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Corporate taxation and the quality of research and development

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Abstract This paper examines the impact of tax incentives on corporate research and development (R&D) activity. R&D tax incentives are commonly provided as special tax allowances or tax credits. In recent years, several countries also reduced their income tax rates on R&D output with the purpose to foster R&D activity. Previous papers have shown that all three tax instruments are effective in raising the *quantity* of R&D related activity. We in turn assess the impact of corporate tax incentives on the *quality* of R&D projects, i.e., their innovativeness and earnings potential. Using rich data on corporate patent applications to the European patent office, we find that a low tax rate on patent income raises the average profitability and innovation level of the projects undertaken in a country. The effect is statistically significant and economically relevant and prevails in a number of sensitivity checks. Generous R&D tax credits and tax allowances are in contrast found to exert a negative impact on project quality.

Keywords Corporate taxation · Research and development · Micro data

JEL Classification H3 · H7 · J5

1 Introduction

In recent decades, corporate tax policies related to research and development (R&D) have been high on governments' agendas in many countries. While, traditionally, tax

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incentives to foster R&D investment have been provided in the form of special tax allowances and tax credits, several countries recently also lowered their tax rates on patent income, including, among others, Luxembourg, the Netherlands and Belgium. The latest addition to the list is the United Kingdom, which reduced its tax rate on patent income from 23 % to 10 % in April 2013 with the intention "to strengthen the incentives to invest in innovative industries and ensure [that] the UK remains an attractive location for innovation."[1]

The economic literature argues that R&D tax incentives, irrespective of their particular design, increase inefficiently low R&D investments in the private sector, as they internalize positive externalities of technological inventions on other agents in the economy (see e.g., Nadiri 1993).[2] On top, R&D tax incentives may be instrumental in attracting internationally mobile R&D activities from abroad. A number of empirical studies assessed the effect of special tax provisions on the quantity of R&D activities undertaken in a country, commonly reporting significant and sizable effects for both, R&D tax allowances/credits and low patent income tax rates (e.g. Hines and Jaffe 2001; Bloom and Griffith 2001; Bloom et al. 2002; Ernst and Spengel 2011; Karkinsky and Riedel 2012).

The purpose of this paper is to analyse the impact of R&D tax incentives on the *quality* of R&D projects. We account for two quality dimensions: the project's profitability before taxes and subsidies and its degree of innovation. As will be shown, project profitability and innovativeness are positively correlated, i.e., high private returns go hand in hand with high levels of innovation, which in turn trigger high social returns through technological spillovers on other agents in the economy.

Our empirical analysis will account for the impact of R&D tax incentives, as captured by the average and marginal effective tax rates, on project quality. At the extensive margin (i.e., if MNEs are capacity constrained and decide on the location of a fixed number of R&D projects), MNEs have an incentive to distort the location of new R&D projects with a high expected profitability towards entities with a low expected average effective tax rate. Changes in expected project value and corporate tax rates may also trigger relocations of ongoing R&D projects (although the latter may involve non-negligible relocation costs).[3] As R&D is well known to earn above

[1] See paragraph 4.40 of HM Treasury, Pre-Budget Report 2009, December 2009. The UK regime will be phased in over four years. In 2013, companies were only entitled to 60 % of the full benefit, which will increase to 70 %, 80 %, 90 %, and 100 % in subsequent years (see Evers et al. 2013).

[2] Empirical evidence confirms that the social returns to R&D substantially outweigh their private returns (see e.g., Griliches 1994; Jones and Williams 1998; Griffith et al. 2004).

[3] Note that recent survey evidence suggests that the average duration of R&D projects until the patent application is rather short, less than two man-years in the large majority of cases (see Sadao and Walsh 2009). As tax reforms are commonly announced months or even years in advance, MNEs that decide on the location of R&D projects and form rational expectations on future tax rates likely obtain a quite precise predictor for the tax burden on the future income stream from the projects. The introduction of the UK patent box regime in 2013 was, e.g., announced in 2009 already. A number of companies declared to boost investment activity in the UK after the government announcement (see e.g., GlaxoSmithKline's press release on November 29, 2010: http://www.gsk.com/media/press-releases/2010/government-patent-box-proposals-transform-uk-attractiveness-for-investment.html). On top, besides the relocation channel spelled out in the main text, the quality of R&D projects may respond to changes in corporate taxation since high corporate taxes reduce the incentive to exert effort and may thus lower the

average returns (e.g. Hall et al. 2010), we will proxy for the average effective tax burden by the patent income tax rate (as the average effective tax converges to the patent income tax if profitability is high, see Devereux and Griffith 2003).[4] Generous R&D tax credits and allowances are, in a very general sense, not expected to be instrumental in attracting a positive selection of highly profitable projects since their value to the firm depends on the size of R&D expenditures instead of expected earnings.[5]

At the intensive margin, low patent income taxes and special R&D tax allowances/credits may induce a genuine increase in the R&D activity undertaken in a country by reducing marginal project costs. With a downward sloping marginal product curve, the new projects have a lower profitability though and thus the average profitability (and in consequence also the average innovativeness) of the project pool is expected to decrease. Our empirical analysis will model the marginal effective tax burden on R&D by the so-called B-index which accounts for R&D tax credits/tax allowances as well as for the country's corporate income tax rate.

The theoretical considerations show that low patent income taxes and generous R&D tax allowances/tax credits may exert very different effects on the average profitability and innovativeness of R&D projects. Taken together, we expect that an expansion of R&D tax allowances/credits reduces the average profitability of projects undertaken in a country, while effects related to low patent income tax rates are theoretically ambiguous. As project profitability and innovativeness are positively correlated, the argumentation furthermore carries over to the R&D's degree of innovation. See also our theoretical discussion in an earlier working paper version (Ernst et al. 2013).

To empirically assess the link between R&D tax incentives and R&D quality, we exploit information on the universe of patent applications to the European Patent Office (EPO) between 1995 and 2007 which is drawn from the PATSTAT data base. To proxy for the earnings potential and innovativeness of the technology protected by the patent, we follow previous research and exploit three indicators: the patent's number of forward citations, its family size (i.e., the number of countries in which the corporation filed for patent protection) and the number of industry classes stated on the patent.The patent information is, moreover, linked to data on multinational firms in Europe that allows us to control for observed and unobserved heterogeneity across patent inventing affiliates. On top, the data are augmented by information on national R&D tax incentives. We include information on the effective patent income tax rate, which accounts for taxes levied on patent income in the royalty receiving country, as well as for withholding taxes levied in the royalty paying country in case

Footnote 3 continued
quality of R&D. This applies for owner-managers, as well as for dependent employees if the latter own shares or stock options in the company or owners adjust incentive contracts in response to tax changes.

[4] While most countries tax patent income at the statutory corporate tax rate, some implemented special low tax rates on patent income (see also Sect. 2).

[5] Since tax authorities commonly do not grant tax refunds, this holds true as long as affiliate profits are high enough to ensure the affiliate can exploit the full value of the tax allowance/credit. If the value of the tax allowance/credit exceeds profits, incentives to select high-value R&D projects to countries with attractive R&D tax credit and allowance schemes may prevail (See Ernst et al. 2013).

of cross-border royalty streams and the unilateral and bilateral method to avoid double taxation. Moreover, we follow the existing literature and construct the B-index that accounts for special R&D tax allowances and R&D tax credits.

Our results suggest that patent income taxation exerts a significantly negative effect on average patent quality. Quantitatively, we find that a decrease in the patent income tax rate (which proxies for the average effective tax rate) by 10 percentage points raises patent quality by around 1–5 %. This result prevails in a number of sensitivity checks which control for observed and unobserved heterogeneity in patent quality across industries, countries, and firms. The B-Index (which captures the tax burden on marginal investment) in turn exerts a negative effect on patent quality. Consequently, while both R&D tax allowances/credits and low patent income taxes raise R&D quantity (as shown by previous research), our analysis suggests that their impact on project quality differs substantially: while low patent income taxes raise average project quality, generous R&D tax allowances/credits tend to reduce it.

