time, a large part of the real activity of this sector is clustered in high-tax locations such as the United States. Profit shifting allows these firms to effectively separate profits and real activity. As more firms develop sophisticated profit shifting strategies, the relevance of profit shifting for the cross-border

[34]For example, see the Base Erosion and Profit Shifting (BEPS) Action 1 of the OECD.

impact on corporate activity is likely to become more relevant over time. However, we caution against interpreting our findings as a positive cross-border effect of tax cuts on welfare. A first-best solution would always be to design a tax system in which the location of both the ownership and creation of an asset are independent of corporate taxation.

We note that our empirical analysis does not address all aspects of the preceding theoretical consideration. In particular, there are two consecutive firm responses to the creation of a foreign patent haven. Companies first raise R&D output and then locate the resulting patent rights to the patent box location. In our empirical estimation we have verified the first step, which is relevant for the cross-border implications of patent boxes on real R&D activity, and have left the analysis of the second step for future research. More generally, we are interested in the impact of patent boxes on corporate innovation rather than on the resulting profit allocation. As it is the case for many corporate investment decisions, the former effect depends on the *expected* tax rate on future profits. Thus, the change of *prospective* taxation induced by the patent box, which we capture in our empirical specification, is decisive. Even though we do not identify the second step, we note that recent findings by Ciaramella (2017) and Gaessler *et al.* (2017) on patent relocation and the implementation of patent boxes strongly point to the relevance of this effect. Furthermore, we note that empirical findings of previous studies suggest that profit shifting via the transfer of patent rights is a very relevant phenomenon (see Dischinger & Riedel, 2011; Karkinsky & Riedel, 2012). In fact, a recent empirical analysis by Koethenbuerger *et al.* (2016) on the effect of patent boxes on cross-border profit shifting suggests that the introduction of these regimes leads to a substantial transfer of profits to the affiliates that are located in the implementing countries.[35] Consistent with our analysis, this effect is confined to patent boxes without sufficient nexus requirements.

[35] On the reverse effect, Chen *et al.* (2016) show that patent boxes reduce outward profit shifting in the countries where they are implemented.

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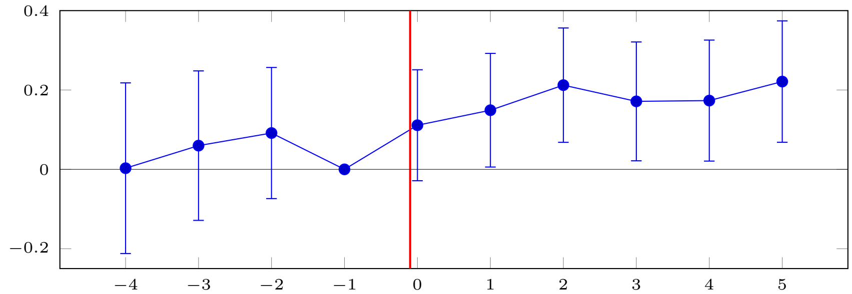
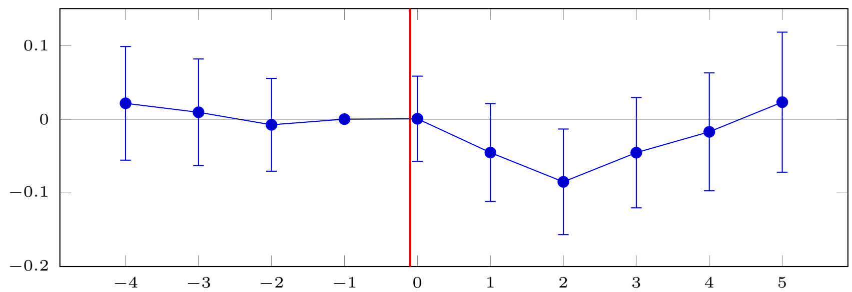
Figure 1: Event-study Design

(a) Patent Havens



(b) Nexus Boxes



This figure plots the event study estimates and corresponding 95% confidence bands. The model specification is explained in Appendix A.5. The plotted coefficients correspond to $\alpha_n, n \in [-4, 5]$. Standard errors are clustered at the firm level. The event variables are indicators for the implementation of a patent haven or a nexus patent box in a foreign affiliate location of the firm.

Table 1: New Patents, 2000-2012

	Number of firms in sample	Number of granted patent applications	Avg. new dom. patents per firm-year	Share of firms with affiliate in patent box location	
				Patent Haven	Nexus Patent Box
AT	1,086	6,162	0.50	0.25	0.26
BG	72	175	0.23	0.11	0.08
CH	1,337	8,604	0.55	0.40	0.39
CZ	808	2559	0.27	0.12	0.11
DE	11,849	67,250	0.48	0.19	0.22
DK	561	2,135	0.36	0.25	0.30
EE	46	97	0.21	0.03	0.06
FI	591	3,457	0.51	0.29	0.32
GB	4,035	17,541	0.38	0.29	0.34
GR	15	55	0.29	0.27	0.13
HR	21	32	0.13	0.14	0.14
IS	9	17	0.16	0.06	0.18
IT	3,288	13,101	0.34	0.11	0.12
LT	21	46	0.17	0.13	0.15
LV	44	87	0.20	0.06	0.06
NO	552	1,828	0.32	0.18	0.23
PL	489	1,743	0.31	0.16	0.18
PT	135	300	0.19	0.27	0.36
RO	157	403	0.22	0.06	0.06
SE	997	5,086	0.44	0.35	0.36
SI	172	621	0.31	0.09	0.09
TR	401	1,173	0.25	0.02	0.05
Total	26,686	132,472	0.43	0.21	0.24

Table 2: Patent box regimes in European countries

Country	Year of implementation	Corporate income tax rate (2015)	Patent box tax rate (2015)	Acquired Patents	Existing Patents
France	2000	34.0	16.8	Yes	Yes
Hungary	2003	19.0	9.5	Yes	Yes
Netherlands	2007	25.0	5.0	No	No
Spain	2008	30.0	12.0	No	Yes
Belgium	2008	34.0	6.8	No	No
Luxembourg	2008	29.2	5.8	No	No
Malta	2010	35.0	0.0	Yes	Yes
Cyprus	2012	10.0	2.5	Yes	Yes
United Kingdom	2013	20.0	12.0	No	Yes
Portugal	2014	22.5	11.3	No	No
Italy	2015	31.4	22.0	No	No
Turkey	2015	20.0	10.0	No	No
Ireland	2016	12.5	6.3	No	No

Source: IBFD; Alstadsæter *et al.* (2018); Evers *et al.* (2015). Note: Ireland initially introduced a patent box regime in 1973 but abolished it in 2010. It was reintroduced in 2016.