The paper contributes to several strands of the economic literature. Firstly, it directly relates to papers which assess the impact of R&D tax incentives on R&D expenditure. For the US, Hall (1993) and Hines (1994) study the responsiveness of corporate R&D to the Research and Experimentation Tax Credit and find significant R&D price elasticities. Similarly, Jaffe and Hines (2001) determine how US R&D expense deduction rules affect the location of R&D by US multinationals. Bloom et al. (2002) confirm a significantly positive effect of R&D tax credits on the level of R&D expenditures using macro data for major OECD countries [see also Hall and van Reenen (2000) and Arundel et al. (2008) for survey papers on the topic].[6] Furthermore, Griffith et al. (2011), Ernst and Spengel (2011) and Karkinsky and Riedel (2012) find a negative effect of patent income taxes on the number of corporate patent applications.

Our paper adds to the sketched literature by stressing that tax provisions for patent income may not only impact on the quantity of R&D and patent holdings but also on their quality. In this sense, the paper is related to recent contributions that emphasize the importance of quality aspects in assessing the welfare consequences of corporate taxation. Becker and Fuest (2007) and Becker et al. (2012) criticize that conventional studies solely focus on the effect of corporate taxes on the quantity of capital investment. The welfare effects of the investment, however, critically depend on the number of jobs created, the associated profit and tax revenue base, and the project's innovativeness. Our results confirm the importance of this argumentation.

The paper is structured as follows: Sections 2 and 3 describe our data set and estimation methodology. The results are presented in Section 4. Section 5 concludes.

6 In a recent paper, Ernst and Spengel (2011) report a faint impact of R&D tax incentives on the number of corporate patent applications. Buettner and Wamser (2009) find positive effects of R&D tax incentives on the volume of foreign direct investment (FDI) of German multinationals.

2 Data

In order to assess the link between R&D tax incentives and project quality, the empirical analysis merges information on corporate innovative activities as captured by patent data to information on R&D tax incentives in Europe.

2.1 Patent and firm data

To proxy for R&D activity, we will make use of the universe of patent applications to the EPO drawn from the PATSTAT data base. Firms seeking patent protection in a number of European countries may file an application directly at the EPO and designate the relevant national offices in which protection is sought.[7] Filing a patent with the EPO firstly enables a firm to make a single application, which is cheaper than filing separately in each national office, and secondly, allows the firm to delay the decision over which national states to further the application in.

The data include information on the patent applicant and inventor, the technology class of the patent and patent citations. The right to patent an invention belongs to the inventor or to anyone who by law or contract is entitled to file the application (see Muir et al. 1999). Commonly the employer is entitled to file an application for an invention made by an employee. In these cases, the employer is the applicant and legal owner of the technology and consequently also the relevant subject for taxation (e.g., Quick and Day 2006; Ernst and Spengel 2011)[8], while the employee has to be listed as the inventor on the application.[9]

Note that in most cases (more than 90 % of the patent applications), inventor and applicant are located in the same country. As recent papers suggest that multinational firms can set up structures which allow them to geographically split the location of inventor and patent applicant in order to shift income to low-tax countries (see e.g., Boehm et al. 2012), we drop the according patents from our analysis and focus on the "standard" case where the inventing unit and the patent owner are located in the same country.

The PATSTAT data base comprises patent applications for the years 1978–2007. In the analysis to come, we will account for patent applications from 1995 onwards as our tax and firm data are restricted to that period and limit the sample to patents that were eventually granted. Furthermore, we merge the patent information to the European firm-level data base AMADEUS provided by Bureau van Dijk. The link between the

[7] The EPO is not a body of the European Union and, as a result, the states which form part of the European Patent Convention (the legal basis for the EPO) are distinct from those in the European Union. See: http://www.epo.org/about-us/epo/member-states.html.

[8] Note, however, that in some countries the principle of economic ownership applies, implying that legal and economic owner may diverge. In such cases, information on the legal owner can be used as a proxy for the party that will eventually be subject to taxation only.

[9] The employer can also transfer ownership of the invented technology to the employee who may then file for patent protection. We consider these cases to be rare events though as firms do not have an incentive to waive ownership of a technology that is expected to earn positive income.

data bases is achieved through standard name matching procedures.[10] Success rates of that procedure are comparable to previous studies (see e.g., Thoma et al. 2010). On average around 67 % of the patents in our data are matched over all sample years and countries. For more details on the matching procedure, see Ernst and Spengel (2011). The match rates for the five largest EU countries by population are 47 % for Spain, 55 % for France, 68 % for Germany, 63 % for Italy, and 72 % for the United Kingdom. Table 1 presents host country statistics for the patent applications in our data.

2.2 Construction of the patent quality indicators

As described above, the purpose of this paper is to assess the effect of the design of the corporate tax system on the quality of R&D projects. In the following, project quality is proxied by the quality of patents invented in a country (see Sect. 4 for a discussion of this approach) as determined by a factor analysis.[11] In line with previous research, the factor model accounts for three separate indicators of the patent's underlying, latent quality: the patent's forward citations, its family size, and the number of technical fields. The estimates of the factor model can be used to construct a measure for patent quality conditional on the indicators. In the following, we will give a brief description of the information employed to derive the quality index. See the online appendix, as well as Lanjouw and Schankerman (2004) and Hall et al. (2007) for more details.

Following previous studies, we consider the patent's family size, i.e., the number of jurisdictions in which the firm has filed for patent protection, to be a good proxy for the patent's expected earnings potential. In particular, as filing for patent protection involves considerable costs (see e.g., Helfgott 1993), it only pays for a firm to protect its invention in many markets if the expected earnings potential is sufficiently large. The number of forward citations received by a patent within the 5-year period from the publication date, in turn, serves as a proxy for the invention's innovativeness, as it indicates whether the technology is the basis for future inventions.[12] Last, the construction of the patent quality index also accounts for the number of technological classes named on the patent which have been shown by previous research to be an indicator of technological quality (see Lerner 1994).[13]

Several authors have also stressed that the value of patents varies across industries and across time. To account for that, we follow previous studies (e.g., Hall et al. 2007) and use quality measures that control for technology and year fixed effects

[10] Following previous efforts (see e.g., Abramovsky et al. 2008), the name of the AMADEUS firm was matched to the name of the applicant on the patent application. Note that corporations may take on the role as patent applicant, while patent inventors are necessarily non-corporates.

[11] See Hall et al. (2007). We are grateful to Grid Thoma for providing us with this data.

[12] Forward citations have an important legal function in the sense that they limit the scope of property rights which are awarded to a patent. In the case of EPO patents, inventors are not required to cite prior technology used in the development of their patent, but the references are added by patent examiners. On the one hand, this implies that not necessarily all innovations which draw on an existing patent in fact acknowledge the reference. On the other hand, an external patent examiner has the benefit of following a consistent and objective patent citation practice.

[13] For the purpose of guaranteeing a reasonable level of precision, the construction of the quality measures accounts for an eight-digit IPC classification reported in the patent document.

(which is not decisive for our results though). Descriptive statistics for the quality measures are presented in Table 2. The composite quality index accounts for all three quality dimensions (forward citations, family size, and industry classes) and controls for technology and year fixed effects. The average index is approximately 0, varying strongly between -2.5 and $+7.3$. There is also substantial cross-sectional and longitudinal variation of the average patent quality across countries and firms (see the online appendix for further details).[14] The separate quality indices for forward citations and family size exhibit a similar distribution. Furthermore note that the family size and forward citation indices are positively correlated (correlation coefficient 0.34, statistically significant at the 1 % level), which suggest that on average, a high level of innovativeness (as measured by the forward citation index) goes along with a high earnings potential (as measured by the family size index).