Table 3: Summary Statistics

	Number of Observations	Mean	Standard Deviation	Min	Max
New patent appl.	310,852	0.426	1.114	0	10
New patent appl. (qual. adj.)	310,852	0.242	0.693	0	9.570
BOX_{Haven}	310,852	0.198	0.399	0	1
BOX_{Nexus}	310,852	0.144	0.351	0	1
Δt (Haven)	310,852	0.134	1.398	-13.1	31.20
Δt (Nexus)	310,852	0.776	3.401	-8.850	40.25
Number of affiliates	310,852	20.028	66.850	1	2,566
Log Age	303,054	2.705	1.042	0.000	6.592
Log Total Assets	310,817	9.388	2.464	-8.151	19.842
Working Capital	310,817	-6.740	1921.617	-769,074	344,886
Log Capital Intensity	300,446	-2.690	2.189	-24.089	10.901
Corporate income tax rate	310,852	31.856	6.925	10	52
User cost of R&D capital	310,852	0.344	0.024	0.115	0.364
Real interest rate	301,420	0.056	0.020	-0.014	0.265
R&D expenditures (% of GDP)	308,611	2.140	0.721	0.323	3.914
Log GDP p.c.	310,852	10.427	0.421	7.920	11.143
GDP Growth	310,852	1.455	2.655	-14.814	11.902

Table 4: Treated vs. Non-treated Firms

Panel A: Distribution Across Industries (Share of firms in industry)

	Manufacturing	Transportation and Storage	Information & Communication	Professional, Scientific & Technical Activities	Administrative & Support Service Activities
Treated	0.7255	0.0042	0.0403	0.2023	0.0277
Non-treated	0.7622	0.0052	0.0486	0.1498	0.0342

Panel B: Means of Key Variables

	User cost of R&D Capital	CIT	Log GDP per capita	Total Assets (th. USD)	Age	No. of affiliates
Treated	0.337	31.523	10.447	160,967.3	24.333	36.160
Non-treated	0.352	32.212	10.406	120,298.9	22.949	2.740
Difference	0.015	0.689	-0.040	-40,668.4	-1.384	-33.421
	(0.000)	(0.025)	(0.002)	(1403.082)	(0.096)	(0.232)

This table reports summary statistics for treated and non-treated firms. Treated firms are all firms that have an affiliate in a patent box country during the sample period. Non-treated firms are all other firms. The third line in Panel B reports the difference in means for the indicated variables, standard deviations are reported in parentheses.

Table 5: Benchmark

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	No. of new Patents						No. of new Patents (quality-weighted)		No. of new Patents OLS		No. of new Patents IV	
BOX_{Haven}	0.140***		0.140***				0.165***		0.042***		0.069*	
	(0.054)		(0.054)				(0.058)		(0.016)		(0.039)	
BOX_{Nexus}		0.005	0.003				-0.022		-0.018**		-0.019**	
		(0.024)	(0.024)				(0.025)		(0.007)		(0.009)	
$BOX_{Haven} \times \Delta t$				0.011***		0.011***		0.012**		0.003**		0.007*
				(0.004)		(0.004)		(0.005)		(0.001)		(0.004)
$BOX_{Nexus} \times \Delta t$					-0.002	-0.002		-0.004*		-0.002***		-0.002**
					(0.002)	(0.002)		(0.002)		(0.001)		(0.001)
R&D Exp.	0.366***	0.368***	0.366***	0.368***	0.367***	0.366***	0.450***	0.446***	0.080***	0.079***	0.075***	0.073***
	(0.058)	(0.058)	(0.058)	(0.058)	(0.058)	(0.058)	(0.063)	(0.063)	(0.011)	(0.011)	(0.011)	(0.011)
Log GDP p.c.	-0.581***	-0.578***	-0.581***	-0.580***	-0.579***	-0.581***	0.517**	0.513**	-0.155***	-0.155***	-0.183***	-0.184***
	(0.208)	(0.208)	(0.208)	(0.208)	(0.208)	(0.208)	(0.218)	(0.218)	(0.033)	(0.033)	(0.033)	(0.033)
CIT	-0.000	-0.000	-0.000	-0.000	0.000	0.000	-0.003	-0.003	-0.000	-0.000	0.000	0.000
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.001)	(0.001)
GDP Growth	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	-0.012**	-0.012**	-0.000	-0.000	-0.001	-0.001
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)	(0.001)	(0.001)
User Cost of R&D	-4.608***	-4.618***	-4.613***	-4.596***	-4.589***	-4.574***	-3.282***	-3.257***	-0.900***	-0.903***	-0.950***	-0.948***
	(0.505)	(0.505)	(0.505)	(0.504)	(0.504)	(0.504)	(0.538)	(0.538)	(0.077)	(0.077)	(0.078)	(0.078)
Real interest rate	-1.149**	-1.146**	-1.150**	-1.146**	-1.144**	-1.145**	-1.524***	-1.525***	-0.220***	-0.222***	-0.230***	-0.233***
	(0.459)	(0.459)	(0.459)	(0.459)	(0.459)	(0.459)	(0.474)	(0.473)	(0.081)	(0.081)	(0.081)	(0.081)
No. of affiliates	0.060**	0.077***	0.060**	0.062**	0.082***	0.066**	0.038	0.048	0.016**	0.018**	0.006	0.006
	(0.029)	(0.028)	(0.030)	(0.030)	(0.028)	(0.029)	(0.032)	(0.032)	(0.007)	(0.007)	(0.009)	(0.009)
Log Age	0.074***	0.074***	0.074***	0.074***	0.073***	0.073***	0.069***	0.069***	0.019***	0.020***	0.017***	0.017***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.021)	(0.021)	(0.004)	(0.004)	(0.004)	(0.004)
Log Total Assets	0.045***	0.045***	0.045***	0.045***	0.045***	0.045***	0.034***	0.034***	0.007***	0.007***	0.006***	0.006***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)
Working Capital	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Capital Intensity	0.016***	0.016***	0.016***	0.016***	0.016***	0.017***	0.015***	0.016***	0.002***	0.002***	0.002***	0.002***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)	(0.001)	(0.001)
N	276,048	276,048	276,048	276,048	276,048	276,048	268,427	268,427	315532.000	315,532	297,480	297,480
No. of firms	24,346	24,346	24,346	24,346	24,346	24,346	23,642	23,642	29,666	29,666	28,915	28,915
Pseudo LL	-154,176	-154,184	-154,176	-154,178	-154,183	-154,176.	-93,473	-93,472	-171,683	-171,686	-158,221	-158,234
F-statistics	–	–	–	–	–	–	–	–	–	–	988.752	291.046