2.3 Corporate taxation

As described above, our analysis will assess the effect of the corporate tax system on patent applications, accounting for two types of tax incentive instruments: the (output-based) patent income tax rate and (input-based) tax credit and allowances measures.

Information on the patent income tax in the host country of the patent applicant is obtained from Ernst and Young's corporate tax guides, the International Bureau of Fiscal Documentation's country analyses and other sources. Most countries tax patent income at the same rate as other corporate income. In recent years, a growing number of countries have, however, introduced special low tax rates on patent income (e.g., Belgium, Luxembourg and the Netherlands). While many of these special provisions were introduced after 2007 and are, thus, not reflected in our data, our tax measure accounts for special tax provisions where applicable. In particular, during our sample period France implemented a special low tax rate on patent income of 19 % in 2000 (standard corporate tax rate: 33 %) which was then, in a second reform, lowered to 15 % in 2005. Ireland furthermore exempted patent income altogether during our whole sample period and Hungary enacted a patent box regime in 2003 which reduced the tax rate on patent income to 9.5 %. Finally, the Netherlands enacted a special low patent income tax rate of 10 % in 2007. See also Evers et al. (2013). Since the analysis to come will account for the sketched cases, we refer to the tax variable as *patent income tax rate* instead of corporate income tax rate.

The average tax rate applicable to the patents in our data is 39 %, varying strongly between 0 % and 59 %. The high average rate reflects that many patents in our data are filed from large economies, like Germany, which also charged high-tax rates on corporate income within our sample period. Furthermore note that the patent income tax rate exhibits significant variation over time (within standard deviation of 0.062).

[14] Note that we do not observe any changes in the quality of a particular patent over time. The analysis, in turn, will focus on changes in the average quality of the *pool* of patent applications. Furthermore note that our data allow us to identify the location of the technology inventor at the time of the patent application only. If an ongoing R&D project was relocated (in response to tax incentives), we do not observe the original location in our data.

Precisely, our sample period saw 15 major reductions in the patent income tax rate (or corporate income tax rate, respectively) of 5 percentage points or more [in the countries of Austria (2005), Belgium (2003), Bulgaria (2007), Germany (2001), France (2000), Hungary (2003), Italy (1998), Lithuania (2002), Netherlands (2007), Poland (2004), Portugal (2004), Romania (2000 and 2005), and Slovakia (2000 and 2004)]. There were, moreover, numerous smaller adjustments in the patent income tax rate.

Yet, using this statutory tax rate as a measure for the tax burden on patent income disregards that several countries additionally levy a so-called withholding tax on royalty payments from their border. In case of cross-border royalty streams, patent income is, thus, not only taxed in the country that receives the royalty income but may also be taxed in the royalty paying country. Withholding tax rates are commonly determined in bilateral double taxation agreements between countries. The according information is retrieved from recent and historic bilateral tax treaties and from Ernst and Young's corporate tax guides. To avoid double taxation, royalty receiving countries commonly grant a tax credit for withholding taxes paid on the royalty income.[15] Thus, the effective tax rate t_e on a cross-border royalty stream is the maximum of the royalty income tax rate t_k in the patentee's host country k and the royalty withholding rate tw_{jk} charged on royalty streams from a country j to country k: $t_e = max(t_k, tw_{jk})$.

To determine the average tax on royalty income related to a particular patent, we have to make assumptions on the structure of royalty streams received by the patent owner. In a first step, we assume that the pattern of the royalty stream corresponds to observed aggregate bilateral royalty payments between countries. However, as the quality and earnings potential of a patent may impact on the structure of royalty flows, using bilateral royalties for the construction of the effective tax measure may give rise to endogeneity concerns in the empirical analysis to come. We will, therefore, alternatively assume that the relative size of the royalty streams associated with a patent corresponds to the countries' size distribution as measured by the countries' GDP. This assumption reflects that corporate production and sales activities are plausibly positively correlated with market size and, thus, trigger higher payments for the use of the protected invention. Alternatively, we will proxy for the pattern of royalty streams related to a patent by exploiting information on the countries in which the firm filed for patent protection for the technology. The underlying rationale is that sales through affiliates in these markets will trigger royalty and license payments to the patent owner. Formally, the definition of the effective tax rate reads

$$t_e = \sum_{j=1}^{J} W_j \cdot \max(t_k, tw_{jk}) \tag{1}$$

where j indicates the host country of the royalty paying party and tw_{jk} depicts the respective royalty withholding rate charged on royalty income paid from country j to the patentee's host country k. W_j stands for the weighting matrix. If W_j is constructed

15 There were a few exceptions to the credit method. If no double tax treaty was in force for a specific country in a specific year (especially in the 1990s) the unilateral method to avoid double taxation was applied to calculate the effective income tax rate, e.g., deduction of the foreign withholding tax.

based on the relative size of aggregate bilateral royalty payments and the countries' GDP distribution, respectively, the effective tax measure accounts for partner countries in EU27 and major non-EU countries, namely Australia, Canada, China, Switzerland, Japan, and the US.[16] If royalty streams are modelled by information on the patent family, W_j is a uniform weighting scheme and the number of partner countries accounted for in the construction of t_e is the subset of the EU27 and major non-EU countries named above, where the firm filed for patent protection.[17]

Another alternative way to construct the effective tax measure is to exploit information on the structure of multinational corporations in our data. Precisely, inventions protected by corporate patents are often exploited within the boundaries of the multinational firm only to avoid knowledge dissipation to competitors (Zuniqa and Guellec 2009). We, thus, reconstruct t_e assuming that royalties are paid to the patentee from all other firms belonging to the multinational group. Ideally, following the above logic, one might want to weigh the information by affiliate size. As size information is missing for a relatively large number of cases in the AMADEUS data base though[18], we follow previous studies (see e.g., Dischinger and Riedel 2011) and construct an unweighted average $t_e = \sum_j \frac{1}{J} \cdot max(t_k, tw_{jk})$ where j indicates each of the J other affiliates within the multinational group (apart from the patenting affiliate), including the parent firm, and tw_{jk} again denotes the withholding tax rate charged by their host country on royalty payments to the patentee. As sketched in the introductory section, for highly profitable investments, this effective tax rate on patent income t_e converges against the average effective tax rate.

Following previous work, we, moreover, construct the so-called B-index which captures the tax component in the costs of an R&D investment (Warda 2001; Guellec and van Pottelsberghe de la Potterie 2003), accounting for special tax allowances and credits, and serves as a measure for the tax burden on marginal R&D investment. Formally,

$$B_k = \frac{1 - Z_k \cdot t_k}{1 - t_k} \tag{2}$$

[16] The information on annual bilateral royalty payments used for the construction of the index was obtained from the IMF. Information on countries' GDP was obtained from the World Development Indicators Database.

[17] Note that, as our main data set comprises patent applications to the EPO, the construction of t_e assumes that the firm filed for patent protection in all countries that were members of the EPO in the year of the patent application. For our first sample year 1995, this comprises the countries of Austria, Belgium, Switzerland, Germany, Denmark, Spain, France, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Sweden. Countries that became members during our sample period are: Bulgaria (2002), Cyprus (1998), Czech Republic (2002), Estonia (2002), Finland (1996), Hungary (2003), Island (2004), Lithuania (2004), Latvia (2005), Malta (2007), Poland (2004), Romania (2003), Slovenia (2002), and Slovakia (2002). Furthermore note that royalties paid from parties in the host country of the patentee itself are also accounted for in the construction of t_e, in the cases where the weighting matrix reflects the country size distribution and the construction is based on the countries in which the firm filed for patent protection. It holds $tw_{jk} = 0$ if $j = k$.