Estimation of a Poisson fixed effects model except for columns (9) to (12) where a linear fixed effects model is estimated using an inverse hyperbolic sine transformation. The dependent variable is the (quality-weighted) number of new domestic patents per year and firm. Columns (11) and (12) report results for an instrumental variable regression. Kleibergen-Paap rk Wald F-statistics for exclusion of the instruments in the first-stage are reported. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 6: Patent Quality

	Patent Quality					
		Full Sample			Restricted Sample	
	(1)	(2)	(3)	(4)	(5)	(6)
BOX_{Haven}	0.036		0.025	0.034		0.025
	(0.027)		(0.028)	(0.027)		(0.028)
BOX_{Nexus}		-0.038***	-0.034***		-0.034***	-0.034***
		(0.010)	(0.010)		(0.010)	(0.010)
R&D exp.	0.079***	0.080***	0.090***	0.079***	0.083***	0.090***
	(0.028)	(0.028)	(0.031)	(0.028)	(0.031)	(0.031)
Log GDP p.c.	-0.132	-0.133	-0.131	-0.123	-0.129	-0.131
	(0.091)	(0.091)	(0.099)	(0.092)	(0.099)	(0.099)
CIT	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
GDP Growth	0.001	0.001	-0.001	0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)
User Cost of R&D	-1.240***	-1.179***	-0.408	-1.242***	-0.401	-0.408
	(0.278)	(0.279)	(0.344)	(0.281)	(0.340)	(0.344)
Real interest rate	-0.494*	-0.482*	-0.281	-0.512*	-0.284	-0.281
	(0.265)	(0.265)	(0.293)	(0.269)	(0.288)	(0.293)
Log no. of affiliates	-0.030**	-0.019	-0.025*	-0.028**	-0.023*	-0.025*
	(0.012)	(0.012)	(0.013)	(0.012)	(0.012)	(0.013)
Log Age	-0.004	-0.005	-0.010	-0.004	-0.010	-0.010
	(0.011)	(0.011)	(0.012)	(0.011)	(0.012)	(0.012)
Log Total Assets	-0.024***	-0.023***	-0.025***	-0.024***	-0.024***	-0.025***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.004)
Working Capital	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Capital Intensity	0.001	0.001	-0.001	0.000	-0.000	-0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
N	62,323	62,323	47,151	61,131	47,786	47,151
No. of firms	23,840	23,840	16,160	23,294	16,369	16,160
R^2	0.014	0.014	0.014	0.014	0.014	0.014

Estimation of an OLS fixed effects model. The dependent variable is the logarithm of average patent quality per year and firm for domestic patents. The full sample is used in the regressions presented in columns (1)-(3), while the sample is restricted to firms which have patent applications before and after the implementation of a foreign patent box in regressions presented in columns (4)-(6). Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 7: R&D Activity and Corporate Taxation

	No. of new Patents			
	(1)	(2)	(3)	(4)
	Full Sample	Domestic Firms	Full Sample	Full Sample
CIT	-0.000	-0.007**		
	(0.002)	(0.003)		
Minimum Tax Rate (Patent Havens)			-0.003**	
			(0.002)	
Minimum Tax Rate (Nexus Boxes)				-0.001
				(0.001)
N	276,048	179,162	276,048	276,048
No. of firms	24,346	16,202	24,346	24,346
Pseudo LL	-154,184	-81,597	-154,180	-154,183

Estimation of a Poisson fixed effects model. The dependent variable is the number of new domestic patents per year and firm. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects and the firm-, location- and group-specific controls of the benchmark model (results are reported in Table A.7). Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table 8: R&D Expenditures

	(1)	(2)	(3)	(4)	(5)	(6)
	R&D Expenditures (all firms)			R&D Expenditures (MNE only)		
	Total	Personnel	Equipment	Total	Personnel	Equipment
BOX_{Haven}	0.184*	0.173**	0.144	0.213**	0.186*	0.245*
	(0.096)	(0.086)	(0.158)	(0.107)	(0.104)	(0.149)
BOX_{Nexus}	0.031	-0.001	0.082	0.020	0.021	0.064
	(0.036)	(0.043)	(0.055)	(0.040)	(0.052)	(0.064)
No. of affiliates	0.043	0.078*	0.054	0.086	0.163	0.103
	(0.038)	(0.041)	(0.056)	(0.099)	(0.102)	(0.134)
Log Age	0.0304	0.057	-0.020	-0.010	0.051	-0.023
	(0.047)	(0.055)	(0.078)	(0.061)	(0.075)	(0.105)
Log Total Assets	0.024***	0.027**	0.015	0.029*	0.036	0.025
	(0.009)	(0.013)	(0.016)	(0.017)	(0.031)	(0.034)
Working Capital	0.002	0.004	0.000	-0.003	-0.009	0.049
	(0.005)	(0.011)	(0.008)	(0.043)	(0.065)	(0.067)
Log Capital Intensity	0.015	0.027*	0.037**	0.025*	0.076*	0.095**
	(0.008)	(0.015)	(0.016)	(0.015)	(0.045)	(0.045)
N	13,006	13,006	13,006	6,156	6,156	6,156
No. of firms	3,762	3,762	3,762	1,712	1,712	1,712
R^2	0.034	0.035	0.008	0.042	0.040	0.017

Estimation of a fixed effects model. The dependent variable is the logarithm of R&D expenditure in the indicated area per year and firm. In columns (1) and (4), we use the total R&D expenditure of a firm while we focus expenditure for personnel in columns (2) and (5) and on equipment expenditure in columns (3) and (6). Columns (1) to (3) use the full sample. We restrict the sample to MNEs in columns (4) to (6). Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.
Data source R&D expenditures: SV Wissenschaftsstatistik GmbH, RDC, R&D Surveys 2001-2011, own calculations.