[18] Note that AMADEUS contains ownership information on a worldwide basis. For most subsidiaries and parents outside Europe, accounting information which allows to proxy for subsidiary size is not available though.

where t_k stands for the corporate income tax rate in country k and Z_k represents a measure for the deductibility of R&D expenditures, including tax allowances or tax credits granted for R&D investments. The numerator reflects the after-tax cost of one unit of expenditure in R&D and the B-index consequently captures the minimum pre-tax earnings required for the project to break even and to go ahead. If an R&D investment can be fully expensed in a fiscal year, the B-Index is equal to one since Z_k equals one. A tax incentive, granting, for example, an additional deduction on top of the normal deduction of R&D expenditures, reduces the value of B_k below one, as Z_k is then larger than one. Consequently, the lower the B-Index, the more attractive is the tax system for R&D investments and vice versa. See also Ernst and Spengel (2011). The average B-index in our sample is .99 (comprising information for the years 1998 to 2007). The variable furthermore exhibits relevant variation over time (within standard deviation of .028). Precisely, our sample countries experienced 10 major adjustments in the B-index by more than 0.05 through the introduction or reform of R&D tax credit and allowances schemes [in the Czech Republic (2005), Spain (2000), France (2004 and 2006), UK (2002), Italy (2004), Portugal (2002, 2004, 2006), and Slovenia (2006)]. Moreover, the sample period has seen numerous smaller adjustments in R&D tax incentive schemes.

2.4 Control variables

Last, we augment our data by information on other country characteristics, like GDP per capita (as a proxy for economic development), the size of population (as a proxy for country size) and a corruption perception index obtained from the World Development Indicator Database and Transparency International, respectively. We furthermore include information on the concomitant qualities of democratic and autocratic authority in a country's governing institutions using the so-called Polity2 Index. Note that Transparency International's corruption perception index ranges from 0 (high corruption) to 10 (absence of corruption), while the Polity2 Index varies from -10 (strongly autocratic) to +10 (strongly democratic).

3 Estimation strategy

As described above, the aim of our analysis is to identify whether the structure of the corporate tax system affects the quality of R&D projects undertaken in a country. To do so, we proxy for project quality by the patent quality indicators described in the previous section and estimate a model of the following form

$$q_{ikat} = \beta_0 + \beta_1 \tau_{kt} + \beta_2 X_{ikat} + \phi_a + \mu_t + \epsilon_{iat} \tag{3}$$

where q_{ikat} indicates the quality of patent i filed at time t by multinational affiliate a located in country k. The explanatory variable of main interest is τ_{kt}, which is the vector of corporate tax parameters comprising the statutory tax rate on patent income levied by the host jurisdiction of the patenting firm and the effective tax rate on patent income (which proxy for the average effective tax rate) and the B-Index described in the previous section (which captures the tax burden on marginal R&D investment).

To control for time-constant heterogeneity in average patent quality across firms and industries, we, moreover, include a full set of affiliate fixed effects and industry fixed effects (as determined by the first industry class named on the patent) in the estimation.[19] The set of regressors is furthermore augmented by a full set of year fixed effects to absorb common shocks to patent quality which simultaneously affect all patents in the data. Additionally, we include time-varying country controls for market size (as measured by the host country's GDP), the degree of development (as measured by the host country's GDP per capita), and the country's political and governance situation (as measured by the Transparency International corruption index and the Polity2 Index). Last, we augment the vector of control variables by firm size information as measured by the affiliate's total assets to control for a potential systematic correlation between corporate taxation, firm size, and patent quality.

4 Results

The estimation results are presented in Tables 3, 4, 5, 6, 7, 8. The tables display the coefficient estimates and heteroskedasticity robust standard errors which are adjusted for clustering at the country-year level.

4.1 Baseline results

In Specification (1) of Table 3, we regress the composite quality measure on the statutory tax rate levied on patent income in the host country of the patent applicant, controlling for country and year fixed effects. The coefficient estimate is negative and statistically significant, suggesting that an increase in the patent income tax rate by 10 percentage points reduces the quality index by 0.035. Evaluated at the sample mean, this corresponds to a decline by 1.5 %.[20]

Specifications (2) and (3) reestimate specification (1) augmenting the vector of regressors by a full set of industry fixed effects and time-varying country controls. The inclusion of the additional control variables leaves the qualitative and quantitative results largely unaffected. Specification (4), furthermore, includes a full set of affiliate fixed effects which absorb any time-constant heterogeneity in the quality of R&D projects across patent inventing firms. The sample is, moreover, restricted to patents filed by firms that are part of a multinational group.[21] Specification (5) adds firm size as measured by the logarithm of the firm's total assets as an additional control variable.

[19] As ownership information is only available in cross-sectional format in the AMADEUS database, affiliates are assumed to not change their host location over time. Consequently, affiliate fixed effects nest host country fixed effects.

[20] As the composite quality index (CQI) may take on negative values, the semi-elasticity is evaluated at the sample average of the variable plus the absolute value of the variable's minimum: $|\min(\text{CQI})| + \text{avg}(\text{CQI}) = 2.5289 - 0.1958 = 2.3331$, cf. Table 2. It follows that $0.035/2.3331 = 1.5\,\%$.

[21] Precisely, a firm is defined to be part of a multinational group if it owns a foreign affiliate with more than 50 % of the ownership shares, or is owned by a foreign parent with more than 50 % of the ownership shares or is owned by a parent firm in the same country which in turn owns at least one foreign affiliate with more than 50 % of the ownership shares.

Both specifications confirm our previous findings and suggest a significantly negative impact of the patent income tax rate on patent quality. Quantitatively, specification (5) indicates that an increase in the statutory tax rate on patent income by 10 percentage points decreases the patent quality index by 0.095. Evaluated at the sample mean, this corresponds to a decline by 4.1 %.[22]

As a robustness check, we further reran the analysis using the patent's number of forward citations and family size as proxies for its degree of innovation and earnings potential. The results are presented in specifications (6)–(9). Similar to the previous estimates, we find that patent taxation reduces the quality measure. An increase in the tax rate by 10 percentage points lowers the family size index and the forward citation index by around 0.07. Evaluated at the sample mean, this corresponds to a decrease by 4.1 % (3.4 %) (cf. specification (7) and specification (9), respectively, of Table 3). To the extent that the patent's family size and forward citations serve as a proxy for the earnings potential and the degree of innovation of the underlying R&D project, the estimates, thus, suggest a significant reduction in the two welfare components.

As sketched in Sect. 2, our sample period saw a number of large patent income tax adjustments. Specifications (10)–(12) separately assess the effect of the largest adjustment in the patent tax rate within our sample frame which was the introduction of a special low patent income tax rate of 19 % in France in 2000 (statutory corporate tax rate: 33.3 % plus surcharges). Precisely, we implement a differences-in-differences model of the following form:

$$q_{ikat} = \alpha_0 + \alpha_1 \mathrm{FRXPOST}_{kt} + \alpha_2 X_{ikat} + \phi_k + \mu_t + \epsilon_{ikat} \tag{4}$$

where $\mathrm{FRXPOST}_{kt}$ indicates patents filed in France after the reform year 2000. The definition of the other variables corresponds to Eq. (3). Note that country and year fixed effects are included and the sample is limited to patent applications filed between 1997 and 2003, i.e., three years prior and after the reform. Specification (10) of Table 3 uses all other countries in our sample as control group, while specification (11) limits the control group to countries that did not experience a major adjustment in their patent income tax rate (i.e., corporate tax rate if no special tax applies for patent income) or adjusted their tax credit or tax allowance scheme. The latter control group comprises the countries of Finland, Ireland, Netherlands, and Sweden. Both specifications suggest that patent quality in France increased after the year 2000 relative to the countries in the

[22] Note that the sample size is reduced, when we restrict the sample to MNEs and augment the model by affiliate fixed effects in Specification (4) and the total asset control in Specification (5). The sample reduction in Specification (4) on the one hand reflects that not all patent applicants can be matched to firms in the Amadeus data base, and on the other hand that some of the matched patents are filed by national firms. The sample reduction in Specification (5) reflects that the total asset information is missing for a relevant number of firm-year-cells. Note that the restriction to multinational firms in Specification (4) increases the absolute coefficient estimate, while the inclusion of the affiliate fixed effect reduces it. Running the model on the sample in Specification (4) but without affiliate fixed effects yields a coefficient estimate of −0.91 (significant at the 1 % level). The absolute increase in the coefficient estimate in Specification (5) relative to Specification (4) is, moreover, driven by the sample restriction. The coefficient estimate for the sample in Specification (5) without the inclusion of the total asset control is −0.96 (significant at the 1 % level).

control group. As Specification (10) includes a number of countries that substantially reduced their corporate income tax rates within this period as well, it is not surprising that the coefficient estimate for the treatment effect increases when the control group is reduced to countries without a major reform in Specification (11). Quantitatively, Specification (11) suggests that average patent quality increased by 0.083, or, evaluated at the sample mean, by 3.6 %. Augmenting the model by affiliate fixed effects in Specification (12) leads to a slight drop in the coefficient estimate which remains statistically significant though.

Moreover, the effective tax burden on patent income does not only depend on the statutory tax on patent income charged by the host country of the royalty recipient but may, in case of cross-border payments, be equally determined by royalty withholding taxes charged by the royalty paying country. As laid out in Sect. 3, we account for this by constructing an effective tax rate on patent income which takes both rates into account. The results are presented in Table 4. Specifications (1)–(6) employ an effective tax rate measure which is constructed based on the assumption that the patentee receives royalty payments from other EU and non-EU countries and that the relative size of the royalty streams matches aggregated observed bilateral royalty streams. The effective tax measure in specifications (7)–(12) [specifications (13)–(18)] assumes royalty payments to be determined by partner country size (the patent family). Finally, Specifications (19)–(24) employ an effective tax rate measure which is constructed based on the assumption that the patentee receives royalties from all other affiliates within the same multinational group. The results confirm our qualitative and quantitative baseline findings for the statutory patent income tax rate, irrespective of whether the composite patent quality index is used as the dependent variable or the indices reflecting forward citations or patent family size.

Note, moreover, that our results are robust to adjusting standard errors for clusters at different levels. While our baseline specifications report standard errors that allow for correlation of residuals in the same country and year cell, we reran our specifications calculating standard errors that account for correlation within country clusters, industry clusters, and firm clusters, respectively. Panel A of Table 5 presents the results of specifications which re-estimate the models presented in columns (3)–(4) of Table 3 (which use the composite quality index as dependent variable). The modification leaves the statistical significance of the coefficient estimates for the patent income tax variable unaltered. Analogous results are found if the family size index or the index for the number of forward citations is used as the dependent variable in Panels B and C.

The specifications presented in Table 6 furthermore test for a potential link between the B-index and patent quality. Specifications (1)–(3) regress the composite patent quality index on the B-index and the host country's patent income tax rate. The coefficient estimate for the tax variable, again, shows a negative sign, indicating a statistically significant and economically relevant impact of patent income taxes on patent quality. Quantitatively, an increase in the tax rate by 10 percentage points reduces patent quality by 0.092 or 3.9 % (cf. Specification (3)). The coefficient estimate for the B-index is positive and turns out statistically significant in Specifications (2) and (3), indicating that reductions in the marginal tax burden on R&D investment, as e.g., induced by an expansion of R&D tax allowances/credits, reduce the average quality of R&D projects undertaken in a country.[23] Quantitatively, a reduction in the B-Index by 0.10 (implying that a 1 Euro investment in R&D has to earn 10 cent lower pre-tax income in order to break even) lowers the average patent quality by 0.059 and thus by 2.5 %. This result is in line with the theoretical notion that, with a downward sloping marginal product curve, marginal R&D projects induced by generous tax allowances/credits or low patent income taxes, reduce the average profitability of the project pool. We furthermore reran the regressions using the patent's family size (cf. specifications (4)–(6)) and its forward citations (cf. specifications (7)–(9)) as the dependent variable. While the coefficient estimates for the patent income tax rate remain statistically significant and large in all specifications, the B-index loses in terms of size and significance in the specifications which employ the number of forward citations as the dependent variable. The results, thus, suggest that while project profitability as proxied by the family size of the patent decreases with a reduction in the marginal effective tax burden, the degree of innovation as proxied by the number of forward citations is not significantly affected.[24]

Furthermore note that the construction of the B-index also accounts for the tax rate on R&D income. To separate out effects related to the policy instruments of low patent income taxes and generous R&D tax credits/allowances, we also ran specifications with a modified B-index variable, which captures the *after-tax* income required for a project to break even and corresponds to the numerator of the B-index defined in Eq. (2). The results are presented in Specifications (10)–(12). Qualitatively, they resemble our baseline findings. The coefficient estimate for the patent income tax somewhat drops in size. Specification (12) suggests that an increase in the patent income tax rate by 10 percentage points reduces the patent quality by 0.038 or 1.6 %.

4.2 Robustness checks and discussion

The analysis so far has accounted for corporate tax incentives in the year of patent application. Two issues are important to discuss in this context. Firstly, as described in the introductory section, MNEs may have an incentive to distort the location of valuable R&D projects to affiliates with a low corporate tax rate. Thus, the decision on the R&D location is, in most cases, made several months prior to the patent application and to the income flow related to the R&D. Note that, for the average R&D project, the time of the project until patenting is rather short though, in 75 % of the cases less than 24 man-months (see a recent survey of US and Japanese firms, Sadao and Walsh (2009) and footnote 3).[25] Consequently, MNEs have to form expectations on the future patent income tax rate that will apply to income from the project at the

[23] Recall that higher tax credits/allowances reduce the B-index.

[24] As a robustness check, we also ran specifications which included the B-index as the only tax measure, which does not change our results.

[25] Man-months of course do not necessarily directly correspond to the actual length of the project until patenting. On the one hand, the project period in months may be shorter since more than one employee may be assigned to the project. On the other hand, the period may be longer as employees may work on several projects simultaneously. In any case, the survey suggests that the time span between the kick-off of the R&D project and the application for patent protection is rather short.

time when it makes its location decision. As corporate tax reforms are commonly announced and enacted months or even years in advance, uncertainty on the taxation of the income stream may be small for projects with a short (scheduled) project horizon. For projects with a longer (scheduled) project horizon, the MNE has to form expectations on the development of the corporate income tax rate in potential host countries. With extrapolative expectations, expectations depend on the history of the corporate tax rate, in the easiest case agents assume the future corporate tax rate to correspond to today's corporate tax rate. With rational expectations, the expected corporate tax rate in turn corresponds to the mathematical expectation of the future tax rate given the available information today. Modeling the tax incentives by the patent income tax rate and R&D tax allowances/tax credits in the year of the patent application, as we did in the baseline analysis, assumes rational expectations of MNEs which have enough information at hand to predict future corporate tax rates at potential hosting locations (at the time when the income stream arises, presumably the year of the patent application) when deciding upon the location of R&D projects. Extrapolative expectation would in turn suggest to include lagged values of the tax variables to proxy for tax incentives at the time when the MNE makes the R&D location decision.