Appendix

A.1 Patent Boxes and Average Patent Quality

The average profits are given by

$$\Pi = \int_{\tilde{\pi}^*}^{\tilde{\pi}} \pi_s f(\pi_s)\, d\pi_s.$$

The change in Π with respect to the tax differential is given by

$$d\Pi = -\left((1-\alpha) \frac{(c_p - c_h)\, \tilde{\pi} f(\tilde{\pi})}{((1-\alpha)\, \Delta t)^2} + \alpha \frac{c_h \tilde{\pi}^* f(\tilde{\pi}^*)}{(1 - t_h + \alpha \Delta t)^2} \right) d\Delta t < 0.$$

A.2 Graphical Illustration of the Theoretical Framework

In Figure A.1 we display the effect of the patent box introduction graphically. We plot the density function of the profits of available research projects and mark the relevant cut-off profits. Initially, the firm realizes projects with profits greater than $\tilde{\pi}^*$ but locates R&D activity of projects with profits greater than $\tilde{\pi}$ to p. The overall share of projects realized in h is thus given by $A+B$. The introduction of a patent box in p shifts $\tilde{\pi}$ and $\tilde{\pi}^*$ to $\tilde{\pi}'$ and $\tilde{\pi}^{*'}$, respectively, such that the share of realized projects is given by $A+B'$. The overall effect relies on a comparison of B and B' which in turn depends on the setup of the patent box. B' refers to the increase of realized R&D projects in h because of the reduction in the user cost of R&D capital captured in the second term of equation (3). B describes the R&D activity which is shifted to p because of the foreign tax cut that reduces the number of projects realized in h and is reflected in the first term of expression (3). For a patent haven, α is close to 1 and $B = 0$ such that we obtain an increase in the share of R&D projects realized in h by B'. In contrast, when a nexus patent box is implemented, B and B' may neutralize each other leaving the number of research projects in h unchanged. Eventually, the direction of the effect is an empirical question and our analysis points out that it is important to take into account the precise incentive structure of the investigated patent box.

A.3 Composite Patent Quality Indicator

Patent quality is a latent variable which is not directly observable in the data. To approximate it, we follow the approach proposed by Lanjouw & Schankerman (2004) and employ a multiple-indicator model with one unobserved common factor. We use three different indicators, namely forward citations, patent family size and number of patent classifications codes (IPC classes). Therefore, the underlying equations for the multiple-indicator model are

$$y_{k,s} = \lambda_k v_s + \boldsymbol{\beta X} + e_{k,s}, \; k \in \{1, 2, 3\}$$

where $y_{k,s}$ is the value of quality indicator k for patent s, v_s indicates the common factor, λ_k represents the factor loading, $\boldsymbol{X}$ contains common controls and $e_{k,s} \sim N(0, \sigma^2)$ is the idiosyncratic component with $Cov(e_{k,s}, e_{k,r}) = 0$, $s \neq r$. Since the term $\lambda_k v_s$ is latent, we estimate the reduced form of the equations:

$$y_{k,s} = \boldsymbol{\beta X} + u_{k,s}, \; k \in \{1, 2, 3\}$$

where $u_{k,s} = \lambda_k v_s + e_{k,s}$ combines a common component $\lambda_k v_s$ and an idiosyncratic component $e_{k,s}$. We estimate these equations using 3SLS where $\boldsymbol{X}$ contains the year of application and the main technology class of the patent. To gather λ_k and v_s, we conduct a factor analysis using maximum likelihood to decompose $u_{k,s}$. The estimated factor loadings are presented in Table A.1.

We use the estimated factor loadings to calculate the composite quality indicator for each patent. The composite quality indicator is a relative measure to determine the quality of patents and is normally distributed with mean zero. To construct the quality-weighted annual patent count, we transform the distribution by adding the value of the patent with lowest patent quality so that all composite quality indicators turn positive. After this transformation the composite quality indicator for each patent has a positive value and can be used as weight for summing up patent output. The implied relative ordering of the quality of patents is unaffected by this transformation.

A.4 User Cost of R&D Investment

The computation of the user cost follows the derivation of Bloom *et al.* (2002) who extend its standard expression as presented by Hall & Jorgenson (1967) to R&D investment. The user cost is defined as the pre-tax financial return ρ for a marginal R&D investment project (i.e. a project with zero economic rent). The economic rent of an R&D project is given by

$$\begin{aligned} R &= (1+i)\, dV_t = dD_t + dV_{t+1} \\ &= \frac{(\rho+\delta)\left(1-\tau^{CIT}\right)+(1-\delta)\, A}{1+r} - (1-A) \end{aligned}$$

where dV_t is the change in the market value of the firm and dD_t is the change in dividends paid out by the firm that results from the investment. i denotes the nominal and r the real market interest rate and δ is the economic rate of depreciation. A is the net present value of allowances. Following Thomson (2013) and Warda (2002), we assume the R&D investment to consist of an investment in labor (60%), machinery and equipment (5%), buildings (5%) and other current expenditures (30%). A accounts for additional deductions, tax credits and accelerated depreciation. To obtain the user cost, we set $R = 0$ and solve for ρ. This yields

$$\rho = \frac{1-\left(A^D + A^C\right)}{1-\tau^{CIT}}\,(r+\delta) \tag{A.1}$$

We compute ρ_{ct} for every country and year and follow Bloom *et al.* (2002) in setting $\delta = 0.3$ and $r = 0.05$. Tax policy variables are obtained from the IBFD database.