Following this notion, Specifications (1) and (2) in Table 7 rerun our baseline specifications replacing the patent income tax rate in the year of the patent application with the first lag of the patent income tax. The coefficient estimates turn out negative and statistically significant, indicating quantitatively slightly smaller effects than the baseline model. Specifications (3) and (4) simultaneously account for the patent income tax in the application year, as well as the patent income tax in the year(s) prior to the application. The results suggest that deeper lags of the patent income tax do have explanatory power and exert a statistically significant effect on the quality of R&D projects. Specifications (5) and (6) rerun the model in Specification (4) using the family and forward citation index as the dependent variable, respectively. Again, the pattern of the results remains unchanged. Specifications (7) and (8) augment the set of regressors by information on the B-index in the year of the patent application, as well as in prior years. The estimates suggest that marginal project costs as modelled by the B-index impact on project quality particularly strongly in years indicated by deeper lags, i.e., the years when the decision on the implementation and (initial) location of the R&D is made. This is intuitive as the size of the B-index is decisively driven by tax allowances and tax credits granted for R&D investments whose benefits largely accrue at the start of the project.

Table 8 furthermore assesses the sensitivity of our results to controlling for transfer pricing legislations that aim to limit multinational profit relocations to low-tax countries. As technologies resulting from R&D are an important input in the production process of modern MNEs, a significant fraction of intra-firm trading activities is related to patented innovations. In general, MNEs have an incentive to distort prices on royalty payments for high- and low-value R&D alike. High-value R&D may, however, be used more intensely within the multinational group and may thus offer more opportunities for tax-motivated price distortions. The implementation of transfer pricing regulations and the associated limitation of profit shifting opportunities (see e.g., Lohse and Riedel 2013 for evidence) may, thus, in particular drive high-value R&D from the country. If changes in transfer pricing laws and R&D tax incentives are correlated, our coefficient estimates of interest may be biased. To assess this possibility, we collected information on transfer pricing legislations in our sample countries. In particular, we defined a dummy variable which takes on the value 1 if transfer pricing rules are implemented into national tax law.[26] The specifications in Table 8 augment our baseline models by this transfer pricing indicator. While we do not find a statistically significant impact of transfer pricing rules on the average quality of R&D projects located in a country, the impact of the patent income tax and the B-index resemble the baseline findings.

Moreover, as described in Sect. 2, the analysis disregards patents where applicant and inventor are located in different countries to avoid findings that reflect tax-motivated international profit shifting through patent relocations to low-tax countries. Geographical splits of patent applicant (i.e., the owner of the technology who is subject to tax) and the inventor can, e.g., be implemented through contract research schemes, where an R&D unit undertakes research for a group affiliate in a tax-haven country which finances the project and bears its risk. The R&D unit earns a small fixed profit margin on its costs, while the residual income accrues with the contracting entity in the low-tax country.[27] In contrast, relocating ownership of the technology after patent protection was granted tends to be unattractive from a profit shifting perspective as tax authorities in high-tax countries would require that a transfer price corresponding to the patent's true value is charged for the transaction.

Another issue that merits discussion is the use of the patent quality measure to proxy for the quality of R&D projects. In particular, strategic patenting may involve that different subparts of one innovation are protected by a number of interconnected patents. This directly implies that increases in the quality of an R&D project may partly show up through increases in the number of patents filed by a corporation. Using the number of patent applications as the main regressand, like done in previous research (see e.g., Ernst and Spengel 2011; Griffith et al. 2011; Karkinsky and Riedel 2012), might thus capture both, responses in the quality and quantity of R&D projects to corporate taxation. The merit of our approach is in turn that it allows for an isolated identification of the quality effect by investigating the impact of patent income taxation and R&D tax incentives on the quality of patents filed by a corporation, conditional on the number of patent applications.

To sum up, the findings suggest that in line with our theoretical considerations, low average effective tax rates on patent income (as proxied by the statutory patent income tax rate) raise the average quality of R&D projects undertaken in a country (by attracting a positive selection of high-value patents to the economy). Low marginal effective tax rates are in turn found to decrease the average patent quality (by triggering new R&D investments with lower quality). This also implies that different R&D tax instruments exert a very different impact on the average quality of R&D projects under-

[26] In doing so, we follow Lohse et al. (2012) and code the dummy as 1 if the country's national tax law requires intra-firm transfer prices to be set according to the arm's length principle and if the tax law provides further details on the applicability of the principle (e.g., specifies methods which MNEs are allowed to pursue to determine arm's length prices).

[27] Boehm et al. (2012) analyse patent applications to the EPO and find that geographical patent splits are partly motivated by tax considerations.

taken in a country. While input-based measures like R&D tax allowances and credits (that influence the marginal tax burden on R&D) exert a negative impact on average project quality, low patent income taxes turn out to be instrumental in raising R&D quality.

4.3 Welfare consequences

Finally note that the welfare consequences of generous R&D tax credits/ allowances and low patent income tax rates are theoretically unclear. From an individual country's perspective, granting special tax incentives may decrease national welfare if the quantitative response of private sector R&D to the incentive is weak and the policies, therefore, only generate windfall gains to the corporate sector, while overall tax revenues decline. The sign and size of the welfare consequences, moreover, critically depend on the existence and structure of technological spillovers to other firms in the economy.

The patent quality effects discussed in this paper decisively affect the welfare assessment of the policy instruments. Precisely, our analysis suggests that R&D tax credits and allowances reduce the average project quality (by expanding marginal R&D investments). Any positive welfare consequences of increases in R&D quantity induced by generous R&D tax credits and allowances are thus counteracted by a reduction in average project quality [i.e., lower profitability (and thus a lower contribution to the country's corporate tax base) and lower innovativeness (and thus less spillovers on other firms in the economy)]. In terms of low patent income tax rates, the welfare assessment is positive from a national perspective as low patent income taxes do not only expand R&D activity (as suggested by previous work) but also trigger the inflow of R&D activity with above average quality. The picture looks less optimistic from an international perspective though. Precisely, as countries compete for internationally mobile R&D projects, projects gained by one country are lost by another. As governments do not account for the consequences of their policy choices on other countries, patent income tax rates are set inefficiently low from a global perspective. Accounting for the quality effects of low patent income taxes discussed in this paper further fuels this race-to-the-bottom.

5 Conclusion

In recent years, a large and growing empirical literature has shown that corporate taxation negatively impacts on corporate investment behavior at the extensive and intensive margin. Most existing papers, however, restrict their view on testing for corporate tax effects on investment *quantity*. The welfare implications of corporate taxation in turn critically depend on the effects of corporate taxation on investment *quality*, e.g., the profitability and innovativeness of R&D activity (see Becker et al. 2012). The aim of this paper was to empirically assess the effect of the design of the corporate tax system on the quality of innovations resulting from R&D activity.

The analysis uses data on patent applications to the EPO between 1995 and 2007 which is linked with firm level information. Proxying for a project's earnings potential and innovativeness by patent quality measures constructed from information on the patent's family size, its number of forward citations and the number of industry classes, we find that low tax rates on patent income tend to increase average patent quality. The effect also turns out to be economically relevant. A decrease in the patent income tax rate by 10 percentage points raises patent quality by around 1–5 %. Tax allowances and tax credits for R&D investment are in turn found to exert a negative impact on observed project quality.