A.5 Event-study design

The event-study design follows the setup and is specified as:

$$
\begin{aligned}
P_{ijct} = \alpha_{-5} \sum_{n=5}^{t-2000} b_{j,t-n}^{Haven} + \sum_{n=-4}^{-2} \alpha_n b_{j,t+n}^{Haven} + \sum_{n=0}^{5} \alpha_n b_{j,t+n}^{Haven} + \alpha_6 \sum_{n=6}^{2012-t} b_{j,t+n}^{Haven} \\
+ \eta_{-5} \sum_{n=5}^{t-2000} b_{j,t-n}^{Nexus} + \sum_{n=-4}^{-2} \eta_n b_{j,t+n}^{Nexus} + \sum_{n=0}^{5} \eta_n b_{j,t+n}^{Nexus} + \eta_6 \sum_{n=6}^{2012-t} b_{j,t+n}^{Nexus} \\
+ \boldsymbol{\beta X_{it}} + \boldsymbol{\gamma Z_{jt}} + \boldsymbol{\delta C_{ct}} + \boldsymbol{\phi_t} + \boldsymbol{\phi_i} \quad \text{(A.2)}
\end{aligned}
$$

P_{ijct} is the number of newly granted patent applications of firm i which is member of multinational group j and is located in country c in period t, and $b_{j,t}^{Haven}$ ($b_{j,t}^{Nexus}$) is a dummy that indicates whether in year t group j has an affiliate in a country where a patent box with(out) nexus requirement is implemented and zero otherwise. Within the first and last year in our sample, 2000 and 2012, we define an event window of 12 years, that is, we observe 5 years before and 6 years after the implementation of the patent box as well as the implementation year itself. In each year, we thus compare the treated firms to those that do not have a foreign patent box affiliate. Following Kline (2012) we adjust the end points of the event window to indicate whether a foreign patent box has been implemented 5 or more years before (upper window limit) and 6 or more years after a given year (lower window limit) in order to mitigate collinearity with the year-fixed effects. To avoid perfect collinearity among the patent box indicators, the regressor in the year before the implementation is dropped and thereby normalized to zero. As a consequence, the remaining coefficients α_t are interpreted as the effect of the patent box implementation on P_{ijct} relative to the pre-reform year. The regression is complemented by a set of control variables which are identical to the main specification (4) as well as a set of firm-fixed and year-fixed effects.

In our benchmark estimate, we estimate a Poisson model to obtain the coefficients of the event study. Below, we also plot the results for a linear estimation. In this case, P_{ijct} is the inverse hyperbolic sine transformation of the number of newly granted patent applications.

A.6 Additional Tables and Figures

Figure A.1: Profit distribution and realized R&D projects

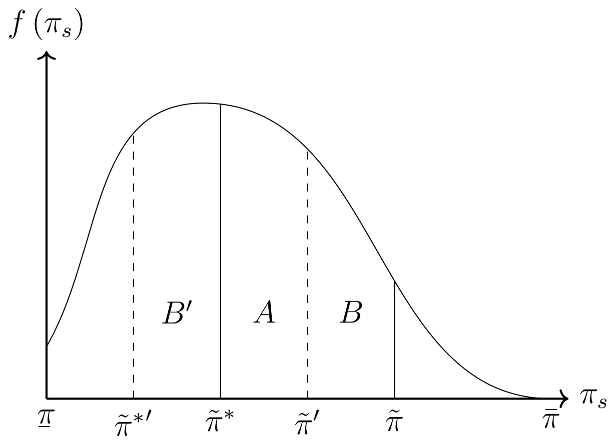
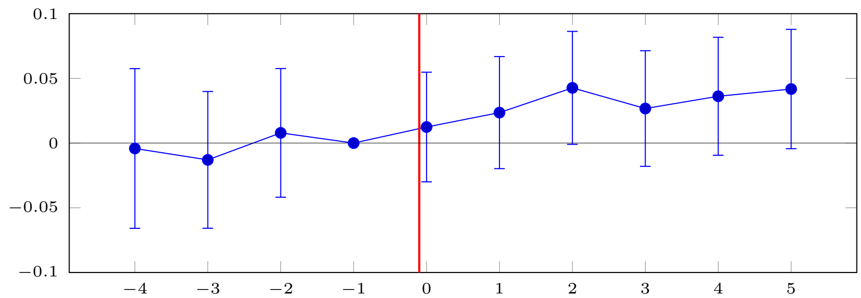
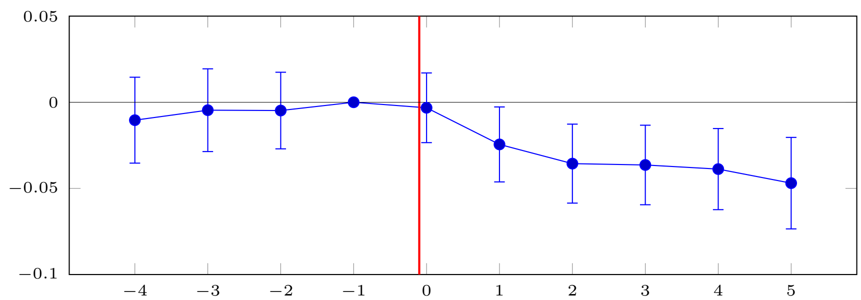


Figure A.2: Event-study Design (Linear Model)

(a) Patent Havens



(b) Nexus Boxes



This figure plots the event study estimates and corresponding 95% confidence bands. The model specification is explained in Appendix Event-study design. The plotted coefficients correspond to $\alpha_n, n \in [-4, 5]$. Standard errors are clustered at the firm level. The event variables are indicators for the implementation of a patent haven or a nexus patent box in a foreign affiliate location of the firm.

Figure A.3: Graphical Illustration of the Conceptual Framework

This figure illustrates the concept of this paper. The focus of the analysis is R&D activity of firm 1, located in country A with an affiliate in country B. We investigate the response of R&D activity of firm 1 to the patent box implementation in country B. Empirically, this is done by comparing firm 1 to another firm 2 which may have a a foreign affiliate in a country C but is not linked via an affiliate to the patent box country B.

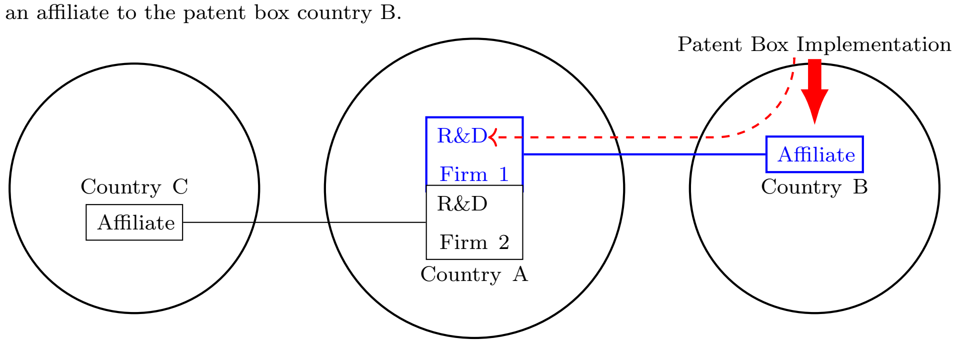


Table A.1: Factor loadings

Indicator	Factor loading
Forward citations	0.6201
Patent family size	0.3593
Patent classification codes	0.1229

Factor analysis of the residuals from regressing each indicator on year and industry class dummies. Factor loadings represent both weighting of the indicator and correlation between indicator and patent quality.

Table A.2: Sample Selection

	Number of Firms in the Sample
Firms in patenting sectors that conduct R&D with data for 2000-2012	38,844
Excluding firms located in patent box countries	31,023
Trimming at the 99% quantile of the patent count	30,927
Excluding firms with no patent application in the observation period	26,686

This table displays the sample selection. Patenting sectors are defined by 2-digit NACE Rev. 2 codes 10-32, 51-53, 58-63, 69-74 and 77-82. Firms that conduct R&D are defined as firms included in the PATSTAT database that have successfully filed a patent application at any point in time.

Table A.3: Extended Sample (2000-2015)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	No. of new Patents						No. of new Patents (quality-weighted)		No. of new Patents Linear Model	
BOX_{Haven}	0.135**		0.135**				0.171***		0.037**	
	(0.054)		(0.054)				(0.059)		(0.015)	
BOX_{Nexus}		-0.001	-0.004				-0.036		-0.015**	
		(0.023)	(0.023)				(0.024)		(0.006)	
$BOX_{Haven} \times \Delta t$				0.010**		0.010**		0.011**		0.002*
				(0.004)		(0.004)		(0.005)		(0.001)
$BOX_{Nexus} \times \Delta t$					-0.002	-0.002		-0.005**		-0.001***
					(0.002)	(0.002)		(0.002)		(0.000)
R&D Exp.	0.447***	0.449***	0.447***	0.448***	0.446***	0.445***	0.540***	0.536***	0.086***	0.086***
	(0.054)	(0.054)	(0.054)	(0.054)	(0.055)	(0.055)	(0.060)	(0.060)	(0.010)	(0.010)
Log GDP p.c.	-0.461**	-0.458**	-0.461**	-0.459**	-0.460**	-0.461**	0.604***	0.597***	-0.153***	-0.153***
	(0.187)	(0.187)	(0.187)	(0.187)	(0.187)	(0.187)	(0.201)	(0.201)	(0.028)	(0.028)
CIT	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.003	-0.003	-0.000	-0.000
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)
GDP Growth	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.014***	-0.014***	-0.000	-0.000
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)
User Cost of R&D	-5.030***	-5.033***	-5.025***	-5.025***	-5.014***	-5.001***	-3.870***	-3.865***	-0.911***	-0.913***
	(0.451)	(0.451)	(0.451)	(0.450)	(0.450)	(0.450)	(0.467)	(0.467)	(0.070)	(0.070)
Real interest rate	-1.202***	-1.198***	-1.201***	-1.198***	-1.200***	-1.200***	-1.677***	-1.681***	-0.270***	-0.271***
	(0.453)	(0.454)	(0.453)	(0.453)	(0.453)	(0.453)	(0.467)	(0.467)	(0.078)	(0.078)
No. of affiliates	0.065**	0.083***	0.066**	0.068**	0.088***	0.073***	0.043	0.055*	0.011	0.013*
	(0.027)	(0.026)	(0.027)	(0.027)	(0.026)	(0.027)	(0.029)	(0.029)	(0.007)	(0.007)
Log Age	0.067***	0.067***	0.067***	0.067***	0.067***	0.067***	0.064***	0.063***	0.020***	0.020***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.020)	(0.020)	(0.003)	(0.003)
Log Total Assets	0.043***	0.043***	0.043***	0.043***	0.044***	0.044***	0.033***	0.033***	0.006***	0.006***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)
Working Capital	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Capital Intensity	0.016***	0.016***	0.016***	0.016***	0.016***	0.016***	0.016***	0.016***	0.002***	0.002***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.001)	(0.001)
N	307,434	307,434	307,434	307,434	307,434	307,434	298,870	298,870	343,903	343,903
No. of firms	25,307	25,307	25,307	25,307	25,307	25,307	24,568	24,568	30,205	30,205
Pseudo LL	-165,431	-165,440	-165,431	-165,434	-165,438	-165,432	-100,202	-100,202	-184,491	-184,493

Estimation of a Poisson fixed effects model except for columns (9) and (10) where a linear fixed effects model is estimated using an inverse hyperbolic sine transformation. The dependent variable is the (quality-weighted) number of new domestic patents per year and firm. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. The sample uses the same observations as the benchmark regression and adds observations for the years 2013-15. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.4: MNEs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(7)	(8)
			No. of new Patents				No. of new Patents (quality-weighted)		No. of new Patents Linear Model	
BOX_{Haven}	0.115* (0.061)		0.114* (0.061)				0.155** (0.065)		0.036* (0.019)	
BOX_{Nexus}		0.027 (0.028)	0.027 (0.028)				0.011 (0.029)		-0.004 (0.009)	
$BOX_{Haven} \times \Delta t$				0.016*** (0.006)		0.016*** (0.006)		0.019*** (0.006)		0.004** (0.002)
$BOX_{Nexus} \times \Delta t$					0.000 (0.002)	-0.000 (0.002)		-0.002 (0.002)		-0.001 (0.001)
R&D Exp.	0.371*** (0.076)	0.373*** (0.076)	0.371*** (0.076)	0.373*** (0.076)	0.373*** (0.076)	0.373*** (0.076)	0.411*** (0.082)	0.411*** (0.082)	0.111*** (0.019)	0.110*** (0.019)
Log GDP p.c.	-0.971*** (0.357)	-0.963*** (0.357)	-0.972*** (0.357)	-0.973*** (0.356)	-0.962*** (0.358)	-0.974*** (0.357)	-0.130 (0.377)	-0.135 (0.377)	-0.295*** (0.077)	-0.299*** (0.077)
CIT	0.005 (0.003)	0.005* (0.003)	0.005 (0.003)	0.005 (0.003)	0.005* (0.003)	0.005 (0.003)	-0.000 (0.003)	0.000 (0.003)	0.001 (0.001)	0.001 (0.001)
GDP Growth	-0.000 (0.007)	-0.001 (0.007)	-0.001 (0.007)	-0.000 (0.007)	-0.000 (0.007)	-0.000 (0.007)	-0.004 (0.007)	-0.004 (0.007)	-0.001 (0.002)	-0.001 (0.002)
User Cost of R&D	-1.482* (0.888)	-1.499* (0.888)	-1.492* (0.888)	-1.440 (0.885)	-1.489* (0.887)	-1.440 (0.885)	-1.475 (0.940)	-1.439 (0.939)	-0.414** (0.190)	-0.410** (0.190)
Real interest rate	-0.028 (0.642)	-0.035 (0.642)	-0.032 (0.642)	-0.019 (0.642)	-0.031 (0.642)	-0.019 (0.642)	-0.732 (0.654)	-0.725 (0.653)	-0.141 (0.156)	-0.141 (0.155)
No. of affiliates	0.065 (0.047)	0.080* (0.045)	0.061 (0.047)	0.069 (0.046)	0.084* (0.045)	0.069 (0.047)	0.035 (0.048)	0.049 (0.047)	0.027* (0.016)	0.030* (0.016)
Log Age	0.066** (0.030)	0.066** (0.030)	0.066** (0.030)	0.066** (0.030)	0.066** (0.030)	0.066** (0.030)	0.052 (0.033)	0.052 (0.033)	0.028*** (0.009)	0.028*** (0.009)
Log Total Assets	0.066*** (0.010)	0.066*** (0.010)	0.066*** (0.010)	0.066*** (0.010)	0.066*** (0.010)	0.066*** (0.010)	0.057*** (0.011)	0.057*** (0.011)	0.015*** (0.002)	0.015*** (0.002)
Working Capital	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000*** (0.000)	-0.000*** (0.000)
Log Capital Intensity	0.021** (0.009)	0.021** (0.009)	0.021** (0.009)	0.021** (0.009)	0.021** (0.009)	0.021** (0.009)	0.022** (0.009)	0.022** (0.009)	0.003 (0.002)	0.003 (0.002)
N	94,112	94,112	94,112	94,112	94,112	94,112	92,716	92,716	107,908	107,908
No. of firms	8,494	8,494	8,494	8,494	8,494	8,494	8,363	8,363	10,397	10,397
Pseudo LL	-70,788	-70,791	-70,786	-70,786	-70,793	-70,786	-47,047	-47,046	-74,886	-74,884