These results may have important implications for the design of tax instruments related to innovation policy. In recent years, several governments in Europe significantly reduced their tax rates on patent income. Policy makers justified the tax adjustment with the aim to attract innovative R&D activities. Our findings confirm this notion and suggest that low patent income tax rates are indeed instrumental in attracting R&D projects with an above average earnings potential and innovativeness. Interestingly, an analogous effect does not exist for R&D tax allowances and R&D tax credits as their deduction value is unrelated to project quality. Thus, while both tax policy measures may help to attract and increase the size of R&D projects (i.e., R&D quantity), only low patent income taxes are found to exert a positive effect on project quality.

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Appendix

Table 1 Country statistics

Country	Number of patents
Austria	3,127
Belgium	2,217
Bulgaria	9
Switzerland	8,495
Czech Republic	75
Germany	74,620
Denmark	2,536
Spain	1,453
Finland	3,788
France	23,842
Great Britain	12,145
Greece	60
Hungary	166

Table 1 continued

Country	Number of patents
Ireland	331
Italy	11,886
Lithuania	1
Netherlands	8,080
Norway	969
Poland	53
Portugal	70
Romania	2
Sweden	6,805
Slovenia	50
Slovakia	10
Sum	160,790

Table 2 Descriptive statistics

Variable	Obs.	Mean	Median	Min.	Max.
Composite quality index	160,790	−0.1958	−0.2494	−2.5289	7.2887
Quality index—forward citations	160,790	−0.2769	−0.3026	−2.3566	7.2058
Quality index—family size	160,790	−0.0801	−0.1349	−1.7970	5.2683
Patent income tax	160,790	0.3904	0.3829	0.0	0.59
B-index	112,058	0.9944	1.029	0.428	1.069
GDP	160,790	1.55e+12	1.80e+12	1.27e+10	2.90e+12
GDP pC	160,790	26,128.32	25,913.16	5,365.83	51,862.42
Polity2	160,790	9.8513	10	8	10
TPI corruption index	160,790	7.6987	7.9	2.9	10
Total assets (in million US dollars)	25,896	6,732.671	232.1615	0.001	128,568

The composite quality index is a measure for patent quality derived from a factor model accounting for the patent's forward citations, its family size and the number of industry classes (conditional on industry and year fixed effects). The forward citations (family size) Index is an analogous measure which accounts for the number of forward citations (family size) of the patent only. Patent income tax stands for the statutory tax rate on patent income.The construction of the B-index follows Eq. (2) in Sect. 3. GDP and GDP pC depict the host country's gross domestic product and gross domestic product per capita, respectively, in US dollars. The polity2 index captures information on concomitant qualities of democratic and autocratic authority in governing institutions. The polity2 index varies from −10 (strongly autocratic) to +10 (strongly democratic). TPI Corruption Index stands for the Transparency International corruption perception index which ranges from 0 (high corruption) to 10 (absence of corruption). Total assets depicts the total assets of the patent-filing firm in millions of US dollars

Table 3 Patent income tax and patent quality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Composite quality index					Family Size		Forward citation		Composite quality index		
Patent income tax	−0.346***	−0.377***	−0.315***	−0.448***	−0.947***	−0.333***	−0.711***	−0.316**	−0.700***			
	(0.076)	(0.074)	(0.080)	(0.110)	(0.212)	(0.073)	(0.180)	(0.136)	(0.230)			
$GDP/10^{14}$			0.594***	0.123	1.620***	0.153	1.410***	0.014	0.934*			
			(0.221)	(0.204)	(0.385)	(0.143)	(0.330)	(0.258)	(0.482)			
$GDPpC/10^4$			−0.119***	−0.169***	0.076	−0.071	0.112	−0.232***	−0.016			
			(0.046)	(0.065)	(0.098)	(0.046)	(0.080)	(0.080)	(0.121)			
Polity2			−0.003	0.164**	0.131**	0.134**	0.152***	0.089	−0.055			
			(0.080)	(0.081)	(0.065)	(0.053)	(0.049)	(0.102)	(0.115)			
TP corruption index			0.003	0.002	0.048**	−0.005	0.035**	0.015	0.044*			
			(0.010)	(0.012)	(0.020)	(0.008)	(0.017)	(0.016)	(0.025)			
Log total assets					−0.020**		−0.023***		−0.008			
					(0.010)		(0.007)		(0.011)			
France, year>1999										0.041**	0.083***	0.074**
										(0.016)	(0.018)	(0.031)
Industry fixed effects		√	√	√	√	√	√	√	√	√	√	√
Country fixed effects	√	√	√			√		√		√	√	
Affiliate fixed effects				√	√		√		√			√
# Observations	160,790	160,790	160,790	116,913	25,896	116,913	25,896	116,913	25,896	113,830	30,196	22,161
R^2	0.0720	0.1298	0.1300	0.4111	0.4657	0.5064	0.5617	0.2578	0.3233	0.1243	0.1226	0.3953

*, **, *** indicate significance at the 10 %, 5 %, and 1 % level. Heteroscedasticity robust standard errors adjusted for country-year clusters in parentheses. The dependent variable is the composite patent quality index [specifications (1)–(5) and (10)–(12)] and the family size and forward citations index, respectively [specifications (6)–(9)]. For details on the variable definition, see the notes to Table 2. Specifications (10)–(12) estimate a difference-in-difference model, compare Eq. (4). All specifications include a full set of year fixed effects

Table 4 Effective patent income tax and patent quality

	Effective patent income tax—weights: royalty flows						Effective patent income tax—weights: GDP					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Comp. qual. index		Family size		Forward citation		Comp. qual. index		Family size		Forward citation	
Effective patent income tax	−0.260***	−0.365***	−0.217***	−0.265***	−0.136**	−0.271**	−0.260***	−0.366***	−0.218***	−0.266***	−0.137**	−0.271**
	(0.070)	(0.096)	(0.054)	(0.064)	(0.067)	(0.118)	(0.069)	(0.096)	(0.054)	(0.064)	(0.067)	(0.119)
Country Controls	√	√	√	√	√	√	√	√	√	√	√	√
Industry fixed effects	√	√	√	√	√	√	√	√	√	√	√	√
Country fixed effects	√		√		√		√		√		√	
Affiliate fixed effects		√		√		√		√		√		√
# Observations	160,790	116,913	160,790	116,913	160,790	116,913	160,790	116,913	160,790	116,913	160,790	116,913
	Effective patent income tax—weights: patent family						Effective patent income tax—weights: MNE group					
	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
	Comp. qual. index		Family size		Forward citation		Comp. qual. index		Family size		Forward citation	
Effective patent income tax	−0.262***	−0.368***	−0.219***	−0.269***	−0.136**	−0.266**	−0.414***	−0.252***	−0.036***	−0.142**	−0.310***	−0.308**
	(0.069)	(0.096)	(0.054)	(0.064)	(0.069)	(0.119)	(0.090)	(0.102)	(0.072)	(0.070)	(0.105)	(0.140)
Country controls	√	√	√	√	√	√	√	√	√	√	√	√
Industry fixed effects	√	√	√	√	√	√	√	√	√	√	√	√
Country fixed effects	√		√		√		√		√		√	
Affiliate fixed effects		√		√		√		√		√		√
# Observations	159,821	116,408	159,821	116,408	159,821	116,408	86,284	86,284	86,284	86,284	86,284	86,284

*, **, *** indicate significance at the 10 %, 5 %, and 1 % level. Heteroscedasticity robust standard errors adjusted for country-year clusters in parentheses. The dependent variable is the composite patent quality index [specifications (1)–(2), (7)–(8), (13)–(14), (19)–(20)] and the family size [specifications (3)–(4), (9)–(10), (15)–(16), (21)–(22)] and forward citations index, respectively [specifications (5)–(6), (11)–(12), (17)–(18), (23)–(24)]. For details on the variable definition, see the notes to Table 2. All specifications include a full set of year fixed effects and the country control variables GDP, GDPpC, Polity2, and TP corruption index