Estimation of a Poisson fixed effects model except for columns (9) and (10) where a linear fixed effects model is estimated using an inverse hyperbolic sine transformation. The dependent variable is the (quality-weighted) number of new domestic patents per year and firm. The sample only contains MNEs. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.5: Heterogeneity Across Industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		ICT				Manufacturing		
BOX_{Haven}	0.158 (0.123)		0.165 (0.123)		0.140** (0.061)		0.143** (0.061)	
BOX_{Nexus}		-0.143* (0.076)	-0.145* (0.076)			-0.016 (0.028)	-0.019 (0.028)	
$BOX_{Haven} \times \Delta t$				0.010 (0.011)				0.011** (0.005)
$BOX_{Nexus} \times \Delta t$				-0.017** (0.007)				-0.002 (0.002)
R&D Exp.	0.155 (0.175)	0.159 (0.175)	0.160 (0.175)	0.141 (0.177)	0.353*** (0.068)	0.355*** (0.068)	0.354*** (0.068)	0.353*** (0.069)
Log GDP p.c.	-0.311 (0.794)	-0.322 (0.781)	-0.328 (0.783)	-0.375 (0.784)	-0.738*** (0.229)	-0.732*** (0.228)	-0.735*** (0.229)	-0.735*** (0.228)
CIT	0.004 (0.006)	0.005 (0.006)	0.005 (0.006)	0.007 (0.006)	-0.002 (0.002)	-0.001 (0.002)	-0.002 (0.002)	-0.001 (0.002)
GDP Growth	-0.003 (0.016)	-0.002 (0.016)	-0.002 (0.016)	-0.003 (0.016)	-0.002 (0.006)	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)
User Cost of R&D	-4.238** (2.108)	-4.103** (2.092)	-4.070* (2.094)	-4.122** (2.090)	-4.518*** (0.553)	-4.490*** (0.553)	-4.486*** (0.554)	-4.484*** (0.552)
Real interest rate	-1.632 (1.612)	-1.650 (1.601)	-1.643 (1.602)	-1.629 (1.598)	-1.465*** (0.566)	-1.451** (0.566)	-1.459*** (0.565)	-1.461*** (0.565)
No. of affiliates	0.142 (0.089)	0.183** (0.081)	0.156* (0.088)	0.184** (0.092)	0.028 (0.039)	0.045 (0.037)	0.030 (0.039)	0.033 (0.038)
Log Age	0.016 (0.056)	0.006 (0.056)	0.005 (0.056)	0.006 (0.056)	0.072*** (0.025)	0.072*** (0.025)	0.072*** (0.025)	0.072*** (0.025)
Log Total Assets	0.050*** (0.016)	0.054*** (0.016)	0.054*** (0.016)	0.054*** (0.016)	0.044*** (0.007)	0.045*** (0.007)	0.044*** (0.007)	0.045*** (0.007)
Working Capital	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Log Capital Intensity	0.034*** (0.013)	0.034*** (0.013)	0.034*** (0.013)	0.034*** (0.012)	0.015** (0.006)	0.015** (0.006)	0.015** (0.006)	0.015** (0.006)
N	28,581	28,581	28,581	28,581	193,114	193,114	193,114	193,114
No. of firms	2,563	2,563	2,563	2,563	16,498	16,498	16,498	16,498
Pseudo LL	-15,441	-15,437	-15,435	-15,430	-109,018	-109,023	-109,017	-109,018