Table 5 Clustering of standard errors at different levels

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: composite quality index						
Patent income tax	−0.315**	−0.315***	−0.372***	−0.448**	−0.448***	−0.448***
	(0.151)	(0.112)	(0.121)	(0.197)	(0.155)	(0.129)
Cluster	Ctry	Ind	Firm	Ctry	Ind	Firm
Panel B: family size						
Patent Income Tax	−0.245*	−0.245***	−0.289***	−0.333**	−0.333***	−0.333***
	(0.125)	(0.077)	(0.092)	(0.142)	(0.094)	(0.100)
Cluster	Ctry	Ind	Firm	Ctry	Ind	Firm
Panel C: forward citations						
Patent income tax	−0.245*	−0.245***	−0.289***	−0.316	−0.316*	−0.316**
	(0.133)	(0.141)	(0.135)	(0.190)	(0.189)	(0.144)
Cluster	Ctry	Ind	Firm	Ctry	Ind	Firm
# Observations	160,790	160,790	128,101	116,913	116,913	116,913
Country controls	√	√	√	√	√	√
Industry fixed effects	√	√	√	√	√	√
Country fixed effects	√		√		√	
Affiliate fixed effects		√		√		√

*, **, *** indicate significance at the 10 %, 5 %, and 1 % level. Heteroscedasticity robust standard errors adjusted for country clusters (“ctry”), industry clusters (“ind”) and firm clusters, respectively, in parentheses. The dependent variable is the composite patent quality index (Panel A) and the family size (Panel B) and forward citations index, respectively (Panel C). For details on the variable definition, see the notes to Table 2. All specifications include a full set of year fixed effects and the country control variables GDP, GDPpC, Polity2, and TP corruption index

Table 6 B-index and patent quality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Comp. qual. index			Family size			Forward citation			Comp. qual. index		
Patent income tax	−0.290***	−0.562***	−0.917***	−0.209***	−0.380***	−0.661***	−0.269***	−0.535***	−0.737***	−0.223*	−0.201	−0.376*
	(0.0794)	(0.140)	(0.192)	(0.0553)	(0.0857)	(0.170)	(0.0861)	(0.188)	(0.232)	(0.133)	(0.196)	(0.225)
B-index	0.137	0.519***	0.590**	0.180	0.533***	0.652***	0.027	0.316	0.071			
	(0.176)	(0.196)	(0.283)	(0.129)	(0.133)	(0.244)	(0.172)	(0.309)	(0.370)			
B-index, numerator										0.099	0.480***	0.788***
										(0.138)	(0.158)	(0.276)
$GDP/10^{14}$	0.613*	0.940**	3.000***	0.512**	0.739***	2.710***	0.447	0.905	1.680**	0.588*	0.846**	2.990***
	(0.317)	(0.399)	(0.674)	(0.219)	(0.280)	(0.523)	(0.392)	(0.555)	(0.837)	(0.326)	(0.419)	(0.681)
$GDPpC/10^{4}$	−0.218***	−0.268***	0.024	−0.102***	−0.146***	0.053	−0.303***	−0.354***	−0.009	−0.206***	−0.212**	0.066
	(0.052)	(0.082)	(0.098)	(0.037)	(0.052)	(0.068)	(0.061)	(0.114)	(0.147)	(0.055)	(0.083)	(0.096)
Polity2	−0.013	−0.039	−0.033	0.091	0.150***	0.136***	−0.252**	−0.449	−0.392	−0.008	−0.013	−0.025
	(0.076)	(0.099)	(0.111)	(0.060)	(0.035)	(0.049)	(0.114)	(0.350)	(0.363)	(0.076)	(0.097)	(0.107)
CPI	0.041***	0.048**	0.026	0.030***	0.026**	0.018	0.040**	0.054*	0.027	0.043***	0.055**	0.031
	(0.014)	(0.021)	(0.023)	(0.010)	(0.013)	(0.019)	(0.019)	(0.031)	(0.029)	(0.015)	(0.022)	(0.022)
Log total assets			−0.018*			−0.020***			−0.006			−0.018*
			(0.009)			(0.007)			(0.011)			(0.009)
Industry fixed effects	√	√	√	√	√	√	√	√	√	√	√	√
Country fixed effects	√			√			√			√		
Affiliate fixed effects		√	√		√	√		√	√		√	√
# Observations	112,058	80,936	25,642	112,058	80,936	25,642	112,058	80,936	25,642	112,058	80,936	25,642

*, **, *** indicate significance at the 10 %, 5 %, and 1 % level. Heteroscedasticity robust standard errors adjusted for country-year clusters in parentheses. The dependent variable is the composite patent quality index [specifications (1)–(3) and (10)–(12)] and the family size [specifications (4)–(6)] and forward citations index, respectively [specifications (7)–(9)]. For details on the variable definition, see the notes to Table 2. All specifications include a full set of year fixed effects

Table 7 Lagged information on tax incentives

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Composite qual. index				Family	Forward	Comp. qual. index	
Patent income tax			−0.261***	−0.243**	−0.195**	−0.086	−0.378***	−0.293***
			(0.097)	(0.100)	(0.084)	(0.112)	(0.109)	(0.102)
Patent income tax, first lag	−0.258***	−0.529***	−0.374***	−0.268***	−0.161**	−0.349**	−0.351**	−0.161
	(0.083)	(0.134)	(0.126)	(0.095)	(0.064)	(0.145)	(0.143)	(0.115)
Patent income tax, second lag				−0.344***	−0.216***	−0.398 **		−0.114
				(0.120)	(0.077)	(0.182)		(0.147)
B-index							0.047	0.241
							(0.206)	(0.206)
B-index, first lag							0.414	−0.079
							(0.282)	(0.253)
B-Index, second lag								0.805*
								(0.482)
Industry fixed effects	√	√	√	√	√	√	√	√
Country controls	√	√	√	√	√	√	√	√
Country fixed effects	√							
Affiliate fixed effects		√	√	√	√	√	√	√
# Observations	147,308	107,085	107,085	96,517	96,517	96,517	70,038	58,125

*, **, *** indicate significance at the 10 %, 5 %, and 1 % level. Heteroscedasticity robust standard errors adjusted for country-year clusters in parentheses. The dependent variable is the composite patent quality index [specifications (1)–(4) and (7)–(8)] and the family size [specification (5)] and forward citations index, respectively [specification (6)]. For details on the variable definition, see the notes to Table 2. All specifications include a full set of year fixed effects and the country control variables GDP, GDPpC, Polity2, and TP corruption index

Table 8 Transfer pricing rules

	(1)	(2)	(3)	(4)	(5)
	Comp. qual. index		Family	Forward	Composite
Patent income tax	−0.308*** (0.0812)	−0.451*** (0.120)	−0.348*** (0.0808)	−0.242* (0.139)	−0.548*** (0.142)
B-index					0.515*** (0.196)
Transfer pricing rules	−0.007 (0.015)	−0.023 (0.020)	−0.005 (0.015)	−0.070*** (0.024)	−0.014 (0.035)
Industry fixed effects	√	√	√	√	√
Country controls	√	√	√	√	√
Country fixed effects	√				
Affiliate fixed effects		√	√	√	√
# Observations	160,790	116,913	116,913	116,913	80,936

*, **, *** indicate significance at the 10 %, 5 %, and 1% level. Heteroscedasticity robust standard errors adjusted for country-year clusters in parentheses. The dependent variable is the composite patent quality index [specifications (1)–(2) and (5)] and the family size [specification (3)] and forward citations index, respectively [specification (4)]. For details on the variable definition, see the notes to Table 2. All specifications include a full set of year fixed effects and the country control variables GDP, GDPpC, Polity2, and TP corruption index

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