Estimation of a Poisson fixed effects model. The dependent variable is the number of new patents per year and firm for which the majority of inventors does not reside outside the country of residence of the firm. Columns (1)-(4) present estimations on the sample of ICT firms, columns (5)-(8) refer to results on the sample of manufacturing firms other than ICT. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.6: Excluding Firms with Patent Box specific Ownership Changes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			No. of new Patents				No. of new Patents (quality-weighted)		No. of new Patents Linear Model	
BOX_{Haven}	0.598***		0.596***				0.574***		0.180***	
	(0.157)		(0.157)				(0.172)		(0.045)	
BOX_{Nexus}		0.011	0.006				-0.034		-0.013	
		(0.031)	(0.031)				(0.033)		(0.010)	
$BOX_{Haven} \times \Delta t$				0.055***		0.055***		0.054***		0.014***
				(0.014)		(0.014)		(0.013)		(0.005)
$BOX_{Nexus} \times \Delta t$					0.002	0.002		-0.002		-0.000
					(0.003)	(0.003)		(0.003)		(0.001)
R&D Exp.	0.323***	0.331***	0.323***	0.326***	0.332***	0.326***	0.429***	0.429***	0.063***	0.063***
	(0.065)	(0.065)	(0.065)	(0.065)	(0.065)	(0.065)	(0.072)	(0.072)	(0.011)	(0.011)
Log GDP p.c.	-0.360	-0.373*	-0.361	-0.363	-0.372*	-0.362	0.916***	0.912***	-0.122***	-0.123***
	(0.224)	(0.224)	(0.224)	(0.224)	(0.224)	(0.224)	(0.234)	(0.234)	(0.033)	(0.033)
CIT	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003	-0.006**	-0.006**	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.000)	(0.000)
GDP Growth	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.016***	-0.016***	-0.000	-0.000
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.001)	(0.001)
User Cost of R&D	-5.257***	-5.284***	-5.266***	-5.274***	-5.294***	-5.298***	-3.930***	-3.977***	-0.943***	-0.951***
	(0.553)	(0.555)	(0.554)	(0.553)	(0.555)	(0.555)	(0.582)	(0.583)	(0.078)	(0.079)
Real interest rate	-1.279**	-1.273**	-1.281**	-1.287**	-1.273**	-1.288**	-1.741***	-1.756***	-0.232***	-0.234***
	(0.536)	(0.537)	(0.536)	(0.536)	(0.537)	(0.537)	(0.557)	(0.557)	(0.086)	(0.086)
No. of affiliates	0.098***	0.122***	0.097***	0.122***	0.122***	0.121***	0.088**	0.111***	0.021***	0.024***
	(0.034)	(0.033)	(0.034)	(0.033)	(0.033)	(0.033)	(0.036)	(0.034)	(0.008)	(0.008)
Log Age	0.082***	0.080***	0.082***	0.081***	0.081***	0.081***	0.077***	0.077***	0.017***	0.018***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)	(0.022)	(0.004)	(0.004)
Log Total Assets	0.038***	0.038***	0.038***	0.038***	0.037***	0.037***	0.026***	0.025***	0.005***	0.005***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.001)	(0.001)
Working Capital	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Capital Intensity	0.015***	0.016***	0.015***	0.016***	0.016***	0.016***	0.015***	0.015***	0.002***	0.002***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)
N	234,113	234,113	234,113	234,113	234,113	234,113	227,037	227,037	268,435	268,435
No. of firms	20,790	20,790	20,790	20,790	20,790	20,790	20,132	20,132	25,570	25,570
Pseudo LL	-119760.804	-119773.336	-119760.744	-119763.501	-119772.873	-119762.897	-70545.726	-70547.510	-133995.500	-134004.975

Estimation of a Poisson fixed effects model except for columns (9) and (10) where a linear fixed effects model is estimated using an inverse hyperbolic sine transformation. The dependent variable is the (quality-weighted) number of new domestic patents per year and firm. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.7: R&D Activity and Corporate Taxation: Controls

	No. of new Patents			
	(1) Full Sample	(2) Domestic Firms	(3) Full Sample	(4) Full Sample
R&D exp.	0.373***	0.308***	0.360***	0.365***
	(0.076)	(0.087)	(0.057)	(0.057)
Log GDP p.c.	-0.963***	-0.306	-0.574***	-0.575***
	(0.357)	(0.255)	(0.208)	(0.208)
GDP Growth	-0.000	-0.003	-0.003	-0.002
	(0.007)	(0.007)	(0.005)	(0.005)
User Cost of R&D	-1.489*	-6.291***	-4.551***	-4.607***
	(0.887)	(0.610)	(0.503)	(0.504)
Real interest rate	-0.031	-1.898***	-1.215***	-1.165***
	(0.642)	(0.662)	(0.445)	(0.445)
Log no. of affiliates	0.084*	0.111**	0.069**	0.073***
	(0.045)	(0.047)	(0.028)	(0.028)
Log Age	0.066**	0.078***	0.073***	0.074***
	(0.030)	(0.025)	(0.020)	(0.020)
Log Total Assets	0.066***	0.034***	0.046***	0.045***
	(0.010)	(0.006)	(0.005)	(0.005)
Working Capital	-0.000	0.000*	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Log Capital Intensity	0.021**	0.015***	0.016***	0.016***
	(0.009)	(0.005)	(0.005)	(0.005)

This table reports the coefficients of the control variables for the estimations reported in Table 7. Estimation of a Poisson fixed effects model. The dependent variable is the number of new domestic patents per year and firm. Cluster robust standard errors (clustered at the firm level) are provided in parentheses. All regressions include firm- and year-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.8: Average treatment effect on the treated using matching

	(1)	(2)	(3)	(4)	(5)	(6)
		No. of new patents			No. of new patents (quality-weighted)	
ATT BOX_{Haven}	0.192***		0.174***	0.222***		0.178***
	(0.055)		(0.062)	(0.059)		(0.067)
ATT BOX_{Nexus}		-0.006	0.000		-0.019	-0.018
		(0.035)	(0.034)		(0.036)	(0.035)
N	55,328	54,191	57,060	54,587	53,658	56,501
Number of firms	4,378	4,281	4,503	4,321	4,240	4,460
Pseudo R^2 (Matching)	0.592	0.561	0.556	0.592	0.561	0.556
Pseudo LL	-43,698	-43,882	-45,675	-29,378	-28,943	-30,054

Results from propensity score matching based on firm characteristics in year 2000 (single nearest neighbor matching). ATT denotes 'average treatment effect of the treated' and is calculated using a Poisson model. The calculation of the ATT includes firm-fixed effects. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

Table A.9: Summary Statistics: R&D Expenditures

	Number of Observations	Mean (logged)	Standard Deviation (logged)	Mean	Standard Deviation
R&D Expenditure, Total	13,633	7.772	1.633	2,373.213	3,946.653
R&D Expenditure, Equipment	13,633	5.442	2.426	230.904	560.171
R&D Expenditure, Employment	13,633	6.527	2.535	683.345	1,732.280

Data source R&D expenditures: SV Wissenschaftsstatistik GmbH, RDC, R&D Surveys 2001-2011, own calculations. Minimum and maximum values are not reported because of data confidentiality. All R&D expenditures in 1000 EUR.